HIGHWAY RESEARCH RECORD

Number 452

Photogrammetric Analysis of Urban and Rural Environments

7 reports
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52nd Annual Meeting

Subject Areas

21	Photogrammetry
22	Highway Design
24	Roadside Development
61	Exploration-Classification (Soils)
84	Urban Transportation Systems

HIGHWAY RESEARCH BOARD

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CONTENTS

FOREWORD

The papers in this RECORD deal with solutions to the many problems of analyzing our environment. Although urban problems are somewhat different from rural problems, both their solutions will depend on collecting data. These papers focus on photogrammetry as the medium to provide the needed data.

Melhorn and Keller present a numerical approach to quantifying aesthetic factors and natural landscape conditions. Measurements and observations from topographic maps, aerial photographs, and field reconnaissance are the primary sources used to derive the descriptive evaluation numbers. The authors describe the use of the system to evaluate the aesthetics of a natural stream, but this type of parametric analysis may also be applied to many highway engineering projects.

Hawkes and Brown deal with an application of mapping and photo-interpretation techniques to the economical analysis of the financial feasibility and environmental and community impacts of a proposed toll road. A low-cost method for assessment of project costs, both initial and long-range, is made to compare with projected revenues. Measures to ameliorate the environmental effects can represent a significant percentage of the cost and thus require identification at an early stage. Mapping and photography provide the most economical methods of determining the effects.

Bird's paper deals with a technique for evaluating environmental changes. A terrain evaluation is made to assess the developmental capability of the area under consideration. This terrain evaluation is delineated by the use of an air-photo interpretation technique from panchromatic photography. The accuracy of the initial interpretation is more than 80 percent.

DeLoach reports on research concerning environmental awareness that creates a need for new approaches to data gathering and interpretation. Large masses of data are needed to define the surrounding environment. This paper deals with an approach to providing and defining these data. Interpretation through stereoanalysis and infrared sensors with variable disciplines has provided a useful system for getting factual answers to many environmental problems. New ways of economically acquiring data input for analysis are presented.

MacLeod and Turner deal with an approach to automated data acquisition and the displaying of data with a large degree of flexibility. The authors describe the philosophy behind their system, the hardware necessary to put the system in operation, and samples in map form of the data bank. The drafted hard copy is "untouched by human hands." The necessity for such a system arose from the problems and costs inherent in maintaining a staff of competent cartographers coupled with the need for greater flexibility in the formatting and handling of masses of data.

Norell reports on recognizing unstable landforms through photo and stereomodel interpretations. A stereo-operator trained in interpreting landslide conditions can delineate this evidence during the mapping process. Research has produced a manual to train new interpreters through the recognition of troublesome areas. This paper is the result of research studies on existing slope failures in Ohio.

Turner's paper deals with the history of aerial surveys for highway engineering. The significant early thoughts and findings relevant to the many professional activities that constitute highway engineering are noted, and the chronological developments in the eventual use of aerial surveys by the highway engineering profession are given.

—R. L. Alston

LANDSCAPE AESTHETICS NUMERICALLY DETERMINED: APPLICATIONS TO HIGHWAY CORRIDOR SELECTION

W. N. Melhorn and E. A. Keller, Department of Geosciences, Purdue University

Because considerable controversy commonly surrounds testimony concerning environmental effects of highway construction, a quantitative method to evaluate aesthetic factors of a landscape is needed. Such an evaluation will help to separate facts from emotions and to provide a means to hierarchically rank various alternative sites or corridors. The LAND system, which is discussed in this paper, provides a preliminary method to quantify aesthetic factors of a landscape and to visually inspect hierarchically ranked alternatives. The model is an extension of Leopold's (1) concept of landscape uniqueness. Descriptive evaluation numbers for various landscape factors are used to derive indexes, which are then used to evaluate and compare different landscapes. Data are obtained from measurements and observations from topographic maps, aerial photographs, and field work. This type of parametric analysis may find application in the planning stages of many highway engineering projects. However, the system is only an additional tool in a decision-making process involving the selection of alternative routes whose construction would significantly modify existing landscapes.

•CURRENT public laws and public policy require evaluation of existing natural landscape conditions as part of an environmental impact statement. Considerable controversy often surrounds testimony during public hearings on the environmental effects of proposals for highway routing and construction. Therefore, it seems desirable to develop a quantitative method to evaluate aesthetic, scenic, and other factors of a particular landscape. Such an evaluation will help to separate facts from emotions and to provide a means to hierarchically rank various alternative sites or corridors.

As stated by Leopold (1), any scheme for comparing landscapes must rest on some philosophical framework. Leopold noted that factors contributing to aesthetic or other nonmomentary aspects of a landscape are difficult to evaluate whereas aspects that tend to lend themselves to cost-benefit comparison, such as location of dams, roads, and trails, are treated in a routine way. He also determined that, if criteria are sought for comparing different landscapes, factors that constitute relevant features of those landscapes must be defined and evaluated. Those are primarily the factors that influence aesthetic impression and human interest in an area. In his study of quantitative evaluation of wild rivers, Leopold's analysis and measurements considered descriptive categories of 3 types: physical factors, biologic and water quality factors, and human use and interest factors. A total of 46 factors was established, and each factor was ranked on an arbitrary scale of 1 to 5 as evaluation numbers.

Leopold's quantitative approach to landscape evaluation is constrained by the fact that his studies included only river valleys and were understaken at on-site locations. However, the basic system can be expanded, as we are doing, to include parametric measurements of total landscapes, for in all landscapes fluvially derived features are the most significant single physiographic element. The concept basic to our philosophy, as with Leopold's, is that any landscape that is unique, in either a positive or negative way, is more significant to society than a landscape that is commonplace. The evaluation of a landscape initially requires an evaluation of its relative uniqueness, which for practical purposes becomes defined as a measure of the relative difference between

landscapes. Those shown to be unique must then be analyzed to determine why they are unique. That is accomplished by defining what is to be evaluated and then numerically determining what part of the uniqueness is owing to characteristics that are antithetical to the definition. For example, if we define aesthetic rivers as those rivers or sections of rivers that are clear, unpolluted, and unlittered, then a stream that is polluted and cluttered with garbage dumps along the banks would be ranked very low as an aesthetic river even though it may be a relatively unique river for the region. If we are evaluating possible highway corridors, a definition of desirable corridor characteristics can likewise be developed, and various alternative corridors can be analyzed and hierarchically ranked.

THE MODEL

The LAND system (landscape aesthetics numerically determined) is a method that quantifies aesthetic factors of a landscape. Only river valleys have been evaluated to date, but the system can be easily modified to evaluate any point of interest of the landscape. The present, preliminary working model is primarily designed to test our data processing procedure. Improvements on the choice of parameters with consequent improvements of results are expected.

The factors evaluated are grouped into Leopold's 3 categories: physical, biologic, and human use and interest. The number of factors used within each category depends on what is to be measured and the detail of the evaluation. In our preliminary model, we evaluated 31 factors (Table 1). Our model is an extension of Leopold's (1) system, which evaluates the relative uniqueness at a site. Each factor is assigned an evaluation number, ranging from 1 to 5; the values are derived from measurements and observations obtained from topographic maps, aerial photographs, and field work (Table 1). The evaluation numbers serve a descriptive function only. For example, the evaluation number 1 is not to be interpreted as better or worse than any other evaluation numbers. What is important is how many of the evaluated landscapes have a common evaluation number for the same factor. That is, if all evaluated landscapes contain polluted streams with foamy water (factor 16, Table 1), then that indicates a common occurrence. However, a clear running stream indicates a unique situation, but that does not negate the commonness of pollution in those landscapes.

The uniqueness value for each factor is determined by its uniqueness ratio, defined by Leopold (1) as the reciprocal of the number of sites sharing the same evaluation number. For example, if 5 landscapes are being evaluated and all have foamy streams, the uniqueness ratio is 1 divided by 5, or 0.20. If one stream is clear, then that stream has a uniqueness ratio of 1 divided by 1, or 1.00, and the 4 remaining streams, all foamy, are assigned a uniqueness ratio of 1 divided by 4, or 0.25 for that factor. This procedure is repeated for all evaluated factors for each landscape. The total uniqueness is computed as the sum of all uniqueness ratios for that landscape.

We define uniqueness index, UI, as the percentage of the total possible uniqueness. For example, if for 10 physical factors the total uniqueness is 5.0 out of a possible 10.0, the uniqueness index for physical factors on a 333.3 point scale is $(333.3 \times 5.0)/10.0 = 167.0$. The 333.3 point scale is used so that the entire uniqueness index for the 3 categories of factors will be on a 1,000-point scale. Figures 1, 2, and 3 show evaluation numbers and uniqueness indexes for 5 stream valleys in Indiana.

The next procedure is to evaluate what part of the uniqueness is contrary to a predetermined definition. For example, aesthetic rivers have been arbitrarily and rather broadly defined as rivers or sections of rivers that are clear, unlittered, and unpolluted. Thus, if we wish to derive an aesthetic river index, ARI, the uniqueness ratio for factors contrary to the definition of an aesthetic river are zeroed and the ARI for each landscape is computed from the equation

$$ARI = UI\left(1 - \frac{x}{y}\right)$$

Table 1. Factors and evaluation numbers for preliminary LAND system.

Factor			Evaluation Number				
Type	Number	Descriptive Category	1	2	3	4	5
Physical	1	Channel width, ft	< 10	10 to 30	30 to 100	100 to 300	> 300
	2	Low flow discharge, ft^3/sec	< 10	10 to 50	50 to 100	100 to 200	> 200
	3	Average discharge, ft^3/sec	< 10	10 to 100	100 to 500	500 to 1,000	> 1,000
	4	Basin area, sq mi	< 10	10 to 100	100 to 500	500 to 1,000	> 1,000
	5	Channel pattern	Sinuous, pool and riffles	Meandering, pool and riffles	Sinuous, without riffles	Meandering, without pool and riffles	Braided
	6	Valley width and height ratio	< 5	5 to 12.5	12.5 to 25	25 to 50	> 50
	7	Bed material[a], percent	A 100	A 75, R 25	A 50, R 50	A 25, R 75	R 100
	8	Bank and valley material[b], percent	U 100	U 75, R 25	U 50, R 50	U 25, R 75	R 100
	9	Bed slope, ft/ft	< 0.0005	0.0005 to 0.001	0.001 to 0.005	0.005 to 0.01	> 0.01
	10	Width of valley flat, ft	< 100	100 to 500	500 to 1,000	1,000 to 5,000	> 5,000
	11	Erosion of banks	Stable	→	Slumping	→	Eroding
	12	Valley slope, x deg	0 to 10	10 to 30	30 to 50	50 to 70	70 to 90
	13	Sinuosity	< 1.25	1.25 to 1.5	1.5 to 1.75	1.75 to 2.0	> 2.0
	14	Number of tributaries	None	1 to 3	3 to 5	5 to 7	> 7
Biologic and water quality	15	Water color	Clear and colorless	→	Green tints	→	Brown
	16	Floating material	None	Vegetation	Foamy	Oily	Variety
	17	Algae	None	Bed and bank partly covered	→	→	Everything covered
	18	Land plants on floodplain	Open	Wooded with brush	Wooded	Cultivated	Mixture cultivated and other
	19	Land plants on hillslope	Open	Wooded with brush	Wooded	Cultivated	Mixture cultivated and other
	20	Water plants	Absent	→	→	→	Abundant
Human use and interest	21	Trash per 100 ft	< 2	2 to 5	6 to 10	11 to 50	> 50
	22	Variability of trash	Equally distributed	→	→	→	Predominantly in localized areas
	23	Artificial control	Free and natural	Partially controlled	Partially channelized	Completely channelized	Dammed
	24	Utilities, bridges, roads	None	< 4	5 to 10	11 to 20	> 20
	25	Urbanization	No buildings	Cabins, trailors, campsites, few farm houses	Farm houses	Mixture of 2 and 3 and urban	Predominantly urban
	26	Historical features	None	1	2	3	> 3
	27	Local scene	Pleasing	→	→	→	Nauseating
	28	View confinement	Open	→	→	→	Closed by hills, cliffs
	29	Rapid and falls	None	→	→	→	Abundant
	30	Land use	Agriculture	Recreation	Urbanization	Recreation and urban	Agriculture and urban
	31	Misfits	None	1	2	3	> 3

[a]A = alluvium, and R = rock. [b]U = unconfined, and R = rock.

Figure 1. Landscape evaluation numbers for 5 selected Indiana stream valleys.

FACTOR	A	B	C	D	E
1 CHANNEL WIDTH	3	3	4	4	3
2 LOW FLOW DISCHARGE	2	2	4	5	2
3 AVERAGE DISCHARGE	3	3	4	5	3
4 BASIN AREA(SQ. MI.)	3	3	4	5	3
5 CHANNEL PATTERN	2	2	1	2	2
6 VALLEY WIDTH/HEIGHT	2	4	5	4	5
7 BED MATERIAL	1	2	1	1	1
8 BANK AND VALLEY MATERIAL	3	2	1	1	1
9 BEDSLOPE	2	3	2	2	1
10 WIDTH OF VALLEY FLAT	3	3	5	4	4
11 EROSION OF BANKS	2	2	1	2	2
12 VALLEY SLOPE	3	2	1	2	1
13 SINUOSITY	3	3	2	3	3
14 NO. OF TRIBUTARIES	5	5	5	5	5
15 WATER COLOR	2	5	2	2	4
16 FLOATING MATERIAL	1	5	2	5	1
17 ALGAE	2	2	1	1	2
18 LANDPLANTS-FLOOD PLAIN	4	5	5	5	5
19 LANDPLANTS-HILLSLOPE	3	2	5	2	2
20 WATER PLANTS	1	1	3	1	2
21 TRASH / 100 FT.	2	3	2	3	3
22 VARIABILITY OF TRASH	5	3	4	2	3
23 ARTIFICIAL CONTROL	1	1	1	5	1
24 UTILITIES, BRIDGES, ROAD	2	3	3	4	3
25 URBANIZATION	2	1	4	4	1
26 HISTORICAL FEATURES	1	1	1	1	2
27 LOCAL SCENE	2	3	3	2	3
28 VIEW CONFINEMENT	3	3	2	2	3
29 RAPID AND FALLS	2	1	1	1	1
30 LAND USE	2	1	1	2	1
31 MISFITS	1	4	2	2	3

LOCATION OF LANDSCAPE

A Big Pine Creek Near Williamsport, Ind

B Deer Creek Near Delphi, Ind

C Eel River Near Logansport, Ind

D Tippecanoe River Near Delphi, Ind

E Wildcat Creek At Owasco, Ind

Figure 2. Uniqueness indexes for the valleys shown in Figure 1.

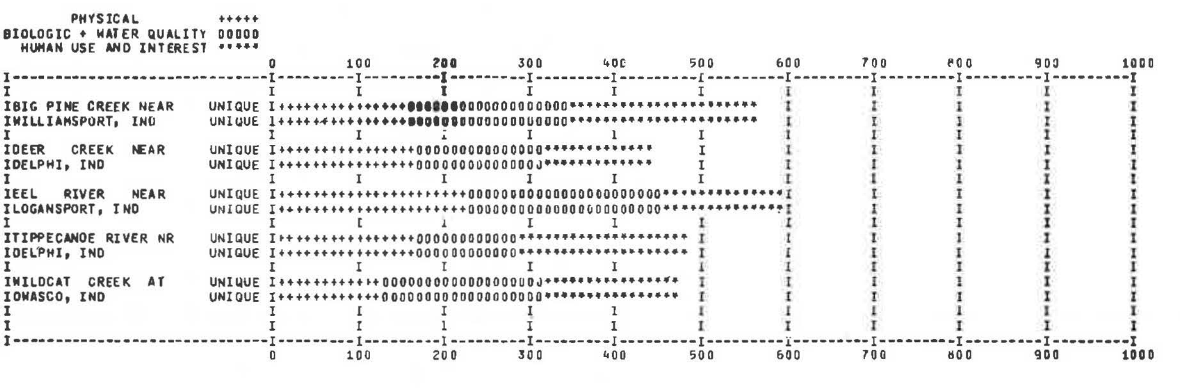
UNIQUENESS MATRIX

	Factor	A	B	C	D	E
		LANDSCAPE LOCATION				
	PHYSICAL FACTORS					
1	CHANNEL WIDTH	.333	.333	.500	.500	.333
2	LOW FLOW DISCHARGE	.333	.333	1.000	1.000	.333
3	AVERAGE DISCHARGE	.333	.333	1.000	1.000	.333
4	BASIN AREA(SQ. MI.)	.333	.333	1.000	1.000	.333
5	CHANNEL PATTERN	.250	.250	1.000	.250	.250
6	VALLEY WIDTH/HEIGHT	1.000	.500	.500	.500	.500
7	BED MATERIAL	.250	1.000	.250	.250	.250
8	BANK AND VALLEY MATERIAL	1.000	1.000	.333	.333	.333
9	BEDSLOPE	.333	1.000	.333	.333	1.000
10	WIDTH OF VALLEY FLAT	.500	.500	1.000	.500	.500
11	EROSION OF BANKS	.250	.250	1.000	.250	.250
12	VALLEY SLOPE	1.000	.500	.500	.500	.500
13	SINUOSITY	.250	.250	1.000	.250	.250
14	NO. OF TRIBUTARIES	.200	.200	.200	.200	.200
	SUBTOTAL	6.37	6.78	9.62	5.87	5.37
	PHYSICAL UNIQUENESS INDICES	152	162	229	163	128
	BIOLOGIC + WATER QUALITY FACTORS					
15	WATER COLOR	.333	1.000	.333	.333	1.000
16	FLOATING MATERIAL	.500	.500	1.000	.500	.500
17	ALGAE	.333	.333	.500	.500	.333
18	LANDPLANTS-FLOOD PLAIN	1.000	.250	.250	.250	.250
19	LANDPLANTS-HILLSLOPE	1.000	.333	1.000	.333	.333
20	WATER PLANTS	.333	.333	1.000	.333	1.000
	SUBTOTAL	3.50	2.75	4.08	2.25	3.42
	BIOLOGIC + WATER QUALITY UNIQUENESS INDICES	194	153	227	125	190
	HUMAN USE AND INTEREST FACTORS					
21	TRASH / 100 FT.	.500	.333	.500	.333	.333
22	VARIABILITY OF TRASH	1.000	.500	1.000	1.000	.500
23	ARTIFICIAL CONTROL	.250	.250	.250	1.000	.250
24	UTILITIES, BRIDGES, ROAD	1.000	.333	.333	1.000	.333
25	URBANIZATION	1.000	.500	.500	.500	.500
26	HISTORICAL FEATURES	.250	.250	.250	.250	1.000
27	LOCAL SCENE	.500	.333	.333	.500	.333
28	VIEW CONFINEMENT	.333	.333	.500	.500	.333
29	RAPID AND FALLS	1.000	.250	.250	.250	.250
30	LAND USE	.500	.333	.333	.500	.333
31	MISFITS	1.000	1.000	.500	.500	1.000
	SUBTOTAL	7.33	4.42	4.75	6.33	5.17
	HUMAN USE AND INTEREST UNIQUENESS INDICES	222	134	144	192	157
	TOTAL	17.20	13.95	18.45	15.45	13.95
	TOTAL UNIQUENESS INDICES	568	448	600	480	474

LOCATION OF LANDSCAPE

A Big Pine Creek Near Williamsport, Ind
B Deer Creek Near Delphi, Ind
C Eel River Near Logansport, Ind
D Tippecanoe River Near Delphi, Ind
E Wildcat Creek At Owasco, Ind

Figure 3. Uniqueness indexes derived from values shown in Figure 2.



where

x = the total value of uniqueness ratio zeroed, and
y = the total value of uniqueness ratio that could have been zeroed.

This equation is used to compute an ARI for each category; the sum is then the final index. The factors, F, and evaluation numbers, E, given in Table 1 that are antithetical to our definition of an aesthetic river, and, therefore, may be zeroed in the calculation of the ARI are as follows:

F	E
15	3, 4, 5
16	3, 4, 5
17	4, 5
21	3, 4, 5
22	1, 2, 3
27	4, 5
31	3, 4, 5

The following example shows how the uniqueness index and the aesthetic index are computed. The indexes are computed for only biologic factors of Deer Creek (B in Fig. 2). An assumption is made that factors 15, 16, and 17 can be contrary to the definition of an aesthetic river and so may be zeroed. For the UI, the ratios are as follows:

Factor	Uniqueness Ratio
15	1.000
16	0.500
17	0.333
18	0.250
19	0.333
20	0.333
Total	2.75

The uniqueness index = 2.75/6 (333.3) or 153. For the ARI, the ratios are as follows:

Factor	Uniqueness Ratio
15	0.000
16	0.000
17	0.333
18	0.250
19	0.333
20	0.333
Total	1.25

The amount zeroed from factors 15, 16, and 17 is 1.500. The amount that could have been zeroed is 1.833. Then,

$$\text{ARI} = \text{UI}\left(1 - \frac{x}{y}\right)$$

where x is amount zeroed and y is amount that could be zeroed.

$$\text{ARI} = 153\left(1 - \frac{1.500}{1.833}\right) = 28$$

The aesthetic indexes for the 5 evaluated Indiana river valleys are shown in Figures 4 and 5.

Figure 4. Aesthetic indexes for the valleys shown in Figure 1.

