A COMPUTER-ASSISTED TECHNIQUE FOR PLANNING MINIMUM IMPACT TRANSMISSION RIGHT OF WAY ROUTES

by

Charles Willard Smart

Dissertation submitted to the Graduate Faculty of the

Virginia Polytechnic Institute and State University

in partial fulfillment of the requirements for the degree of

DOCTOR OF PHILOSOPHY

in

Fisheries and Wildlife Science

APPROVED:

R. H. Giles, Jr., Chairman

H. E. Burkhart

B. S. McGinnes

R. T. Lackey

T. H. Ripley

May, 1976

Blacksburg, Virginia 24061

ACKNOWLEDGEMENTS

The author wishes to express his appreciation to all who aided in this study. Financial support was provided by the State Corporation Commission of the Commonwealth of Virginia.

I wish to express my sincere appreciation to Dr. Robert H. Giles, Jr., Professor of Wildlife Management, whose encouragement, counseling, and patience were significant factors in the success of this study. I would like to thank Dr. Harold E. Burkhart and Dr. Robert T. Lackey, Division of Forestry and Wildlife Sciences, Dr. Burd S. McGinnes, Leader of the Virginia Cooperative Wildlife Research Unit, and Dr. Thomas H. Ripley, Director of the Division of Forestry, Fisheries, and Wildlife Development, Tennessee Valley Authority, who served as members of my graduate committee and reviewed this manuscript. Thanks are also due Dr. Hewlette S. Crawford and Dr. Robert E. Taylor who participated as committee members in the initial phases of this study.

I wish to thank Dr. Charles D. Buffington and Dr. F. Paul Baxter, Division of Forestry, Fisheries, and Wildlife Development, Tennessee Valley Authority, whose encouragement facilitated the completion of this study.

I appreciate the technical support provided by Technical Associates, Incorporated, particularly that of Mr. Ken C. Strobl and Dr. Micheal J. Ileo.

I am indebted to Mr. A. Blair Jones III who provided essential computer programming support and lost as much sleep as I did.

Finally I wish to express my sincere appreciation to my wife, Shelley, for her patience and understanding throughout this study.

<u>TABLE OF CONTENTS</u>

Page

Page

LIST OF TABLES

LIST OF FIGURES

Figure | Page

LIST OF APPENDICES

INTRODUCTION

Statement of the Problem

Within the United States the creation and management of electric utility transmission corridors is one factor in the land use planning problem. The recent growth of transmission systems has made this a factor of increasing significance. In 1971 the nation was traversed by over 100,000 circuit miles of electric transmission lines, covering an estimated four million acres of land (U.S. Departments of Interior and of Agriculture 1971). Pressures due to continued population growth and technological expansion, as well as the promotional activities of the utility industry, have generated a stepped-up demand for electrical energy. This demand has resulted in the allocation of thousands of acres of land for transmission facilities as well as power generation sites. Assuming present rates of expansion, the U.S. Federal Power Commission (1971) has predicted that over 7 million acres of land will be under management as power transmission rights of way by 1990. The magnitude of the changes in natural vegetation communities likely to result from this development will cause significant impacts on the quantity and quality of wildlife habitat in the nation.

Until recently the primary objective of the expansion of electrical energy transport networks has been to assure constant supplies of cheap power to sectors of high demand. In general, generation and transmission facilities were located to maximize the ratio of electricity production to the economic cost of production. In many cases this criterion dictated the location of generation facilities near large sources of cheap fuels, often widely separated from the geographic location of demand. Transmission lines were then constructed to connect the energy supply and the consumer. In the planning process, however, minimal consideration was given to the potential environmental impact of such lines or to their spatial relationships with other rights of way.

However, the same pressures which have generated the tremendous demand for electrical energy are also active in generating other demands on the land, for recreation, housing, agriculture, and urban expansion. The result in many localities is a severe competition between alternate land uses for each parcel of land. In addition, American society's attitudes concerning environmental quality are rapidly changing. In response to previous abuses of land and aesthetics caused by technological advance, organized opposition to land development in all its forms has appeared in many localities. American society is modifying the philosophical viewpoint which results in the evaluation of project benefits and costs in terms of market commodities and dollars. The trend, both in the private and government segments of society, is toward adopting a holistic viewpoint which incorporates nonmarket benefits as well as social costs into the analysis of the worth of technological development. Private citizen groups who feel that they will realize excessive environmental costs while reaping little or no benefit from new power transmission facilities grow more active in seeking judicial injunctions barring such construction. Sympathetic court decisions not only encourage similar litigation, but also provide an impetus for the legislative development and executive enforcement of enviromental protection statutes. The result is that both industrial planners and governmental regulatory agencies are obliged to examine more critically all alternative actions as well as all their potential impacts when planning or approving electric transmission facilities expansion.

The task of evaluating all alternative actions is not a simple one. The number of possible alternative routes for power transmission between two distant localities is incalculabe. It is infeasible to evaluate objectively all possible routes. Therefore, it is imperative that the planner be able to delineate a subset of optimum and near-optimum alternatives for consideration, based on some objective measure of overall impact.

"Impact" is a multidimensional entity. The impact of power transmission facilities may be assessed in economic, social, and ecological terms. Economic impacts are such things as the costs of facilities construction and maintenance which must be borne by the utility ratepayer, tax base changes due to right of way construction, and changes in the value of property which borders right of way development. Social impacts include the aesthetic characteristics of tower and substation facilities as well as the resultant changes in the values of nearby historic, recreational, residential, and institutional sites as perceived by users and residents. Ecological impacts are diverse and integrally related to the preconstruction rates of runoff, soil erosion and stream siltation, microclimate modification, and changes in floral and faunal communities as a result of construction and maintenance activities. These dimensions of impact are measurable in a wide variety of nonequivalent units. Some impacts may be beneficial to society, but the connotation of such change is usually negative. In addition the several impacts are interrelated, not independent, and change in severity over time.

The resultant decision situation in which industrial planners and governmental agencies find themselves is one of choosing among innumerable alternative routes, each one having been evaluated on the basis of many seemingly incompatible measures of impact. The complexity of planning and assessing the impact of electric transmission facilities is well summarized by Goodland (1973). What is required to meet the challenge of better land use planning within this complex environment is not the creation of more governmental regulatory agencies, but the development of better planning procedures within industry and existing agencies. Power transmission planners must adopt a systems approach to the routing problem.

With the term "systems approach" I refer to a viewpoint which possesses characteristics outlined by general systems theory (vonBertalanffy 1968). First, the attack on the problem must be multidisciplinary in nature. The planner must incorpate concepts of economics, engineering, ecology, sociology, operations research, and decision theory in his analysis of alternate routes. Second, the system of route planning must include both analysis and design functions. It should afford the planner the capability of evaluating proposed routing alternatives as well as establishing optimal routes based on stated public objectives and criteria. Third, the system should be dynamic in nature. It should incorporate feedback functions which allow the planner to be flexible and responsive to changing social value structures. Finally, the planning system should encourage a futuristic viewpoint, enabling the planner to incorporate predicted future social, economic, and environmental characteristics as well as those of the present.

Objectives

In the Commonwealth of Virginia the agency responsible for regulating and licensing electric power generation and transmission facilities is the State Corporation Commission. In a sense, the members of the Corporation Commission are a group of environmental decision makers. Although not actively involved in the route planning process for power transmission facilities, they have a significant effect on the environmental quality of the state by virtue of their regulatory powers over the electric utilities. Under Virginia state law all new facilities acquisition or construction must be certified by the Commission:

> It shall be unlawful for any public utility to construct, enlarge or acquire, by lease or otherwise, any facilities for use in public utility service, except ordinary extensions or improvements in the usual course of business within the territory in which it is lawfully authorized to operate, without first having obtained a certificate from the Commission that the public convenience and necessity require the exercise of such right or privilege. Such certificate shall be issued by the Commission only after formal or informal hearing and after due notice to interested parties (Anon. 1950).

The Corporation Commission is the group which must make the ultimate decision as to whether a new right of way should be built, after weighing the potential impacts of such construction. In addition to protecting the economic interests of the utility ratepayers and the Commonwealth of Virginia, the Commission is specifically charged with the consideration of visual, environmental, and historic impacts (Anon. 1972a; Jordan 1972).

This research project was undertaken in order to enable the Corporation Commission to be responsive to environmental as well as economic values in its regulatory decisions. The goal was to develop an automated system which would allow the objective evaluation of industry-proposed transmission routes and the development of alternative proposals based on an optimality criterion of minimal combined economic, social, and ecological impact. The system was to be regional in nature and applicable as a tool in the initial stages of route planning as well as for regulatory purposes.

The specifically stated objectives were:

1) To develop a computer-based system for identifying optimum routes for high voltage electric transmission rights of way, combining economic and environmental quality criteria.

2) To develop a practical weighting procedure to reflect the relative importance of various environmental parameters in the transmission right of way routing decision.

3) To describe the parameters to which the transmission right of way routing decision is most sensitive and develop appropriate measurement techniques for these parameters.

LITERATURE REVIEW

Electric Power Transmission and Associated Impacts

With construction of any type of electric power transmission facilities there are always a set of associated changes, or impacts, to the preconstruction environment. These impacts may be of dramatic importance to society, or they may be very subtle in their effects. The overall impact of a power transmission development may be viewed in dimensions of economic, social and ecological impact. Each of these general dimensions is comprised of a set of more specific impact dimensions, some of which have been recognized and discussed extensively in engineering and environmental literature while others have only recently been identified and articulated.

Economic Impacts

The monetary costs of power transmission facilities are generally clearly recognized. Ileo (1973) presented an overview of the considerations involved in the determination of the total cost of a new powerline. He classified the overall cost of powerline construction into several categories including right of way acquisition, construction, maintenance, depreciation, property taxes, interest, income taxes, and equity return. The capital and operating costs incurred by the electric utility are eventually passed on to the consumer. Therefore, it is the utility ratepayer who ultimately bears the major economic costs of power transmission developments. Permar (1971) summarized the corporate and regulatory environments within which the costs of power facilities are incurred and distributed.

Other economic costs which may result from powerline construction include the loss of resources and resource production capacity, notably in terms of agricultural and forest products. Little definitive work concerning this form of economic cost has been published, but several workers have suggested (Giles 1973, personal communication) that this aspect may be approached as an opportunity cost, measured by the value of the acreages of crops and stumpage and foregone as a result of construction. The economic impact of transmission rights of way in terms of the devaluation of neighboring property is also a dimension which has received minor attention and remains relatively unquantified, although some industry based study has been undertaken (Edison Electric Institute 1968).

Social Impacts

The social impacts of power transmission facilities are closely connected to the visual disutility commonly associated with the clearing of vegetation during right of way construction and with the structural characteristics of individual towers. In fact, it is the visual impact of powerlines which is the overwhelming object of public criticism when conflicts arise (Randall 1973: 93). It is signficant to note that many governmental regulations concerning right of way construction, while termed "environmental" criteria, are more precisely aesthetic criteria (U.S. Departments of Interior and Agriculture 1971; U.S. Federal Power Commission n.d.). Industry has recognized the public pressure for visually unobtrusive development and much discussion has been devoted to concepts of blending of aesthetics and utility in power transmission right of way construction (Johnson 1966), even if economic sacrifices may be required (Sibley 1966). Much of the emphasis devoted the right of way aesthetics by the electric utility industry has been focused on tower design (Dreyfuss 1972; Chang 1967). There is a growing body of experience in vegetation management along rights of way for the reduction of visual impact (Anon. 1972b; Randall 1973: 93-94) including practices of selective cutting and vegetation screening.

Closely related to the visual impact of the power transmission right of way is the negative impact on the social value of certain recreational and historic resources, resulting from line construction nearby. The value of right of way clearings for certain types of recreational activities, notably hiking, horseback riding, cycling and picnicing, has been recognized (Barrett 1971; Brown 1969). However, other types of recreational pursuits involving aesthetic or historic environments are completely incompatible with power transmission facilities. For safety reasons, even some of the currently acceptable stationary activities may become hazardous with the advent of ultra high voltage lines (Curran Associates 1973).

Other social costs of electric transmission rights of way, unrelated to their visual impact, have been recognized in at least one survey of public tastes (Anon. 1973). These include radio and television interference, noise generated from overhead lines, potential safety hazards, as well as psychological losses resulting from right of way acquisition through private property. The restriction of available land-use alternatives due to right of way development may assume increasing significance if public demands for already limited resources and services increase. Psychological damages and frustration resultant from private land condemnation are additional undesirable social impacts associated with right of way construction (Young 1973).

Ecological Impacts

The ecological component of impact is multidimensional, affecting biotic, geologic, and atmospheric systems. Probably the most obvious ecological impact of right of way construction is the change in vegetation communities as a result of construction activities. For safety and reliability reasons it is necessary to clear the tall, woody vegetation on either side of a power transmission line. Currently, a total cleared width of 150 feet is standard. One major effect of the vegetation clearing operation is, of course, diminished aesthetics. However, the destruction of unique communities of plants or the encouragement of undesirable plant species by right of way management procedures may comprise a significant ecological cost (Egler 1960). Even though plant community compositional change is required for transmission line construction, it has been suggested (Egler 1954; Richards 1973) that stable, treeless communities composed of native plants may be maintained with minimal spraying or cutting activity.

The efficient management of vegetation along power rights of way is of major importance to the utility industry (Stalter 1973).

However, the effects of vegetation management are often observed in parts of the ecosystem other than the plant communities. The composition of the wildlife population which an area of land supports is integrally linked with the composition of the vegetative community. Egler (1953, 1957), Bramble et al. (1957), and Arner (1960) have recognized the potential of right of way management for wildlife production, chiefly by encouraging wildlife food plants. The potential benefits of increased food and habitat for wildlife may be partially offset by increased susceptibility to avian predation, electrocution hazards (Michener 1928), and collisions with lines and towers. Soil erosion caused by vegetation removal during right of way construction, that which continues in sparsely vegetated areas, as well as that from maintained access roads, is another significant ecological impact (Goodland 1973: 9-13). The result is not only a visual cost, but also a reduction in the quality of related acquatic ecosystems through siltation, and terrestrial ecosystems due to topsoil losses. Reduced life expectancy of reservoirs and channel dredging is an associated economic impact. Climatic modification resulting from right of way construction and vegetation control has been discussed in detail by Herrington and Heisler (1973). They conclude that microclimate modifications may be significant, but that little postconstruction change in regional climatic conditions may be expected. A final ecological consequence of powerline construction and maintenance is chemical herbicide pollution of neighboring ecosystems. Egler (1953) noted the concentration of herbicides near rights of way as a result of vegetation control activities and advocated the selective use of basal spraying, as opposed to blanket spraying procedures, to reduce unwarranted chemical pollution.

It now seems apparent that power transmission lines may contribute significantly to the nation's atmospheric pollution problems, chiefly through the production of ozone. Scherer et al. (1972) stated that ozone production from high voltage transmission lines is due to the phenomena of corona losses. The volume of ozone evolution may vary with weather, as well as conductor characteristics and voltage. Ozone is directly lethal to plants and animals, but Goodland (1973: 23) stated that power transmission lines do not generate sufficient concentrations to pose a public health hazard. Goodland (1973: 23-24) cited a less direct danger from ozone generated from transmission lines--its role in photochemical reactions which result in atmospheric pollution. He suggests that the ozone generated by dense nets of transmission lines in urban areas could severely aggravate problems related to photochemical smog.

Potential Methods for Minimizing Adverse Impacts

Research is continuing in order to develop alternative methods of electric power transmission which reduce the negative impacts inherent in overhead transmission systems. The use of advanced microwave and laser technology present potential for transmission methods which require no rights of way. However, such methods are not expected to be economically feasible for several decades (Goodland 1973: 25-26).

Underground construction of transmission lines is a popular method of reducing the social and ecological impacts of overhead lines. Although this technique eliminates the need for unsightly towers and is an extremely popular panacea for the adverse visual impacts of powerlines, several authors have pointed out that underground transmission may actually increase the severity of the economic and ecological impacts of powerlines, and may still entail significant visual costs (Goodland 1973: 25-26; Dohrenwend 1973: 60). Both of these authors noted the tremendous economic costs involved in underground line construction, asserting that the expense of undergrounding over long distances is prohibitive. It seems likely, however, that undergrounding technology will continue to develop and that it may soon compete economically with overhead transmission (Rose 1970). The visual impact of underground transmission is as great as, or greater than, that of conventional overhead lines since a wider right of way is required for underground lines. In addition, the underground right of way must be kept completely clear of all woody vegetation (Goodland 1973: 25), presenting a sharp visual contrast in forest communities. Direct current transmission may provide some reduction of the visual impact of the traditional AC systems due to reduced right of way width requirements (Applegate 1968). Dohrenwend (1973: 60) noted the increased potential for environmental pollution by oil contamination due to leaking coolant from underground transmission facilities. However, continued development of electrical superconductors may reduce the need for large volumes of coolant in underground lines (Snowden 1972).

An alternate approach to underground power transmission as a method for reducing overall impact is the concept of parallel construction or the establishment of "utilidors" (Brown 1969). The principle of joint utility corridor use is that, if new facilities are constructed parallel to preexisting rights of way, the additional environmental disruption will be minimized. The concept holds a great deal of public appeal, but suffers from two potential flaws. Goodland (1973: 5) pointed out that if the initial right of way was located with little environmental consideration it may be preferable to establish a completely new route and revegetate the old one, assuming that the powerlines can be moved and the vegetation can be restored. However, even if joint right of way use by several different utilities is the best routing practice in an environmental sense, as advocated by Hill (1972), it may be infeasible due to present technical deficiencies. For instance, high voltage transmission lines may not be built parallel to communication lines without undue interference (Energy Policy Staff 1970).

Multiple use of power transmission rights of way is encouraged as a means of reducing their competition for limited land with other types of use (Goodland 1973: 20-21; Randall 1973). Randall (1973: 95-106) suggested such diverse potential uses as transportation routes, parking lots, industrial uses such as warehouses, annual agricultural crops, Christmas tree culture, many types of recreational use, and wildlife sanctuaries. Despite some potential legal, economic, safety, and compatibility drawbacks it seems likely that as environmental concern increases and as pressures between competing land uses grow, multiple use of rights of way will become much more common that it is at present (Randall 1973: 109).

Limited work has been done on the possibility of eliminating the electricity transmission problem altogether. The contemporary "energy crisis" has spurred developmental work on a host of alternate local power sources, including solar energy and the power cells (Giles, personal communication). However, it is not yet apparent that alternate techniques of local power generation are practical on a large scale and a shift from centralized generation and mass distribution of electricity is not likely.

At present, the key to minimizing the environmental and social problems which result from electric power transmission is advance regional planning, as advocated by Goodland (1973: 7). Power facilities planning on a regional level, dealing with power nets and utilizing modern concepts of optimization and forecasting, can be of aid in the design of effective systems by making available to the designer the tools to evaluate the probable costs and benefits of a wide variety of alternatives. Such planning allows the power system planner to design transmission networks which will be adaptable to social needs, and not obsolete in a decade or two because of unforeseen shifts in energy demand.

Measuring the Social Values of Impacts

Inherent in the planning process for the routing and construction of electric power transmission lines is the question of valuation. Since no route selected is completely impact-free, it is the responsibility of the planner to evaluate the importance of each of the known or potential social losses incurred as a result of right of way construction. Coomber and Biswas (1973) presented an excellent summary of techniques currently used to evaluate environmental intangibles, particularly those of outdoor recreation. They recognized two types of valuation systems: those which seek to express environmental values in monetary terms and those which use nonmonetary terms, either subjective or directly measurable (Coomber and Biswas 1973: 10-11).

Monetary Evaluation Systems

Traditional economic evaluation of recreational resources has been based on the work of Clawson (1959) and Knetch (1963). The approach is to establish demand curves for nonmarket recreational resources by estimating the user's willingness to pay for recreation in terms of the expenses he incurs, both monetary and in terms of travel time. More recently Krutilla (1970) and Fisher et al. (n.d.) have addressed the problem of evaluating the overall impacts of natural resources development versus preservation. Their approach toward natural resource valuation is heavily dependent on recreational utility and the dollar values used are, in fact, imputed values of various types of fishing and hunting experiences.

Gosselink et al. (1973) have attempted a more general approach toward establishing economic values for the environmental characteristics of tidal marshes. They combined concepts of economic value derived from fisheries (commercial and sport), shellfish production, waste treatment potential, and total energy production to compute annual per acre values for marshland and estuaries.

Giles (1971: 7-9) summarized an assortment of methods potentially usable to impute the values of wildlife resources, including several techniques based on the concept of "shadow pricing" (replacement costs or values foregone to preserve wildlife populations). Lobdell (1971) used an alternative method of valuing wildlife resources, based on determining a dollar value per man-day of deer hunting.