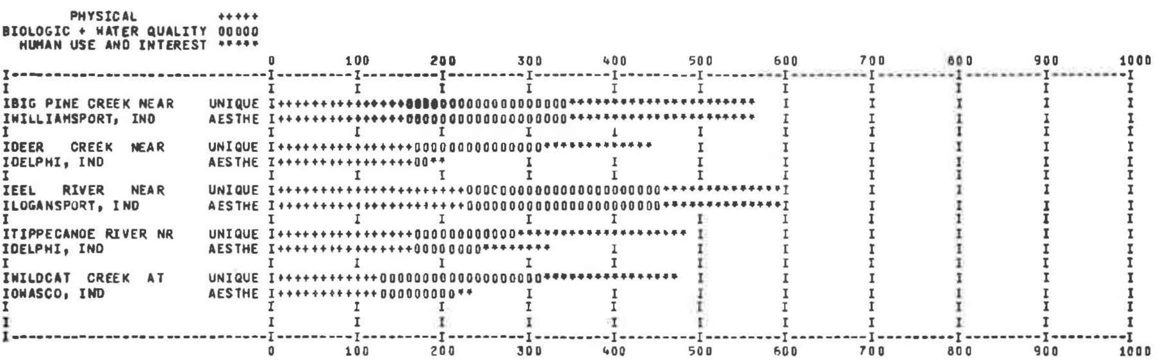
AESTHETIC MATRIX

		LANDSCAPE LOCATION A	B	C	D	E
	PHYSICAL FACTORS					
1	CHANNEL WIDTH	.333	.333	.500	.500	.333
2	LOW FLOW DISCHARGE	.333	.333	1.000	1.000	.333
3	AVERAGE DISCHARGE	.333	.333	1.000	1.000	.333
4	BASIN AREA(SQ. MI.)	.333	.333	1.000	1.000	.333
5	CHANNEL PATTERN	.250	.250	1.000	.250	.250
6	VALLEY WIDTH/HEIGHT	1.000	.500	.500	.500	.500
7	BED MATERIAL	.250	1.000	.250	.250	.250
8	BANK AND VALLEY MATERIAL	1.000	1.000	.333	.333	.333
9	BEDSLOPE	.333	1.000	.333	.333	1.000
10	WIDTH OF VALLEY FLAT	.500	.500	1.000	.500	.500
11	EROSION OF BANKS	.250	.250	1.000	.250	.250
12	VALLEY SLOPE	1.000	.500	.500	.500	.500
13	SINUOSITY	.250	.250	1.000	.250	.250
14	NO. OF TRIBUTARIES	.200	.200	.200	.200	.200
	SUBTOTAL	6.37	6.78	9.62	6.87	5.37
	PHYSICAL AESTHETIC INDICES	152	162	229	163	128
	BIOLOGIC + WATER QUALITY FACTORS					
15	WATER COLOR	.333	0.000	.333	.333	0.000
16	FLOATING MATERIAL	.500	0.000	1.000	0.000	.500
17	ALGAE	.333	.333	.500	.500	.333
18	LANDPLANTS-FLOOD PLAIN	1.000	.250	.250	.250	.250
19	LANDPLANTS-HILLSLOPE	1.000	.333	1.000	.333	.333
20	WATER PLANTS	.333	.333	1.000	.333	1.000
	SUBTOTAL	3.50	1.25	4.08	1.75	2.42
	BIOLOGIC + WATER QUALITY AESTHETIC INDICES	194	28	227	78	86
	HUMAN USE AND INTEREST FACTORS					
21	TRASH / 100 FT.	.500	0.000	.500	0.000	0.000
22	VARIABILITY OF TRASH	1.000	0.000	1.000	0.000	0.000
23	ARTIFICIAL CONTROL	.250	.250	.250	1.000	.250
24	UTILITIES, BRIDGES, ROAD	1.000	.333	.333	1.000	.333
25	URBANIZATION	1.000	.500	.500	.500	.500
26	HISTORICAL FEATURES	.250	.250	.250	.250	1.000
27	LOCAL SCENE	.500	.333	.333	.500	.333
28	VIEW CONFINEMENT	.333	.333	.500	.500	.333
29	RAPID AND FALLS	1.000	.250	.250	.250	.250
30	LAND USE	.500	.333	.333	.500	.333
31	MISFITS	1.000	0.000	.500	.500	0.000
	SUBTOTAL	7.33	2.58	4.75	5.00	3.33
	HUMAN USE AND INTEREST AESTHETIC INDICES	222	21	144	82	24
	TOTAL	17.20	10.62	18.45	13.62	11.12
	TOTAL AESTHETIC INDICES	568	210	600	324	238

LOCATION OF LANDSCAPE

A Big Pine Creek Near Williamsport, Ind
B Deer Creek Near Delphi, Ind
C Eel River Near Logansport, Ind
D Tippecanoe River Near Delphi, Ind
E Wildcat Creek At Owasco, Ind

Figure 5. Aesthetic river indexes and uniqueness indexes derived from values shown in Figures 2 and 4.



In connection with the current study, other riverine indexes have been derived and can be similarly computed. Unlike the working definitions for uniqueness index and aesthetic river index already cited, statutory definitions of wild river, scenic river, and recreational river are contained in Public Law 90-542, thus simplifying development of appropriate indexes to fit these definitions. Examples of the measurement and computation involved are, however, omitted from this paper.

METHODOLOGY AND DATA REQUIREMENTS

Information concerning many physical and some biological factors and factors involving land uses and human interest is commonly best obtained from topographic maps and aerial photography. The remaining data are obtained from field observations. Table 2 gives information on how evaluation numbers were obtained for the 31 factors used.

The best currently available topographic maps are the 1:24,000 (7½-min) USGS map series. Typically, those maps supply information on slope, topography, and human use and interest. However, maps are not yet available for many areas. Therefore, aerial photographs are a very important data source. We have used undodged black-and-white aerial photos at 1:20,000 scale obtained from government agencies. Larger scale photos and color or color-IR films are potentially useful for more detailed studies. The photos normally supply much basic data on vegetation, land use, and human use and interest. Many factors given in Table 2, cited as being obtained from field observation or map measurements, might easily be obtained from aerial photographs. In our preliminary model, we have emphasized field observations as a necessary step to test the validity of the evaluation categories; in developing future models, data obtained from aerial photography analysis will become increasingly important.

Our preliminary model evaluates a length of stream valley 500 times the stream channel width. For example, a stream 100 ft wide would be evaluated for a reach of about 9.5 miles. The decision to evaluate a valley reach 500 times the channel width is completely arbitrary. What is desired in choosing a study reach is to base the length of valley evaluated on some standard parameter that varies directly with the evaluated reach. Thus, a short valley reach is evaluated for small streams, and a longer reach is evaluated as the channel width increases. The only other qualification is that there be sufficient stream gauge data (generally 10 years) to determine flow duration and average discharge. The procedure in evaluating a given river valley is as follows:

1. Measure the channel width on a topographic map or aerial photograph to determine the length of valley reach to be evaluated;
2. Divide the study reach into 10 equally spaced stations;
3. Record measurements and observations in terms of evaluation numbers (Table 1); and
4. Evaluate and hierarchically rank the landscape with other river valleys similarly analyzed.

The data are analyzed by computer. Output includes tables and graphs that list and hierarchically rank the evaluated landscapes in terms of desired indexes. Figures 1, 2, 3, 4, and 5 show examples of the output.

DISCUSSION AND CONCLUSIONS

We have discussed only one example of how the LAND system can be currently used as a simple tool in a decision-making process involving evaluation of alternative river valley sites or reaches. It can just as easily evaluate possible or existing highway corridors, for stream valleys are naturally occurring corridors and network systems that are analogous to highway corridors and regional or areal transportation networks. The 3 descriptive categories of factors are still applicable, and the inherently flexible model allows for additional categories or factors to be included as needed. The number and designation of factors and the number of data collection stations will obviously differ from those used to evaluate stream valleys, but the analysis procedure will not change. Examples of other factors currently under study for possible inclusion in a

Table 2. How evaluation numbers were obtained for preliminary LAND system.

Data Source	Factor	Descriptive Category	Basis for Evaluation Number
Field measurement and observation	5	Channel pattern	General observation for entire study reach
	7	Bed material	Closest fit based on observations at 10 stations
	8	Bank and valley material	Closest fit based on observations at 10 stations
	11	Erosion of banks	Closest fit based on observations at 10 stations
	15	Water color	Closest fit based on observations at 10 stations
	16	Floating material	Closest fit based on observations at 10 stations
	17	Algae	Avg of 10 stations
	18	Land plants on floodplain	General observation for entire study reach
	19	Land plants on hillslope	General observation for entire study reach
	20	Water plants	Closest fit based on observations at 10 stations
	21	Trash per 100 ft	Avg of 10 stations
	22	Variability of trash	Closest fit based on observations at 10 stations
	23	Artificial control	General observation for entire study reach
	24	Utilities, bridges, roads	Count of occurrences over entire study reach
	25	Urbanization	General observation for entire study reach
	26	Historical features	Count of occurrences over entire study reach
	27	Local scene	Avg of 10 stations
	28	View confinement	Avg of 10 stations
	29	Rapids and falls	Count of occurrences over entire study reach
	30	Land use	General observation for entire study reach
	31	Misfits	Count of occurrences over entire study reach
Air-photo measurement and observation	1	Channel width	Avg of 10 stations
	13	Sinuosity	
	14	Number of tributaries	Count of occurrences over entire study reach
	18	Land plants on floodplain	General observation for entire study reach
	19	Land plants on hillslope	General observation for entire study reach
	23	Artificial control	General observation for entire study reach
	24	Utilities, bridges, roads	Count of occurrences over entire study reach
	25	Urbanization	General observation for entire study reach
	29	Rapids and falls	Count of occurrences over entire study reach
	30	Land use	General observation for entire study reach
Map measurement and observation	1	Channel width	Avg of 10 stations
	6	Valley width and height ratio	Avg of 10 stations
	9	Bed slope	Avg of 10 stations
	10	Width of valley flat	Avg of 10 stations
	12	Valley slope	Avg of 10 stations
	13	Sinuosity	
	14	Number of tributaries	Count of occurrences over entire study reach
	23	Artificial control	General observation for entire study reach
	25	Urbanization	General observation for entire study reach
	26	Historical features	Count of occurrences over entire study reach
	30	Land use	General observation for entire study reach
Gauge station records	2	Low flow discharge (90 percent flow duration)	
	3	Avg discharge	
	4	Basin area	

Note: Many factors listed as obtained from field or map observations might easier be obtained from aerial photographs. The information here represents how we obtained data in our preliminary model.

total landscape evaluation system include the following: in the physical category, drainage frequency, drainage density, amount and type of surficial dissection, and soil-rock material types; in the biologic category, percentage and type of vegetation; and in the human use and interest category, land use, population density, transportation network density, and historical-archeological features. The LAND system allows quantification of what previously was not easily quantifiable and provides for visual inspection of hierarchically ranked alternatives. We believe that this type of parametric analysis can be applied to many highway engineering projects, particularly in the planning and land aquisition phases prior to construction. The LAND system is primarily a potentially valuable, additional tool in the decision-making process where the impact of engineering projects that involve landscape modification must be determined by legal statute or public policy.

ACKNOWLEDGMENTS

This research is in part supported by the Office of Water Resources Research, Purdue University Water Resources Research Center.

REFERENCE

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APPLICATION OF AERIAL MAPPING TO DEVELOPMENT OF HIGHWAYS

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Aerial photography can effectively be applied to the development of preliminary engineering plans, environmental analysis, community impact studies, and financial feasibility studies for limited-access highways. New methodology and techniques provide an excellent tool for rapidly and inexpensively developing preliminary data required for technical and scientific investigations. The Atlanta Tollway Project is a $200 million system composed of 35 miles of limited-access highways and 10 miles of high-speed rapid transit in the median. Most of the aerial mapping techniques discussed in this paper were used in the development of the financial feasibility, the environmental, and the community impact studies for that project.

•THE GEORGIA Department of Transportation, in cooperation with local and federal agencies, has developed a comprehensive transportation plan for the metropolitan Atlanta area. This long-range plan envisions a balanced system of arterial and limited-access highways and transit facilities. As in most large American cities, the transportation needs are far greater than the state's ability to finance them through conventional methods.

In an attempt to implement the highest priority projects at the earliest possible date, the department turned to an alternate method of highway financing: revenue bonds. This type of financing for urban and rural highway projects has been successfully used throughout the country for many years. Such a procedure appeared to offer the greatest potential for early construction of the most desperately needed limited-access highways identified in the Atlanta Transportation Study.

The initial step in developing highway projects that anticipate revenue-bond financing is to determine relative financial feasibility, that is, to estimate the cost to provide the facility and the anticipated revenues the project will generate from tolls collected from motorists using the highway.

Until financial feasibility has been determined, the planning process for projects financed by revenue bonds is different from that of projects financed by conventional methods. The initial step, after the decision has been made to explore revenue-bond financing, is to develop a rapid low-cost assessment of the total project cost for comparison with projected revenues.

Aerial photographs, remote sensing, and photogrammetric mapping techniques offer the best method for expeditiously and inexpensively determining existing topographic features.

In addition to conventional data that are historically obtained from aerial mapping, pertinent information can also be compiled to evaluate the potential environmental and community impact effects of the proposed highway facility. These are important factors that can greatly influence the location of the proposed facility and should be considered at an early stage in project development. Ameliorative measures to offset some of the environmental and community problems represent a significant percentage of the project cost and must be identified prior to feasibility testing. Aerial photography techniques can adequately satisfy the needs.

THE PROCEDURE

On projects that have little or no preliminary engineering history, alternate route locations within the corridors established in the regional transportation plan must be identified and examined. Conventional aerial photographs are used to identify existing demographic features and other route constraints. Next, test alignments are prepared and evaluated for adequacy of geometrics, traffic service, and basic route quality.

After the various feasible alternates have been identified, aerial mapping is obtained for the alternate alignments. Standard photogrammetric plotters are used to compile topographic features, usually to a scale of 1 in. = 100 ft. The manuscript is then used to begin development of preliminary engineering data required to obtain construction costs. Topographic features for all alternates can be ascertained from the raw manuscripts, without elaborate final scribing, thus saving time and money at a very critical stage in the feasibility analysis process (Fig. 1).

On projects where electronic computers are employed, a terrain model is defined for computer processing from photogrammetric mapping. The data can be obtained by manually tabulating cross sections from contours or from a digital terrain recorder. If terrain data for the study corridor are available in the computer, various combinations of vertical and horizontal alignments are examined (Figs. 2 and 3). At this stage, relative route quality and preliminary estimates of construction costs for potential alternates are determined, and a preliminary assessment of potential environmental impact is made.

COMMUNITY IMPACT ANALYSIS

Each of the community impact (socioeconomic) and scientific environmental disciplines are investigated by the use of aerial mapping techniques. Existing demographic barriers, both natural and man-made, are identified from aerial photography and depicted on transparent overlays. Land use characteristics are shown on the demographic base maps; the data are obtained from field reconnaissance and census tapes. Superimposing alternate highway alignments over the demographic and land use maps gives a general indication of relative community impact of the various alternates (Fig. 4).

At this point, experienced judgment is needed to interpret preliminary indications from generalized values. Although photo-identifiable route constraints and basic impact on community settlement areas are the initial values to be considered, early adoption of a specific alignment at this point could result in a project cost far greater than financing capabilities. An exchange of data among traffic, revenue, and engineering investigations is in order so that a relative degree of estimated patronage of the various alternates can be obtained.

ENVIRONMENTAL ANALYSIS

Aerial photography offers unique opportunities to make an accurate assessment of environmental impact at an early stage in the planning process. Environmental factors that are particularly amenable to investigation by aerial mapping techniques include ecology, acoustic noise, seismic noise, hydrology, and erosion control.

Ecological impact, or the natural biotic communities that may be altered by a highway project, warrants special concern. The procedure usually employed to assess environmental impact on such natural areas is to examine aerial contact prints in stereoscopic pairs with a minimum of 60 percent end overlay. These prints are reviewed generally for identification of area and gross topographic features and cover types. Individual photographs are then inspected in detail by stereoscope, and individual features, i.e., forest types, residential structures, pavement covers, are marked on the prints. The marked prints are verified in the field where features and objects not identifiable from photographs alone are identified.

A photomosaic is constructed from the contact-size photograph, and the photograph interpretation is depicted on transparent material at the same scale as the demographic and land use base maps.

Figure 1. Alternative alignments on raw manuscripts.

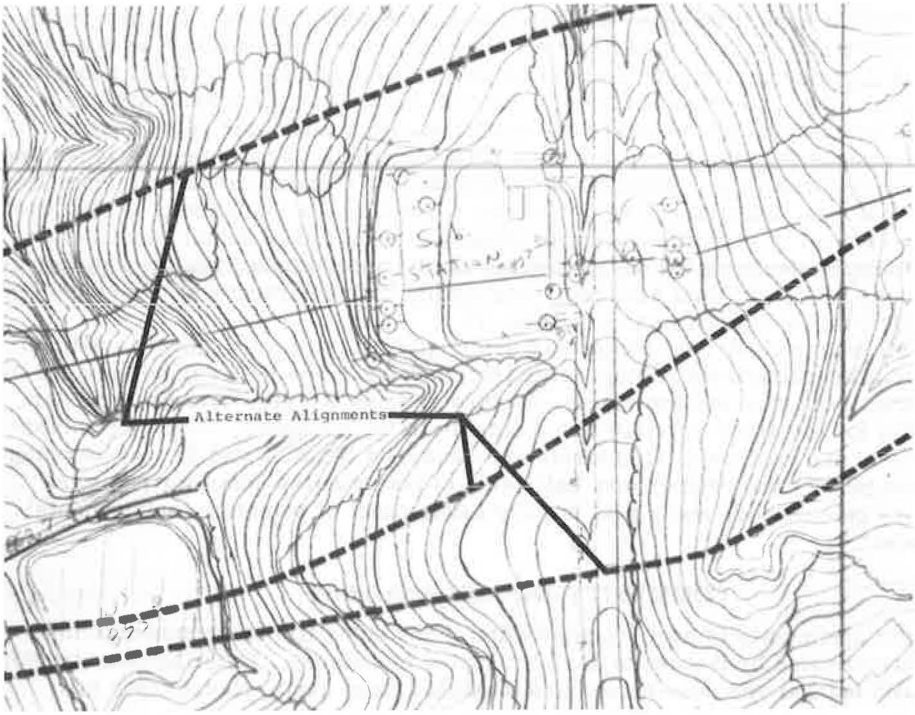


Figure 2. Earthwork information.

BL STA	CL STA	CUT VOL	FILL VOL	ACUM CUT	ACUM FILL	MASS HAUL	CUT A	FILL A
32800.00	32800.00	0.0	-22926.4	3766394.	-2206426.	1559968.	0.0	-5006.7
32900.00	32900.00	484.1	-15283.4	3766878.	-2224766.	1542112.	261.4	-3246.3
33000.00	33000.00	484.1	-9705.2	3767362.	-2236412.	1530950.	0.0	-1994.5
33100.00	33100.00	1550.3	-4864.2	3768912.	-2242249.	1526663.	837.1	-632.1
33200.00	33200.00	6088.2	-1364.4	3775000.	-2243886.	1531114.	2450.4	-104.5
33300.00	33300.00	10583.6	-193.6	3785584.	-2244118.	1541465.	3264.7	0.0
33400.00	33400.00	8443.0	-436.3	3794027.	-2244642.	1549385.	1294.5	-235.6
33500.00	33500.00	3129.4	-613.0	3797156.	-2245377.	1551778.	395.3	-95.3
33600.00	33600.00	7352.0	-176.6	3804508.	-2245589.	1558919.	3574.7	0.0
33700.00	33700.00	7008.5	-764.5	3811516.	-2246506.	1565010.	209.8	-412.8
33800.00	33800.00	1000.5	-2561.5	3812517.	-2249579.	1562937.	330.4	-970.3
33900.00	33900.00	4525.1	-1797.0	3817042.	-2251735.	1565306.	2113.1	0.0
34000.00	34000.00	6800.4	-504.5	3823842.	-2252341.	1571501.	1559.0	-272.4
34100.00	34100.00	8950.3	-504.5	3832792.	-2252946.	1579845.	3274.1	0.0
34200.00	34200.00	8310.2	0.0	3841102.	-2252946.	1588155.	1213.3	0.0
34300.00	34300.00	3877.6	-1193.3	3844979.	-2254378.	1590601.	880.5	-644.3
34400.00	34400.00	3751.4	-1213.7	3848730.	-2255834.	1592896.	1145.2	-11.0
34500.00	34500.00	5395.4	-20.4	3854125.	-2255859.	1598266.	1768.2	0.0
34600.00	34600.00	6681.4	-2.9	3860806.	-2255862.	1604944.	1839.7	-1.5
34700.00	34700.00	7846.4	-58.1	3868652.	-2255932.	1612720.	2397.3	-29.8
34800.00	34800.00	4549.3	-1610.4	3873201.	-2257864.	1615337.	59.2	-839.7
34900.00	34900.00	109.7	-13347.7	3873311.	-2273881.	1599430.	0.0	-6368.0
35000.00	35000.00	0.0	-25631.1	3873311.	-2304638.	1568673.	0.0	-7472.8
35100.00	35100.00	0.0	-29327.2	3873311.	-2339830.	1533480.	0.0	-8363.9
35200.00	35200.00	0.0	-28893.2	3873311.	-2374502.	1498809.	0.0	-7238.4
35300.00	35300.00	0.0	-23230.8	3873311.	-2402379.	1470932.	0.0	-5306.1
35400.00	35400.00	0.0	-17103.3	3873311.	-2422902.	1450408.	0.0	-3929.6
35500.00	35500.00	273.0	-10666.7	3873584.	-2435702.	1437881.	147.4	-1830.4
35600.00	35600.00	1160.4	-5882.4	3874744.	-2442761.	1431983.	479.2	-1346.0
35700.00	35700.00	2369.7	-2959.7	3877113.	-2446312.	1430801.	800.4	-252.1
35800.00	35800.00	7682.0	-467.0	3884795.	-2446872.	1437923.	3347.8	0.0

Total Waste (cu. yd.)

Total Fill (cu. yd.)

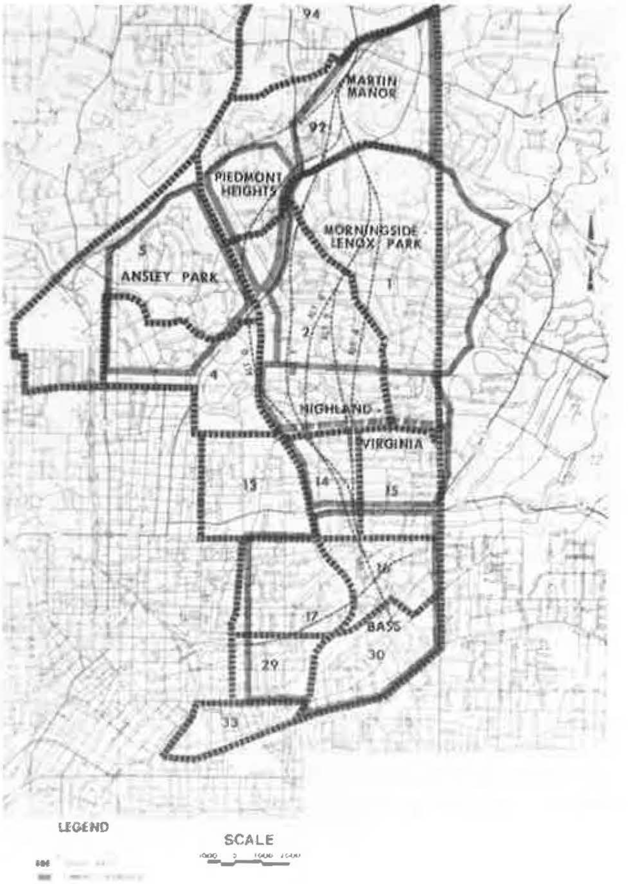
Total Cut (cu. yd.)

Figure 3. Slope-stake information.

BASELINE STATION	C/L		SLOPESTAKES LEFT	SLOPESTAKES RIGHT
3800.00	STA=	3800.00	OFF=-124.60 GR	OFF= 161.89 GR
	EL=	870.36	EL= 842.50	EL= 823.80
3900.00	STA=	3900.00	OFF=-113.50 HF	OFF= 154.89 GR
	EL=	871.97	EL= 860.00	EL= 828.90
4000.00	STA=	4000.00	OFF=-118.60 MF	OFF= 134.10 GR
	EL=	873.80	EL= 864.40	EL= 841.19
4100.00	STA=	4100.00	OFF=-126.00 HF	OFF= 121.10 GR
	EL=	875.83	EL= 860.69	EL= 849.69
4200.00	STA=	4200.00	OFF=-119.80 GR	OFF= 121.00 GR
	EL=	878.06	EL= 852.59	EL= 852.00
4300.00	STA=	4300.00	OFF=-127.50 GR	OFF= 120.69 GR
	EL=	880.50	EL= 851.19	EL= 854.50
4400.00	STA=	4400.00	OFF=-136.20 GR	OFF= 113.80 GR
	EL=	883.07	EL= 849.40	EL= 860.59
4500.00	STA=	4500.00	OFF=-110.60 GR	OFF= 116.30 GR
	EL=	885.64	EL= 864.69	EL= 861.90
4600.00	STA=	4600.00	OFF= -90.50 LF	OFF= 120.80 GR
	EL=	888.22	EL= 884.30	EL= 862.19
4700.00	STA=	4700.00	OFF=-115.60 HC	OFF= 130.30 HF
	EL=	890.79	EL= 898.50	EL= 874.59
4800.00	STA=	4800.00	OFF=-130.60 HC	OFF= 124.30 MF
	EL=	893.36	EL= 908.59	EL= 883.09
4900.00	STA=	4900.00	OFF=-128.30 HC	OFF= 119.19 HC
	EL=	895.93	EL= 910.00	EL= 905.40
5000.00	STA=	5000.00	OFF=-124.39 HC	OFF= 152.80 HC
	EL=	898.50	EL= 910.59	EL= 924.80
5100.00	STA=	5100.00	OFF=-125.60 HC	OFF= 159.89 HC
	EL=	901.07	EL= 913.80	EL= 931.00
5200.00	STA=	5200.00	OFF=-134.10 HC	OFF= 178.60 HC
	EL=	903.40	EL= 920.40	EL= 942.59
5300.00	STA=	5300.00	OFF=-129.39 HC	OFF= 189.89 HC
	EL=	905.32	EL= 919.90	EL= 950.19
5400.00	STA=	5400.00	OFF=-161.50 HC	OFF= 190.20 HC
	EL=	906.83	EL= 937.50	EL= 951.80
5500.00	STA=	5500.00	OFF=-176.50 HC	OFF= 166.50 HC
	EL=	907.94	EL= 946.09	EL= 941.09

These Codes Indicate Cut or Fill, High or Low, etc.

Figure 4. Community boundaries and census tracts.



Alternate test alignments depicting route details and tentative right-of-way requirements are overlaid on the biotic community base maps to determine the total number of areas removed by each alternate (Fig. 5). In addition, the relative impact on the communities adjacent to each alternate can be assessed, and the opportunities can be considered for acquiring lands adjacent to the proposed roadway to preserve the existing biotic communities. Those areas have been designated as "hold-and-save" areas and serve to provide in perpetuity a buffer of natural growth between the roadway and existing communities. Those areas are evaluated with respect to both environmental and community considerations.

Acoustic sound (the audible noise generated by highway traffic) is generally considered to be an offensive by-product of urban highways. An early evaluation of the impact of highway traffic noise for the various alternates under consideration is essential because of the high cost to provide ameliorative devices. Computations of acoustic noise production can be made from basic alignment geometrics developed from aerial mapping as previously discussed. Locations of toll barriers, points of ingress and egress, horizontal curvature, and profile gradients for the various alternates are all parameters in computing traffic noise. Noise levels, based on volume, operating characteristics, and vehicular mix of traffic, are depicted as contours (Fig. 6). These raw contours are superimposed over terrain contours shown on the photogrammetric mapping. Adjustments are made for topographic relief to obtain anticipated sound conditions that could result on the site when the highway is operating.

Land uses and physical installations sensitive to increases in acoustic noise are located on the photogrammetric mapping. In addition, other areas that may be subjected to increased noise levels are defined. Noise attenuation devices such as acoustic berms and barriers are located in critical areas and depicted on the photogrammetrics. Line-of-sight protection from the attenuating devices is tested by plotting random angular and right-angle sections from terrain data obtained from the terrain contours. Acoustic berms and barriers or a combination of both is depicted on the base maps, and quantities are obtained for cost estimating.

Seismic noise (vibrations) generated by highway construction and operation is generally transmitted by surface soils. Topographic relief is one of the best forms of attenuation of seismic noise; another is total distance from the point of production to location of observer. Seismic noise investigations of the Atlanta Tollway Project (Table 1) have provided some of the first available literature on seismic noise production from highway construction and operation. The conductivity of the surface soils can be determined from available geologic data by the use of seismic generation magnitude (particle velocity). Terrain features can be obtained from photogrammetric mapping.

Facilities where levels of seismic noise may be "easily felt" can be readily identified, and ameliorative measures, such as slope contours and intermediate berms, can be located on the aerial base maps. Costs to provide attenuating devices can then be estimated.

Photogrammetric mapping, with large or small contour intervals, provides the necessary topographic data to make preliminary hydrological and drainage investigations. Drainage areas can be delineated from contours to determine total watershed size. Run-off characteristics and times of concentration are developed from ground cover conditions and topographic relief obtained from the aerial mapping and contours. From those data, tentative sizes for openings of watercourses under the highway project are calculated.

High water data from geological survey records or other local sources and contours shown on the photogrammetric mapping can be used to define floodplain storage areas. The impact on the floodplain by the various alternate highway alignments can be determined, and the amount of excavation required to replace any storage volume lost as a result of the highway embankment can be computed.

Upstream and downstream watercourses are examined for adequacy to discharge design storms. Outfall requirements are determined, and preliminary outfall designs and cost estimates are developed.

Erosion potential from highways has taken on new significance in recent years. Soil erosion, especially during construction, can raise turbidities in the receiving water-

Figure 5. Biotic communities and alternate alignments.

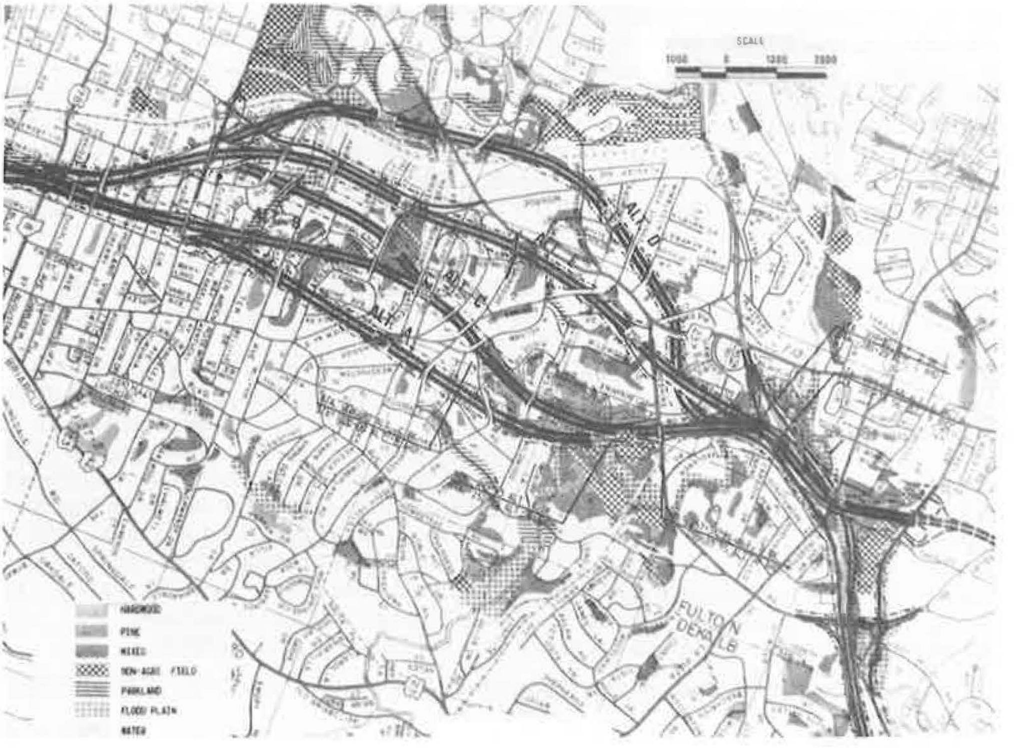
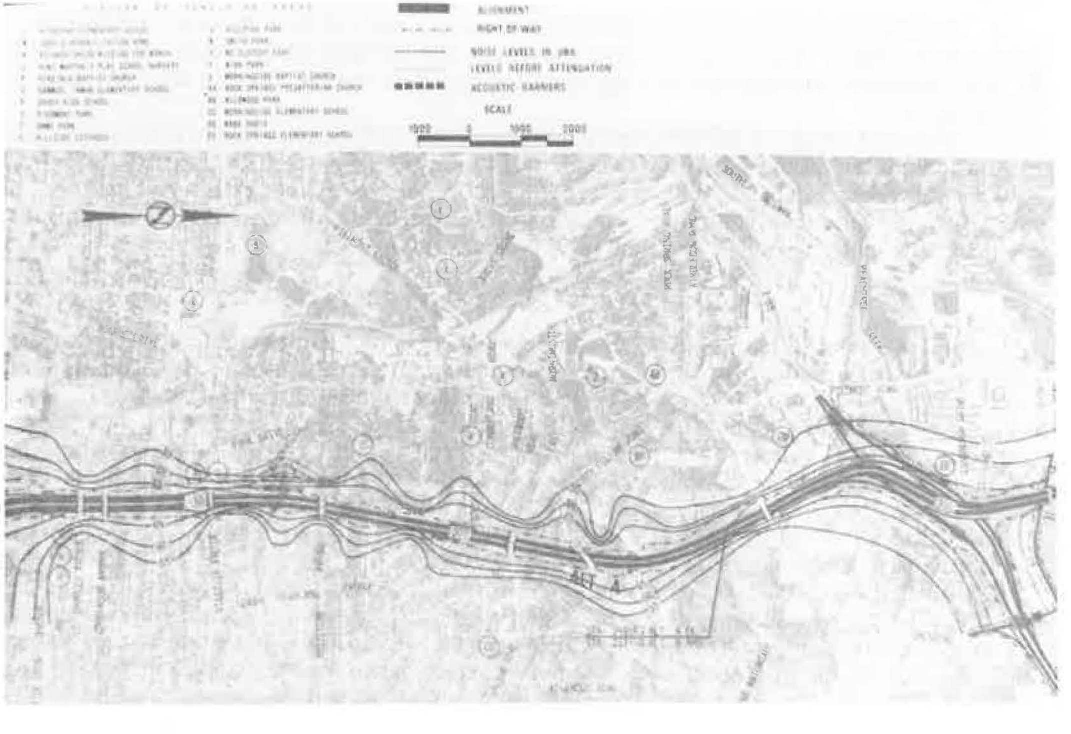


Figure 6. Noise contours and attenuation by barriers.



courses to levels above the tolerance of marine biota. Permanent damage can result, even if the increase in turbidities is only a temporary phenomenon that will subside to preconstruction levels after protective ground cover has been established.

To determine the degree of erosion hazard that can be expected, an analysis is made of generalized soils classifications from geological survey data and agricultural maps. These data are supplemented by field borings at selected locations to verify the existing geological data. The boundaries of the various soils classifications are delineated on the topographic maps to determine the existing slopes for each type. The ecological base maps depicting cover types are superimposed over the soil classification maps to assess gross areas of each degree of erosion hazard (Fig. 7).

After the areas of high erosion potential are determined, locations of temporary and permanent erosion-control devices are depicted on the photogrammetric mapping. Estimated quantities of material required to construct the various devices are estimated for use in developing construction costs.

In addition to more conventional methods of obtaining data from aerial and photogrammetric mapping, remote sensing provides additional opportunities to obtain data quickly and inexpensively. Remote sensing traditionally has meant recording, with cameras, invisible portions of the electromagnetic spectrum. Two principal types of remote sensing are employed in obtaining data for environmental analysis: ultraviolet sensing in the spectrum range below visible light and infrared scanning in the range above visible light. The data obtained from photography and infrared scanning offer scientists a unique means of examining vast areas within a project's influence. Remote sensing is normally accomplished by cameras located aboard low-flying aircraft. On large rural turnpike projects, sensing from satellites should be considered.

The following data are obtained from the various types of photography:

1. Black and white infrared photography identifies edge of water and soil and delineates drainage areas;

2. Color infrared photography detects and portrays some information that the human eye cannot see, is used for previsual detection of diseases and infestation of plants and trees, readily records by means of changing vegetative vigor effects of environmental changes—especially man-made changes, and is used by scientists to portray and quantify natural phenomena such as marsh grass in estuarine locations;

3. Multispectral photography (simultaneous exposure of film through 4 different lenses and filters) enables qualitative interpretation of natural resource data and ability to color enhance information in a more or less infinite manner and is used in resource analyses; and

4. Thermal imagery detects and portrays subtle differences in the emissivity (nonvisible) of things on the earth's surface, such as current patterns of water, heated water discharge, chemical and biological pollution of water, vegetation on surface or near to water surface, vegetation vigor due to respiration differences, soil moisture content, drainage patterns, and potential leaks in levees.

RIGHT-OF-WAY AND UTILITIES

Aerial mapping is also used to estimate right-of-way requirements and prepare an estimate of acquisition costs. Tax records and identifiable features, such as fences, back of sidewalks, and hedges, from photogrammetric mapping are used to establish existing property lines and street rights-of-way. From this base information, preliminary right-of-way strip maps are prepared that depict existing property lines and right-of-way requirements for each alternate under consideration. The right-of-way requirements are based on normal roadway needs and environmental and community considerations. The preliminary right-of-way strip maps are then used in preparing preliminary estimates of right-of-way acquisition costs.

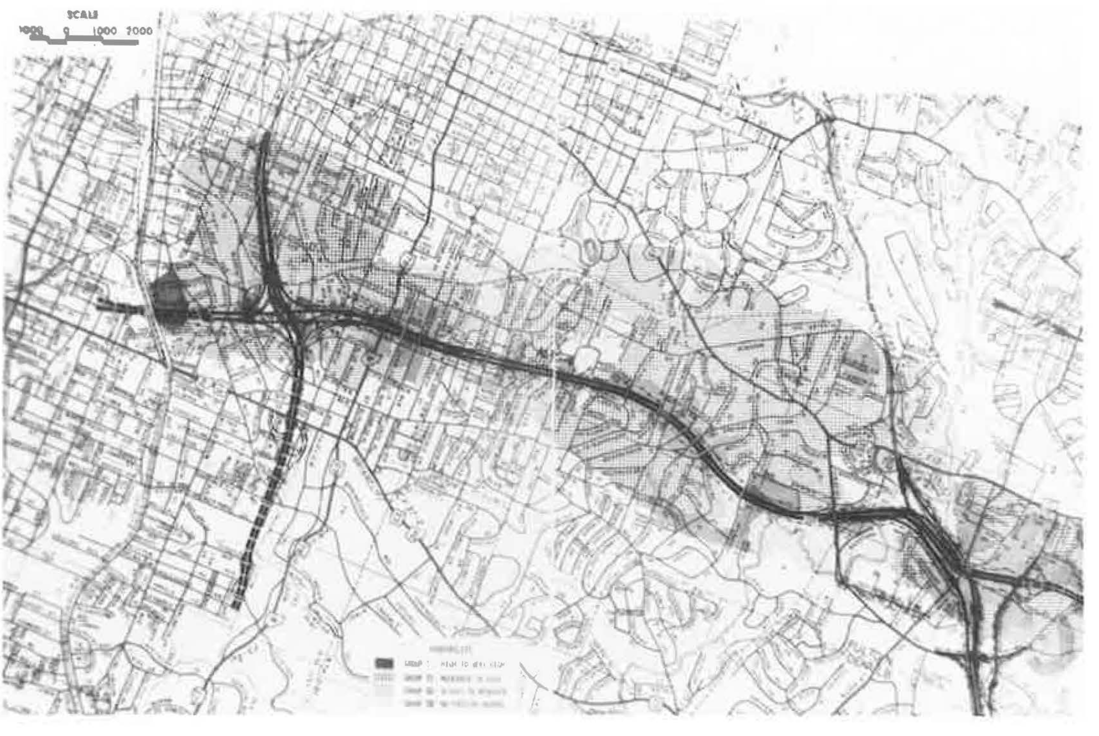
Preliminary utility data for use in determining highway feasibility are developed by novel applications of aerial mapping. Before aerial photography is obtained for use in compiling photogrammetric maps, a field reconnaissance is made to target all identifiable utilities on the surface, i.e., manhole covers, water valves and hydrants, gas valves and drips, and telephone and electrical manholes and vaults. A legend is established for marking the photo-identifiable targets on the photogrammetric maps.

Table 1. Seismic noise levels of alternative routes.

Route	Sensitive Area	Distance From Near Lane of Roadway (ft)	Seismic Noise Level (mm/sec)
A	Closest right-of-way	40	0.680[a]
	Orme Park	100	0.100
	Greater St. Peter AME Church	200	0.045
	Christian Fellowship House of Prayer	400	0.016
C	Closest right-of-way	40	0.068[a]
	Hillpine Park	100[b]	0.100
	Greater St. Peter AME Church	200	0.045
	Christian Fellowship House of Prayer	400	0.016
	Virginia Baptist Church	400	0.016
D	Closest right-of-way	40	0.680[a]
	Piedmont Park	50[b]	0.500[a]
	Greater St. Peter AME Church	200	0.045
	Christian Fellowship House of Prayer	400	0.016
	Virginia Baptist Church	400	0.016
	McClatchey Park	400	0.016
E	Closest right-of-way	40	0.680[a]
	Hillpine Park	150[b]	0.060
	Greater St. Peter AME Church	200	0.045
	WABE Radio	200	0.045
	Christian Fellowship House of Prayer	400	0.016
	Virginia Baptist Church	400	0.016
	Morningside Baptist Church	400	0.016

[a]Little intervening topography. [b]Right-of-way.

Figure 7. Soil erosion characteristics.



Both the available utility company records and the legend of identifiable targets are used to develop and depict the fabric of the utility systems on the photogrammetrics. The utility strip maps are then used, in conjunction with the horizontal and vertical alignment features previously developed for the various alternates, to identify conflicts and estimate replacement and relocation costs.

ENVIRONMENTAL CRITERIA FOR RECREATIONALLY ORIENTED HIGHWAY PLANNING

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Recreational land use activities are rapidly increasing and are tending toward multiple-use, year-round complexes. This trend is placing a severe strain on highway location, design, and subsequent improvements. Environmental criteria affecting the developmental capacity near inland lakes and rivers have become more refined and are of increasing concern to both public and governmental bodies. Therefore, it is necessary to explore economical techniques of evaluations of these terrain parameters, which provide reliable information to engineers, planners, and the public. The methodologies employed are a function of the areal extent of the study, the geological complexities, the controlling governmental agency, the extent of existing and projected development, and the involvement of the public. Three case studies are described, each employing the same basic air-photo technique but varying in the functions listed above, the specific factors analyzed, and the modes of data compilation and presentation required. Numerical developmental constraints, specific land use capabilities, and particular problem areas are each discussed in their relations to highway engineering planning.

•THE rapid changes in recreational land use patterns and the subsequent effects on the location and design of highways and access roads through these areas have prompted the views expressed in this paper. Having performed consulting and research work in the field of air-photo interpretation and terrain evaluation for the past 8 years, the author has had the opportunity to observe these changes as they have taken place and has recognized the difficulties of predicting the area trends and intensities of recreational developments.