Nonmonetary Evaluation Systems

Leopold (1971) proposed a "matrix method" for evaluating the magnitude and importance of development project impacts on the environment. The method was based on the development of a table of 100 different impacts which might result from various projects and 88 environmental characteristics which might be impacted. The user of the martix was to rate subjectively both the magnitude and importance, on a scale from one to ten, from each of the 8,800 combinations of impact and characteristic. However, no overall index of impact could be derived and the method was presented primarily as a technique for outlining environmental impact statements.

Environmental impact analysis based on the Harvard GRID system relies heavily on the use of subjective ratings in the development of "attractiveness," "vulnerability," and "impact" models. Examples of the GRID approach are documented in Murray et al. (1971) and Frederick and Luty (1972). The resultant impact models derived by this method do not ascribe any absolute value to various types of impact. Rather these models serve to calculate and display the spatial distribution of probability levels for the occurrence of significant impacts to existent natural resource systems as a result of proposed developmental activities. The indices of probable impact are related to physical site characteristics.

Zieman et al. (1971) proposed a subjective ranking scheme for evaluating the potential impacts of interstate highway construction on land units possessing various environmental characteristics. As in the GRID system, they used subjective ranking to model the severity of overall impart. Two additive ranks were used to reflect the dynamic nature of impacts to environmental systems, one rank for "short-term" impact and one for "long-term" impact.

Niemann and Miller (1973) have developed an evaluation system for assessing the overall impact of power transmission line construction in Wisconsin. Their "Environmental Decision Alignment Process" is based on a set of seven "determinats," the major dimensions of environmental impact:

1. Urban land-use compatibility
2. Agriculture land-use compatibility
3. Recreation land-use compatibility
4. Natural system compatibility

5. Potential right of way use sharing

6. Visual determinant

7. Minimum cost

Overall evaluation of powerline impact on any parcel of land is determined by the physical characteristics of the area, the proportionate degree to which each of these characteristics is important to each impact dimension, and the proportionate importance of each determinant to overall impact. The evaluation is accomplished subjectively and is in unitless terms (percentages).

Resolution of Nonequivalent Measurement Systems

A major criticism leveled at environmental impact evaluation systems which rely on subjective ranking schemes is that they incorporate no checks on the accuracy of the values derived. However, workers in the field of operations research and decision theory have developed practical techniques for making such checks on the ranks assigned by planners to outcomes expressed in nonequivalent units. One such technique is the procedure developed by Churchman and Ackoff (1954) which is based on a systematic set of comparative judgments to be made by the planner. Choices are made among various combinations of potential outcomes. The authors cited several industrial applications of their ranking technique at the time of its publication (Churchman and Ackoff 1954: 180-181). Turban and Metersky (1971) used a slightly modified version of the Churchman-Ackoff technique in the evaluation of the effectiveness of alternative air defense systems. More recently Lobdell (1972) applied this technique to the evaluation of various wildlife species and management objectives.

Transmission Routing Procedures

Traditionally power transmission lines have been routed between source and load locations in as direct a manner as possible, since straight-line routing tends to minimize construction cost as well as electric current losses during transmission. Under this routing methodology, social and environmental costs are reflected in a series of general rules which serve to indicate minor adjustments to linear routes at points of significant conflicts. Such guidlines are exemplified in U.S. Departments of Interior and Agriculture (1971) and U.S. Federal Power Commission (n.d.). Once potential right of way corridors have located in this manner it is customary to perform a more detailed engineering and environmental analysis in the immediate vicinity of the corridor. Final tower siting decisions are made on the basis of these findings. The use of environmental guidlines in adjusting linear corridor location, while including noneconomic values in the routing decision, does not, however, guarantee optimal results. The decision maker's attention is focused on a prechosen subset of all possible routes, a choice largely influenced by a geometric relationship rather than explicit economic and environmental factors.

Alternate procedures do exist for planning the geographic location of manmade facilities when the impacts to several environmental and economic characteristics must be minimized. These techniques are based on the "overlaying" methodology proposed by McHarg (1969). The planner must construct a series of maps of the area under consideration for development, each one portraying the distribution of a significant economic, social, or environmental characteristic in shades of distinctive color. Typically, light shading at any point indicates that the proposed development would have little adverse impact, while darker shades denote increasing severity of impact. Routes of minimum overall impact are selected by overlaying transparent copies of these impact maps and seeking the "lightest" colored areas. This graphical procedure has been demonstrated for transmission line routing problems by Schall (1972).

Graphical procedures based on colored transparencies suffer from several deficiencies. The process of constructing overlays is generally tedious and expensive. Too few impact maps may be considered simultaneously for decision-making in most complex environmental systems. Indeed, after only four or five overlays of different impacts have been combined, the resultant color pattern is likely to be little more than a uniform shade of brown. In addition, such procedures afford the planner no practical means of including the relative importance of each impact to society in his analysis. By default, each impact is assumed to be of equal value to all others.

Computer automation of graphical overlaying methods tends to alleviate these deficiencies. Initial data collection and recording may be just as expensive and time consuming as in manual procedures, but large capacity computers may be used to combine a potentially unlimited number of impact maps and apply suitable value ranks to each impact. Computer-based mapping systems are now being effectively used in environmental impact analysis for many types of development. These include reservoir construction (Murray et al. 1971), land-use planning in general (Swanson 1969), urban expansion (Nez 1970; Frederick and Luty 1972; Voelker 1973), natural resource management (Amidon 1964; Fales 1969; Bonham 1971), and highway location (Zieman et al. 1971). Computer graphics procedures have been applied to electric transmission line routing decisions by Commonwealth Associates (1973).

Although a valuable planning aid, graphical techniques are not guaranteed to yield optimum routing decisions. They provide the planner a simultaneous overview of the impact of all possible routes between two points. He is able to evaluate a set of designated routes on the basis of their several impacts. However, the human decision maker is generally incapable of selecting the optimum, or minimum impact, route visually (Krauskopf and Bunde 1972). He is simply overwhelmed by the task of calculating the total impact for every conceivable route and selecting the minimum.

A few computer-based optimization procedures have been developed for treating routing decisions in a multidimensional environment. Niemann and Murray (1972) reported on a technique currently used for locating transmission lines in the western United States. Their methodology involves a blend of subjective value ranking of potential impacts and computer optimization of routing deisions. Krauskopf and Bunde (1972) applied dynamic programming to highway routing problems and reported success with transmission line routing.

The Environmental Decision Alignment Process, developed by Niemann and Miller (1973), is based on a complex percentile system of subjective impact valuation and uses an optimization algorithm to determine minimum impact right of way routes as well as computer mapping for display of the results.

PROCEDURES

Description of the Analysis Area

The impetus for developing the powerline route selection technology described herein was a construction application submitted for approval of the Corporation Commission of the Commonwealth of Virginia by the Virginia Electric and Power Company. The facility to be constructed was a 500 kilovolt transmission line connecting a generating plant at Mount Storm, West Virginia, with a nuclear power plant under construction near Lake Anna, Virginia. The industry-proposed route is displayed in Fig. 1. It was to enter Virginia in the southern part of Frederick County and proceed on a southeast path to a substation at Morrisville, Virginia. From that point it was to branch, one short line leading to a substation at Bristers, Virginia, while another proceeded south to the North Anna Nuclear Plant. As an alternative to the construction of this completely new right of way, environmentally concerned citizen groups had proposed that the new facilities be planned to parallel existing transmission lines as much as possible. The alternate proposal, pictured in Fig. 1, was that the new line be constructed parallel to an existing line east from Mount Storm to a substation in Maryland, then south past the Bristers substation to North Anna. Only a short section of new right of way construction through Spotsylvania County would be required to connect the North Anna Nuclear Plant. Although geometrically longer than the industry-proposed route this alternative was presented as being less disruptive to the environment due to decreased land acquisition

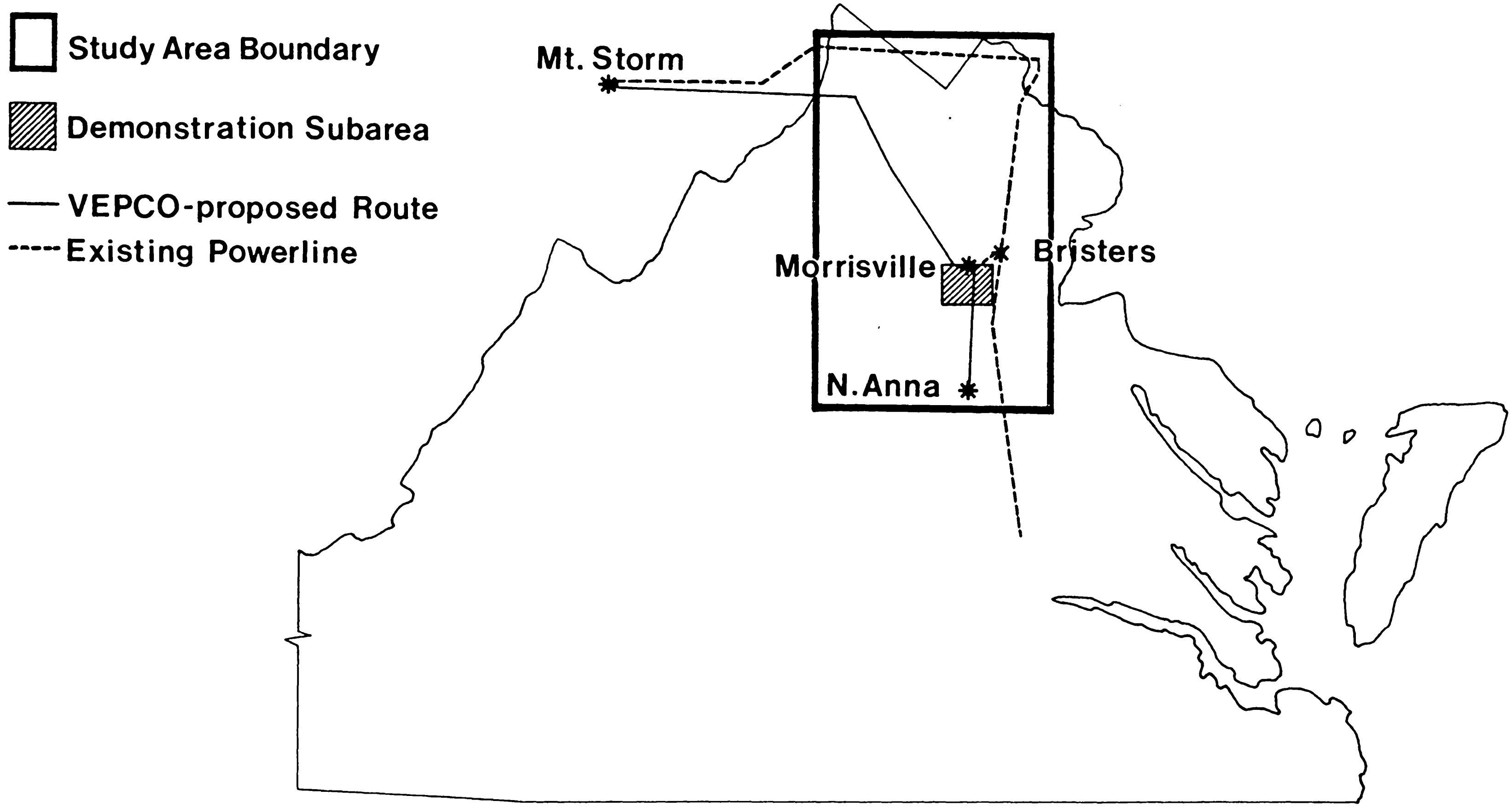


Fig. 1. Study area and subarea selected for a demonstration of transmission corridor routing procedures.

requirements and the reduced incremental impacts, both ecological and aesthetic, associated with construction on land already impacted by a transmission right of way.

As an aid in the evaluation of the potential economic and environmental consequences of selecting either of these two routes the Corporation Commission supported the development of the techniques reported in this thesis. Consideration of right of way impacts was limited to the segments of the routes inside Virginia. The area under study was bounded by the 77° 22' 30" and 78° 30' 00" meridians and the 38° 00' 00" and 39° 20' 00" parallels (see Fig. 1). The enclosed area was approximately 5,000 square miles in size. Due to resource limitations, a subarea was designated within the analysis area to be used for detailed demonstrations of the techniques presented in this thesis. The demonstration subarea was defined as the area contained within the Germanna Bridge and Richardsville 7.5 minute series U.S. Geological Survey quadrangle maps (see Fig. 1).

Development of A Right of Way Selection System

The first step in satisfying the information needs of the Corporation Commission was that of developing a data base for the analysis area. The area was to be divided into many small, discrete units of land, hereafter referred to as "cells." Then for each cell a number of socioeconomic and physical parameters were to be measured from existing maps and recorded in computer-compatible form. Techniques were then to be developed, based on the data retrieval and manipulation capabilities of the computer, to enable the planner to display automatically maps of selected parameters over the entire analysis area, build indices of probable environmental impacts resulting from right of way construction, evaluate proposed routes in terms of these indices, and determine routes which tend to minimize total adverse environmental impact due to right of way construction and maintenance activities.

Data Base Development

The process of data base development was divided into five sequential steps:

1. Definition of a data coding grid system.
2. Data capture, including the development of techniques, specification of pertinent land characteristics, determination of appropriate data sources for each characteristic, and the actual transfer of data from its source to computer compatible form.
3. Data file creation procedures, including the organization of computer files, data editing procedures, and the actual storage of data on permanent files.
4. Development of data file update procedures.
5. Development of procedures for the construction of complex indices of potential environmental impacts based on physical land characteristics.

Grid System Definition

In order to construct a computer information system for land characteristics it is necessary to establish a coordinate system which can reference individual items of data to specific ground locations. Early in the development of the data base the investigators decided that a cellular data recording scheme would be used. Computer-based procedures were available for digitizing, storing, and retrieving exact representations of geographic information in the form of polygons. However, such polygon systems become unwieldy when several resource characteristics for the same geographic area are to be analyzed or displayed in combination.

Cellular data recording systems tend to reduce the cartographic accuracy of retrieved geographic data, since they require that a map of irregular resource patterns be portrayed as a two-dimensional matrix of uniform rectangles. However, for purposes of regional analysis this loss in cartographic accuracy is offset by a gain in data processing efficiency.

Given that a cellular data recording format has been chosen, the geographic coordinate system used to define cell boundaries must be specified. Three possible candidates were considered for the powerline routing data system:

1. State plane coordinates, or some related coordinate system specific to Virginia.
2. A geodetic coordinate system based on latitude and longitude.
3. The Universal Transverse Mercator (UTM) coordinate system.

The UTM system was chosen as the basis of the geographic data system under construction. The use of a state plane-related coordinate system was rejected because it was the desire of the investigator to develop a technique of general utility, not specific to any particular state. The geodetic coordinate system was rejected due to the changes that occur in the size of geodetically defined cells at different latitudes. Geodetic cells near the equator are larger than are those at more polar latitudes. Although the latitude-size relationship is predictable, the additional data processing complexity required to adjust for it was considered to be unacceptable. Since the Universal Transverse Mercator system provides global coverage with uniform, square data cells, one kilometer on a side, it was selected as the basis for the geographic gridding system.

Data cell size also had to be chosen carefully. UTM cells one kilometer in size were considered to be too large to specify powerline rights of way with sufficient precision. Typically 500 kilovolt rights of way are no wider than 150 to 200 feet, while a UTM square kilometer cell is 3,300 feet in width. To increase the precision of the powerline routing system it was decided to select some subdivision of the UTM cell as the basic unit of data. However, data processing costs dictated some constraints on precision. To subdivide the UTM cell into subcells 150 feet in size would have multiplied the amount of data to be processed and stored by a factor of 484. A compromise cell size of one-ninth of the basic UTM cell was finally selected in an effort to achieve reasonable analysis precision under budgetary and data processing constraints. These square cells were 1,100 feet wide and approximately 27 acres in size.

The following numbering convention was established to enable the identification and retrieval of information related to any specific data cell in Virginia.

1. The 7.5 minute geodetic quadrangle was designated as the basic block of data to be stored and retrieved during this study. Therefore, a numeric method of postionally relating the quadrangles was devised. Each quadrangle was identified by two numbers. The southwestern-most quadrangle pictured on the index sheet for Virginia (Middlesboro South) was assigned the coordinates (1, 1). All other quadrangles were then identified by their row and column position in the matrix of maps covering Virginia, relative to the Middlesboro South quadrangle. For example, the Richardsville and Germanna Bridge quadrangles selected for detailed demonstration were numbered (15, 49) and (15, 50) respectively. Both were in the fifteenth row of maps north of the southern index boundary, and individually in the forty-ninth and fiftieth columns of maps east of the western index boundary.
2. Individual data cells were designated by their row and column position in the matrix of cells contained in each quadrangle. The southwestern-most cell was assigned the coordinates (1, 1) and all others were referenced by their position north and east of that origin.

Therefore, each data cell could be explicitly identified by four numbers: map row, map column, cell row, and cell column.

Since the UTM coordinate system does not align perfectly with geodetic quadrangle boundaries, it was necessary to approximate the contents of each quadrangle. Fig. 2 is a graphic example of this approximation. Complete rectangular matrices of cells were associated with each quadrangle. At quadrangle boundaries a judgement was made as to which of the two neighboring maps should contain particular rows or columns of cells. A row (or column) of cells was associated with a specific quadrangle if more than 50 percent of the cells in question lay predominantly inside the boundaries of that quadrangle. Otherwise, that entire set of cells was associated with the neighboring quadrangle.

<u>Data Capture</u>

It was decided that information to be entered into the data base would be obtained, whenever possible, from 1/24,000 scale base maps. A process of transcribing map information to computer readable form was designed. In the absence of sufficient resources to acquire mechanical digitizing equipment a manually oriented process was implemented. Transparent acetate overlays were constructed for data coding. Each was a large rectangle of cell boundaries drawn at the appropriate 1/24,000 scale. The overlay grid was placed on top of each base map and oriented with the UTM coordinates indicated at the map margins. Map features within each cell were visible through the acetate. Cellular row and column coordinates were marked on the grid borders with a grease pencil. Then data were digitized for each resource

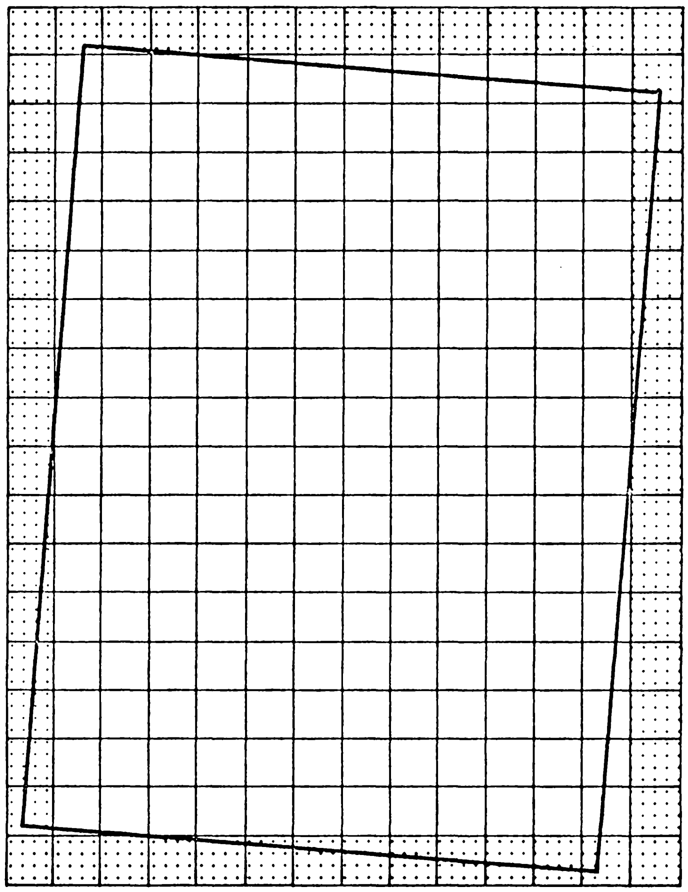


Fig. 2. An example of grid misalignment with geodetic quadrangle boundaries. The heavy line represents a quadrangle. Unshaded cells are those which most closely approximate the area inside the quadrangle.

parameter by visually scanning the gridded map and recording cell characteristics manually on computer card coding forms. Scanning of the cellular matrix was always performed in a prescribed order. Beginning at the northwest corner, the data coding personnel scanned all cells in the top row of the matrix, left to right. Then each row was processed in an identical manner, proceeding sequentially from the top to the bottom of the matrix. For each cell to be processed, three numeric values were recorded: row number, column number, numeric data code for the parameter being examined. To achieve maximum efficiency this information was not recorded for every cell in the matrix, merely for those cells at which the numeric data code differed from the previous cell recorded in the scan. Computer programs were developed to fill in missing data values. The data values were immediately written on standard 80-column data coding forms. No specific coding format was required. The only restriction was that at least one blank space should separate numeric values. The data coding process was repeated for each quadrangle in the study area and for each resource parameter to be recorded. Once data coding was complete for a quadrangle, the data were keypunched onto computer cards which served as the basis of permanent computer files.