Increased leisure time, combined with a greater public concern over environmental control, has resulted in the addition of a vast number of both physical and social parameters in the planning process, thus creating new concepts of highway planning and design. Consequently, governmental authorities at all levels (municipal, provincial, and federal) have been placed in the difficult position of making rapid adjustments to meet the increased demands of the public. The significant increases in traffic flow, year-round uses of what were originally intended to be summer cottages, and development of high-density multiple-activity resorts have caused rapid increases in land values. As a result applications to government planning agencies have increased for intense developments in areas that were considered to be virgin land only 5 years ago. The situation is particularly difficult in southern Ontario, an estimated 250,000 lakes being contained within the province. Moreover, a large number of such lakes are located within a 150-mile radius of metropolitan Toronto, which has a population of approximately 2.5 million people.

It is the objective of this paper, therefore, to briefly consider the effects of these changes on the physical environment. The terrain considerations involved in improving access roads to highway standards, highway widenings, and highway relocation will be examined in the multiple land use planning concept. The methodologies being employed by various government agencies will be discussed, and three examples from the author's experience will be used to illustrate the effectiveness of these techniques.

REGIONAL CONSIDERATIONS IN HIGHWAY LOCATION AND DESIGN

The ideal highway route location is considered to be over relatively level terrain, consisting of deep, coarse soils, well drained internally. In the distant past, when it was impossible to foresee the demand on potential recreational areas, highways and access routes that later became highways were located through this type of terrain wherever possible. However, what is physically ideal for highways is also ideal for any type of recreational development. Therefore, the result has been in many cases a strip of development along the highway, primarily of a commercial nature. Where the highway or access route passed in close proximity to inland lakes because of the existence of excellent terrain conditions, these lakes invariably became densely developed, resulting in a network of access roads from the highway along the shoreline. This process eventually led to the development of back lots, thus increasing the traffic volume. Subsequently, the more heavily traveled access routes became secondary highways. The resulting increase in volume on the main highway made necessary the widening of pavements. Because the high-density development within resort areas could not be predicted prior to the location of the original highway, overpass bridges had to be either constructed or widened, level crossings became serious hazards, and drainage structures had to be either enlarged or replaced.

Because the original highway locations were not designed for high-speed heavy-volume traffic, alignments had to be improved and small towns bypassed. Thus, the primary and secondary highway system developed so quickly in areas of rapid recreational growth that the government authorities responsible for highway improvements had no choice but to consistently meet the ever-increasing public demands.

Improved methods of water quality detection, technological advances in the detection of air pollution, and substantially increased traffic congestion at peak periods have caused all concerned government agencies to consider the consequences of widening the existing primary highways and creating secondary highway networks geared to meet the demands of the public. The demands on municipalities, such as snowplowing and local improvements, should also be noted.

The district municipality of Muskoka, a highly developed recreational area lying between 80 and 160 miles north of Toronto, encompasses an area of approximately 2,000 square miles. The municipal government is currently in the process of evaluating the terrain capability for development of this large land area with the objective of preparing an official development plan based on, among other factors, the realities of the available land for future development and the realization that the pattern of development adopted will strongly influence the future transportation system within the municipality.

The treaty Indians of Canada have begun to realize the economic development potential of the federal reserve lands over which they have jurisdiction. The extended highway networks and the increased mobility of the general public have increased the accessibility of these lands, and the demand for recreational property, even with the prospect of a short-term (20-year) lease, has created a new awareness within the native peoples of the value of the reserve lands.

Studies are now being undertaken by, for example, the Ontario Ministry of Transportation and Communications. This Ontario government agency is currently investigating the possibilities of partial relocation of some of the established highway routes through densely populated recreational areas.

Each of the situations previously described involves a different level of government authority. An example will therefore be cited from each case to illustrate the effectiveness of the methodology described in the next section of this paper.

METHODOLOGY FOR REGIONAL AND DETAILED TERRAIN EVALUATIONS

A recent study, carried out by a multidisciplinary team from the Institute of Environmental Sciences and Engineering, University of Toronto, revealed that the most influential physical parameters affecting the capacity of an inland lake for recreational development are the physiographic characteristics of the water and land area within the watershed (1). Therefore, the input to this study by all disciplines concerned resulted in the recognition of the fact that the basic geological terrain conditions represent, to

a large extent, the controls on recreational development capacity. Consequently, the physical dimensions of the watershed area, the topographic slopes, the type of soil and depth of overburden, the type of underlying bedrock and fracture structure, the soil moisture conditions and height of water table, and density and type of vegetative cover were considered to be of basic importance.

Because the septic tile bed is a common method of sewage disposal in recreational areas, this facility must be evaluated based on the preceding criteria to permit logical intensities of development. The Ontario Ministry of the Environment is currently investigating the capability of Precambrian soils to absorb septic tile bed effluents. Certain remedial measures can be undertaken to either prevent or substantially delay the return of septic tile bed effluents to a source of surface or groundwater supply.

Sources of potable water supply are dependent on a variety of physiographic and local terrain factors. Potentials of continuing groundwater supplies are partially assessed by the effectiveness of the disposal of septic tile bed effluents and potential contributions of the pollutants from other land uses within the watershed area. Surficial sources of water supply may be evaluated initially by examination of the runoff factors, the proximity of the tile beds to the lake in question, and type and density of encroaching aquatic vegetation around the shoreline.

During the study, the existence of man-made changes in surface runoff characteristics, particularly power lines, access roads, and highways, was considered to be highly significant in determining the capacity of the watershed to sustain recreational development without detrimental effects on the water quality. Therefore, proposed access routes paralleling the shores of an inland lake must now be investigated from the standpoint of environmental changes brought about primarily by the changes in surface and subsurface drainage.

Most recreational development areas pose the types of problems previously outlined. Therefore, any transportation route, be it a railway, waterway, access road, or highway, will have some positive effect on the original terrain conditions. For example, the construction of a highway and the soil compaction involved have a significant effect in certain cases on the direction and volume of groundwater flow. This effect may be beneficial or detrimental depending on the local terrain conditions.

Because of the interacting factors outlined previously, it has become increasingly evident that a regional terrain evaluation is necessary to assess the developmental capability of the area under study, thus aiding in the determination of the economic development potential, prior to any decision regarding the location of a new access route or the improvement of an existing highway. The significant environmental terrain factors must be known within a high degree of certainty in order that the problems of the past may be avoided. The increase in recreational activities has been established, and methodologies of a practically oriented nature should be used to assess the terrain conditions and present these parameters in an easily understood fashion. All existing data from the various provincial government agencies within the study area should also be evaluated with respect to their relevancy to the objectives of the study, and the frequency of investigation and accuracy of determination of the data must also be examined.

INDIVIDUAL CASE STUDIES

The specific examples discussed in the following paragraphs have been selected primarily to illustrate the variations in the presentation and significance of environmental terrain conditions as these affect future highway considerations within these areas. The first example discusses a large land area, controlled by a municipal government, wherein the environmental terrain considerations have been coded, based on the most recent technological considerations, to provide a logical basis for future land use planning and route locations. The second example cited involves a relatively small area of federal lands, having a high degree of economic development potential, wherein specific land use capabilities have been designated based on the terrain conditions. The third case study analyzes the cause and effect of a specific development problem on an existing highway and the use of previous aerial photography combined with infrared photography to resolve the situation.

The District Municipality of Muskoka

This district municipality is undergoing considerable pressures for intensive recreational development. In addition, although the final figures have not yet been compiled, this municipality now supports approximately 31,000 year-round residents, an estimated increase of 16 percent during the past 5 years. This area is traversed by more than 200 miles of primary provincial highways and more than 100 miles of supporting secondary highway routes.

The complexities of planning and zoning for development within the municipality, combined with assessments of the existing and proposed highway networks, necessitated an examination of the environmental terrain factors throughout the complete district area.

The legend shown in Figure 1 was selected to define existing terrain conditions and to rate septic tile bed performance and potential sources of water supply. The basic terrain conditions of topography, depth of overburden, type of soil, soil drainage conditions, septic tile bed performance, and potential sources of water supply were assessed for areas having similar terrain conditions and are shown in Figure 1a. It should also be noted that those items shown in the lower portion of the legend were also evaluated and mapped throughout the study area. Encroaching aquatic vegetation indicated the presence of excessive nutrients and stagnant bays and areas subject to flooding or soil failures that are potential hazard zones. In particular, localized heights of land, watershed boundaries, and existing drainage channels are important for the location of transportation routes and subsequent development.

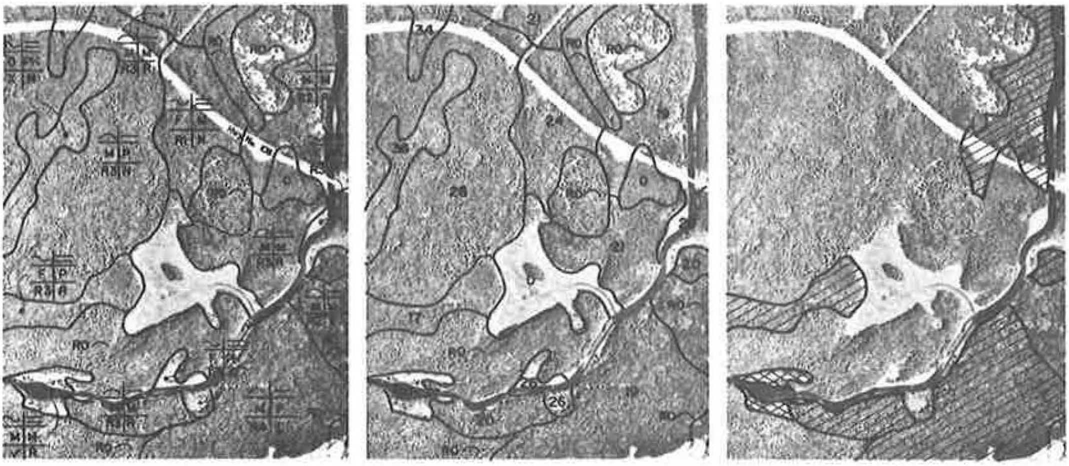
The environmental factors were interpreted from existing panchromatic photographs. Selective field checking was carried out to verify all factors indicated within each terrain evaluation boundary to an accuracy of 90 percent.

The numbers shown for each mapping area (Fig. 1b) represent a weighting system of not only the environmental terrain conditions within each area but also the influence of their immediate surroundings. One example of a consideration external to the immediate mapping area would be the existence of a potential drainage outlet, whereby lowering of the water table could be effected at minimal cost. The numerical designation for each environmental factor is primarily based on the experience of the terrain evaluator, his assessment of available potable water supplies, and the most recent technological advances in methods of sewage disposal. Therefore, these numerical evaluations, although considered to be valid at the time of the study, are subject to modification as further development takes place or as more effective means of sewage treatment become economical. For example, higher land values and more intensive development may justify a piped water system over difficult terrain, or a vacuum sewage removal system to a nearby lagoon site may become practicable.

Figure 1c shows the final stage in the environmental considerations and is normally prepared in the form of a clear plastic overlay that may be placed over white prints of the photoflexes of the mosaics on which the other factors previously discussed have been delineated. It is at this point that particular questions should be considered regarding future development, possible realignment of the existing primary Highway 103, or the provision of access roads to the shaded areas. It is evident from Figure 1 that the original considerations for the location of the highway in this particular area were relatively level topography and between 5 and 10 ft of overburden together with the alignment restrictions and the engineering and economical considerations of normal highway location and design. However, the highway was located and constructed at a time when the demand for recreational facilities on the lakes within this region of Muskoka, let alone the connecting rivers such as the Musquash, was virtually nonexistent.

These regional environmental evaluations, performed at different times and under substantially changed economic demands, permit both the planner and the engineer to evaluate the existing highway location and possible changes using definitive environmental information. For example, should direct highway access be provided to the single shaded area, designated by the number 19 in the lower right portion of the study area to the main highway? Should development within this area be encouraged by any form of service access routes, due to the constraints of shallow overburden, poor soil

Figure 1. Development constraints based on physical terrain evaluation.



(a) (b) (c)

Scale: 1 inch = ½ mile

Physical terrain evaluation boundary

TOPOGRAPHY
- Gently undulating slopes (0-10%)
- Moderately rolling (10-20%)
- Steeply rolling slopes (>20%)

DEPTH OF OVERBURDEN
- Shallow (<5')
- Moderate (5'-10')
- Deep (>10')

SOIL TYPE
- C COARSE - Sand and gravel
- M MIXED - Tills or medium grain sizes (e.g. - Fine sands)
- F FINES - Silts and clays
- O ORGANIC - Peat

SOIL DRAINAGE
- W Well drained soils
- M Moderately drained soils
- P Poor drainage conditions
- H High water table

SEPTIC TILE PERFORMANCE
- ✓ No apparent constraints
- REMEDIAL MEASURES NECESSARY
- R1 Requires tile bed extension
- R2 Requires individual site location
- R3 Requires fill or lowering of water table
- R4 Requires both R1 and R2
- X Unfeasible

WATER SUPPLY
- G Ground water
- L Lake
- R River
- C Combination of above
- N No water supply

- RO Rock outcrop and topographic slope (See topography legend above for slope symbols)
- O Deep organic soils
- Φ Deep organic soils (with drainage outlet)
- Windbreak, vegetation
- V Encroaching aquatic vegetation
- Sb Stagnant bay
- F Flooding
- C Existing culvert (and direction of flow)
- ✱ Hilltop
- Height of land
- Gradual slope (0-10%)
- Moderate slope (10-20%)
- Steep slope (>20%)
- Watershed boundary
- Drainage channels
- X Completed field check point
- FC Field check to be performed
- ④ Ground photograph (Number and direction)

drainage conditions, and the septic tile bed constraints indicated? Would provision of access to this last mentioned area encourage development in those shaded areas adjacent and to the left, and what would be the ultimate effect on the water quality in the lake downstream along the Musquash River?

The questions raised in the preceding discussion have serious environmental and social implications. The answers must be arrived at primarily through consultations between engineers and planners familiar with the implications of their actions. The answers to these questions could not possibly be contemplated by considering only that small portion of the total study area shown in Figure 1. However, the fundamental environmental considerations, together with their weighted developmental and engineering constraints, are available in a usable format to aid in making logical engineering and planning decisions.

Federal Lands: Sucker Creek Indian Reserve

The Sucker Creek Indian Reserve is located approximately 4 miles south of Little Current, Ontario, near the northernmost point of Manitoulin Island. This area has 8,000 ft of frontage on the north channel of Lake Huron (Fig. 2). The land area contained within the reserve boundaries consists of approximately 1,600 acres, the southerly portion of which is traversed by Highway 540, a secondary provincial highway having undergone improvements in alignment and servicing because of gradually increasing traffic counts. The cause of this increase is primarily improved primary road access and realization of the recreational development potential of this large freshwater island containing a number of inland lakes. Consequently, this area has been selected for discussion because of its accessibility to the north end of the island and the significant number of economic development potentials, from a terrain capability standpoint, within a relatively small land area.

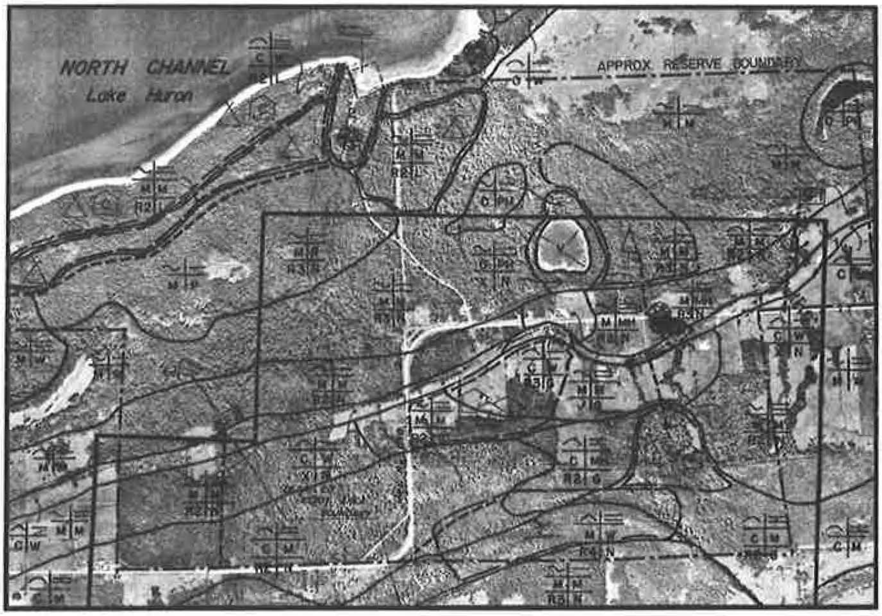
The legend shown in Figure 2 gives a symbology for potential land use and route location areas. (Fig. 1 legend shows physical terrain evaluation symbols.)

This study essentially involves a regional physical terrain evaluation for the entire reserve area, with specific reference to those land uses symbolized. Initially, topography, depth of overburden, type of soil, and soil drainage conditions were evaluated, and, in areas having terrain capability for the potential land uses shown, septic tile bed performance and water supply were also indicated. The portion of the reserve designated as "detailed study area" in Figure 2 was examined specifically with regard to suitable locations for townsite expansion and potential new townsite development in addition to economic development potentials. The study requirements were initiated by the Indian Band Council, sponsored by the Federal Department of Indian Affairs and Northern Development, and a 1-day field investigation was carried out to verify the airphoto evaluation.

The potential for intense cottage development along 8,000 ft of highly desirable shoreline, the associated potential of an excellent marina site, and the topographic suitability for ski slopes along the southerly boundary of the reserve combine to form a significant year-round potential recreational complex in an area previously not used extensively for this purpose. Even when evaluating an area for specific potential land uses, multiple land use capabilities are indicated, such as potential cottage and campsite development along the shoreline of the North Channel. Two potential townsite developments are indicated in order of preference as designated by number. The establishment of these communities in combination with the collective services, such as water supply, currently being installed would substantially improve the living conditions on the reserve for the native people. This factor, combined with the economic development potential, will, at the discretion of the Indian people, lead to staged recreational development of this highly desirable area.

Physical terrain evaluation and subsequent economic development potential assessment provide information that could affect the future development of Highway 540. As in the previous example, the highway has been located through terrain presenting a minimum number of engineering construction problems. However, in consideration of the economic development potential of the area, would relocation of the highway route

Figure 2. Economic land use potential based on physical terrain characteristics.



Scale of reserve area: 1 inch = 2,000

Scale of study area: 1 inch = 800

Potential land use boundary

No apparent constraints

Remedial measures necessary

Townsite

Residential

Commercial

Light industrial

Heavy industrial

School

Airstrip

Agricultural

Pasture

Domestic garden

Sewage lagoon

Sanitary landfill

Cottage development

Institutional

Marina development

Camping grounds

Picnic grounds

Golf course

Ski hill

Snowmobile trails

Merchantable timber

Gravel

Borrow

Highway with drainage structure location and direction of flow

Transmission line

Pipeline

Access road with drainage structure location and direction of flow

Scenic lookout

POTENTIAL LAND USE RATING AND ROUTE LOCATION EVALUATION - Numbers adjacent to or colors within the above symbols indicate relative capabilities.

EXISTING LAND USE AND ROUTE LOCATION - 'E' appearing adjacent to the above symbols indicates existing land use

from the central portion of the reserve toward and along the North Channel be economically feasible? Gravel is more available along this route, and what affect would this have on this decision? The existence of a potential marina site and the adjacent gravel deposit would, in all probability, result in lakeshore development of other lands off the reserve area; how would this affect the eventual location of Highway 540?

It may be seen from the preceding observations and questions to be considered that the future of Highway 540 within this particular area is dependent on a thorough knowledge of the physical environmental conditions and the interacting social and economic factors. Consequently, it is evident that prior knowledge of terrain capability within this local area will aid in consultations among the Indian Band Council, the Federal Department of Indian Affairs and Northern Development, and the Ontario Ministry of Transportation and Communications.

Specific Problems: Ski Resort Area

The ski resort shown in Figure 3 occupies the slope and foothills of Blue Mountain in the Delphi Point area south of Highway 26. The area is located in close proximity to the south shores of Nottawasaga Bay, approximately 90 miles north of Toronto in the southern portion of Georgian Bay. The section of Highway 26 shown in Figure 3 has two culverts designated as A and B to channel the flow originating from Blue Mountain into Nottawasaga Bay.

In 1969, the date of the photography shown in Figure 3, the ski resort filed a complaint against the Ontario Ministry of Transportation and Communications alleging that flooding of basements and tennis courts had occurred on its property. The resort owners attributed this to inadequate highway culverts and ditches. Subsequent ground investigations revealed that there was silting occurring in the highway drainage system and that organic pollutants were also present.

Therefore, two immediate problems existed: the cause of siltation of the highway drainage system and the source of the organic pollutants as these would eventually be discharged into Nottawasaga Bay through the highway drainage system.

A search for historical photo coverage revealed photography taken in the summers of 1954 and 1966. In addition, vertical panchromatic and infrared photography was taken in April 1969, and infrared color obliques were obtained in October 1969.

Drainage boundaries were established for each culvert referred to in Figure 3 for each set of aerial photographs, beginning with the 1954 photography. Preliminary examination revealed that ski runs were located on the side of Blue Mountain between 1954 and 1966, resulting in a significant reduction in vegetation cover.