Data about 17 land or resource parameters were collected for every cell in the analysis area. These parameters were selected as most appropriately representing the ecological, economic, and cultural characteristics of each cell within the constraints of data availability. The following discussion will document the source, method of collection, and range of possible cell characteristics for each parameter. Detailed information about specific numeric codes selected to depict cellular characteristics is contained in Appendix I.

Parameter 1 - roads

Information about the presence or absence of roads in each cell was derived from the most currently available 1/24,000 scale U.S. Geological Survey (USGS) topographic maps. Cells were assigned data values depending upon the presence of a road in any portion of the cell, and the classification of that road on the source map. The road classes recognized were: light duty, secondary road, and major highway.

Parameter 2 - counties

Each cell was characterized by the county in which the highest proportion of the cell was located. County boundary information was obtained from 1/24,000 scale USGS topographic maps.

Parameter 3 - planning district

The state planning district (of which there are 22) in which the highest proportion of each cell was located was recorded, based on county boundary information.

Parameter 4 - water resources

The presence of water, either occurring naturally or resulting from human activity, was recorded for each cell. The data source was 1/24,000 scale USGS topographic maps. The water resource classes recognized were: rivers, small streams, ponds, sewage facilities, swamps, and marshes.

Parameter 5 - preexisting powerlines

The existence of power transmission rights of way was determined for every cell from 1/24,000 scale USGS topographic maps and recorded. Only the presence or absence of rights of way was recorded. No information about voltage or physical characteristics was captured.

Parameter 6 - other existing utilities

The presence or absence of railroads, pipelines, and telephone cables was determined for each cell from 1/24,000 scale USGS topographic maps.

Parameter 7 - land use and ownership

Each cell was classified by its predominant land use or ownership characteristic. This classification was derived from the cultural, text, and vegetative information displayed on 1/24,000 scale USGS topographic maps.

Parameter 8 - airports

The presence or absence of airfield facilities in any part of a cell was recorded. Land areas falling within airport boundary fences marked on 1/24,000 scale USGS topographic maps were classified as airports.

Parameter 9 - transmitter zones

Powerline rights of way construction was excluded from all lands within a five-mile radius of two United States government radio transmitters at Midland, Virginia, and LaGrange, Virginia. The transmitter sites were located on USGS 1/24,000 scale topographic maps and five-mile zone boundaries were drawn. Each cell was classified as to whether it lay predominantly inside or outside these restricted zones.

Parameter 10 - elevation

The elevation at the center of each cell, in feet above mean sea level, was determined from contour information on 1/24,000 scale USGS topographic maps.

Parameter 11 - slope

The terrain of each cell was classified into a predominant slope class, as determined by visual examination of the spacing of contour lines on 1/24,000 series USGS topographic maps. Slope classes of less than 5 degrees, 5 to 15 degrees, and greater than 15 degrees were recorded.

Parameter 12 - aspect

Each cell was further classified by the predominant direction of slope. Aspect data were recorded simultaneously with slope data, using the same source map. Eight slope directions were recognized, in addition to ridge tops and bottom land.

Parameter 13 - soil association

Data from existing Soil Conservation Service county soil surveys was hand drawn on 1/24,000 scale base maps prior to data coding. Each cell was classified by the predominantly occurring soil association in that 27 acres.

Parameter 14 - precipitation

The average annual precipitation, in inches, was recorded for each cell. Rainfall isopleths obtained from the U.S. Weather Service were recorded by hand on 1/24,000 scale base maps prior to data coding.

Parameter 15 - historic sites

Information on the presence or absence of historic landmarks in each cell was obtained from 1/24,000 scale base maps maintained by the Virginia Historic Landmarks Commission. Potential, proposed, and registered sites were recorded.

Parameter 16 - recreation resources

The presence of existing or potential recreation resources in each cell was recorded. Data were collected from 1/24,000 scale base maps maintained by the Virginia Outdoor Recreation Commission. A variety of characteristics were recorded, including public parks and natural areas, commercial recreation facilities, scenic easements, trails, beaches, and boat landings.

Parameter 17 - land value

Per acre land value data were accumulated for each cell by Technical Associates, Incorporated. Data coding personnel obtained tax maps from the Commissioners of Revenue in all counties of the study area. Data coding grids were generated for the various map scales encountered in the tax documents. Each cell was characterized by the land value, per acre, which dominated that cell on an area basis.

Processing of the Digitized Data

Fig. 3 illustrates the flow of information through the computer-assisted right of way evaluation and selection system developed for the Virginia Corporation Commission as a result of this study. The remainder of this chapter will be a discussion of the purpose and general capabilities of each modular computer program in the system. Data formatting specifications, job control language considerations and source lists of each module, as implemented on the Virginia Polytechnic Institute and State University IBM 370/158 computer system at Blacksburg, have been documented by Jones et al. (1976). Program decks and additional information may be obtained from the author.

Data File Creation

Entry of the keypunched cell characteristic information into the host computer and storage on permanent magnetic devices was a two-step procedure. The data cards first had to be edited and all errors and illogical data relationships had to be resolved. Once editing was complete, the computer was used to calculate the characteristics of those cells for which it was unnecessary to record data during the map scanning process. The completely filled matrices of numeric data values for each quadrangle map were then ordered and stored in the basic data files.

Prior to editing, the data cards had to be sorted and ordered appropriately. For each quadrangle map in the analysis area there were 17 decks of data cards, one for each parameter. These decks varied in size in a direct relationship with the complexity of the data patterns on each map.

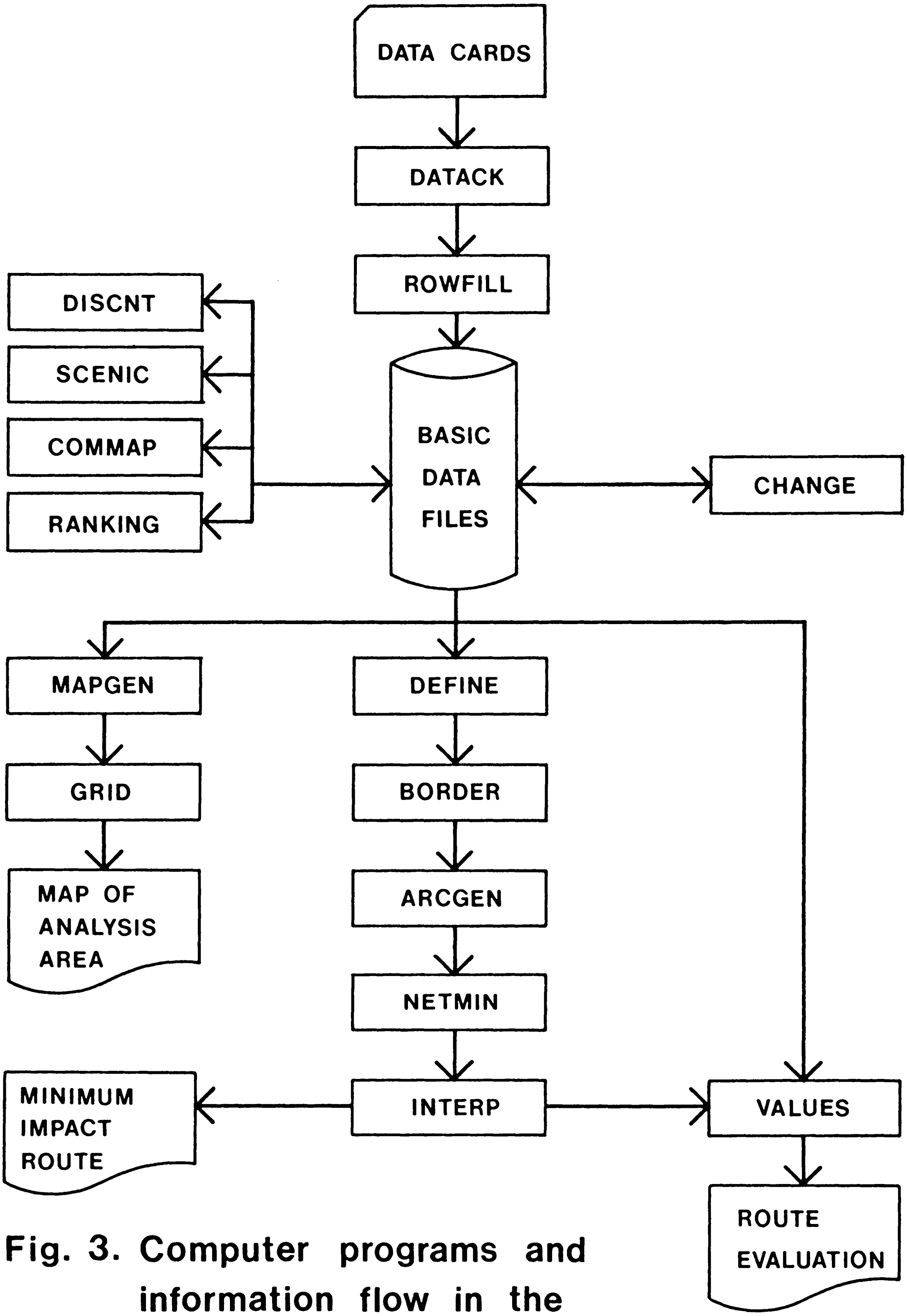


Fig. 3. Computer programs and information flow in the corridor selection system.

A special header card was prepared for each data deck. The header contained information about the associated quadrangle, including quadrangle name (as assigned by the U.S. Geological Survey), quadrangle coordinates in the reference system described in the grid system definition discussion, and the size of the matrix of cells describing the quadrangle (number of rows and columns of cells to which the data deck referred). A delimiter card, containing three X's separated by blanks, was placed at the end of each deck.

Data were processed one parameter at a time. For each parameter the card decks for all quadrangles were hatched. The decks were ordered by quadrangle row number (in ascending order), and by quadrangle column number (in ascending order) within each row. The 17 master data decks, each containing all the data for a particular parameter were then edited and submitted to the ROWFILL program individually.

Data editing

The master data deck for each parameter was submitted to the DATACK editing program. This program scanned the contents of the deck for the following data conditions:

1) Proper ordering of quadrangle decks.
2) Proper order of row and column pairs in each quadrangle.
   A data value and set of coordinates must be supplied for the upper left cell in the data matrix. Thereafter each pair of row and column coordinates must occur in the order dictated by the map scanning rules discussed under data capture techniques.

3) Proper ranges of row and column coordinate values. No values less than one or greater than the maximum recorded on the quadrangle header card are appropriate.

4) Proper data codes. Each pair of row and column coordinates must be followed by a valid numeric data code.

If any of these conditions were violated during the processing of a master deck by DATACK, a message describing the probable error was printed.

After each run of DATACK the list of associated error messages was scanned by the investigator and appropriate changes were made to each master data deck. DATACK was reexecuted cyclically until all logical errors were removed from the data.

Data entry

When each master data deck had been completely checked it was supplied as input to the ROWFILL program for entry into the basic data files. The purpose of this program was to read the master data deck and process the information by quadrangle. Based on the coordinates and characteristics recorded, a complete matrix of numeric codes for the particular parameter being processed in each quadrangle was constructed. These data matrices were subsequently loaded on permanent magnetic storage devices in the order of their occurence in the master data deck. A separate, sequential data set was created for each parameter measured. The records in each data set were organized in a one-to-one manner positionally. A data value at a specific physical position in any data file represented information about the same geographic point as did data values at the same position in any of the other files. This organization of separate, parallel data sets for each parameter was chosen to increase the efficiency of data handling during analysis and display operations.

Data File Update Procedures

In recognition of the fact that all data errors could not be corrected prior to computer processing and that some of the parameters to be used were dynamic over time, a procedure for updating the basic data files was designed. The CHANGE program was developed to allow the investigators to make appropriate changes to cellular data values already stored on magnetic files. Since data for each parameter was stored in a separate data set, multiple runs were required to change data values for more than one parameter. However, for one parameter all cells in the analysis area were accessible in each run and the codes previously assigned to any of them could be modified.

Index Construction Procedures

The objective of developing the corridor location system was to supply the land management decision maker, in this case the Virginia Corporation Commission, with a means of evaluating a complex set of interactions: The probable environmental, economic, and social impacts of powerline right of way construction through a geographic area. Data capture techniques were developed in order to provide baseline information on resource characteristics prior to construction. Parameters were selected for examination if they would supply useful and nonredundant information about resources. Each parameter was measurable and available on base maps. However, in order to translate measurable information about known resource characteristics into unmeasurable information about probable impacts a great deal of complex manipulation was necessary. Computer storage and processing techniques were selected to maximize the efficiency with which the large anticipated volumes of data could be processed. After data storage was complete each individual data cell could be quickly characterized by its measurable resource characteristics. However, little useful information was gained from immediate display since the raw data already existed in map form prior to being entered in the computer.

In order to turn one-dimensional resource information into multidimensional estimates of probable impacts, several modules were provided to:

1) access information from one or more of the basic data files
2) construct for each data cell, according to specific rules, an index of probable impact resulting from powerline construction
3) create a new file of these index values for inclusion in the basic data files.

<u>Probable economic impact</u>

The DISCNT program was provided to predict an index of the economic consequences of right of way construction in any particular cell. The procedure was conceived and programmed by Mr. K. C. Strobl of Technical Associates, Incorporated. Although details of the procedure are documented elsewhere (Strobl, 1973), a brief discussion is included here for completeness.

This program calculates, for each cell, an estimate of the total per acre land acquisition, right of way construction, and maintenance costs incurred if a powerline were to be constructed there. Four basic data files were used in the calculation of this index:;

1) assessed land values
2) slope classifications
3) county boundary information
4) presence of road systems

Assessed land value was accepted as a valid index of land acquisition costs in each cell. This was converted to market value by means of a multiplier reflecting the assessment rate of the county in which the cell lay. Right of way construction and maintenance costs were estimated based on the degree of slope in each cell and existence of public roads. An average traverse of 1,100 feet was assumed for a right of way crossing any cell. The contents of Table 1, resulting from discussions with engineers from the Virginia Electric and Power Company, summarize the cost values used for cells of varying characteristics. Once the per acre construction, acquisition, and maintenance costs were calculated they were combined to reflect the social cost of constructing and operating a transmission corridor over a series of years. The present value of the social cost was defined by Ileo (1973):

Table 1. Per acre right of way installation and maintenance costs per cell.

	Terrain		
	Rolling (0^0-5^0 slope)	Hilly (5^0-15^0 slope)	Mountainous (over 15^0 slope)
Standard Clearing Cost	$ 450	$ 500	$ 700
Construction Cost	4,745	5,196	5,647
Maintenance Cost (per year)	24	35	51
Cleanup Cost	200	375	825
Total Standard Costs	5,419	6,106	7,223
Screening Cost (if a road is present)	90	90	90
Total Cost	$5,509	$6,196	$7,313

Source: Strobl 1973

$$PVSC = C + \sum_{i=1}^{n} \frac{M_i}{(1+r)^i}$$

where: C = cost of construction and right of way qcquisition

M_i = maintenance cost in year (i)

r = discount rate

n = life of the project (years)

The output of the DISCNT program is a file of cost values which correspond positionally to the data codes in the basic data files. A project life of 30 years and a discount rate of 8 percent were selected by Technical Associates, Incorporated, personnel as being representative at the time of this study.

Probable aesthetic impact

The SCENIC program was written to calculate an index of the potential aesthetic impact of powerline construction for every cell in the analysis area. This index is defined as the number of data cells within a one mile radius of a point from which a transmission tower constructed at that point could be viewed. The calculation is based on topographic relationships. The SCENIC program accepts as input the basic data file of centroid cell elevations. For each cell in the analysis area, the program tallies the number of cells within one mile from which a standard tower on the target cell could be seen. A tower height of 90 feet and a viewer eye level of five feet were assumed. The algorithm counts a cell as visible if any portion of the tower would be visible, based on the elevations of the viewer cell, the target cell, and any cells lying between the two. No attempt was made to scale the raw index by viewing distance or viewer audience characteristics.

Upon completion of processing by this program, each cell in the analysis area had been assigned an aesthetic impact between 0 and 100, the larger indicating more severe impacts since tower construction would be visible from a large number of viewing points. This file of indices was added to the basic data files in a compatible format.

Index of environmental constraints

One objective of this study was to provide the Corporation Commission with a methodology for determining minimum impact power transmission corridor routes, a route being defined as a continous path of cells between two points. Such alternative routes could be compared with applicant-proposed routes evaluated on an equivalent basis. If significant differences were apparent, redesign of the applicant's route might be advised. However, as indicated previously, impact is a multidimensional quantity which may be evaluated in economic, environmental, and social terms. Optimization may only be logically accomplished on the basis of one dimension at a time. Therefore, it was imperative that some index of combined economic, environmental, and social impact due to powerline construction be developed for each cell. The technique initially adopted to construct indices of overall impact was the application of "environmental constraints."

Each cell in the analysis area had been characterized by the probable present valued cost of powerline construction, maintenance, and land acquisition, using the method previously described. This was considered to be an adequate measure of the economic dimension of impact. Based on this characteristic, an optimization algorithm, to be discussed later, could be used to delineate a minimum cost right of way corridor between any two points. It was hypothesized that certain cells in the analysis area might possess physical characteristics, unrelated to dollar costs, which would make them undesirable as powerline construction sites. The COMMAP program was written to compare the characteristics of each cell (in terms of the 16 noneconomic parameters captured) with a user-specified list of "critical characteristics." The economic cost of any cell which had one or more undesirable characteristics could be incremented by an arbitrarily large amount. Passing the resultant file of "modified" economic indices through the optimization procedure could potentially result in the selection of a route much different from that which had been selected solely on the basis of economic criteria. In effect, environmental "constraints" would have been applied to the economic optimization. If the incremental costs added to the basic economic descriptor of environmentally sensitive cells were sufficiently great, such cells would be effectively excluded from any "minimum impact" path.

The COMMAP program accepts a user-supplied list of "critical characteristics" and appropriate economic increments to be applied to cells possessing such traits. The program examines the traits of each data cell in the analysis area and constructs an incremented index of economic impact for those which would be undesirable right of way sites. The resultant file is stored as a new member of the basic data files, available for future analytical use. The procedure can be repeated several times with varying lists of critical characteristics during the route selection process.

Index of overall impact

The major weakness of the "environmental constraint" approach to the expression of combined economic and environmental impacts was the requirement that the user establish directly the relationships between probable economic costs and other environmental impacts. The process of equating dollar values with the noneconomic consequences of constructing transmission facilities across land of certain physical characteristics is tenuous at best. First, it is difficult, if not impossible, for one person to consider simultaneously all possible combinations of environmental impacts and the relative social importance of each. Secondly, the use of dollars as a measure of overall impact is debatable in light of economic theories concerning nonlinear utility as well as the difficulty of assessing communal utilities. Thirdly, even though an analyst may be confident that a set of economic costs for environmental impacts which he may have developed is appropriate, it is extremely difficult to justify the choices made. Without a rational, step-by-step procedure for estimating economic costs, one man's set of values is as defensible as another. At best, the environmental constraints used to portray overall impact should be viewed as absolute constraints. The increment to the economic cost of construction on any cell with undesirable characteristics would be sufficiently great to exclude that cell from further consideration as a right of way site.

During this study a second method of expressing overall right of way construction impact was designed as an alternative to the environmental constraint formulation. This index of overall impact was formulated with several objectives in mind:

1. To provide the decision maker with a rational, stepwise method of translating physical characteristics of land units into some index of the probable impact of right of way construction.
2. To allow for input from recognized experts in fields related to the various dimensions of total impact to be considered (economic, social, environmental, aesthetic, and political).
3. To provide a flexible index of impact, adaptable to variable decision environments.
4. To combine the concept of constraints with the valuation of various impacts.
5. To incorporate in the analysis the factor of dynamic impact levels over time.

In the context of selecting "optimum" power transmission corridor routes, the objective of the decision maker (in this case the Corporation Commission) should be to minimize the overall impact of the right of way, subject to specific constraints. However, "impact" may be viewed as a multidimensional entity, composed of several aspects each of varying importance to society. The aspects, or dimensions of impact may be symbolized by the set of items:

D_i ; $i=1,2,\ldots,n$

where n = the number of independent impact dimensions recognized by the decision maker.

Examples of these dimensions may include such general items as economic impact (cost to utility ratepayers), aesthetic impact, environmental impacts, or social impact. In general, these "dimensions" are not directly measurable. The set of constraints under which the minimization process should take place may be defined as:

C_i ; $i=1,2,\ldots,t$

where t = the number of constraints recognized by the decision maker.

Constraints are usually measurable characteristics of land which make it completely unsuitable for powerline siting for legal or other reasons. An example might be the existence of an airport runway.

To apply this index construction technique for a particular routing decision, the analyst must compile an exhaustive list of the impact dimensions and constraints in effect. This may be done by polling the responsible decision makers, convening a representative panel of citizens, or as result of repeated list development by the analyst followed by approval by the decision making body. In addition to listing the impact dimensions, the analyst must also compile a subjective index of the relative contribution of each dimension to the realization of overall impact. The result should be a list of numeric weights, W_i, one for each impact dimension, subject to the requirements:

$$0.0 \leq W_i \leq 1.0, \text{ for all } i$$

and

$$\sum_{i=1}^{n} W_i = 1.0$$

To ensure that subjectively derived weights are consistent measures of the relative importance of each dimension it is suggested that a procedure, such as the modified Churchman-Ackoff technique (Churchman and Ackoff, 1954) used by Lobdell (1972), be applied to their raw values.

A unit of measure must be selected for each dimension of impact. These measurement units will vary in precision from one dimension to another. Some impacts may be measured in terms which are relatively easy to define. The use of dollars as a unit of economic measure is a widely accepted convention. Measurement units for some impacts may be more difficult to define or agree upon. The number of cells within a specified radius from which a tower might be seen is a simplistic measure of aesthetic impact the validity of which experts in the field of landscape architecture might debate. It is not a comprehensive measure of aesthetic impact, but it does reflect a major aspect of the problem and could be efficiently included in the system in the time available for development. Some impacts may be practically immeasurable and must be compared merely on some subjective scale ranging from no noticeable impact to most severe impact conceivable (social impact of right of way construction on historic sites, for example).

As discussed earlier one assumption of this study is that certain cells, or units of land, are undesirable as locations for powerline rights of way construction because they possess one or more "critical characteristics." A critical characteristic is an attribute which, if construction were undertaken on the cell in question, would cause the decision maker to realize one or more of the dimensions of impact at varying levels of severity, denoted by:

c_{ij}; $i=1,2...,n$; $j=1,2,...,m$

where m = the number of critical characteristics identified by a panel of experts in environmental, sociological and economic affairs.

The analyst must then, in conjunction with the responsible decision makers and selected experts, construct two "impact matrices" of c_{ij}'s. One matrix should express the probable impacts associated with constructing a right of way across a cell having specific critical characteristics and no preexisting right of way. The other matrix should summarize the same relationships, assuming that there was already at least one right of way in the cell (see Fig. 4). Since the impacts of right of way construction are not instantaneous, but extend through time, the decision makers should be encouraged to think in terms of "impact functions," which portray the expected severity of an impact for an appropriate span of time, T_{ij}, after the initiation of construction. The time frame may vary for each combination of impact dimension and critical characteristics. Fig. 5 illustrates an

	Impact Dimension and Weight					
Critical Characteristics	D_1 W_1	D_2 W_2	· ·	· ·	· ·	D_n W_n
1	c_{11}	c_{21}	·	·	·	c_{n1}
2	c_{12}	c_{22}	·	·	·	c_{n2}
·	·	·				·
·	·	·				·
·	·	·				·
m	c_{1m}	c_{2m}				c_{nm}

Fig.4. Generalized impact matrix of severity measures. Each measure $[c_{ij}]$ is expressed in the units appropriate to the related impact dimension $[D_i]$.

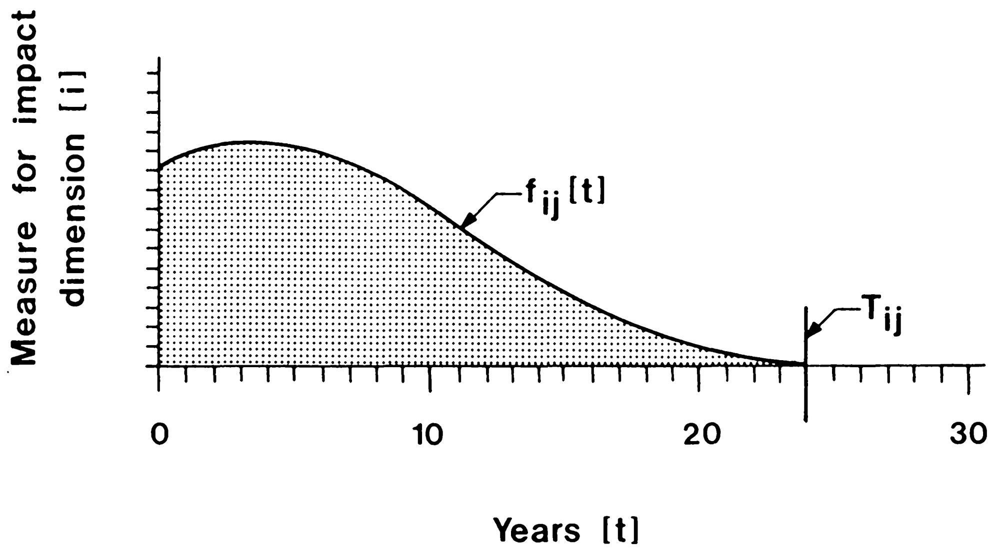


Fig. 5. Hypothetical impact function [f_{ij}[t]] for critical characteristic [j] and impact dimension [D_i] over time span [T_{ij}].

hypothetical impact function. The value of c_{ij}, then, is the value of the cumulative impact function; $F_{ij}\ (T_{ij})$:

$$c_{ij} = F_{ij}\ (T_{ij}) = \sum_{t=1}^{T_{ij}} f_{ij}\ (t)$$

where T_{ij} = the probable duration of the impact (i) caused by routing a powerline through any cell having critical characteristic (j).

Then for each cell (k) and impact dimension (i) define the "basic cell impact," I_{ik}, as:

$$I_{ik} = \sum_{j=1}^{m} \phi_{jk}\ c_{ij}$$

where ϕ_{jk} = 1, if critical characteristic (j) is present in cell (k)

0, otherwise

To compensate for the disparity in measurement units among the impact dimensions, define the "normalized cell impact," I'_{ik}, as:

$$I'_{ik} = \frac{(I_{ik} - \min_k I_{ik})}{(\max_k I_{ik} - \min_k I_{ik})}$$

Finally, for each cell (k) the "overall cell impact" may be defined as:

$$I^*_k = \sum_{i=1}^{n} W_i\ I'_{ik}$$

The value for I^*_k is an index of overall impact within a cell which may range from zero to one.

The objective of determining the optimum or minimum impact corridor route may then be restated as the task of finding the set of contiguous cells connecting the designated endpoints which minimizes the total line impact:

$$TI = \sum_{k=1}^{z} \theta_k \, I_k^*$$

where $\theta_k = \begin{cases} 1, & \text{if cell (k) lies in the selected corridor} \\ 0, & \text{otherwise} \end{cases}$

and z = the total number of cells in the designated study area, excluding those cells which possess attributes which would serve as absolute constraints on construction.

This index of impact can effectively combine the expert judgement of two groups of individuals whose inputs are important to the route selection decision. The inputs of technical experts in various scientific disciplines are incorporated in the process of defining critical cell characteristics and the impact functions which relate those characteristics to probable impacts. The specification of impact dimensions and their associated weights is the contribution of the decision maker. The index calculated by this technique is a model of the true impacts realized by society. As with any abstract model it has an associated set of assumptions which must be recognized by the user. These are:

1) The set of impact dimensions, D_i, is exhaustive.

2) The impact dimensions are independent.

3) The set of subjective weights, W_i, determined by the decision maker, are a true measure of the desire to minimize each dimension of the overall impact of right of way construction.

4) For each impact dimension the set of critical characteristics is an exhaustive list of the cell attributes which, if right of way construction were initiated, would cause realization of that impact in some degree.

5) For each impact dimension the effects of the critical characteristics are independent.

6) The impact functions, $f_{ij}(t)$, are valid measures of the expected severity of impact.

The RANKING program was written to perform the above series of calculations on every cell in a specified analysis area. It required three files of information from the user:

1. A description of the dimensions of impact.
2. A description of the constraint set in terms of data parameters and characteristics.
3. A description of the critical characteristics and their coefficients (c_{ij}) in the impact matrix.

The result of the RANKING program was a file of I_k^* index values for all cells which was incorporated in the basic data files.

Use of the Data Base for Selecting Powerline Routes

Once the basic data files were completed, a set of three computer based procedures was developed to enable the Corporation Commission to use their contents in evaluating proposed right of way routes and defining alternative routes. Each procedure was composed of one or more computer programs executed in a specific sequence.

Data Display Procedure

A data display procedure was provided to enable the user to map the entire analysis area in terms of any parameter or derived data value in the basic data files. The product is a shaded map produced on the computer printer. Each cell is represented by one printer character and shading, denoting different cell characteristics, is accomplished by multiple strikes of the printer ar the same spot on the paper. The GRID program, originally developed at Harvard University (Sinton and Steinitz, 1971), was adapted to the characteristics of the basic data files and used for all map display. The MAPGEN program was developed to interface the GRID program with the basic data files and prepare GRID control commands from abbreviated user input. Numerous examples of the map products of these programs are contained in the following chapter of this paper, which reports the results of the routing evaluations undertaken.

Route Evaluation Procedure

The VALUES program was developed to provide the capability to evaluate any proposed right of way route in terms of one or more of the sets of information stored in the basic data files. To use the VALUES procedure the user is required to provide two sets of information. First it is necessary for him to specify the parameters which are to be used in evaluating a particular route and their positions within the basic data files. Second, a sequential file of the coordinates of all cells in the route must be furnished by the user. Each cell be identified by its four coordinates: row and column of its associated map in the Virginia coordinate system and row and column of the cell within that map. The result of the VALUES program is a printed table, listing each cell to be evaluated and specified parameters of those cells as recorded on the basic data files. For data parameters reflecting cost data, the program can calculate the sum of the observed values for all cells listed. This program was designed primarily as a means to aid the decision makers in an objective comparison of industry proposed routes with those proposed by other parties as well as with the "minimum impact" solution obtainable from the computer.

Route Optimization Procedure

As an alternative to the passive role of approving or disapproving right of way routes proposed by others, the Corporation Commission was also provided with an aid for active participation in the route definition process. A series of five computer programs was written which would allow the decision maker to specify a relevant measure of impact stored in the basic data files, along with the coordinates of the origin and destination of a proposed transmission line, and find the contiguous set of cells which connect the endpoints with the minimum total impact. The measure of impact selected may be any of the one-dimensional aesthetic, ecological, or economic parameters discussed previously or it may be an index of overall impact based on subjective weighting by the Corporation Commission or its staff.

The selection of a minimum impact route is accomplished with the aid of a least-cost path seeking algorithm proposed by Dijkstra (1959). The formulation of the transmission line routing problem as a least cost path search through a network may be demonstrated with the following example.

Fig. 6 illustrates a hypothetical analysis area composed of 20 data cells. Each cell has been uniquely labeled by the integer value encircled at its center. Each cell has also been characterized by a measure of impact which would be realized if powerline construction was to be undertaken there. These measures appear in the upper right corner of each cell. Cells 13 and 4 have been defined as the endpoints of a transmission corridor. The problem of selecting that series of contiguous cells which connect these endpoints with the least total impact may be approached in the following manner.

1. Define the center of each cell as a "node" in a conceptual network. The routing of a transmission corridor from one cell to its neighbor can be represented by a "directed arc" connecting the origin and target cells. The cost (impact) of that route can be defined as the impact incurred by traversing the target cell, since in order to define that route the powerline must already be impacting the origin cell. If all possible routes connecting cells to their neighbors are defined, the resultant network of arcs and nodes is represented by Fig. 7. Dotted lines signify routes which may potentially be included in the minimum impact solution.

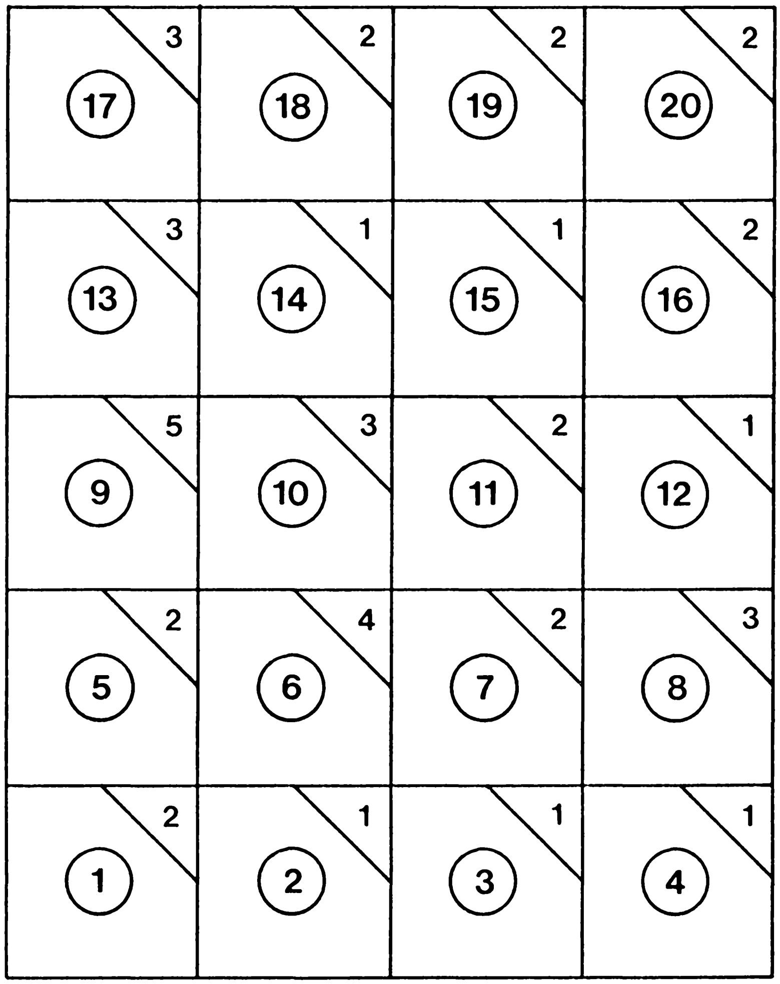


Fig.6. Hypothetical analysis area composed of 20 data cells. Each cell is labeled by a circled integer at its center. A numeric index of probable right of way impact is indicated in the corner of each cell. Cells 13 and 4 have been chosen as route endpoints.

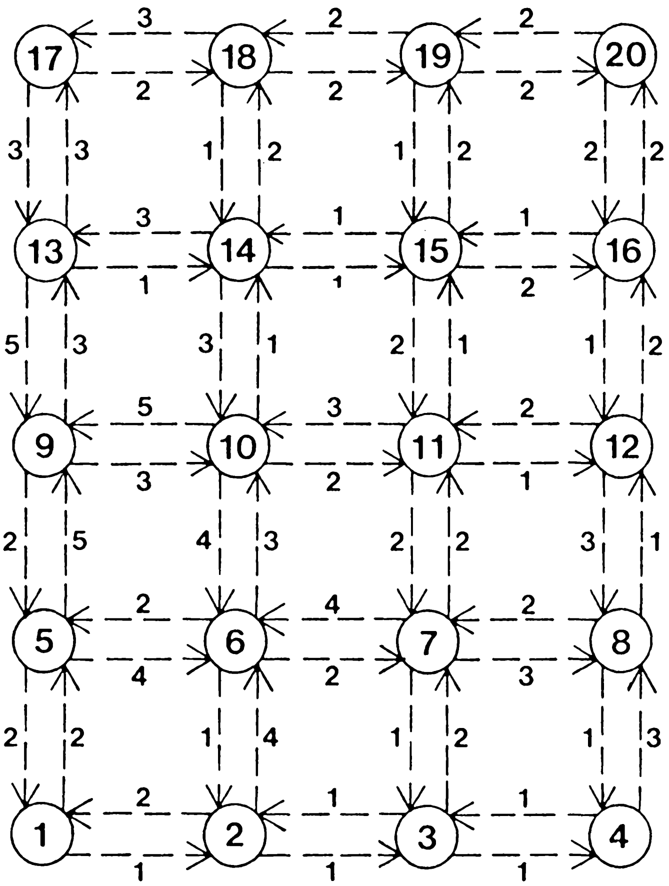


Fig. 7. Network representation of the minimum impact route selection problem. Dotted arrows represent potential intercellular paths and the impact associated with each.

2. Define cell 13 as the "root," or beginning, of the minimum impact solution. In other words, include node 13 in the set of nodes which are potential starting points for the next arc to be included in the minimum impact solution. In order to avoid the possibility of a cyclic path being selected through cell 13 again, delete from future consideration all arcs which point to node 13 (Fig. 8).
3. Examine all possible moves from node 13 and select that which has the minimum associated impact. The arc from node 13 to node 14 is the least costly, with an associated impact of one unit. Label that arc as part of the minimal route solution (denoted by a solid line), delete all other arcs pointing to its target node (14), and include the target node in the set of nodes which are potential origins for the next arc entered into the solution (Fig. 9).
4. Examine all arcs starting from any of the potential origin nodes and select that which has the minimum cumulative associated impact. Cumulative associated impact is defined as the sum of the associated impact of an arc and all the arcs which connect its origin node to the root of the solution. In the example the arc from node 14 to node 15 would be selected, next, with a cumulative associated impact of 1 + 1 = 2 units. Label the selected arc as part of the minimal route solution, delete all other arcs pointing to its target node, and include the target node in the set of potential origins. Fig. 10 illustrates the result of this operation.

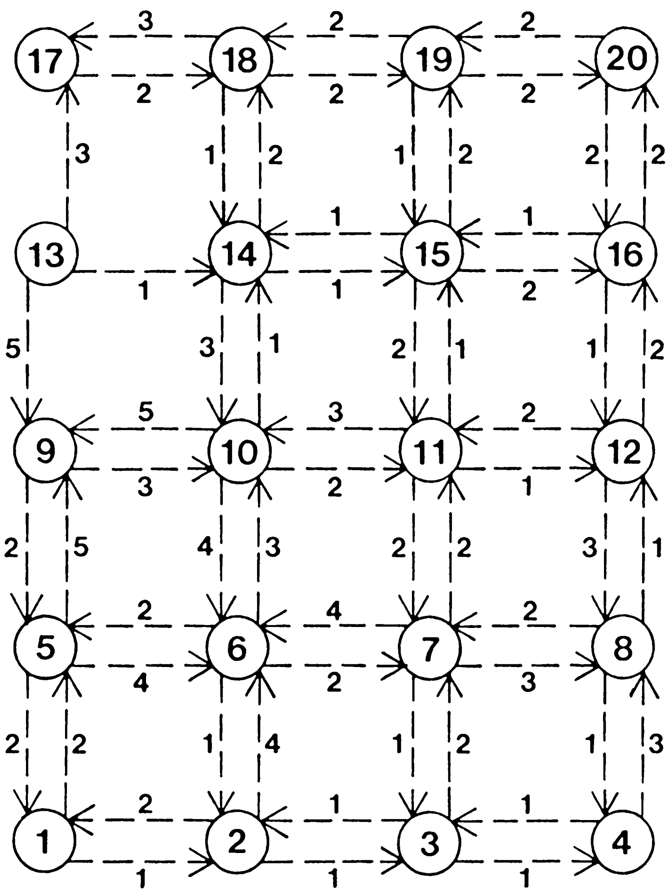


Fig. 8. Result of root definition, step 2 of the minimum impact route selection procedure.

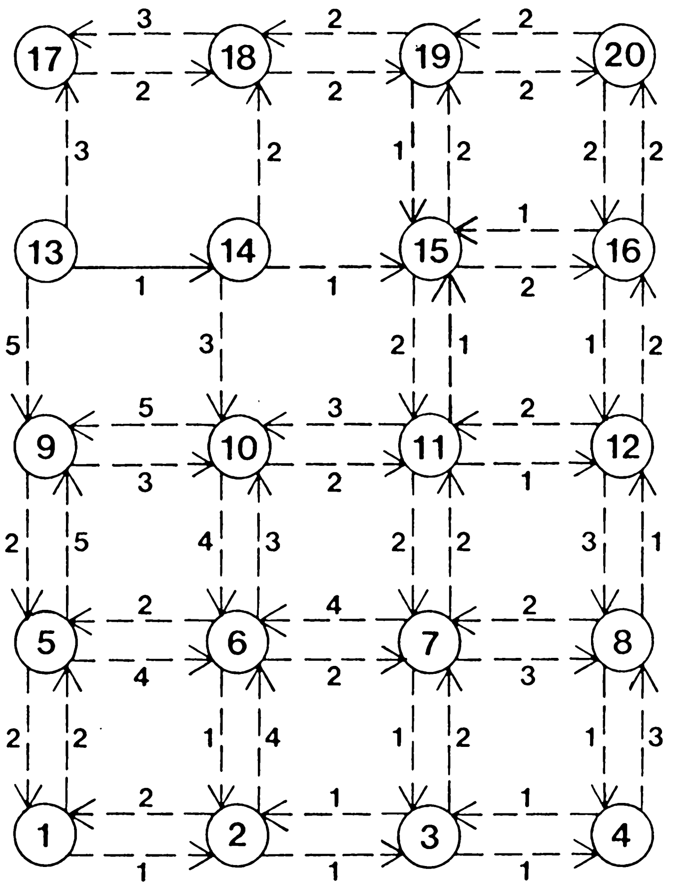


Fig. 9. Result of the first arc selection, step 3 of the minimum impact route selection procedure. The solid line represents an intercellular path which has been incorporated as part of the minimum impact.