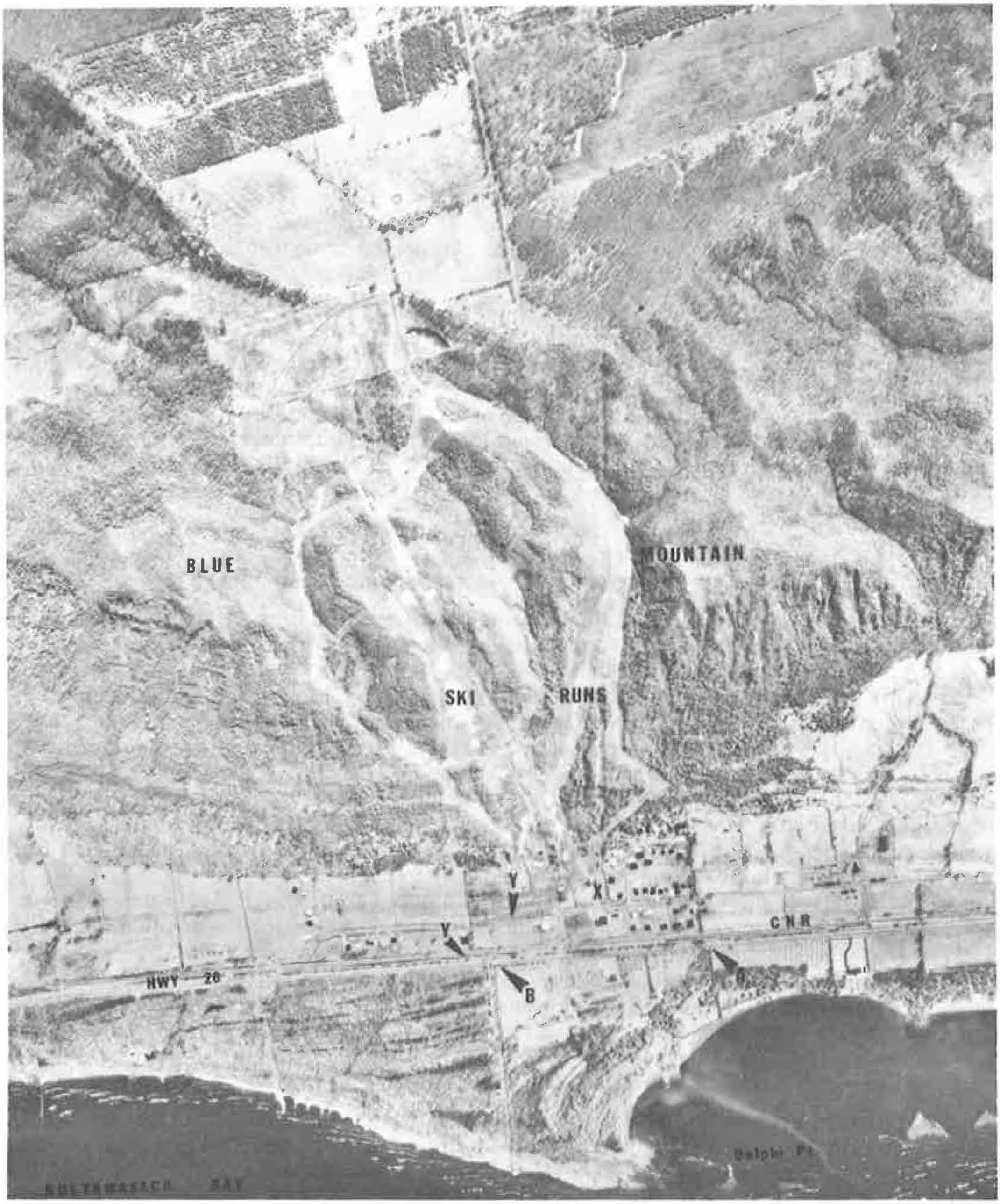
Comparison of the 1954 and 1966 aerial photography revealed the following:

1. Fifteen percent of the bush area had been removed for ski runs;
2. Thirty-five buildings consisting of cottages, chalets, clubhouses, and restaurants had been erected; and
3. The catchment areas of culverts A and B had been reduced by 5 percent and 8 percent respectively as a result of the shifting of the drainage boundaries caused by the location of the ski runs.

Primarily because of clearing of the bush for the ski runs (varying in width from 100 to 300 ft), surface runoff was increased and erosion of the soil accelerated. The majority of the eroded material was carried through natural watercourses within the catchment areas, resulting in the silting up of the culverts and a reduction in their capacity. Improper treatment of the sewage facilities for the 35 buildings previously mentioned, combined with flooding, caused raw sewage to enter the highway drainage system. Therefore, the combined runoff through culverts A and B was substantially increased. Between 1966 and 1969 an additional 15 buildings were constructed, thus increasing the organic pollutant concentration. Ditches, installed within the original catchment of culvert B, indicated substantial overloading (Y, Fig. 3), probably caused by the partial diversion of water at point X as shown in Figure 3.

Although the resort management stated that the slopes had been stabilized by sodding, thus reducing the erosion and partially stabilizing the runoff, oblique infrared color

Figure 3. Blue Mountain ski resort.



Scale: 1 inch = 1,676 feet

photography, taken in 1969, indicated that the roots of the sod had not yet taken, thus negating this theory. Therefore, through the use of historical photography and the oblique infrared color photographs, the following points were established:

1. Bush clearing, slope grading, building construction, and installation of service roads and parking facilities between the summer of 1954 and the spring of 1969 had increased the runoff significantly, thus causing rapid erosion especially on steep slopes because of the nature of the soil (this resulted in the accumulation of silts and clays within the highway drainage system);
2. The catchment areas of the culverts were changed as a result of the construction of new ditches, thus increasing their flow beyond the original design value; and
3. The construction of 50 buildings during the period from 1954 to 1969, located on the resort property, provided the only possible source of organic pollution, which accumulated in the highway ditches and culverts.

The preceding example substantiates the value of historical aerial photography in tracing land use changes to solve a specific highway maintenance problem and also indicates the value of specific types of film such as infrared color in further substantiating the environmental conditions under particular circumstances. As a result of this investigation, the owners of the Blue Mountain resort have taken specific corrective measures to reduce the siltation, thus eliminating the flooding of septic tile beds and reducing the emanation of pollutants.

CONCLUSIONS

Following is a summary of the conclusions supported by this paper:

1. A thorough knowledge of the environmental terrain factors within both a regional and localized band of existing and proposed highway routes is a necessary input for logical engineering and planning decisions;
2. This environmental terrain information can be specifically delineated using airphoto interpretation techniques from existing panchromatic photography (the accuracy of the initial interpretation is more than 80 percent, and this increases to 90 percent when selective field investigation methods are used);
3. Development rating systems using numerical values for environmental characteristics, based on experience and the most recent technological innovations, provide a realistic assessment of developmental capabilities and provide a flexible system for adaptation to technological advances;
4. Specific land uses should be evaluated and delineated, particularly within federally and provincially controlled lands, thus providing more definitive developmental information whereby highway needs may be more accurately predicted; and
5. The use of historical photography and special photographic emulsions, when required, are valuable in tracing land use developments, environmental changes, and existing terrain conditions to solve both regional and local concerns.

ACKNOWLEDGMENTS

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REMOTE-SENSING APPLICATIONS TO ENVIRONMENTAL ANALYSIS

W. C. DeLoach, Florida Department of Transportation

Environmental legislation has forced the highway planner to look for new aids to help provide input for the complex environmental reports now necessary for highway location approval. This paper reviews two remote-sensing methods used to date by the Florida Department of Transportation for environmental data acquisition and analysis. A corridor study prepared by photo interpretation and the use of infrared scanning for water temperature studies and underground void detection are explained in detail. The results of these studies confirm that remote-sensing techniques can contribute significantly toward furnishing factual answers to many environmental problems.

•WITH passage in 1969 of the National Environmental Policy Act, a new era began in highway location. No longer was the highway engineer able to make a decision based primarily on economics for highway location. The law required that an extensive report of the environmental impact of a project on the surrounding area be prepared. Project justification, corridor alternatives, environmental factors, and long-term effects of the project must be outlined and explained in detail before final location approval is granted by the Federal Highway Administration.

To provide data to highway planners for the preparation of the environmental impact statements, as well as for special environmental studies, the topographic office of the Florida Department of Transportation established a remote-sensing unit in 1970. This unit is staffed with personnel who have expertise in the areas of highway engineering, engineering geology, forestry, biology, and geography and who have training in remote-sensing techniques. To date, this unit has made extensive use of two remote-sensing methods of data acquisition and analysis: basic photo interpretation from black-and-white photography and thermal infrared scanning analysis.

BASIC PHOTO INTERPRETATION

The first project undertaken by the remote-sensing unit was the mapping of a 4-mile wide, 40-mile long corridor using photo interpretation of black-and-white photography. This mapping was to be used to study the location of I-75 east of Tampa, Florida.

The general intent of this project was to locate and identify features to a degree of detail consistent with some of the information needs for preparation of the environmental impact statement. Five separate phases of mapping were deemed necessary to provide the required information: land use, key features, property boundaries, drainage, and engineering soils.

Aerial photographic mosaics (scaled at 1 in. = 1,000 ft) were used as base maps for delineating the preceding five categories. This base allowed for an adequate degree of detail while maintaining a convenient sheet size.

Land Use

For the land use map to reflect the actual use of the terrain, a use classification system is required. The classification system must be broad enough to include all important uses of land and also one that can be used accurately and consistently at a photo scale of 1 in. = 2,000 ft. To meet this requirement, a system was developed

that included 96 different identifiable land uses grouped into 12 major divisions. Of the 96 uses, 51 were actually used in the I-75 project. Figure 1 shows an example of the land use map; the classifications used are given in Table 1.

Key Features

The land use maps, with their classification consisting of 51 categories, give quite a detailed picture of current land use. There are, however, certain categories that greatly influence the location of a highway. In order to emphasize the location of these more important features, a key features map was produced. This map delineates only 30 of the original 51 land use categories (Fig. 2).

Property Boundaries

This map set provides the planner with information concerning the limits of individually owned parcels of land and their approximate areas in acres. The aerial mosaic is used as the base map on which the properties are delineated. Property information was extracted from tax maps of the area. Figure 3 shows a typical property map.

Drainage

Impact statements require the planner to include a detailed explanation of the effect the project location will have on water pollution, drainage, and the water table. The drainage map will provide the planner with input for this phase of the report. This map details the existing drainage pattern within the study area. Again, the aerial mosaic was used as a base map. An explanation of the different types of lines used in delineating the drainage is shown on the drainage map (Fig. 4).

Engineering Soils

The soil maps provide a general description of the engineering soil types along the corridor. The classification was developed so that a very general correlation could be made with the AASHO classification. A sheet of the soils mapping is shown in Figure 5.

With the exception of the property information that came from tax maps, all information was obtained by photo interpretation. The interpreters used black-and-white contact prints (scaled at 1 in. = 2,000 ft) and a stereoscope with two and four power lenses. The data were then transferred to the base maps. The remote-sensing unit produced the 65 map sheets in 13 weeks using 240 man-hours. Even though our planners had made use of aerial mosaics for route study for many years, they were not trained interpreters; therefore, only minimal information was obtained. The general consensus of the planners who used this corridor study was that it contributed significantly toward furnishing factual answers now necessary in highway location.

THERMAL INFRARED SCANNING

Water Temperature Study

In March of 1971, the city of Tallahassee requested the assistance of the U.S. Department of Transportation in a study to determine the distribution effect of the thermal effluent into the St. Marks River from its electric generating facility. After reviewing the problem, a decision was made to use thermal infrared scanning because of its potential to differentiate variations in temperature of surface water within a degree centigrade.

Six overflights were made during a 24-hour period. These flights occurred at 11:50 a.m., 5:00 p.m., and 7:30 a.m. the following morning at altitudes of 500 and 1,000 ft. The thermal imagery was acquired using a scanner manufactured by Daedalus Enterprises, Inc. Concurrent absolute temperature recordings were also made along the flight lines using a radiometer manufactured by Barnes Engineering Co.

The evaluation of the data was based primarily on the radiometric profile that was recorded simultaneously with the thermal imagery. Because we did not have access

Figure 1. Land use map.

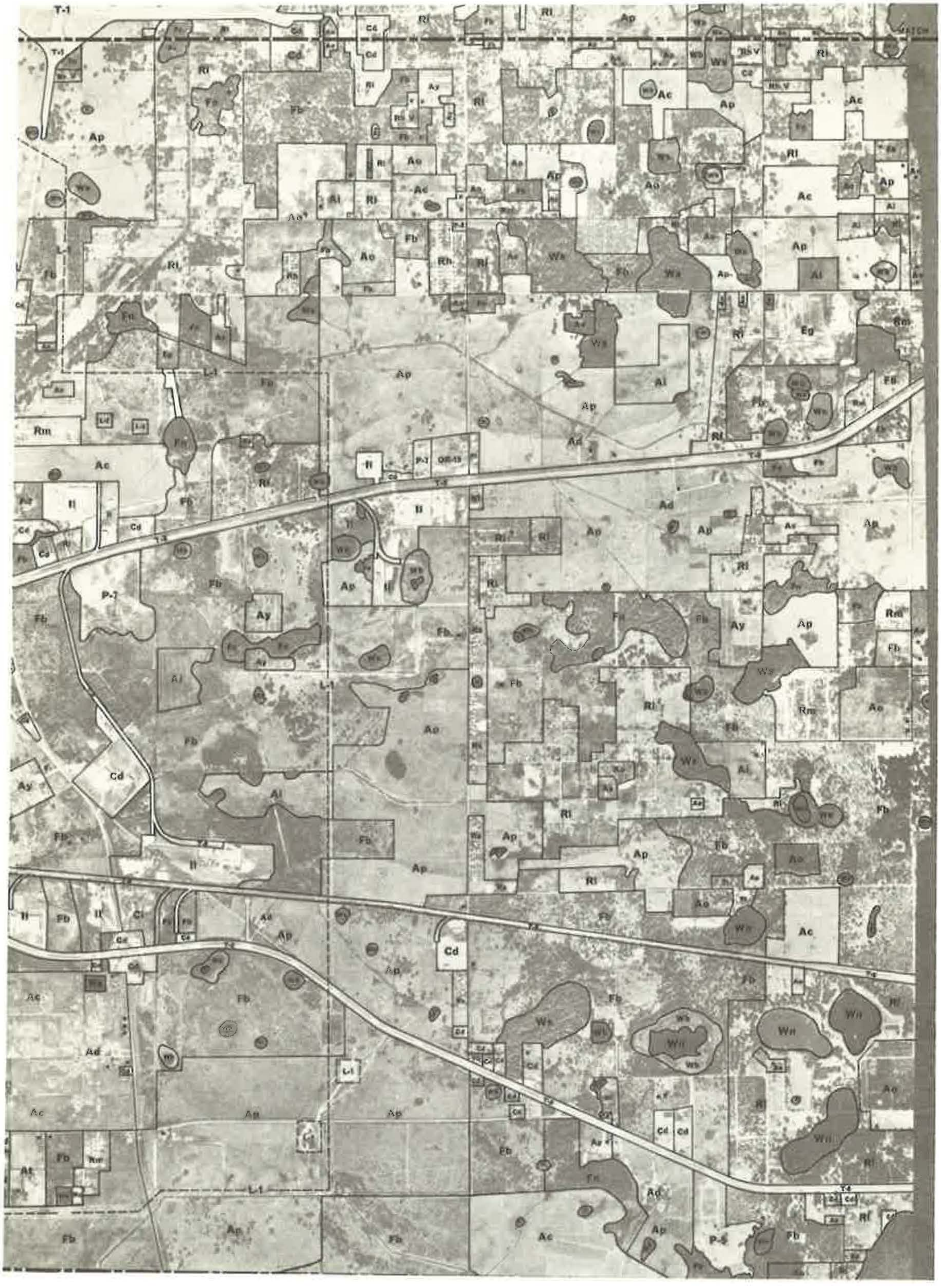
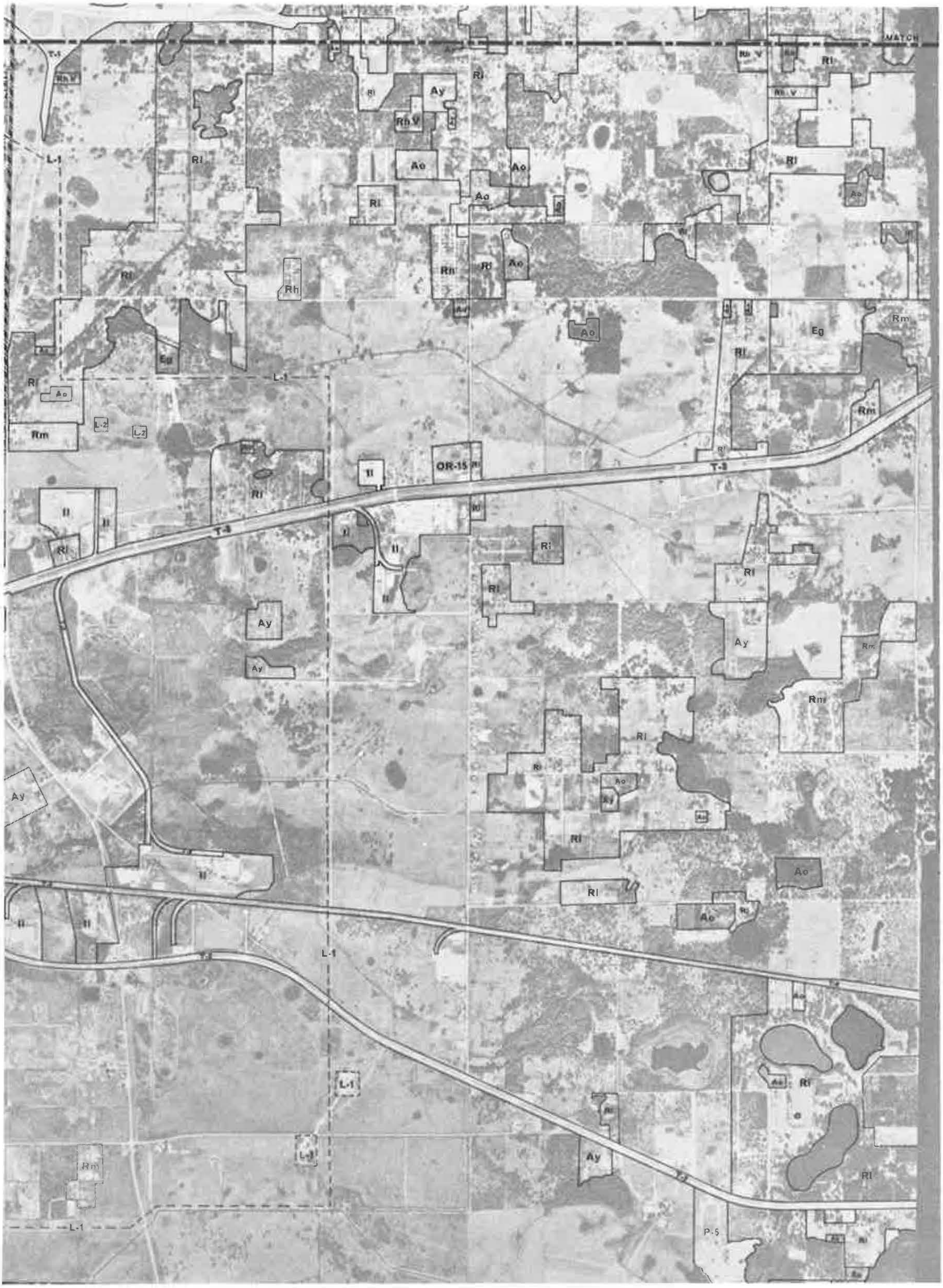


Table 1. Land use classification for Figures 1 and 2.

Classification	Specific Use	Code
Residential	High density (less than 1/8 acre)	Rh
	Medium density (1/8-1/2 acre)	Rm
	Low density (greater than 1/2 acre)	Rl
	Shoreline developments	Rs
	Under construction	Ru
	Inactive (street pattern, weeds, no houses)	Ri
	Apartment buildings (Rh-z)	Z
	Trailer parks (Rh-v)	V
Agriculture	Groves or orchards	Ao
	Specialty farms (horticulture, aquatic agriculture)	Av
	Cattle and dairy farms	Ad
	Horse farms	Ae
	Hog farms	Ah
	High intensity cropland	At
	Cropland (improved pasture)	Ac
	Pasture (unimproved)	Ap
	Inactive	Ai
Commercial	Shopping center	Cc
	Commercial strip development	Cs
	Industrial business	Cd
Industrial	Light manufacturing	Il
Extractive industries	Gravel, sand, clay	Eg
	Minerals	Em
Public facilities	Education institutions	P-1
	Religious institutions	P-2
	Health institutions	P-3
	Cemeteries	P-5
	Water supply, sewage treatment	P-6
	Dumps, junk yards	P-7
	Fire towers	P-10
Outdoor recreation	Golf courses	OR-1
	Developed public parks	OR-8
	Race tracks	OR-9
	Outdoor museums and monuments	OR-12
	Community recreational facilities	OR-13
Transportation	Four-lane roads	T-2
	Railroad	T-8
	Abandoned railroad	T-9
	Personal airport	T-12
	Noncommerical	T-13
Communications	Transmission lines (power and telephone)	L-1
Forestland	Rangeland	Fb
	Fully stocked natural stand	Fn
	Plantation (planted woodlands)	Fp
Wetland	Marsh	Wb
	Swamp	Ws
	Marine	Wm
Water	Natural (greater than 1 acre)	Wn
	Artificial (greater than 1 acre)	Wc
	Streams and rivers (greater than 100 ft)	Wr
	Natural ponds (less than 1 acre)	n
	Artificial ponds (less than 1 acre)	p

Figure 2. Key features map.



Note: Symbols are same as given in Table 1 except Ay is specialty farms, OR-10 is outdoor museums and monuments, and OR-15 is community recreational facilities.