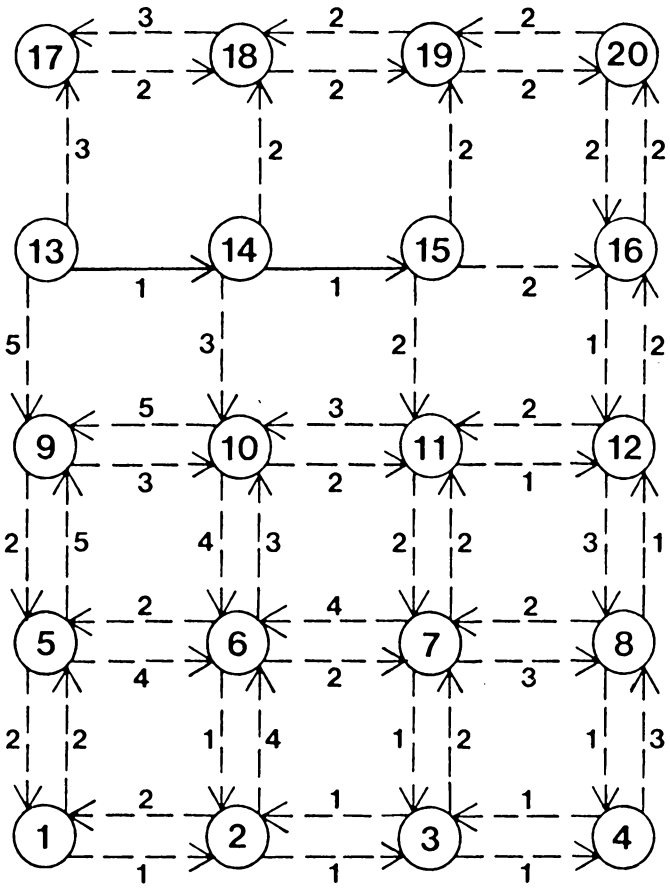


Fig. 10. Result of the second arc selection, step 4 of the minimum impact route selection procedure.

5. Repeat Step 4 until the ever-expanding list of potential origin nodes includes the other endpoint of the route. At this point a minimum impact route can be determined by tracing the trail of arcs and nodes which led from the starting node to the endpoint. From Fig. 11 it can be seen that the series of nodes (cells) which connect nodes 4 and 13 is 4, 3, 7, 11, 15, 14, and 13. The expected impact of right of way construction through these cells is the sum of the impacts associated with each arc in this example:

   1 + 1 + 2 + 2 + 1 + 1 = 8 impact units

Five computer programs were written to formulate the powerline routing problem as a least-cost path search, construct the description of the network to be searched, and execute the search algorithm. The DEFINE program was designed to accept the user's definition of the study area boundaries. It reads a list of quadrangles and their row and column coordinates and extracts a subset of information from the basic data files. The BORDER program establishes the necessary logical linkages between cells at the borders of neighboring quadrangles and appropriately labels those cells at the margins of the selected analysis area. The ARCGEN program constructs a computer-compatible description of the network of arcs and nodes in the analysis area. The NETMIN program actually performs the calculations described in the previous example and constructs a list of the cells on the selected minimum impact path. The INTERP program interprets the results of the NETMIN optimization and translates the cell coordinates from their one-dimensional computer form to the four-part coordinate system defined

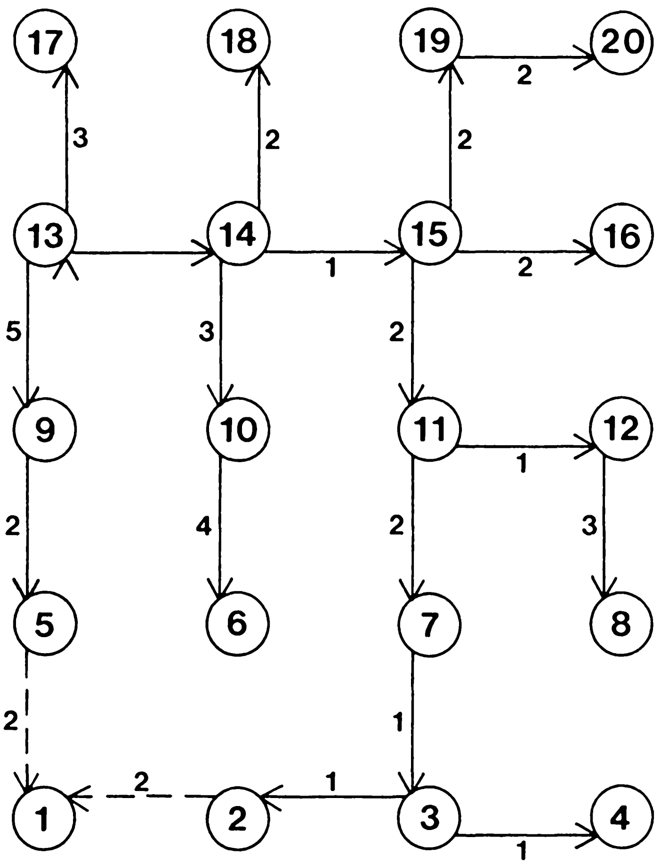


Fig. 11. Minimum impact solution to the sample routing problem.

earlier. The results of INTERP may then be passed to the VALUES program for detailed evaluation of the total route impacts as well as those associated with the individual cells.

<u>Analyses Performed</u>

A detailed set of 10 routing analyses was performed on the demonstration subarea composed of two 7.5-minute quadrangles. The objective was to demonstrate the full spectrum of capabilities provided in the route selection system. The cells (15, 48, 3, 3) and (15, 49, 17, 29) were selected as endpoints for the hypothetical right of way to be designed.

<u>Analysis 1 - minimum economic cost route</u>

The first analysis was performed on the basis of the present-valued costs of construction, maintenance, and land acquisition calculated for each cell. The route selected can be considered to be the route which minimizes the total cost to the utility ratepayer, irrespective of any associated environmental impacts.

<u>Analyses 2 through 7 - constrained economic optima</u>

Following the optimum route selection performed solely on the basis of economic criteria, six analyses were performed to demonstrate the impact of environmental constraints on economic optimization. Six constrained sets of present-valued dollar costs were calculated for all cells in the demonstration subarea using the techniques described in the previous section of this chapter dealing with environmental constraints. The constraints active in each set are displayed in Table 2. For each analysis, the critical characteristics listed, plus

Table 2. Critical characteristics used as environmental constraints to the process of least cost route selection in Analyses 2 through 7.

Analysis 2:

- Registered historic sites
- Airports
- Federal transmitter zone (five-mile radius)

Analysis 3:

- Existing scenic easements
- National parks
- Existing public parks and recreation areas
- Existing public natural areas
- National forests

Analysis 4:

- Miscellaneous state-owned natural resources
- Existing private, noncommercial recreation resources
- Slope of land greater than 15 degrees
- Marshes and swamps

Analysis 5:

- Recommended historic sites
- Proposed scenic easements
- Existing trails

Analysis 6:

- Potential historic sites
- Residential areas
- Proposed public parks and recreation areas
- Urban and industrial areas

Analysis 7:

- Proposed private, noncommercial recreation resources
- Orchards
- Proposed trails
- Beaches
- Boat landings

those listed for all prior analyses, are considered to be the constraints in action. Every cell in the subarea possessing one or more of these critical characteristics was assigned an economic cost of construction and maintenance of one million dollars. A value of this magnitude was used to insure that such a cell would not be included in the optimum route if it could be avoided. If no critical characteristics were present in a cell, the economic cost calculated during Analysis 1 was unchanged. The effect of these six analyses executed in sequential order was an ordered "tightening" of the constraints on the minimization of economic routing impacts.

Analyses 8 through 10 - minimization of overall impact, three viewpoints

After the route selections performed on constrained and unconstrained economic costs, the behavior of the route selection system while working on indices of overall impact was explored. To demonstrate a range of solutions, three analyses were performed, each based on cellular impact indices designed to reflect the values of a separate segment of society. In the absence of actual interviewees from these generalized social groups, the principal investigator, with the aid of Dr. R. H. Giles, constructed hypothetical value systems intended to exaggerate the interests of each group. The cellular impact indices were formulated via the technique for constructing an overall impact index described previously. The minimum cost path-seeking algorithm was then applied to these indices instead of economic cost values.

For purposes of demonstration, three stereotypic viewpoints were selected. Analysis 8 was performed on a set of impacts believed to represent the viewpoint of electric utility management, emphasizing the economic and scenic impacts of right of way construction and land-use conflicts. Analysis 9 was designed to reflect the values of an "environmentalist" population, highly concerned with aesthetic, ecological and recreational impacts but caring little about economic impacts or conflicts with industrial land uses. Analysis 10 attempted to reflect a more balanced viewpoint, a socioeconomic overview of a population concerned primarily about scenic impacts, conflicts with residential and agricultural land-use practices, and changes to vegetative and aquatic communities. A variety of value systems was employed to demonstrate the flexibility of the index construction algorithm and its use as a simulation of the diversity of social viewpoints. In the absence of one universal, absolutely defined value structure this is an alternate method of examining costs to society in general.

Twelve dimensions of the impact perceived by these hypothetical populations were delineated. A subjective weight portraying the relative importance of each impact dimension was then specified for each of the three value systems to be represented. Table 3 presents the 12 dimensions of impact and their associated weights used in the three analyses. Four critical characteristics were recognized as absolute constraints on right of way construction. They were:

1. Existing airports
2. National park lands

Table 3. Impact dimensions and their subjectively-weighted importances used for Analyses 8 through 10.

	Impact Dimension	Units of Measure	Weights: Utility Industry (Analysis 8)	Environmentalist (Analysis 9)	Socio-Economic (Analysis 10)
1.	Economic costs	Present-valued dollars	0.21	0.03	0.05
2.	Scenic impacts	Number of visible cells	0.11	0.15	0.09
3.	Vegetative change	Subjective scale (0-100)	0.04	0.13	0.11
4.	Faunal change	Subjective scale (0-100)	0.04	0.12	0.05
5.	Aquatic ecosystem impact	Subjective scale (0-100)	0.06	0.13	0.09
6.	Recreation use conflicts	Subjective scale (0-100)	0.09	0.09	0.06
7.	Historic site conflicts	Subjective scale (0-100)	0.09	0.10	0.07
8.	Residential use conflicts	Subjective scale (0-100)	0.09	0.05	0.11
9.	Agricultural use conflicts	Subjective scale (0-100)	0.08	0.06	0.14
10.	Forestry use conflicts	Subjective scale (0-100)	0.04	0.06	0.10
11.	Institutional use conflicts	Subjective scale (0-100)	0.06	0.06	0.07
12.	Industrial use conflicts	Subjective scale (0-100)	0.09	0.02	0.07
	Weight Totals		1.00	1.00	1.00

3. Military installations

4. Federal transmitter zones

A set of 42 critical characteristics was identified for use in the demonstration analyses. They are listed and numbered in Table 4. Two impact matrices were then constructed to relate the critical characteristics of each cell in the analysis area to the probable dimensions of impact realized if the cell was to be traversed by a power transmission right of way. Table 5 displays the impact matrix for cells on which no right of way has been previously constructed. The numeric entries in the body of the table below the first two rows are values of c_{ij}, expressed in units of measure appropriate for the associated dimension of impact. The graphic representation of the impact functions from which these values were derived is presented in Appendix II. The tabular entries for the first two critical characteristics are multipliers which are to be applied to the contents of parameter sets already expressed in the appropriate units of measure and stored in the basic data files. Critical characteristic number 1 (present valued costs) is reflected in the file of derived right of way acquisition, construction and maintenance costs. Critical characteristic number 2 (cell observability) is reflected in the derived indices of aesthetic impact previously discussed. Table 6 displays the impact matrix developed for cells on which one or more power transmission rights of way have been previously constructed. As indicated in the definition of the index of overall impact, the contents of these

Table 4. List of critical characteristics used in analyses 8 through 10.

1. Total present valued costs
2. Cell observability
3. Large streams and rivers
4. Small streams
5. Lakes and ponds
6. Swamps
7. Wooded marsh
8. Submerged marsh
9. National forest
10. Miscellaneous forested land
11. State-owned natural resources
12. Commercial orchard land
13. Agricultural field and pasture
14. Residential areas
15. Urban areas
16. Slope class 5 to 15 degrees
17. Slope class greater than 15 degrees
18. Registered historic sites
19. Recommended historic sites
20. Potential historic sites
21. Existing public parks and recreation areas
22. Potential public parks and recreation areas
23. Existing public natural areas
24. Proposed public natural areas
25. Existing private, noncommercial recreation
26. Potential private, noncommercial recreation
27. Existing commercial recreation areas
28. Potential commercial recreation areas
29. Existing scenic easements
30. Potential scenic easements
31. Potential recreation resources
32. Existing trails
33. Potential trails
34. Existing boat landings
35. Existing beaches
36. Potential beaches
37. Erosion-prone soil type 61.13
38. Erosion-prone soil type 137.10
39. Erosion-prone soil type 47.06
40. South facing slopes
41. Southwest facing slopes
42. Ridge tops

Table 5. Impact matrix for lands without a preexisting right of way.

Critical Characteristic	Impact Dimension 1	2	3	4	5	6	7	8	9	10	11	12
1	1	0	0	0	0	0	0	0	0	0	0	0
2	0	1	0	0	0	0	0	0	0	0	0	0
3	0	0	0	0	310	0	0	0	0	0	0	0
4	0	0	0	0	310	0	0	0	0	0	0	0
5	0	0	0	0	310	0	0	0	0	0	0	0
6	0	0	200	1215	600	0	0	0	0	0	0	0
7	0	0	650	1215	600	0	0	0	0		0	0
8	0	0	200	1215	600	0	0	0	0	0	0	0
9	0	0	950	600	0	0	0	0	0	750	0	0
10	0	0	900	600	0	0	0	0	0	750	0	0
11	0	0	900	0	0	0	0	0	0	0	0	0
12	0	0	0	0	0	0	0	0	2	0	0	0
13	0	0	0	0	0	0	0	0	144	0	0	0
14	0	0	0	0	0	0	0	1500	0	0	0	0
15	0	0	0	0	0	0	0	900	0	0	300	300
16	0	0	0	0	30	0	0	0	0	0	0	0
17	0	0	600	0	150	0	0	0	0	0	0	0
18	0	0	0	0	0	0	1500	0	0	0	0	0
19	0	0	0	0	0	0	1200	0	0	0	0	0
20	0	0	0	0	0	0	900	0	0	0	0	0
21	0	0	0	0	0	1500	0	0	0	0	0	0
22	0	0	0	0	0	3000	0	0	0	0	0	0
23	0	0	0	0	0	1500	0	0	0	0	0	0
24	0	0	0	0	0	3000	0	0	0	0	0	0
25	0	0	0	0	0	1500	0	0	0	0	0	0
26	0	0	0	0	0	150	0	0	0	0	0	0
27	0	0	0	0	0	1500	0	0	0	0	0	0

Table 5. Impact matrix for lands without a preexisting right of way (continued).

Critical Characteristic	Impact Dimension 1	2	3	4	5	6	7	8	9	10	11	12
28	0	0	0	0	0	150	0	0	0	0	0	0
29	0	0	0	0	0	3000	0	0	0	0	0	0
30	0	0	0	0	0	3000	0	0	0	0	0	0
31	0	0	0	0	0	1500	0	0	0	0	0	0
32	0	0	0	0	0	1500	0	0	0	0	0	0
33	0	0	0	0	0	1500	0	0	0	0	0	0
34	0	0	0	0	0	1500	0	0	0	0	0	0
35	0	0	0	0	0	2100	0	0	0	0	0	0
36	0	0	0	0	0	1500	0	0	0	0	0	0
37	0	0	165	0	30	0	0	0	0	0	0	0
38	0	0	165	0	30	0	0	0	0	0	0	0
39	0	0	165	0	30	0	0	0	0	0	0	0
40	0	0	300	0	0	0	0	0	0	0	0	0
41	0	0	300	0	0	0	0	0	0	0	0	0
42	0	0	0	90	0	0	0	0	0	0	0	0

Table 6. Impact matrix for lands with a preexisting right of way.

Critical Characteristic	Impact Dimension 1	2	3	4	5	6	7	8	9	10	11	12
1	0.7	0	0	0	0	0	0	0	0	0	0	0
2	0	0	0	0	0	0	0	0	0	0	0	0
3	0	0	0	0	78	0	0	0	0	0	0	0
4	0	0	0	0	78	0	0	0	0	0	0	0
5	0	0	0	0	78	0	0	0	0	0	0	0
6	0	0	150	450	360	0	0	0	0	0	0	0
7	0	0	300	450	360	0	0	0	0	0	0	0
8	0	0	150	450	360	0	0	0	0	0	0	0
9	0	0	360	360	0	0	0	0	0	450	0	0
10	0	0	340	360	0	0	0	0	0	450	0	0
11	0	0	340	0	0	0	0	0	0	0	0	0
12	0	0	0	0	0	0	0	0	1	0	0	0
13	0	0	0	0	0	0	0	0	60	0	0	0
14	0	0	0	0	0	0	0	360	0	0	0	0
15	0	0	0	0	0	0	0	360	0	0	0	0
16	0	0	0	0	30	0	0	0	0	0	0	0
17	0	0	600	0	150	0	0	0	0	0	0	0
18	0	0	0	0	0	0	0	0	0	0	0	0
19	0	0	0	0	0	0	0	0	0	0	0	0
20	0	0	0	0	0	0	0	0	0	0	0	0
21	0	0	0	0	0	0	0	0	0	0	0	0
22	0	0	0	0	0	0	0	0	0	0	0	0
23	0	0	0	0	0	0	0	0	0	0	0	0
24	0	0	0	0	0	0	0	0	0	0	0	0
25	0	0	0	0	0	0	0	0	0	0	0	0
26	0	0	0	0	0	0	0	0	0	0	0	0
27	0	0	0	0	0	0	0	0	0	0	0	0

Table 6. Impact matrix for lands with a preexisting right of way (continued).

Critical Characteristic	Impact Dimension 1	2	3	4	5	6	7	8	9	10	11	12
28	0	0	0	0	0	0	0	0	0	0	0	0
29	0	0	0	0	0	0	0	0	0	0	0	0
30	0	0	0	0	0	0	0	0	0	0	0	0
31	0	0	0	0	0	0	0	0	0	0	0	0
32	0	0	0	0	0	0	0	0	0	0	0	0
33	0	0	0	0	0	0	0	0	0	0	0	0
34	0	0	0	0	0	0	0	0	0	0	0	0
35	0	0	0	0	0	0	0	0	0	0	0	0
36	0	0	0	0	0	0	0	0	0	0	0	0
37	0	0	99	0	30	0	0	0	0	0	0	0
38	0	0	99	0	30	0	0	0	0	0	0	0
39	0	0	99	0	30	0	0	0	0	0	0	0
40	0	0	180	0	0	0	0	0	0	0	0	0
41	0	0	180	0	0	0	0	0	0	0	0	0
42	0	0	0	0	0	0	0	0	0	0	0	0

matrices should represent the opinion of experts in fields related to the various dimensions of impact and do not change for each analysis, as do the ranks reflecting different value systems.

RESULTS

Demonstration Subarea

The following section will describe the demonstration of the optimum route selection technique on the two quadrangle analysis subarea defined in the Procedures chapter. Results of the associated data acquisition activities, the process of calculating derived information, and the conduct of Analyses 1 through 10 will be summarized for the hypothetical transmission right of way described in the Procedures chapter.

Basic Data Parameters

Figs. 12 through 26 are computer-generated maps of the distribution of the parameters and resource characteristics which were obtained from existing maps and documents. These maps are examples of the products available from the GRID module of the POWER system. Each printer character represents one 27-acre data cell. The origin and destination of the hypothetical transmission right of way are indicated by triangular symbols. In each figure the two quadrangles are offset one cell in the vertical direction. This offset is a result of the imprecise match between geodetic quadrangle boundaries and the UTM-based data coding grid, as discussed in the Procedures chapter.