Figure 3. Property boundaries map.

Figure 4. Drainage map.

Figure 5. Soils map.

Engineering soils classification: C is silty or clayey sand, R is fine sand, Rx is fine sand (clean and very well drained), F is clayey soils, P is peat and muck, H is man-made land (filled area), and ◌ is sinkhole.

to a densitometer, no attempt was made to determine temperatures in other portions of the imagery. It was felt that the temperature profile along the center of the imagery provided sufficient data for this study. A sample of the imagery is shown in Figure 6.

From the temperature data extracted from the imagery of the six overflights, we found that the maximum temperature increase in surface water within the river was only 4 C. This increase could be attributed directly to the effluent from the power plant because a delimiting line between the two temperature zones was very evident.

Underground Cavity Location

At the present time, the remote-sensing unit is involved in an extensive research project directed toward the location, by remote-sensing techniques, of limestone voids that occur in the general vicinity of existing and proposed bridge foundations. Thermal infrared scanning is being investigated extensively to determine its usefulness in delineating these sink-prone areas.

A portion of US-19 just north of Chiefland, Florida, has been chosen as a test site for this investigation because of recent sink and solution pipe activity in the area. Thermal imagery was taken during the night of November 16, 1971, at an altitude of 1,000 ft in a bandwidth range of 8 to 14 microns. From this imagery, 70-mm positives were made.

After visual analysis of the positive film with the aid of a light table and magnifying glass, several anomalous patterns were delineated. The anomalies selected were generally "cool" patterns. This selection was based on the hypothesis that the ground surface temperature should cool more rapidly if an underground cavity or deep fissure in the bedrock exists below.

The true ground conditions associated with the surface anomalies were established by a boring program. Anomalous trends were transferred from the 70-mm positives to enlarged photographs so that the exact position of the anomaly could be scaled for field location of the drill sites. Figure 7 shows an enlargement of the thermal imagery with the anomalous areas delineated. (As mentioned, the anomalies were selected using the 70-mm positive and magnifying glass. They are not obvious on the enlargement.) Sixteen borings were made in the selected areas, twelve of which encountered either deep fissures in the bedrock or cavities above the water table. Thus, the apparent correlation between thermal anomalies and subsurface solution activity is 75 percent reliable. Considering the extremely crude method used to interpret the thermal imagery, this correlation appears to be excellent. The overall success of this test has definitely established the utility of thermal scanning, combined with interpretation and analysis by qualified personnel, for locating areas of high sink activity.

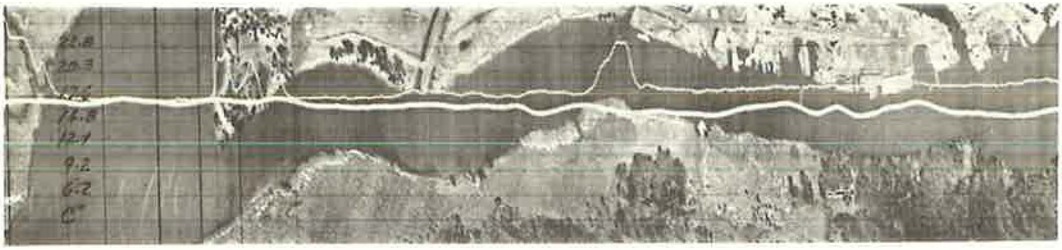
The NASA test facility, Bay St. Louis, Mississippi, has made available to us the use of their microdensitometer. We are now in the process of performing microdensitometer analysis on the thermal imagery. If this analysis confirms the apparent success of our program to date, we will be ready to proceed with plans to implement scanning as a means of detecting underground voids hazardous to highway and bridge locations.

SUMMARY

The field of remote sensing has experienced rapid growth during the past several years. Increasing concern toward the preservation of our surrounding environment has directly affected this growth. Today, the remote-sensing scientist has at his disposal a broad variety of remote-sensing instruments for data acquisition. The sophistication of these sensors tends to overshadow the most important phase of this field, interpretation and analysis.

In order to obtain the maximum result from sensor data, we must use a team of talented personnel with diversified backgrounds. Using the team approach, data analysis of the geology, forestry, biology, and geography of a study area can be used to give a more complete study.

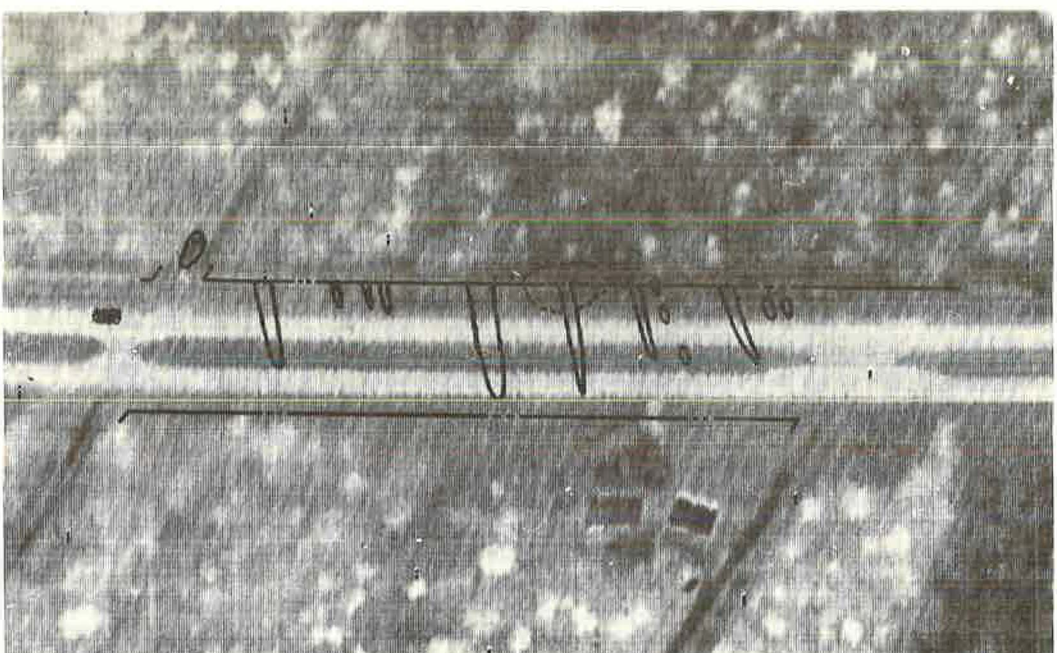
Figure 6. Imagery map.



70mm positive of thermal imagery of St. Marks River
Flown at 11:50 am - altitude 500 feet

70mm positive of thermal imagery of St. Marks River
Flown at 11:46 am - altitude 1000 feet

Figure 7. Thermal imagery map.



The remote-sensing unit of the Florida Department of Transportation is now contributing valuable information for use in solving environmental problems. As the personnel of this unit gain experience with the many sensors and become more knowledgeable of the physical features of Florida, remote sensing will be invaluable as a tool for environmental analysis.

SEMIAUTOMATED LARGE-SCALE MAPPING

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Ministry of Transportation and Communications, Ontario

A semiautomated map-making system has been devised. It consists of placing an information-bearing magnetic tape into a computer system to produce two-dimensional representations of terrain via an automatic drafting machine. Stages in map production and coding, data processing, and drafting procedures are described. The system has been operating successfully for more than 3 years.

•IN 1969, the photogrammetry office of the Department of Highways, Ontario [now the Ministry of Transportation and Communications (MTC)], prepared an engineering report that advocated the Department's entry into automated techniques and therein recommended the purchase of an automatic drafting machine (ADM). The Department accepted the recommendations of that brief after cost-benefit and computer feasibility studies. In April 1970, a Gerber 1232 ADM system was installed. It took 1 month to get this system installed and tested and an additional month to get the input from the stereoplotting instruments oriented toward the standard drafting software provided by the Gerber Scientific Instrument Co. At this point, the system was in an initial production stage.

This initial production stage lasted for 1 year, during which time the programmers wrote the necessary editing software to implement what is considered to be a fully production-oriented automated system.

In the past, a map was generally considered as being a two-dimensional representation of the terrain presented on paper. We suggest that the magnetic tape, which contains all of the necessary x, y, and z coordinate data along with related topographic codings, can also be considered as a map. As a matter of fact, the magnetic tape becomes the map. Our semiautomated system then places this map (magnetic tape) into a computer system to produce any number of by-products, some of which could be conventional two-dimensional representations of the terrain on paper, i.e., via an automatic drafting machine. Each of these by-products can be produced in the scale, content, density, symbol, area, medium, and state requested by the map user.

Economic and technical considerations dictated the development of a semiautomated system that would replace certain human activities by machines. In particular, the system utilizes minicomputer hardware and software to replace much of the more mundane work previously included in the conventionally oriented mapping systems. However, by using the appropriate computer software, it is possible to retain some of the cartographic "license" that is necessarily removed by full automation.

The system was developed within a highway authority, which has a large and continuing demand for large-scale mapping at scales ranging from 480:1 to 12,000:1 (40 ft to 1 in. to 1,000 ft to 1 in.). However, experience with the system and some experimental studies demonstrate that most of the concepts can be equally applied to the areas of small- or medium-scale mapping.

In producing large-scale maps through semiautomated techniques, the main objective was to produce a plan that was equal to or better than the plan that was produced through the traditional manual drafting techniques. Of course, this dictated that the drafting be performed on stable base materials, that there be the capability of drawing many shapes or symbols, that a certain amount of cartographic "license" be incorporated into the plan, and that there be the capability of editing and completing topographic features. A second objective was the production of a digital "picture" of the terrain on the magnetic tape, which subsequently can be "eaten and digested" by computers.

DESCRIPTION OF THE SYSTEM

The present semiautomated cartographic system contains the following hardware elements: four stereoplotters (Zeiss Planimats), four digitizers (two Wang 2300 and two Instronics Gradicon), minicomputer (Hewlett Packard 2116B with 16K 16-bit words), magnetic tape read unit (Gerber M12 to read seven-track tape, 200 or 556 bpi), punched paper tape reader (Gerber), teletype (ASR 33), magnetic tape I/O (HP 7970 to I/O 800 bpi EBCDIC code, IBM compatible), computer disk unit (HP disk, 1,200K words), drafting table (Gerber 32 table, having screw gear drive in both axes), and light-beam drafting head (Gerber optical exposure head OEH-B). The interrelations among all these hardware elements are shown in Figure 1.

EQUIPMENT SELECTION

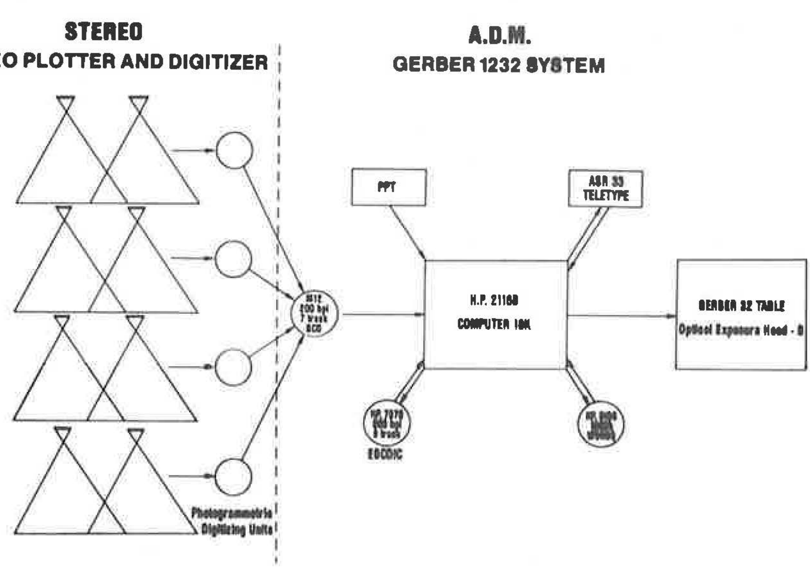
Stereoplotters

The selection of the Zeiss Planimat stereoplotter as the instrument for use in this system followed a complete investigation of the available instruments. The search was conducted to identify an instrument satisfying all the following requirements. The Zeiss Planimat was found to be the only instrument satisfying all requirements and was accordingly selected. Optimum requirements of the system stereoplotter are that it accommodate the range of focal lengths from 300 to 85 mm; be designed as a large-scale plotter (i.e., 2X to 3X enlargement from photo scale to model scale); accommodate a pencil manuscript immediately in front of the stereo-operator (this pencil manuscript being used as a control document, an edit document, and an aid to interpolation); and accommodate the absolute orientation element kappa (K) inherent in its design.

Automatic Drafting Machine

The selection of the Gerber 1232 automatic drafting system followed a similar period of careful product evaluation. Three factors were considered paramount in any acceptable drafting system: It must be fully developed and tested in a production environment, rather than being a new system's prototype model; it must have a minicomputer controlling unit to allow addition of specialized software; and it must have the capability of producing cartographic products having a "strength of presentation" and accuracy that exceed manually drafted products.

Figure 1. MTC mapping system (hardware configuration).



These considerations led to the selection of the Gerber 1232 system because it consisted of a Hewlett Packard 2116B computer as the control unit; the "32 model" drafting table with an accuracy of better than 0.001 in., good operation speed, and a 48- by 60-in. usable area; and the OEH-B optical exposure head that is capable of supplying up to 24 apertures or special symbols or both.

The optical exposure head was deemed critical because only by this method can high-quality plotted products be produced reliably at high speeds. The optical exposure system, also called "light-beam drafting" causes lines to be produced on photosensitized materials by exposing them to a light beam of appropriate width. The subsequent development of the completed plot produces the black lines. The method requires that the drafting table be placed in a photographic darkroom.

The computer control unit was also important because data manipulation is necessary in addition to controlling the drafting machine's functions.

SYSTEM OPERATION

Photogrammetric Procedures

The first three stages in map production with the system are the same as with conventional photogrammetry: Overlapping aerial photographs are taken of the area to be mapped; the aerial photographs are developed by standard techniques; and a stereoscopic model, utilizing those photographs, is created with a stereoplotter/digitizer.

At this point, however, instead of producing graphical information from the stereoplot, digital information is output to a magnetic tape recorder. This output consists of x, y, and z coordinate values, plus topographic codes (for features such as roads, contours, or buildings), subcodes (designating individual topographic features), and accuracy codes (scale of photograph). The completed digital tape recording constitutes, in effect, the entire map and contains all the information that the stereomodel is capable of yielding.

Methods of Data Coding

The coding procedure was developed by the MTC engineers and programmers. It is central to the successful operation of the system. Two types of data recording are possible: a time-mode recording, in which the x, y, and z coordinate values and associated data are continuously placed on the tape automatically at a sequence of equally spaced time intervals for as long as the stereoplotter operator depresses his "record" pedal; and a point-mode recording, in which one set of x, y, and z coordinate values and associated data are placed on the tape each time the stereoplotter operator depresses his "record" pedal. The time-mode method is used to record most natural-made features such as contour lines, forest outlines, and streams, whereas the point-mode method is used for most man-made features.

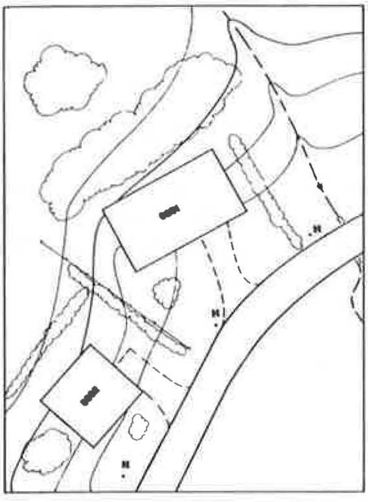
Additional data are required for feature specifications and identification. These numeric codes are entered by a fixed-address facility incorporated in the digitizing equipment. The following sequence is automatically recorded for every topographic feature record: end of data block [an asterisk (*) is used], code value of three digits, subcode value of four digits, an accuracy code value of one digit, and the corresponding x, y, and z data values.

The code defines the type of feature, and the subcode differentiates among the features. For example, one house shown in Figure 2 has the code-subcode combination of 6000001, while the other house has 6000002. The accuracy code defines the relative true placement of the measured data values. It is based on the scale and quality of the photography, level of ground control, etc. The single-digit value is chosen with reference to a hierarchy of data bases.

Data Processing and Drafting Procedures

All the digitized tape data are passed through the ADM system twice. The MTC system includes a computer unit with somewhat larger than minimum memory requirement to facilitate this data processing function. On the first pass through the system, all the hardware shown in Figure 1 is used except the table; on the second pass, all the hardware is used except the magnetic tape read unit (seven-track).

Figure 2. MTC mapping system (topographic-code configuration).



END OF BLOCK	CODE	SUB CODE	ACCURACY CODE	X	Y	Z
*	C	SC	AC	X	Y	Z
(1)	(3)	(4)				

EXAMPLE:
BUILDINGS

*	600	0001	4	X_{1_1}	Y_{1_1}	Z_1
*	600	0001	4	X_{1_2}	Y_{1_2}	Z_1
*	600	0001	4	X_{1_3}	Y_{1_3}	Z_1
*	600	0001	4	X_{1_4}	Y_{1_4}	Z_1
*	600	0002	4	X_{2_1}	Y_{2_1}	Z_2
*	600	0002	4	X_{2_2}	Y_{2_2}	Z_2

etc.

During the first pass, the following data manipulations are performed:

1. The input data are cleaned up of any stray parity errors caused by dust or other interferences.
2. The human errors are removed. These errors fall into two categories. First, mistakes are errors that the stereo operator makes while he digitizes. He is conscious of these errors, and, having made the error, he puts more information onto the magnetic tape to say that the previous information is erroneous. He then proceeds with valid information. Second, blunders are the unconscious errors that the stereo operator makes during his digitizing process. These blunders are sought out with software programming that puts the input data through certain logic subroutines to ensure its compatibility.
3. The input data are then subjected to software routines to "square up" building outlines.
4. The input data can be "blocked" into predefined geographical areas corresponding to the provincial (Ontario) coordinate grid system.
5. The data are copied onto nine-track magnetic tapes.

The nine-track tape so produced forms the actual data base and in effect constitutes the entire plan.

On the second pass, this information is passed onto the automatic drafting machine. On line with this operation, the punched paper tape unit reads in a program of instructions to the ADM. Apart from plotting commands, directions as to scale, content, density, symbols, orientation, and area are generated at this stage.

The Gerber model 32 high-precision drafting machine with OEH-B optical exposure head operates automatically on the instructions from the computing unit and transfers the information onto photosensitive film. Line width is controlled automatically by selection of the appropriate aperture from a bank of 24 apertures. In addition, a number of standard symbol flashes are available as an alternative to programming the symbol drawing information in its entirety.

A special feature of this machine is automatic exposure compensation to prevent exposure differences due to variations in traveling speed of the optical head. A closed-loop servo feedback system increases or reduces the light intensity proportional to the velocity of the photo head.

CONCLUSIONS

The system has been in production for 3 years and 2 months. It has been most successful as the following statistics indicate:

1. The four stereoplotters have been working two shifts, or $14\frac{1}{2}$ hours per day; and
2. The drafting system has logged more than 11,000 hours (an average of 14 to 15 hours daily), which break down to 17 percent data edit mode, 69 percent drafting mode, 7 to 8 percent research and development, and 6 to 7 percent maintenance and installation.

The preceding statistics are valid for the period ending June 1, 1973.

An economic analysis prior to purchase indicated that such a system would effect the following savings: unit costs (map), 46 percent; expended man-hours, 58 percent; lapsed time for production, 75 to 80 percent; and considerable reduction of resurveying efforts. A detailed check on these figures has not been run. However, a rough review does indicate that they are realistic, perhaps even conservative. The last factor (reduction of resurveying efforts) probably requires additional comment. It was anticipated that the availability of terrain data on magnetic tape would allow rapid reanalysis of the data to produce digital terrain models, design volume calculations, etc., without additional field or photogrammetric surveys. This has begun to occur in practice. Further savings occur when new information is merged with older data to update them.

MEASURING AND DEPICTING TROUBLE AREAS IN STEREOMODELS

Wayland Norell, Ohio Department of Highways

Landslide detection by applying geology and photo interpretation to photogrammetrically produced highway route investigation and design maps is a continuing policy of the Ohio Department of Highways. Federal Highway Administration funds permitted landslide research and development of an air-photo manual relating to this foundation problem. Stereocompilers, who are trained to detect landslides, can earn their entire career salaries by calling attention to slope instability that, if otherwise undetected, would result in a highway embankment failure. Implementation is based on anomalous contour configuration that contradicts normal topographic expression. One unexpected result of the research was detection of a regional troublemaker with a signature, the Upper Conemaugh red beds. They occur in an arc 100 miles long and 15 to 40 miles wide. As predicted, highway construction provoked numerous back slope slides on the red beds. Further, in the landslide manual, anomalies in the form of bulges were tentatively indicated as potentially more unstable than the visibly sliding slopes. One bulge proved to be the site of one of the worst slides ever involved in a highway cut in Ohio.

•BY the early 1950s, southeastern Ohio had been acknowledged to be an area of landslide prevalence. Condit (2) repeatedly mentions landslides in his assessment of terrain in Ohio. In their study (1), Baker and Chieruzzi rate the region as "severe" with regard to landslides.

Other evaluations have concurred with these opinions, and a study of landslides was initiated because the aerial engineering section of the Ohio Department of Highways had air-photo coverage of numerous route corridors that had been recorded for photogrammetric mapping.

CASE STUDIES

In 1957, a state highway terrain analysis revealed a convergence of evidence that indicated a slope was not stable. The evidence included texture and photograph tones above the existing highway showing that the portion of the field is untillable, fence misalignment indicating slope movement, and topographic position at headward end of drain (Fig. 1).

Field investigation resulted in special highway design to treat this unstable condition. The treatment consisted of cutting a 20-ft wide trench into the existing slope and placing suitable embankment material to backfill to the proposed design grade.

In contrast to the previous unstable condition, this unstable condition was detected and symbolized during highway design mapping.

Convergent evidence of unstable conditions include light and dark photograph tones of slope slumping, springs issuing from midslope, small alluvial fans, and an unfarmed wet meadow from the toe of the slope to the run that drains the valley (Fig. 2). An embankment superimposed on this slope failed prior to paving (Fig. 3).

These case studies demonstrated that our stereocompilers could detect, recognize, delineate, and symbolize foundation problem areas during route investigation and highway design mapping.

Figure 1. Evidence of slope instability (1 is uncultivated portion of slope, 2 is fence misalignment, and 3 is topographic position at headward end of drain).

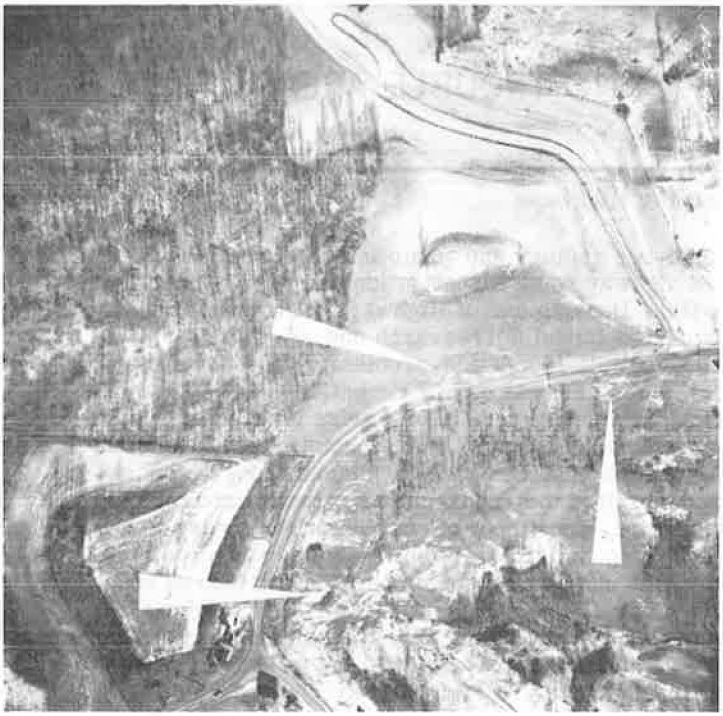
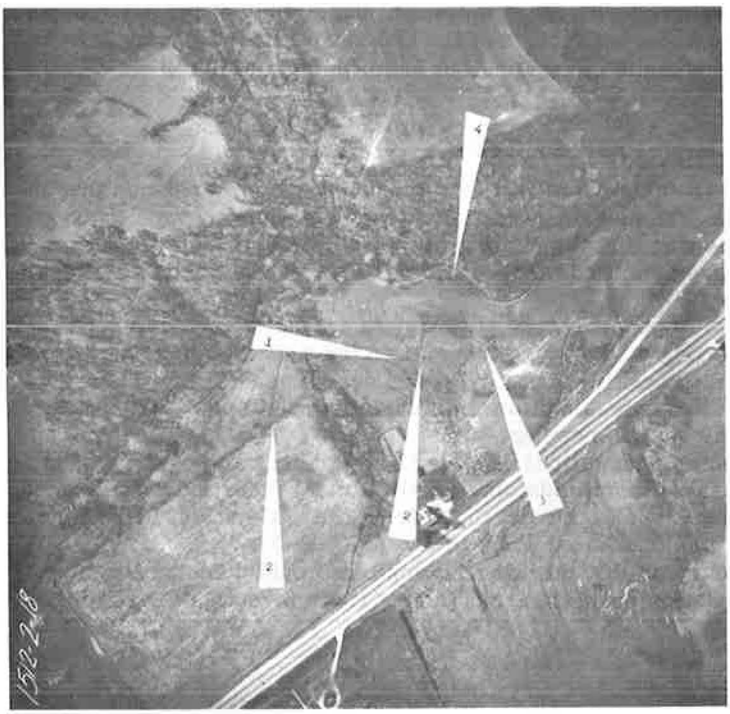


Figure 2. Unstable soil conditions (1 is soil slumping, 2 is springs, 3 is small alluvial fans, and 4 is wet, unfarmed meadow).



The criteria for locating unstable slopes include anomalous contour configuration when contrasted with adjacent stable slopes and the associated visible evidence as seen in the projected stereomodel.

As a result of these findings, Federal Highway Administration funds were granted for researching and developing photograph patterns of potential highway foundation problem areas. These stereopair studies are produced for the compilers who photogrammetrically map route corridors and terrain where highways are to be designed.

Initial research was devoted to landslide conditions, and a manual consisting of appropriate three-dimensional air-photo views and information sheets was developed. The compilers were then given a short course in the research findings. Their knowledge of the appearance of landslides and the associated anomalous contour configuration they observed during compilation enabled them to detect, recognize, and delineate unstable areas.

Figure 4 shows a portion of a highway design map. It was produced prior to the landslide research. Disorientation of the contours on one area of the slope vividly contradicts the adjacent contours where the slope is stable.

A proposed highway centerline traverses the lower portion of the slide area.

To preserve the original appearance of the map no delineation has been done. This enables the viewer to judge the contour anomalies.

After the landslide research had been completed and the compilers trained to recognize unstable conditions, a landslide was detected during highway design mapping (Fig. 5).

Apparently removal of the toe-of-slope material to construct the earthen dam and the associated saturation resulting from the ponded water conjoined to trigger the landslide.

The diagonal line above the landslide is an interceptor ditch that was apparently installed to divert upslope water away from the slide.

Figure 6 shows a portion of the highway design map produced by a stereocompiler using the photography shown in Figure 5.

The limits of instability are indicated by the dashed line shown in Figure 6.

The arrows symbolize the slope movement and its direction.

Contour configuration is anomalous thereby delineating the unstable area and the interceptor ditch.

Special highway design to treat this instability was provided because part of an embankment was to be placed on the landslide.

Implementation of this research is a continuing policy in Ohio. Each compiler has the skill to detect landslides that, if otherwise undetected, could result in a repair cost equivalent to his entire career salary.

THE DESPICABLE UPPER CONEMAUGH RED BEDS

The previous remarks will serve to introduce an interesting chain of events that led to the detection of a regional troublemaker that presented serious highway construction problems.

In 1963, a terrain analysis for an Interstate highway revealed abrupt changes in the slope angles that reflected the rock types within the landforms. More resistant stratigraphic members above and beneath served to bracket about 140 ft of softer strata.

At the northern boundary of this project, the gentle slope occupied a midslope position. The regional trend of the strata along the proposed highway is southward, decending about 30 ft per mile; therefore, at a point 6 miles south along the study area, the lower resistant rocks and the lower part of the softer strata had passed below the point to which erosion had progressed. Figure 7 shows the gentle, unstable slope bracketed between more resistant stratigraphic members.

The findings of this terrain analysis and the subsequent foundation investigation resulted in special highway design relating to the gentle slope because of its persistent indications of instability.

Figure 3. Embankment failure.

Figure 4. Highway design map.

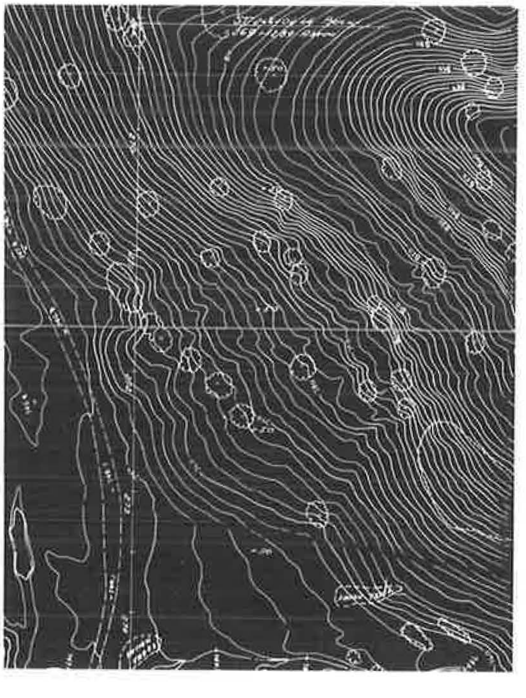


Figure 5. Landslide area (1 is landslide, 2 is interceptor ditch, and 3 is proposed centerline for highway).

Figure 6. Highway design map produced from Figure 5.

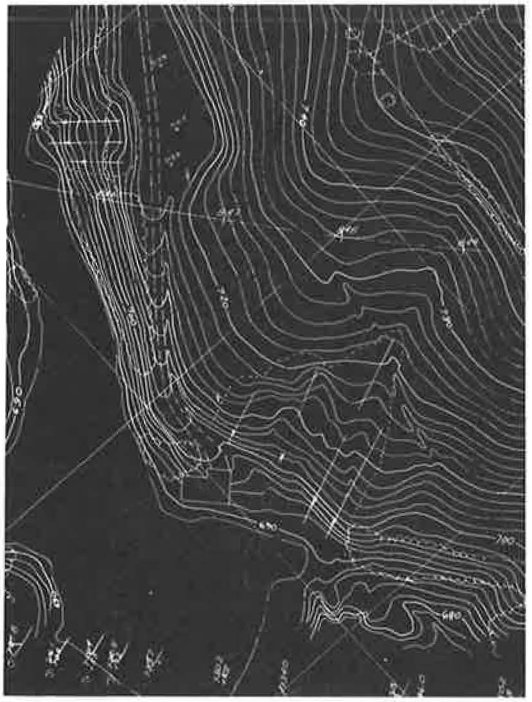


Figure 7. Stereopair showing gentle slope bracketed between resistant rocks.

When the landslide research was initiated in 1965, countless air photographs were studied to select categories and stereopairs for the landslide manual. These had been recorded for photogrammetric work in southeastern Ohio (3). At that time a large percentage of the existing state routes had been photographed. It was during this phase of the research that there evolved the realization of a persistent landform condition in many locations. Recurring views of a gentle, unstable slope bracketed between steeper slopes were found to be common. This was the same type of topography noted during terrain study for the Interstate highway 2 years before.

Further investigation revealed that the capping-resistant rocks are the Monongahela formation and the unstable, gentle slopes are formed on the Upper Conemaugh formation.

Figure 8 shows a classic Upper Conemaugh landform including the steeper Monongahela rocks capping the hill. Note that lower resistant rocks, from the reservoir shore to the Upper Conemaugh red beds, have drainage channels incised into them, but they tend to terminate at the base of the gentle slope.

Following detection of this regional photograph pattern, a section of the manual was devoted to examples from the counties where the Upper Conemaugh red beds outcrop. The slopes shown in Figure 9, photographed 35 miles southwest of the landform shown in Figure 8, make up one of the best stereopairs obtained. The text contained this statement: "Sliding is so prevalent that mapping the areas which are not sliding would greatly simplify the plotter operator's task."

UPPER CONEMAUGH RED BEDS INVOLVED IN HIGHWAY CONSTRUCTION

A review of post-construction photography recorded several years after the Interstate highway was opened to traffic substantiated the term "despicable" for the Upper Conemaugh red beds.

At least 33 backslope movements can be detected where cuts were made involving red beds along a 4-mile stretch of Interstate highway.

Although special highway design had been incorporated into the plans to minimize the problems associated with these strata, Figure 10 shows delineations of detectable backslope movements along approximately 9,000 ft of the new highway.

ANOMALOUS BULGES ON UPPER CONEMAUGH SLOPES

It has been established that the Upper Conemaugh red bed can be observed in an area at least 100 miles long and varying between 15 and 40 miles wide. The regional similarity of the landforms and the persistent instability were documented during a 1-year concentrated study of landslides.

The most fascinating contradiction found on the Upper Conemaugh topography was not, however, its persistently visible unstable condition; rather, it was the presence of certain anomalies. For this reason, additional research time was requested because, as was stated in the text accompanying the manual, "On many landforms the sliding can be observed everywhere. On other landforms some segments of the slope reveal a bulge where the slope appears to be stable. These perplexing anomalies may be potentially more unstable than the visibly sliding segments, when involved in construction."

Figure 11 shows that red beds occur from the floodplain up to the Monongahela caps. The lower resistant rocks have dipped below the point to which erosion has progressed. The delineator indicates a bulge that "appears to be stable."

Figure 12 shows the bulge during highway construction. The delineator indicates the scarp of the landslide involving the bulge.

Excerpts from a paper given by Marshall (4) relating to this bulge include the following:

> One of the largest slides we have ever had in a cut slope occurred on I-77 . . . in Noble County . . . . In January of 1967, a slide occurred in the east slope . . . . This slide did not stop at the roadway as is usually the case with a cut slope landslide, but caused a lateral displacement of the cut slope on the west side and a heaving in the embankment south of the cut and displacement of a bridge abutment for a small county road which was to be abandoned . . . . The method of treatment consisted of flattening the slope to 2:1 . . . . It was thought removal of this large amount of material, approximately 350,000 yards . . . had a reasonable chance to stabilize the slide. However, further major movement occurred during the summer of 1967, and we therefore elected to lay the slope back to 3:1 through the lower 70 feet of the cut . . . . This second slope flattening required an additional 150,000 yards

Figure 8. Stereopair showing drainage channels in lower resistant rocks and lack of channels on Upper Conemaugh red beds.

Figure 9. Stereopair showing sliding red bed gentle slopes.

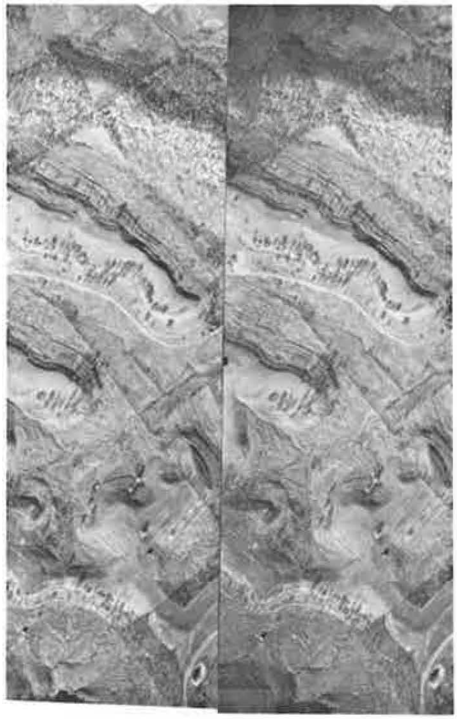


Figure 10. Back slope movements in red beds.

Figure 11. Occurrence of red beds.

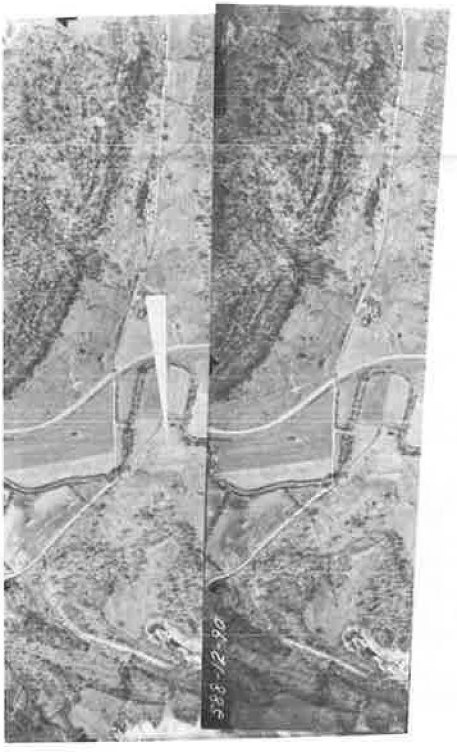


Figure 12. Bulge during highway construction.

Figure 13. Red bed performance on east-west Interstate highway (1 is back slope slide during construction, 2 is closed ramp, and 3 is location where westbound lanes were closed).

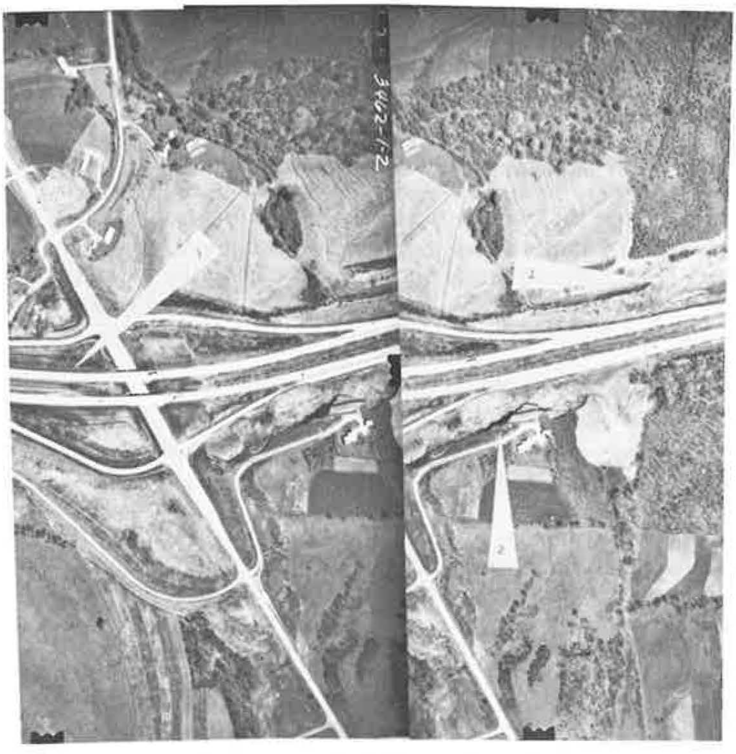
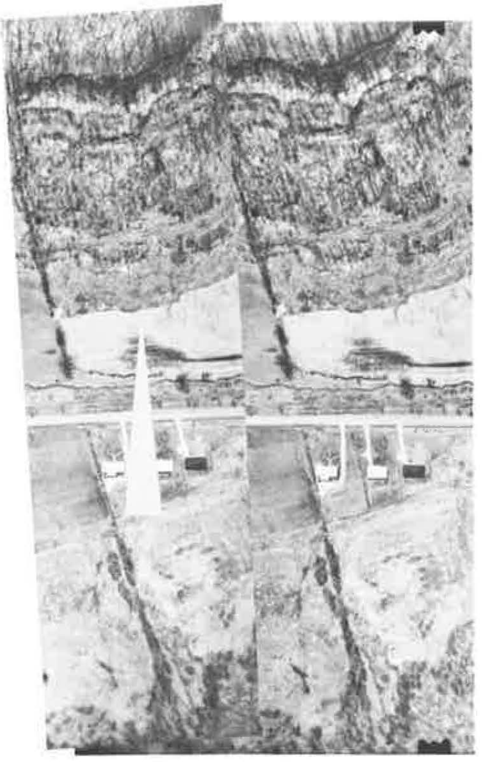


Figure 14. Spoil slide bulldozed to red bed slope.



> of excavation; however, it too turned out to be not enough and late in the fall there was further movement in the cut slope and upheaval in the bench and subgrade area for the northbound lanes. An upward revision of the grade for the northbound lanes only . . . provided enough surcharge to establish a temporary balance from July 1968 until January of 1969, during which time the pavement and shoulders were completed and the road opened to traffic . . . . In all, we have removed about one-half million yards more material from this cut than the plan quantity. This is not the end; however, in the past month further movement has occurred in the slope with resultant heaving in the paved shoulder and in the outside lane . . . .

Miles away the red beds also outcropped along this east-west Interstate highway (Fig. 13).

Figure 13 shows the location of back slope slides that occurred during highway construction and the location where the westbound lanes were closed during the summer of 1971 due to slope instability. Also shown is a closed on-ramp. Today the entire back slope has been flattened, and the residence has been moved.

MINING PROBLEMS ASSOCIATED WITH UPPER CONEMAUGH RED BED TOPOGRAPHY

The basal member of the capping Monongahela formation is the Pittsburgh No. 8 coal. Bedded approximately 30 ft above is the position of the Redstone 8a (Pomeroy) coal.

Where these seams are of minable thickness, abandoned drift mines continue to collect landform water. Particularly in the down-dip portion of the mine, constant saturation of the Conemaugh slopes goes on, aggravating the deformation of the plastic soil that formed on the red beds.

Where strip-mining has been done, the spoil piles have been piled on the slope, in essence loading the slope. When they slide they virtually bulldoze the soil that formed on the red beds into piles lower on the slope. Although the natural slope instability cannot be seen from air photographs, knowledge of the regional instability of this stratigraphic group permits inferred evaluation based on its past performance.

Figure 14 shows a spoil slide that has carried with it trees and slope soil. It is encroaching into a portion of a cultivated field as delineated.

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AERIAL SURVEYS FOR HIGHWAYS IN NORTH AMERICA

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The brief history of aerial surveys contained here is an effort to recount as accurately as possible the adoption and use of aerial photography methods throughout North America. Specifically, the uses referred to are those especially applicable to highway engineering. Considerable development and progressive work were accomplished in the field of photogrammetry and stereophotogrammetry many years before their adoption and use by the highway engineering profession. Consequently, identification of several first uses do not pertain to uses in the highway engineering field but are early developments or uses in other fields of endeavor that preceded adaptations and developments for highway engineering purposes.

PHOTOGRAMMETRY is the art and science of making measurements by use of photography. Added thereto in recent years is interpretation for obtaining qualitative information from aerial photography and other types of imagery. Accordingly, aerial surveys are the taking and use of aerial photography and other imagery to accomplish whatever is required, and aerial surveying includes photogrammetry and interpretation and any other aspect of use of aerial photography and other imagery.