Roads

Fig. 12 represents the road systems present on the Germanna Bridge and Richardsville quadrangles. The shaded intensity of each character indicates the type of road, if any, present in the associated cell. Two major highways, U.S. Route 17 and Virginia Route 3, traverse the

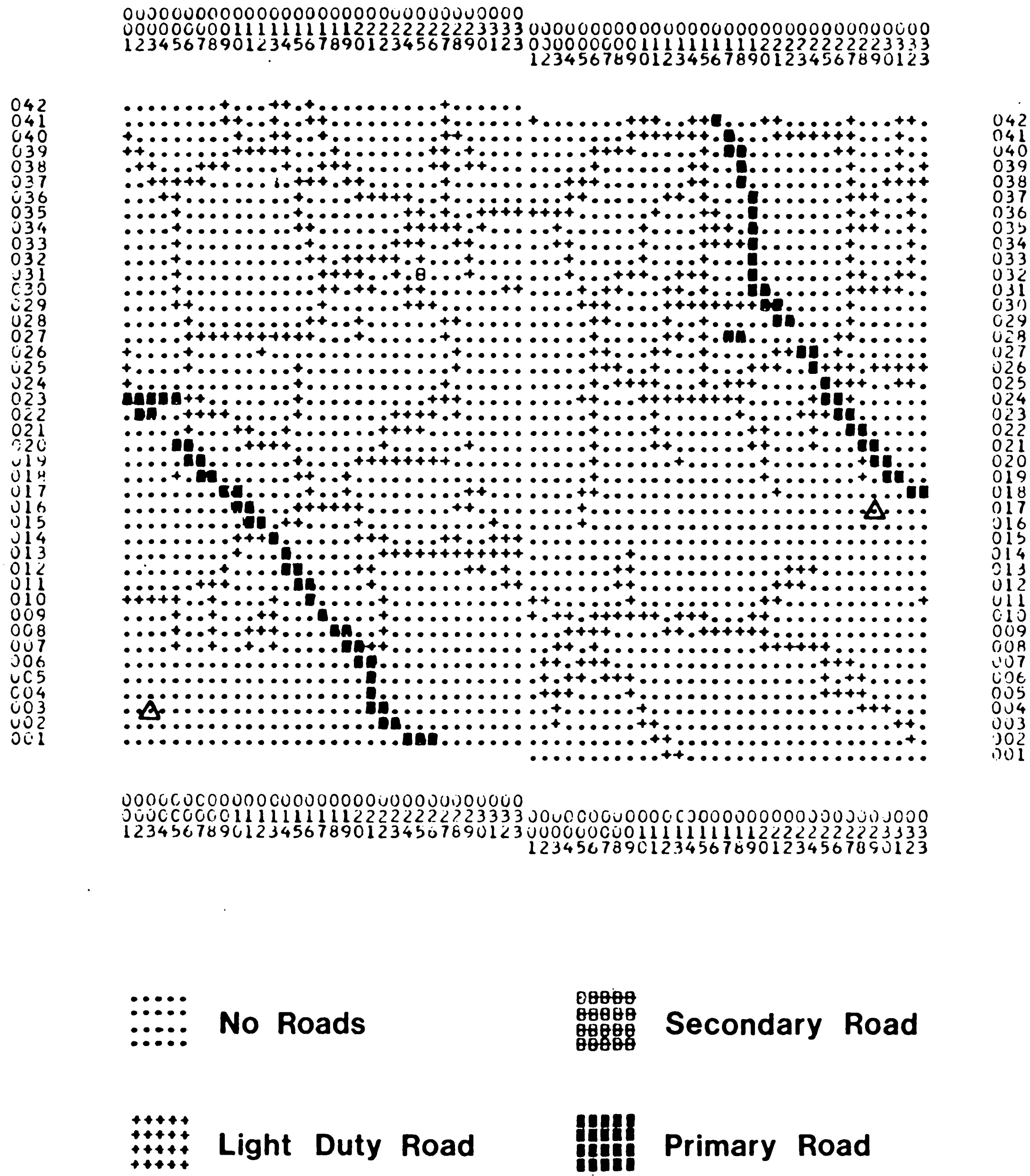


Fig. 12. Computer-generated map of the road system of the demonstration subarea.

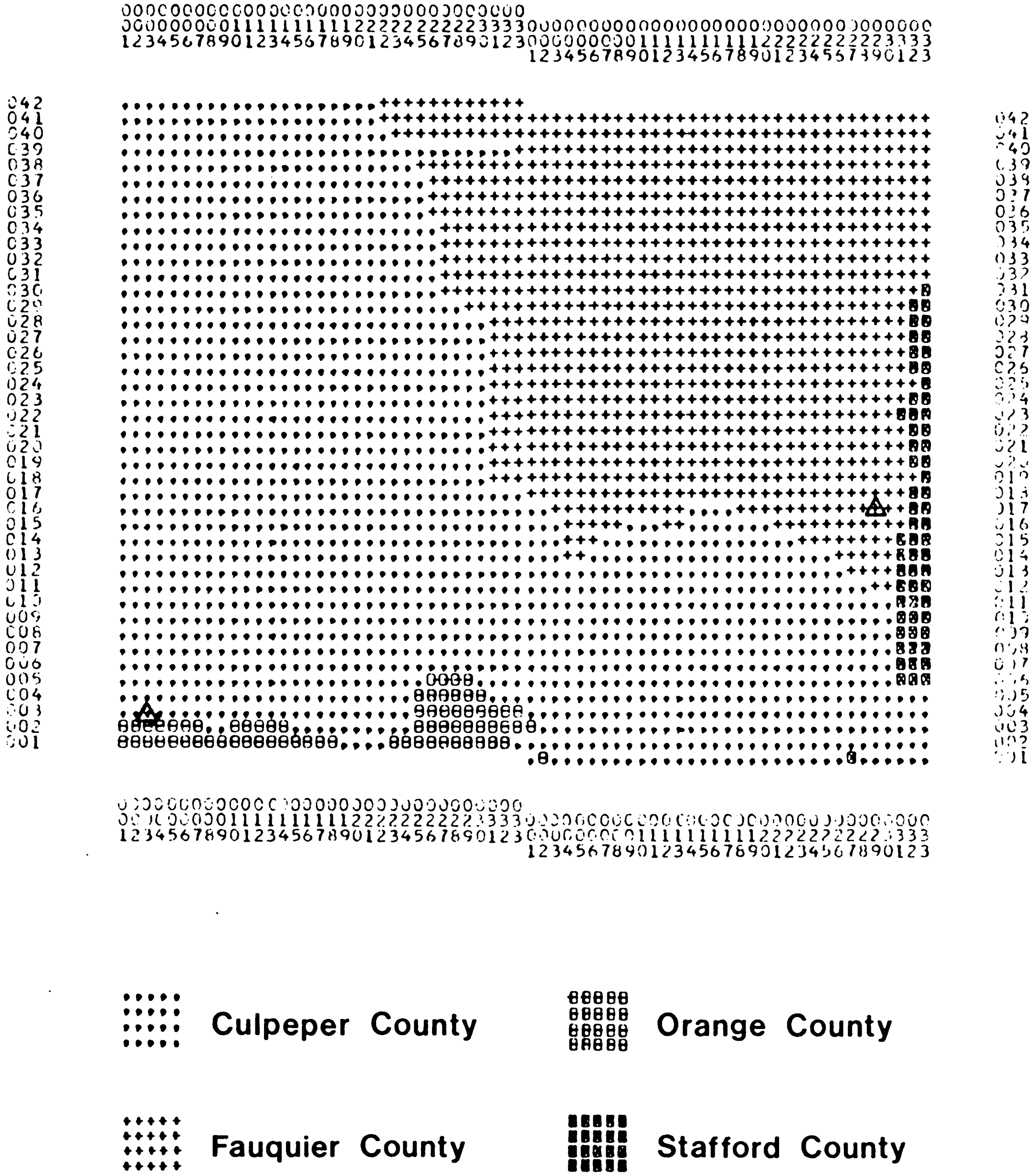
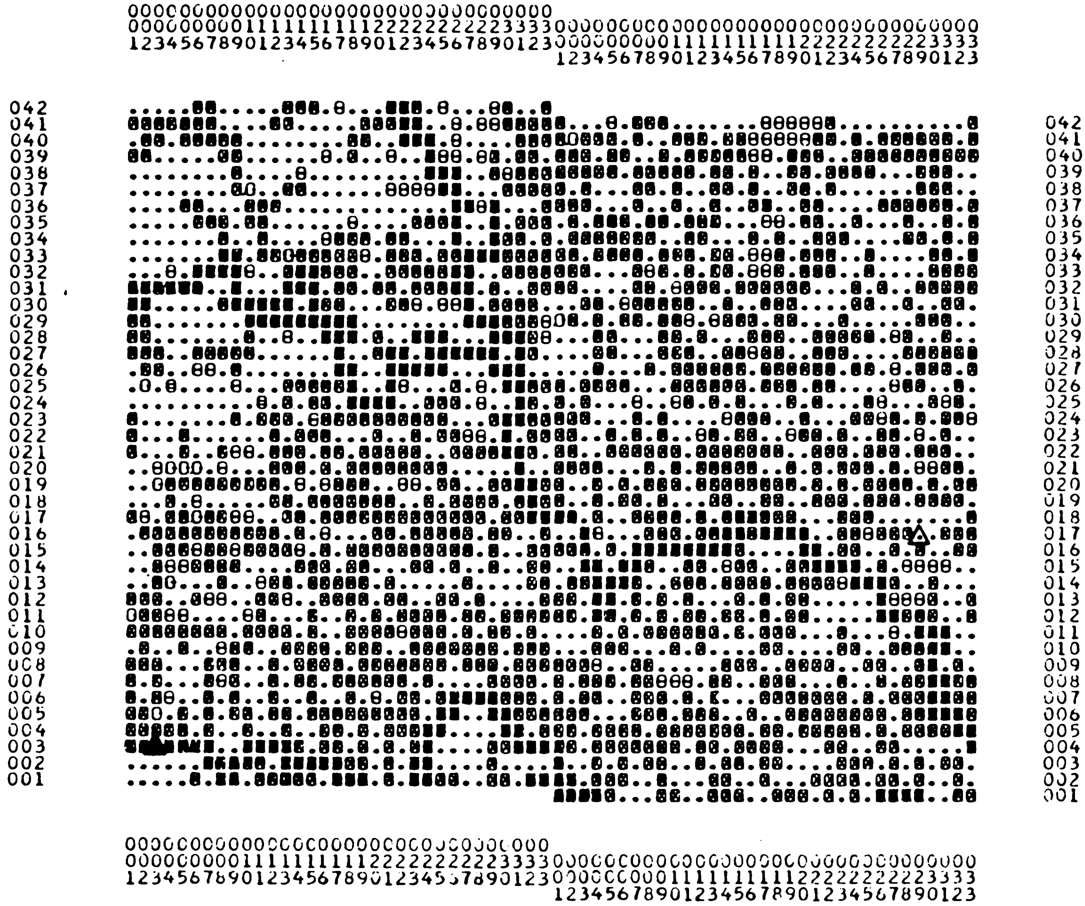


Fig. 13. Computer-generated map of the demonstration subarea counties.



No Water

Marshes and Swamps

Sewage Facilities

Small Streams

Farm Ponds

Rivers

Fig. 14. Computer-generated map of the water resources in the demonstration subarea.

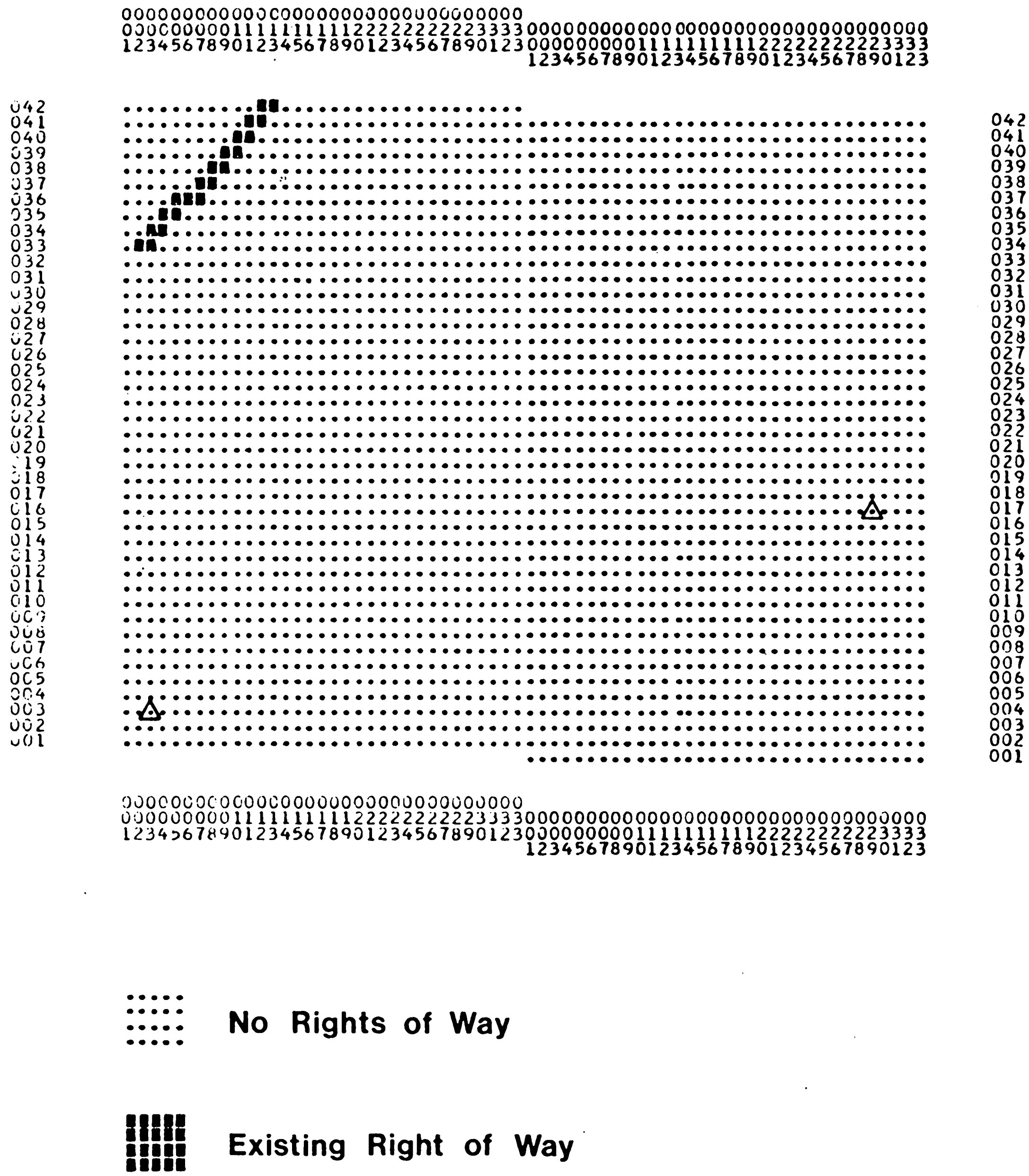


Fig. 15. Computer-generated map of the pre-existing transmission facilities in the demonstration subarea.

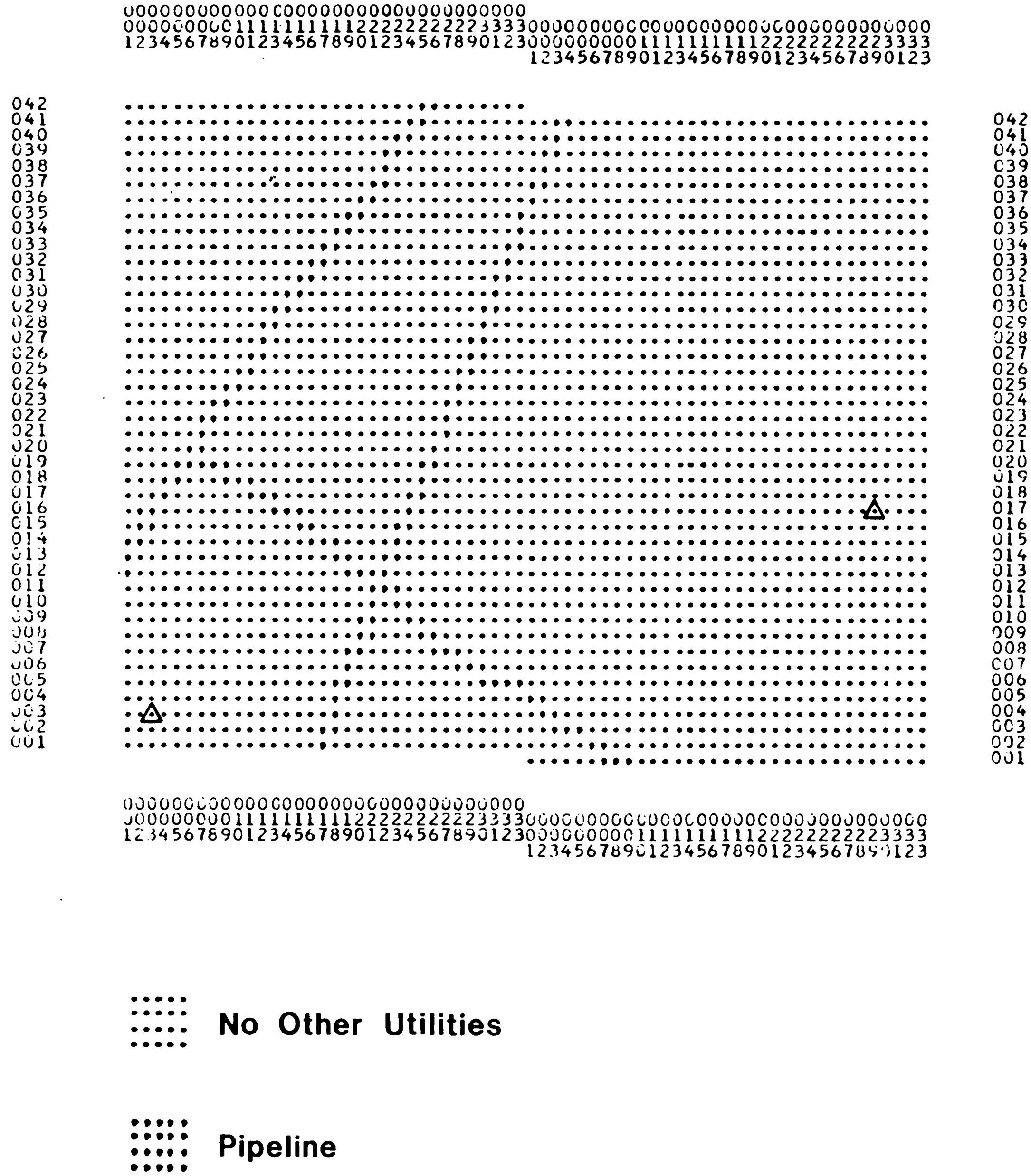
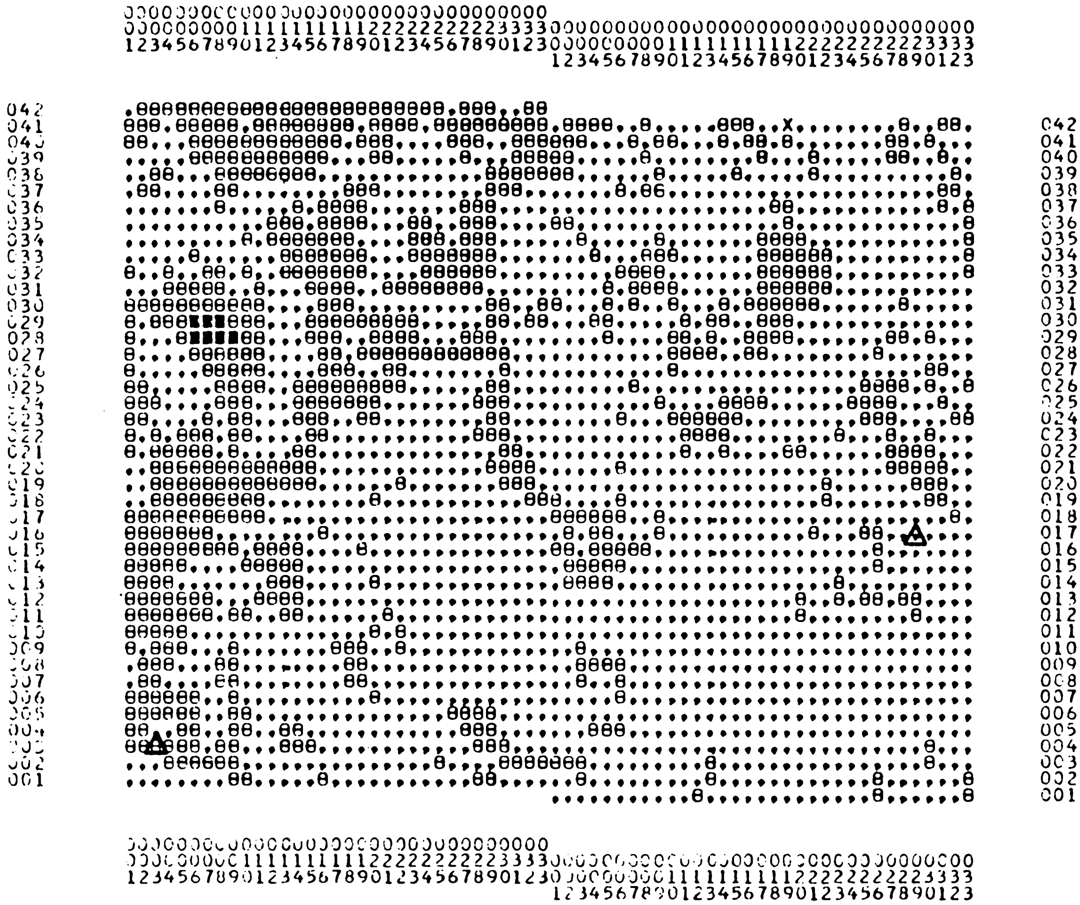


Fig. 16. Computer-generated map of other existing utilities in the demonstration subarea.



Miscellaneous Forested Land

Field and Pasture

Military Reservations

Fig. 17. Computer-generated map of land use and ownership in the demonstration subarea.

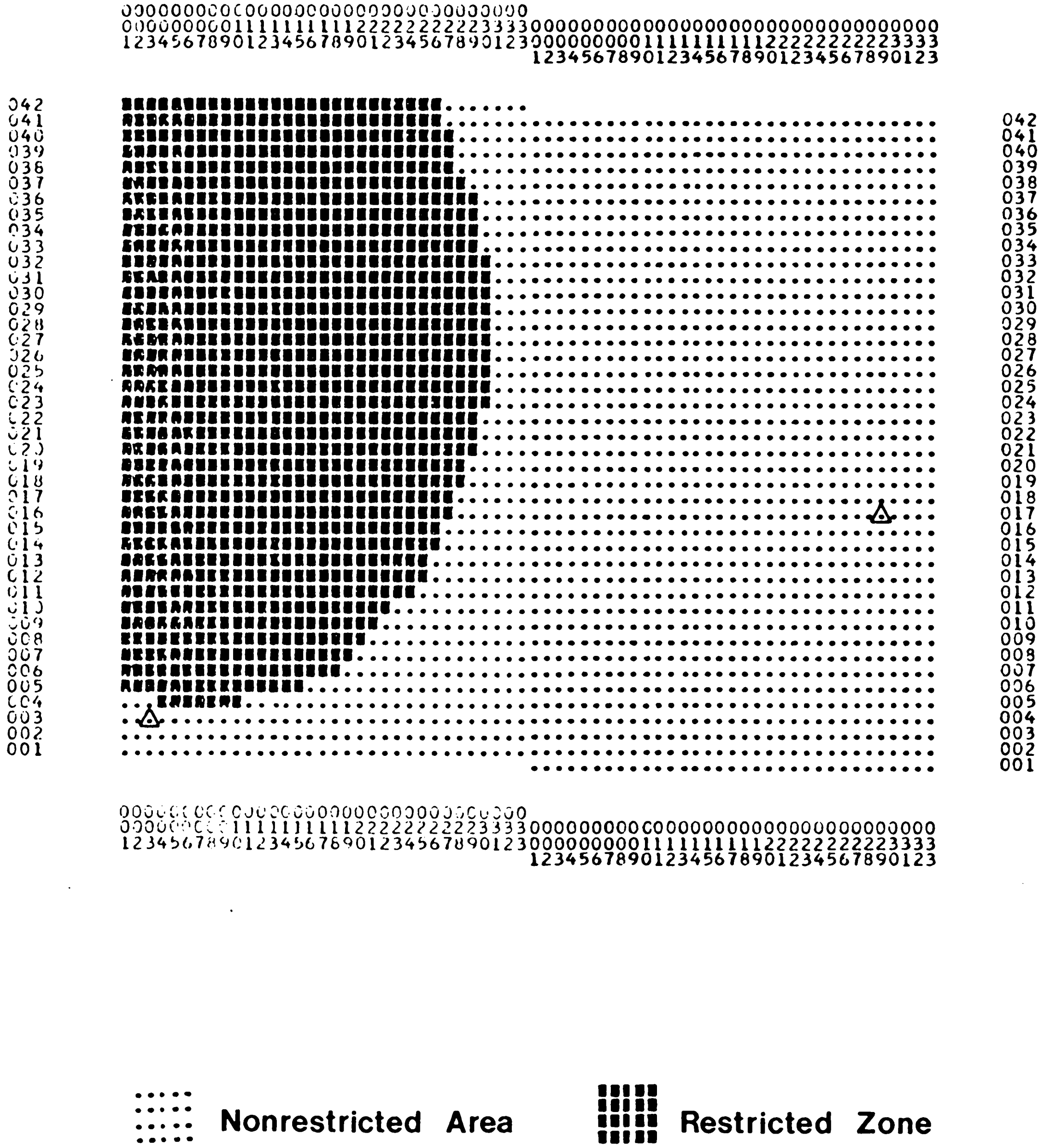


Fig. 18. Computer-generated map of the restricted federal transmitter zone in the demonstration subarea.

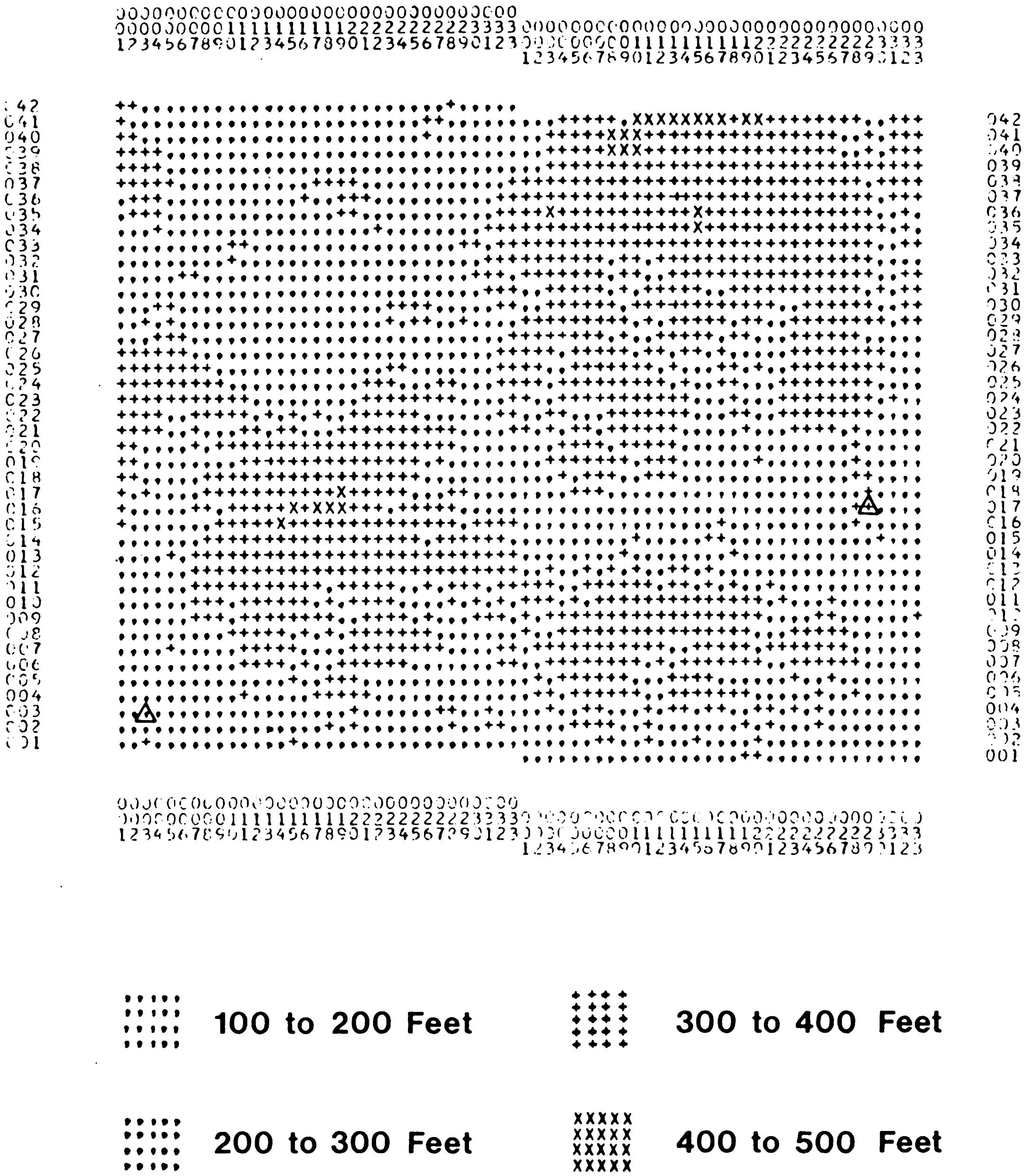
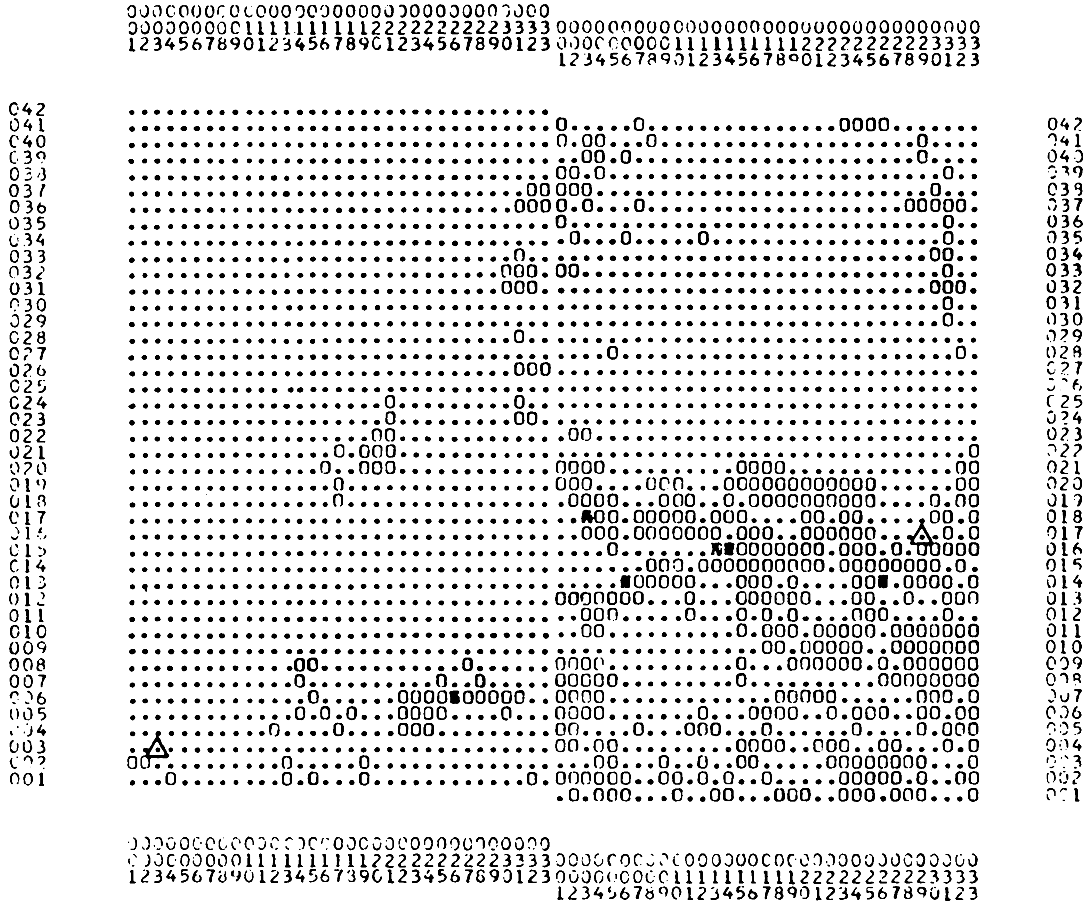


Fig. 19. Computer-generated map of the elevation above sea level of all cells in the demonstration subarea.



Less Than 5 Degrees Slope

5 To 15 Degrees Slope

Greater Than 15 Degrees Slope

Fig. 20. Computer-generated map of cellular slope classes in the demonstration subarea.

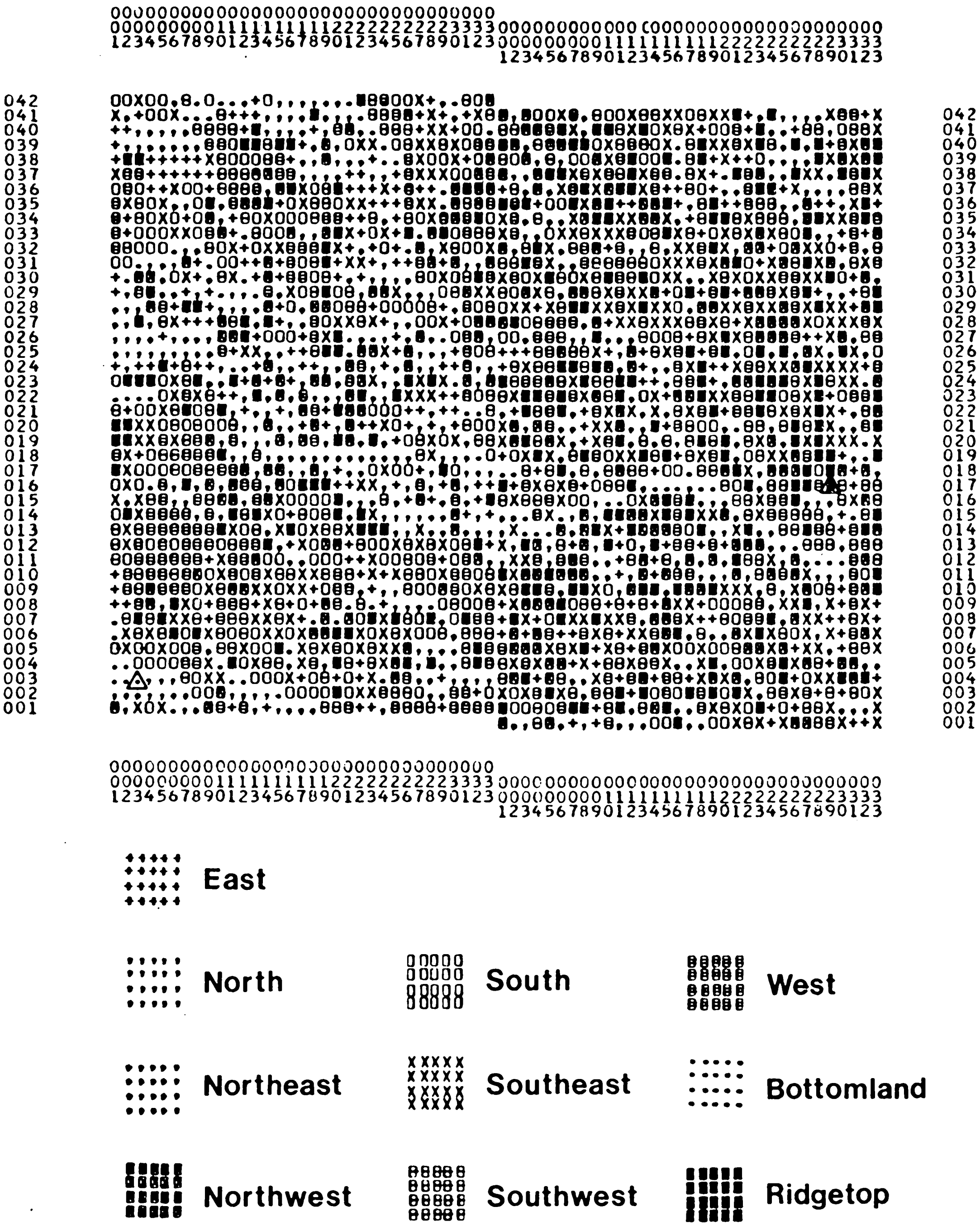


Fig. 21. Computer-generated map of slope directions in the demonstration subarea.

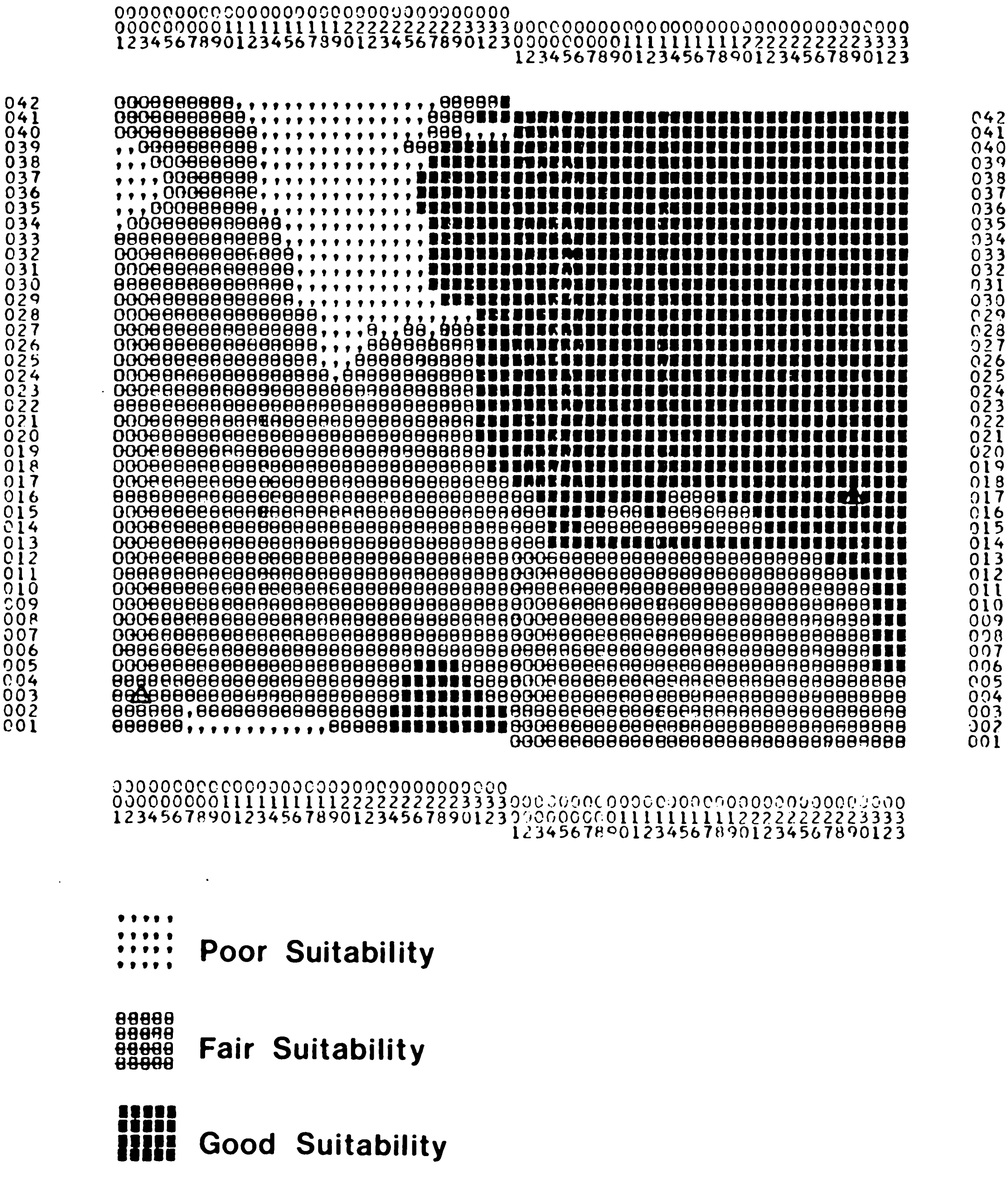


Fig. 22. Computer-generated map of the construction suitability of soils in the demonstration subarea.