A completed and functional highway is a complex amalgamation of a diversity of ingredients blended into one composite form. A highway is created, from beginning to end, by combining the talents and services of a wide variety of specialists who are skilled in many disciplines such as planning, location, design, photography, aircraft use, ground surveying, photogrammetry, cartography, drafting, landscaping, ecology, conservation, history, archeology, materials engineering, and construction equipment operation and use. Mention, therefore, is made of some of the more significant and early thoughts and findings relevant to many professional activities that together constitute highway engineering. Then, the chronological beginnings are given for some, not all, developments leading to progressive changes in and eventual use of aerial surveys by the highway engineering profession.

HISTORICAL CHRONOLOGY OF AERIAL SURVEYS

The first state road building policy in the United States was inaugurated by Kentucky in 1821 when Abraham Lincoln was a boy of 12. Forecast was made in 1839 that aerial photography could be used as an aid in the preparation of maps. This forecast came as a consequence of photography discoveries in France by Niepce and Daguerre. A stereoscope was developed and demonstrated by Wheatstone during his investigations on binocular vision between 1832 and 1838. His work was followed in 1844 by a refracting type of stereoscope developed by Brewster.

The first practical adaptation of a camera to take photographs for surveying was accomplished by Laussedat, who began his work in 1849. His work lead to terrestrial photogrammetry and was the forerunner of the photoalidade.

In 1856 Nadar took the first aerial photograph from a free-flight balloon over Paris, France. The first aerial photograph in the United States was taken by Black and King on October 13, 1860, from a captive balloon at a height of 1,200 ft over Boston, Massachusetts. Several other photographs were taken the same day from a free-flight balloon. In May 1862 Lowe took the first aerial reconnaissance photograph from a captive balloon over Richmond, Virginia. This photograph was obtained for use by the Union Army for observing troop movements of the Confederate Army defending Richmond.

The first photograph taken from an airplane was by Maurisse in 1909 from flight heights of 100 and 200 ft. The first known taking of motion pictures from an airplane was by an unknown cameraman riding with Orville Wright over Centocelli, Italy, on April 24, 1909. The first specific use of aerial photographs as maps was reported by Tardivo on September 25, 1913, at a meeting of the International Society for Photogrammetry in Vienna, Austria. The photographed area was Bengasi, Italy. The first aerial photograph used for illustrative purposes by a newspaper had been taken of a fire at Salem, Massachusetts, on June 26, 1914.

The first major American development in photogrammetric instrumentation is known as the Brock process. Development of the instruments used in this process began during World War I by the Arthur Brock Tool and Manufacturing Works of Philadelphia, which later became the Precision Engineering Co. Developmental work continued into the early 1920s. In 1938 all assets of the Brock and Weymouth Co. were acquired by the Aero Service Corp., which still owns all rights to the process.

In addition to the Brock process of mapping, the earliest aerial cameras used in the United States were built by the Brock Co. One of its earliest models, using tin types, was tested at Fort Sill, Oklahoma, in 1915. Later, during World War I in Europe, nearly all aerial cameras were made by the Brock Co.

Within the United States, the early 1920s mark the beginning of photogrammetric compilation of topographic maps using aerial photographs. An early report of such use of aerial photography pertains to topographic map compilation completed in 1922 by Brock and Weymouth for reservoir and hydroelectric purposes. Another early compilation of topographic maps using aerial photographs was in 1924 by the Pioneer Aerial Engineering Co. and the Photomap Co. These jointly operating firms used a "parallaxer," similar in principle to the stereocomparagraph.

One of the earliest strips of aerial vertical photography specifically designed for stereoscopic examination and interpretation to make route investigations was taken in 1927 and 1928 for the Mt. Vernon Memorial Highway. There were 262 photographs of 7- by 9-in. format exposed at a scale of 1:6,000.

A large plan for development was prepared by use of this aerial vertical photography. This earliest plan for development has significant historic interest because it was prepared from enlarged photographs and mosaics fitted to the ground survey controls established by the Bureau of Public Roads for the 15-mile length of the memorial project. This is the first known example of preparation and publication of a complete plan for construction of a highway on a route location determined using aerial photography specifically taken for stereoscopic examination and interpretation.

The first mapping projects in the United States were controlled originally by the use of radial templates. This is a graphic method of extending supplemental control to all the points required to orient each stereoscopic model. A U.S. patent was issued to Adams in 1893 for the use of radial templates in connection with photographs taken from balloons. Added attention was focused on the radial template method developed by Schiempflug in 1906 and Finsterwalder in 1921. The real impetus to the use of radial templates was provided by Bagley in 1923.

Radial line templates continued in use throughout the 1920s and into the 1930s. In 1935, while watching personnel struggle with the hand templates, Collier of Fairchild Aerial Surveys developed the idea for the slotted template method.

In 1933, Fairchild Aerial Surveys introduced into the United States two German developed instruments, the stereoplanigraph and the multiplex. These instruments began to replace the radial template method for extension of horizontal control. The stereoplanigraph performed analog extension of control, and the multiplex performed an analog aerial triangulation by so-called bridging techniques. These procedures continued to be used until the implementation of analytical aerial triangulation for effective and economical use in about 1964.

Aerial analytical triangulation had its beginning at the College of Applied Science of Syracuse University during a 4-year period starting in 1929. This work was accomplished using Guggenheim funding. The photographic measurements were made with monocomparators, stereocomparators, and photogoniometers. The method did not gain general use until the early 1960s when agencies became equipped with the necessary electronic computers to facilitate the lengthy computations.

The second significant photogrammetric instrument development in the United States is credited to Kelsh. He developed the Kelsh double-projection stereoscopic plotter in 1948.

Aerial surveying in highway engineering made another giant step in 1956. That year the Ohio Department of Highways initiated and completed development of the first analog to a digital recording instrument to record automatically the measured dimensions of profiles and cross sections as well as cadastral data.

During October 1959, development was started in Region 9 of the U.S. Bureau of Public Roads, and completed in March 1960, of an instrument that became known as the Auto-trol Scaler. This instrument was also an analog convertor to digital data of stereoscopic model measurements made using a double-projection instrument.

These instrumental developments were the forerunners of electronic recording of photogrammetric measurements made by optical train instruments, monocomparators, stereocomparators, and double-projection instruments.

One of the first reported tabulations to compare earthwork quantities determined by photogrammetric methods and ground surveys was released in November 1944. The report indicated a difference of only about 4 percent, even in those early days of predominantly manual methods of performing the work.

The year 1956 was notably significant for other reasons. The Federal-Aid Highway Act of 1956 initiated the Highway Trust Fund and financing for the Interstate Highway System on a 90 percent federal and 10 percent state sharing basis. Also, the Act authorized federal-aid funds for employing photogrammetry on a professionally negotiated basis to make highway surveys. In addition, the Act revised the definition of construction and authorized use of federal-aid funds appropriated for highway construction for financing the making of basic control surveys along highway routes to specifications of the U.S. Coast and Geodetic Survey (now the National Ocean Survey). That same year, use of electronic computers was started for computing highway alignment, for volumes of excavation and embankment using photogrammetrically made measurements, and for numerous other engineering purposes.

HIGHWAY ENGINEERING USES

It is difficult to determine the earliest writings that pertain especially to photogrammetric use of aerial photographs for highway engineering purposes. Scattered and casual comments in papers and reports were usually written with other emphasis, but some of them indicate utilization of aerial surveys in an elementary way for highway engineering purposes beginning early in the 1920s. Nearly all first uses were photographic, interpretive, and illustrative. In most cases, the photographs were assembled and used as photographic mosaics, generally referred to as maps.

Among the early works containing information on aerial surveys for highways is a paper by Sarason (1). In his paper, Sarason noted that George Washington, early in his life, had training as a surveyor. He continued by saying,

> It is therefore not surprising to find that as early as May 7, 1784, a committee of the Continental Congress, headed by no less than Thomas Jefferson, reported 'An ordinance for ascertaining the mode of locating and disposing of lands in the western territory.' This ordinance provided for 'townships 6 miles square containing 36 sections of one mile square by lines running North and South and others crossing these at right angles.' These were the first specifications for land surveys....

Most surveys for highways, before the acceptance and use of aerial surveys, were made by staking and measuring on the ground angle line traverses along each selected route, measuring its profile and cross sections, and making ties from the traverse, known as the P-Line for preliminary survey, to all topographic, cadastral, and land use details of concern. Nevertheless, planimetric maps were usually compiled, and occasionally topographic maps were made based on the preliminary survey measurements.

Significantly, Sarason mentioned mapping for highway location purposes. Seemingly, however, some of his thoughts were not widely accepted and applied until the advent of

the use of aerial surveys, for he wrote:

> The State of Illinois was one of the first to recognize the value of maps for highway location. No new location is authorized without a strip topographic map about 3 or 4 miles in width on a scale not less than 2,000 feet per inch with 5-foot contours. An agreement has been made with the U.S. Geological Survey to furnish these maps, the State paying the additional cost above the usual Geological maps of (a scale of) an inch to a mile. It has been suggested to the Federal Bureau of Public Roads that it require a proper map before approving a highway location where Federal aid is given. This Bureau has the power to fix the grade and curvature and an economic location involves these and other factors.

Although Sarason indicated that Illinois was the first state to pay the extra cost of producing large-scale maps for highway engineering needs, Missouri actually used topographic maps published on a quadrangle basis at a scale of 1 in. = 1 mile as early as 1921.

Only within the past two decades have some highway departments cooperatively financed topographic mapping on a quadrangle basis by the U.S. Geological Survey at a scale of 1 in. = 2,000 ft. Wherever these maps are available, they are invaluable for use in conjunction with recently taken aerial photographs of the areas of concern for accomplishing area analysis, determining feasible highway route alternatives, selecting a route by comparing the alternatives, and making a preliminary survey at adequately large scale of the selected route for accomplishing highway design and preparing detailed construction plans.

Before World War II, only one significantly large route topographic mapping project was undertaken using aerial surveys. This project comprised the mapping of a route selected by stereoscopic examination of photographic coverage through the Lochsa River region of Idaho, now known as the Lolo Pass Highway, extending between Lowell, Idaho, and Missoula, Montana. Approximately 600 miles of route alternatives were compared to select the more than 50-mile segment of highway route that was mapped at a scale of 1 in. = 500 ft with a contour interval of 10 ft for a width of 1,000 to 2,500 ft. This work was completed by the state of Idaho in 1930 by the Aerotopography Corp. of America.

Three projects of major significance on which aerial photography served as a primary source of information and topography dimensions for feasible route determination, comparison, and selection were the Inter-American Highway, the Alaska Highway, the Pan American Highway, and the Mississippi River Parkway.

On the Inter-American Highway, aerial photography was taken as early as 1932. It was not used to any great extent until 1948 when the areas were rephotographed. During 1948 photography was used to make an area reconnaissance survey, locate route alternatives, and select the route for the closing 120-mile link in Costa Rica and Panama. Again during 1964 and 1965, use of aerial photography enabled engineers of the Bureau of Public Roads, now Federal Highway Administration, to close the gap in the Pan American Highway of North and South America through southeastern Panama and northern Colombia by locating a route to and across the large Rio Atrato Swamp in Colombia, which had previously been considered uncrossable.

Early in 1942, long segments of the Alaska Highway through Canada were located with the aid of aerial photography, augmented by intensive reconnaissance surveying on the ground.

Probably the most extensive use of photography on one project during the period of 1950 to 1952 occurred when a reconnaissance survey was made to determine the feasibility and probable cost of the proposed Mississippi River Parkway (the Great River Road). This particular project involved the purchase of nearly 40,000 aerial vertical photographs covering an area of approximately 100,000 square miles throughout the 10 states bordering the Mississippi River. The river has a winding length of 2,552 miles between Lake Itasca in Minnesota and the Gulf of Mexico.

By stereoscopic examination and interpretation of the photographs, plus use of parallax measurements, more than 10,000 miles of feasible route alternatives were located and compared at a total cost of $140,000 for all salaries, travel, equipment, training,

aerial photographs, and preparation of a report to the Congress of the United States. This low cost represents only $14 per route-mile located and only $70 per route-mile for one 2,000-mile route extending the full length of the project.

Following World War II, topographic mapping, using aerial surveys for engineering purposes, gradually began to be accepted and used. Impetus for this had its beginnings during the war in a few eastern states—Connecticut, New York, Massachusetts, and Rhode Island—and in California.

Some early papers (2-8) that influenced the acceptance and use of aerial surveys by highway engineers focused on the following areas: photographic mosaics, stereoscopic pairs, photogrammetric compilation of topographic maps, and aerial survey procedures.

Contemporaneous with and subsequent to these early publications, numerous other articles pertaining to principles and practices in the use of aerial surveys in the highway engineering field were published. These papers mention procedures and accomplishments and, in some instances, indicate first use. Some of the earliest and most significant applications are given in Table 1. It is not intended to imply that the applications given in Table 1 were actually the earliest, as compared to uses in the manifold fields of endeavor. Moreover, no attempt has been made to consider all procedures and techniques of employing aerial surveys.

Early uses were essentially pictorial and qualitative. Gradually, the dimensional aspects were applied in the photogrammetric use of aerial photographs on an analog basis.

Graphical determination of horizontal position of pass points for supplemental control was begun in the mid-1950s at scales as large as 1 in. = 100 ft, using stereotemplates. Concurrently, where available, optical train instruments were used to determine supplemental control by analog methods. It was not until 1964 that analytical techniques began to be used effectively for determining supplemental control. The principles, of course, of aerial analytical triangulation had been known for many years. Despite frustrations and seeming setbacks, steady progress has been made in the improvement of techniques and procedures.

Of the 50 state highway departments reporting, Massachusetts indicated the earliest date (1941) for sending highway engineers to attend a school in aerial photography. Michigan followed in 1946, Mississippi in 1947, and Louisiana and Texas in 1948. These four schools were conducted by Abrams Aerial Survey Corp.

Michigan was also one of the first states to establish a position of photogrammetric engineer in its highway department. This was done in 1949 through their Civil Service Commission, and the classification required professional registration.

Aerial surveying schools have been conducted on a request basis since 1950 for state highway departments and field officers of the Bureau of Public Roads and the Federal Highway Administration. These schools were conducted by qualified engineers of the Federal Highway Administration primarily for giving the highway engineer an insight into the basic principles, techniques, procedures, and stages of use of aerial surveys for engineering and associated purposes. Accordingly, engineers who are concerned with traffic, location, design, soils, construction materials, drainage, rights-of-way, maintenance, conservation, aesthetics, and so forth attended these schools, which served as a bridge between the taking of aerial photographs and their interpretation and photogrammetric use for accomplishing essential engineering and related work.

The leaders in aerial surveying use are those states from which the engineers attended the schools and thereafter followed through in using aerial surveys. The most extensive and comprehensive uses are within the states that have become equipped and staffed to take aerial photographs and use them photogrammetrically for making essential measurements and compiling maps that are photographic, planimetric, topographic, or all three.

During the past 20 years, a substantial part of the photogrammetric use of aerial photographs has been accomplished through the use of double-projection instruments, mostly the Kelsh stereoscopic plotter.

Optical train instrumentation for engineering had its beginning in the United States when photogrammetric engineering firms first became equipped during the 1950s with stereoplanigraphs, or wild autographs, or the Gallileo-Santoni stereocartograph and

Table 1. Early aerial surveys for highway purposes.

Year	Early Use by State and Organization: Photographic Mosaics	Stereoscopic Pairs	Mapping From Photographs[a]	Cadastral Surveying	Supplemental Control[b]	Automatic Recording[c]
1922	California					
	New York					
1923	Illinois					
1924	Connecticut					
	Florida					
1925	Michigan					
1927	Virginia		Indiana[d]			
1928	Alabama	California				
	Maryland					
	Pennsylvania					
1929	Ohio	Colorado				
	Texas	Ohio				
1930	Bureau of Public Roads	Idaho	Connecticut			
	Idaho		Idaho			
	Massachusetts					
	Tennessee					
1931		Michigan				
1932	Mississippi	Texas				
	New Jersey	Washington				
1934	Arizona	Arizona				
	Indiana					
1935		Mississippi				
1936	Colorado	Missouri				
1937	Minnesota	Bureau of Public Roads				
		Delaware				
		Minnesota				
1938		Virginia				
1940	Georgia	Georgia				
		Nebraska				
		New York				
1941			New York			
1942	Alaska	Alaska				
1943			Massachusetts			
1944	Kansas	Kansas	California			
	North Carolina	Utah				
1945		Maryland				
1946	New Hampshire	Florida	Florida			
			Ohio			
			Virginia			
1948				Connecticut	Public Roads Administration	
1949		Kentucky				
1950		New Mexico	Colorado			
		North Carolina	Maryland			
			North Carolina			
			Texas			
1951		Arizona	Washington			
1952			Arizona	Idaho		
			Oregon			
1954	North Dakota		Kentucky			
			North Dakota			
1955			District of Columbia	Bureau of Land Management		
1956			Illinois	Maine		
			Maine	Nebraska		
			Montana			
			Vermont			
			Wyoming			
1957		Hawaii	Hawaii			
1958			Georgia	Illinois	Arizona	
			Texas	Indiana		
			Pennsylvania			
1959				New York		Bureau of Public Roads
1960				North Carolina		
1961						California
1962					California	Virginia
1963						North Carolina
						Texas
						Washington
1964			New Mexico	California	Federal Highway Administration	Georgia
					Georgia	Pennsylvania
					Texas	
					Washington	
1965				Georgia		Wyoming
1966					Virginia	Kentucky
						New Mexico
1967						Idaho
						Illinois
						Vermont
						Wisconsin
1969					Illinois	Kansas
					Pennsylvania	New York
						Oklahoma
1970				Florida	Florida	
				Oregon	Texas	

[a]This tabulation indicates the earliest date for which mapping was done either by consultants or by state staffs using state-owned equipment. The tabulation does not necessarily indicate all states now employing aerial surveys for doing survey mapping.
[b]Photogrammetric determination of supplemental control (radial templates, analog, and analytical).
[c]Automatic recording of measured profile and cross sections.
[d]Source: Photogrammetric Engineering, Vol. 17, No. 5, Dec. 1951, p. 725.

stereosimplex. In the 1960s a few states also acquired optical train instruments, namely, the wild autograph in Georgia and Washington and the stereoplanigraph in Texas and California, and the Zeiss planimat in the Ontario Department of Transportation and Communications. Also, in the 1960s with the advent of aerial analytical triangulation, stereocomparators were obtained by California, Pennsylvania, and Arizona. Monocomparators were obtained by Virginia, Florida, and Illinois in the late 1960s.

Ohio was the first state (in 1946) to become equipped to provide photogrammetric services for its highway department. Engineers in Ohio were also the first (1956) to complete development of an analog to digital recording instrument for use with a double projection instrument to record automatically the measured dimensions of profile and cross sections. Ohio is also the first and only state, thus far, to procure a Nistri analytical stereoscopic plotter, model AP/C. This occurred about 20 years after Ohio's initial start in aerial surveys for accomplishing its highway engineering and associated work.

In 1955, and culminating in 1956, proposals were made for developing an instrument that would, in effect, embody the advantages of double-projection and optical train instruments; be free from the restrictions caused by projection lenses and focal length limitations; use any photographic emulsion; digitize or graphically delineate details as desired; and produce orthophotographs when required. Within the succeeding 4 years, progress was gradually made in the development of a prototype instrument that proved the feasibility of this concept. In the interim, digital scalers and recorders for use with double-projection instruments were developed effectively. Since 1960, budgeting roadblocks have retarded further development of this all-purpose instrument called the omnistereomeasurer.

Other developments involving numerous instrumental approaches have gradually moved in the direction of the initial concept. Among these instruments are the analytical stereoscopic plotter, the stereomat, from which orthophotographs are made automatically, and adaptations of the planimat by which orthophotographs and also automatic digitization and recording of map dimensions are easily done. Also, coordinatographs have been automated that use the coordinate dimensions of photogrammetrically measured details for the automatic plotting of planimetric, topographic, and cadastral maps, and of profile and cross sections as desired.

In the early 1940s most photogrammetrically made map compilations were not based on a plane coordinate system. Instead, no coordinates were used. The maps were purported to be sufficiently accurate for origination of subsequent work, such as rights-of-way and centerline staking on the ground, from features identifiable on the maps that could be found on the ground. By the late 1940s, either a local system or the state plane coordinate system was used. Currently, most maps compiled photogrammetrically for engineering purposes have their basic control surveys originate and close on station markers in the national network of geodetic control, as initially surveyed by the U.S. Coast and Geodetic Survey.

Photographic base plans as a production item were first used in 1950 by the state of Florida. This system allows highway engineers to see all topographic detail, as delineated by contours, as well as all cultural features on the photographs.

The progressive changes from using aerial photographs in assembled form of usually uncontrolled photographic mosaics through stereoscopic examination and interpretation, mapping, photogrammetric determination of supplemental control, and measuring and automatically recording profile and cross sections (also cadastral data in some states such as California, Georgia, Illinois, Ohio, Texas, and Virginia) are easily discerned by study of Table 1. It is not purported to be definitive in every aspect but is the most complete of its kind thus far compiled.

CONCLUSIONS

Progressive use of aerial surveys in the highway engineering field was slow for many years. The literature written regarding uses and successes, the aerial surveying schools conducted during the past 22 years, and the increase in highway engineering and construction, especially since 1956, contributed separately and effectively toward

the progress that has been made. The advances in photogrammetric technology and instrumentation were also significant factors, coupled with the joining together in 1956 of aerial surveys and electronic computers. New and improved techniques of making ground control surveys made important contributions also. The latter include electronic distance measuring instruments and the augmenting use of theodolites.

Although the techniques and procedures of making surveys on the ground are essential and are in continuing use for staking designed centerlines, structures, rights-of-way, slope stakes, and so forth on the ground, aerial surveys have become the foundation on which all engineering and construction are based.

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