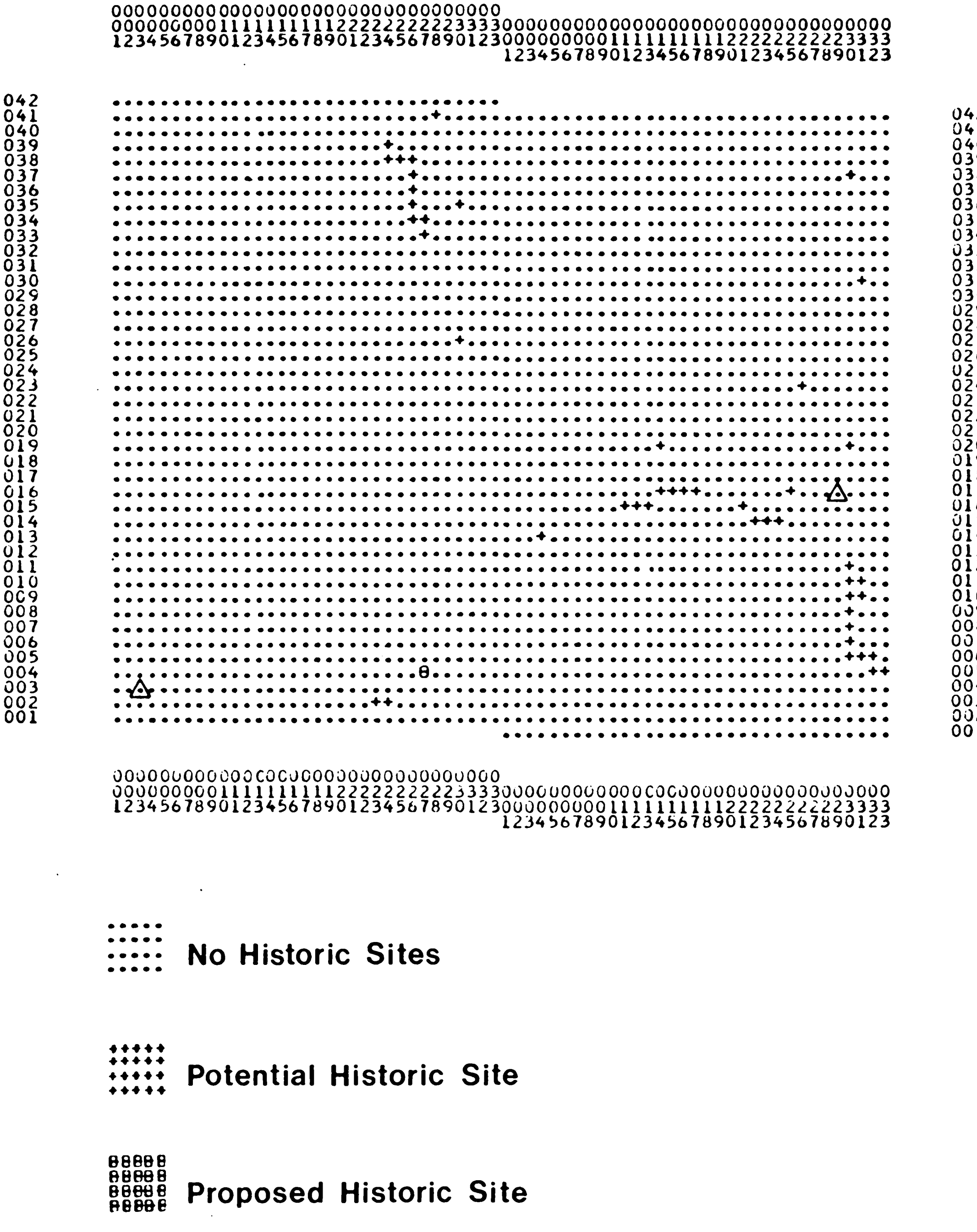
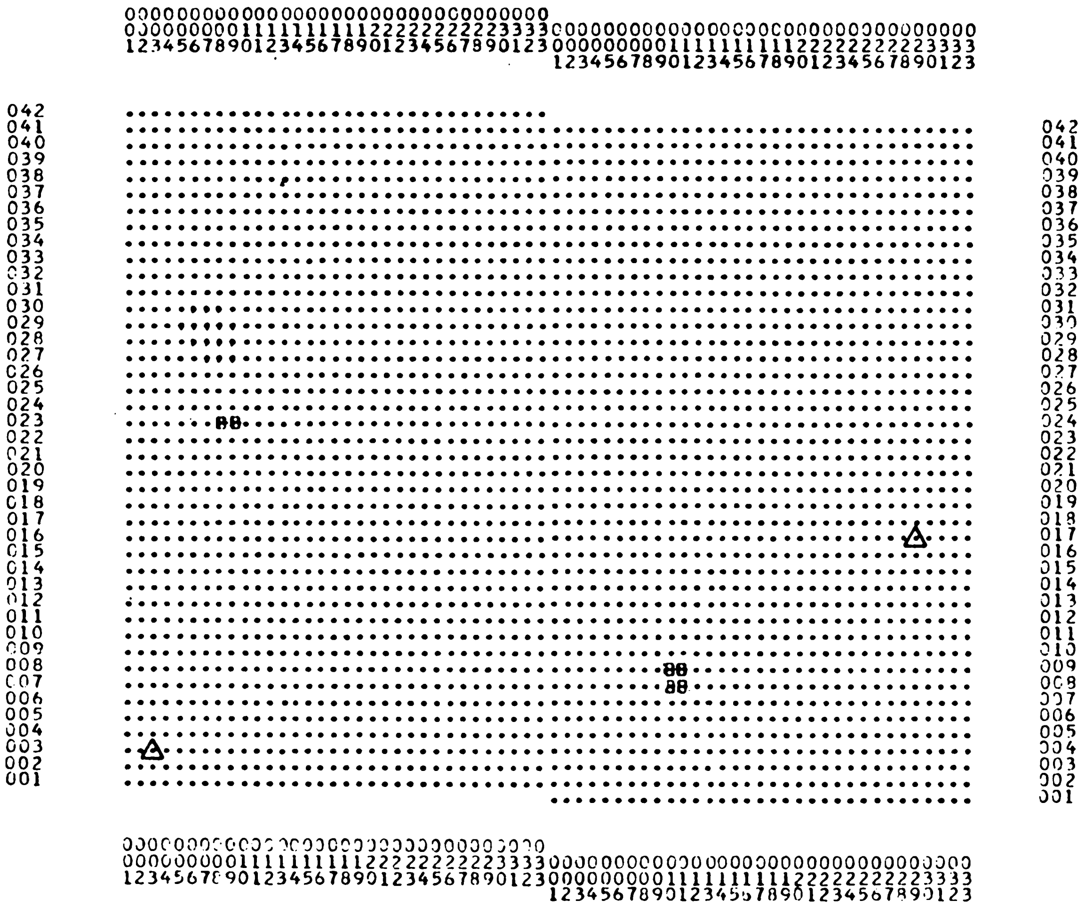


Fig. 23. Computer-generated map of historic site locations in the demonstration subarea.



No Recreation Resources

Commercial Recreation

Miscellaneous Public Lands

Fig. 24. Computer-generated map of existing recreation resources in the demonstration subarea.

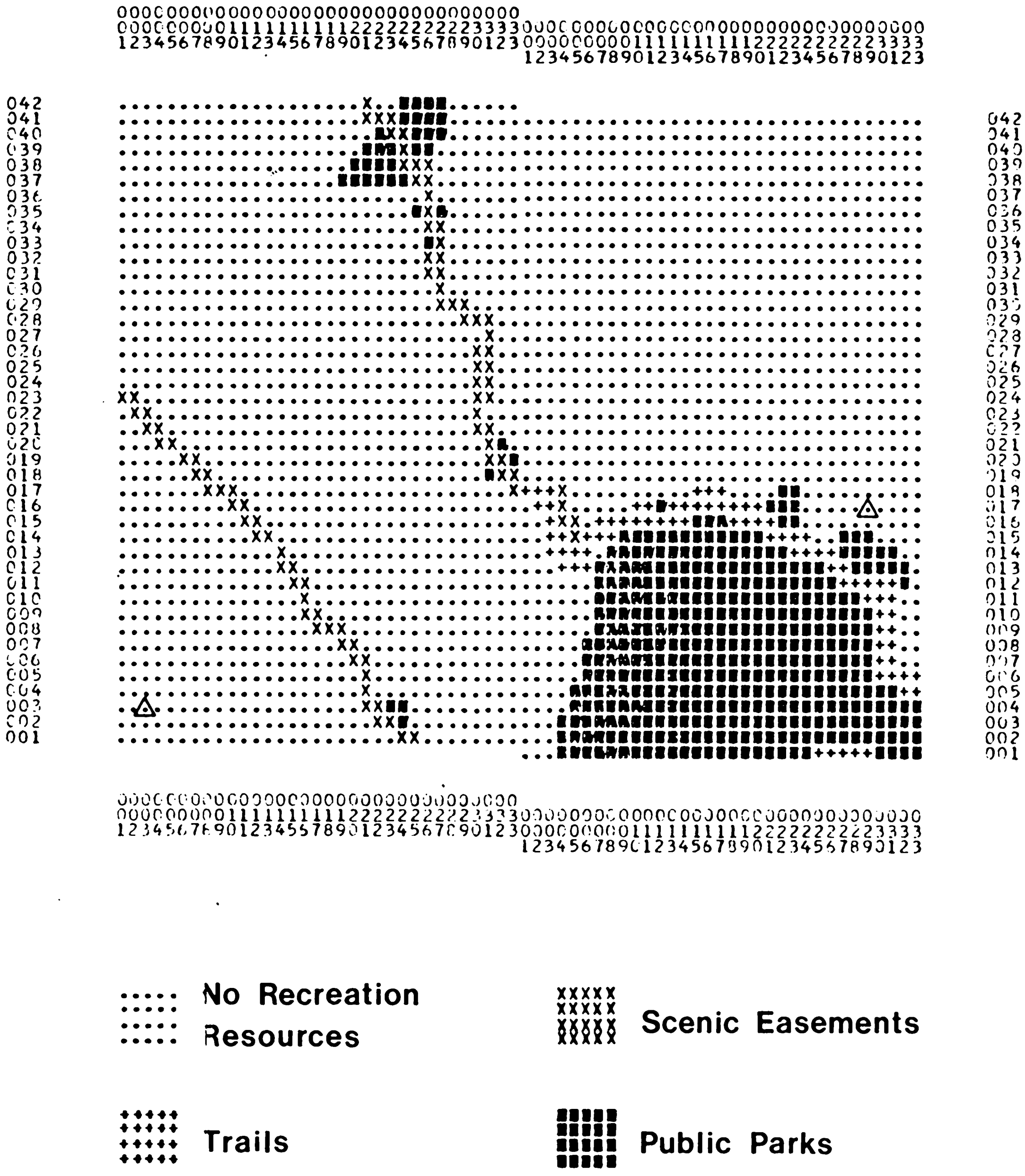


Fig. 25. Computer-generated map of potential recreation resources in the demonstration subarea.

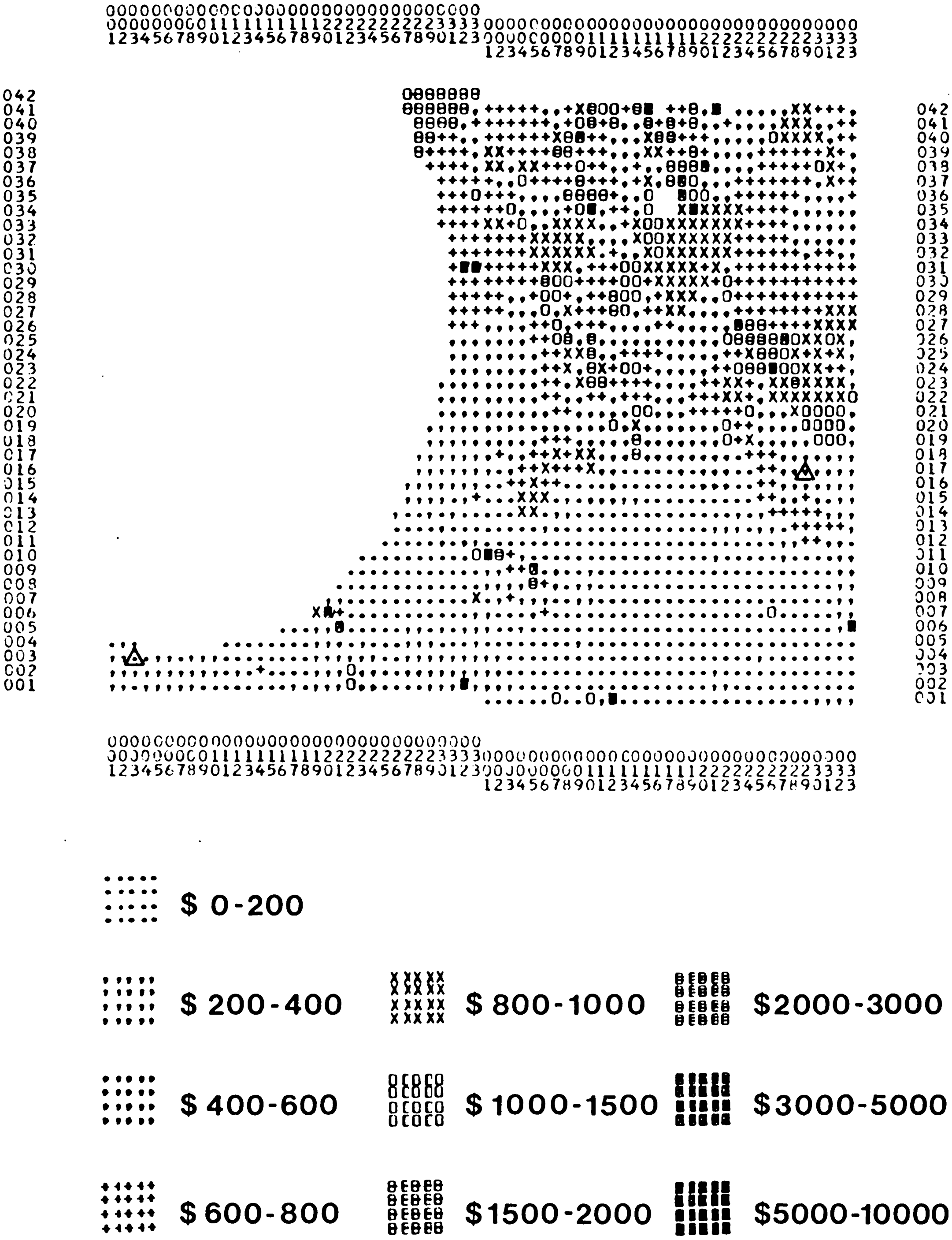


Fig. 26. Computer-generated map of per acre land values in the demonstration subarea.

subarea. The entire subarea is served, by a network of light duty roads. The presence of roads is one of the factors operational in the selection of an optimum transmission right of way route between the two locations indicated on this map. Each time that a corridor crosses a road a supplementary cost of $90 is incurred to provide vegetative screening of the right of way. In order to minimize the overall economic impact of a route, the computer algorithm will tend to minimize the number of roads that the route intersects.

Counties

Fig. 13 delineates the portions of the demonstration subarea in each of four counties: Culpeper, Fauquier, Orange, and Stafford. The property tax rate established in each county was one parameter required to calculate the probable long-term maintenance costs for transmission facilities in each data cell.

Water resources

Fig. 14 displays the water resources present in the subarea. Three major streams or rivers are in the area. The Rappahannock River defines the boundary between Culpeper County and both Fauquier and Stafford Counties.. It is joined in the western half of the subarea by Mountain Run. The Rapidan River traverses the southern part of the subarea and forms the boundary between Culpeper and Orange Counties. Small streams are present on nearly 40 percent of the cells in the subarea. Manmade farm ponds are found scattered throughout the subarea.

The presence of water resources was an environmental characteristic active both in the placement of environmental constraints on minimum economic cost routes as well as in the construction of indices of overall right of way impact.

Preexisting powerlines

Fig. 15 shows the location of all preexisting transmission facilities in the demonstration subarea. Existing rights of way of appropriate configuration offer attractive routes for new transmission lines. Less additional land is required for a parallel right of way than for one which does not parallel existing facilities. Since many social and ecological impacts have already been incurred as a result of the initial right of way construction it is probable that little additional impact in several dimensions would result from construction of parallel facilities.

Only one transmission right of way was found to cross the demonstration subarea. This line occurred in the northwest portion of the subarea, somewhat displaced from the route under consideration.

Other existing utilities

The presence of other utilities in the subarea is shown in Fig. 16. A network of three pipelines traversed the western half of the subarea.

Land use and ownership

Fig. 17 is a display of the current land use patterns existing in the demonstration subarea. The land is approximately evenly divided between agricultural or pasture cover and forest cover. Small settlements occur at various road intersections, but never in sufficient density to qualify for a residential land use classification. The Warrenton Training Center, in the northwest corner of the subarea, was recorded as a U.S. military reservation.

Federal transmitter zones

Fig. 18 is the cellular representation of a five-mile radius zone circumscribed around Federal radio transmission facilities at the Warrenton Training Center. This area was treated as a constraint to the selection of right of way routes. No routes were allowed to traverse this zone.

Elevation

Fig. 19 is a shaded map of the centroid elevation of each data cell, to the nearest 100 feet. An area of relatively high topographic relief separated the two hypothetical right of way end points. Because of the engineering problems associated with transmission tower construction on topographically variable land, least cost right of way routes would tend to avoid those sites where elevation change is greatest.

Slope

In order to represent the topograpny of the subarea in the most reliable fashion, each cell was also classified by its predominant slope class. Fig. 20 is a slope map for the demonstration subarea. The slope classes recognized correspond to those related to engineering costs, presented in Table 1.

In addition to its economic implications, slope was also an important input to the process of estimating probable environmental impacts (siltation and loss of fertility) of right of way construction. Steep slope was considered both in the environmental constraint analyses (Analyses 4 through 7) and as a critical characteristic in the calculation of overall impact indices (Analyses 8 through 10).

Aspect

Fig. 21 is a map of the slope direction, or aspect, predominant in each data cell in the demonstration subarea. Slopes facing south or southwest were considered to be sites of ecological significance. The vegetative communities normally found on such sites are often less resistant to damage than those typical of other sites. Right of way construction on such sites could lead to undesirable changes in existing plant populations and potential erosion hazards, particularly on steep slopes.

Soil suitability

Each soil association found in the demonstration subarea was classified with respect to its relative probability of damage or erosion due to tower construction activities. Fig. 22 is a display of the suitability of the soils as a base for transmission facilities.

Historic sites

Fig. 23 is a map of historic site locations within the demonstration subarea. No Federally registered sites or landmarks were found in the area. Forty-six data cells had been classified by the Virginia Historic Landmarks Commission as having potential historic value. Most of these were adjacent to the Rappahannock River.

Recreation resources

Based on data obtained from the Virginia Outdoor Recreation Commission only two existing recreation resources were identified in the subarea. Both were commercially operated camps. These are indicated in Fig. 24.

Fig. 25 displays the potential recreation resources in the area. Of special importance in the consideration of the hypothetical right of way route is the classification of much of the Rappahannock River's shores as suitable for hiking trails and the potential future development of a large block of land nearby as a state park. Both are future land uses which are likely to conflict with the present development of transmission facilities. In addition, the lands surrounding Route 3 and the northern section of the Rappahannock have been designated for potential acquisition as scenic easements by the State of Virginia.

Land value

Fig. 26 displays the distribution of land values within the demonstration subarea. Shading density is indicative of assessed value, the darkest cells designating the most valuable land. Land values were not gathered for parcels inside the transmitter zone since this was to be used as a constraint to selected routes. In the southern half of the subarea, where the hypothetical right of way was to be located, land acquisition costs were likely to be relatively low. Only a few parcels of residential or high quality agricultural land were present.

Derived Data Parameters

The following two parameters are derived data items. Values of these parameters for each data cell were not gathered directly from source maps. Rather they were calculated via rules described previously in the Procedures chapter, using one or more of the basic data parameters as input information.

Probable aesthetic impact

Fig. 27 displays a measure of the adverse aesthetic impact likely if right of way construction were undertaken at any of the data cells in the demonstration subarea. The value represented for each cell is the estimated number of cells, within a one-mile radius, from which transmission facilities would be visible. The observed values range from zero to a maximum of 100. As expected, the most visible cells are those in the relatively level agricultural lands in the northwest section of the subarea. In the areas of more diverse topography no well defined patterns of visibility are apparent.

Total present valued costs

The estimated total costs of right of way acquisition, construction and maintenance, discounted over a 30-year period, are displayed in Fig. 28. The degree of shading at each printer position denotes the relative cost of building transmission facilities in the corresponding data cell. Darker shades indicate the more costly sites. Costs calculated for cells inside the previously described Federal transmitter zone are artifically high, effectively excluding this area from consideration for possible right of way routes.

Least Cost Optimization Results - Analysis 1

Superimposed on Fig. 28 is the minimum cost right of way route determined by the minimum cost path search algorithm during Analysis 1. Fig. 28 is a representation of the "map" of probable land acquisition, engineering and maintenance costs which were scanned to determine the least expensive connection between the two end points of the right of

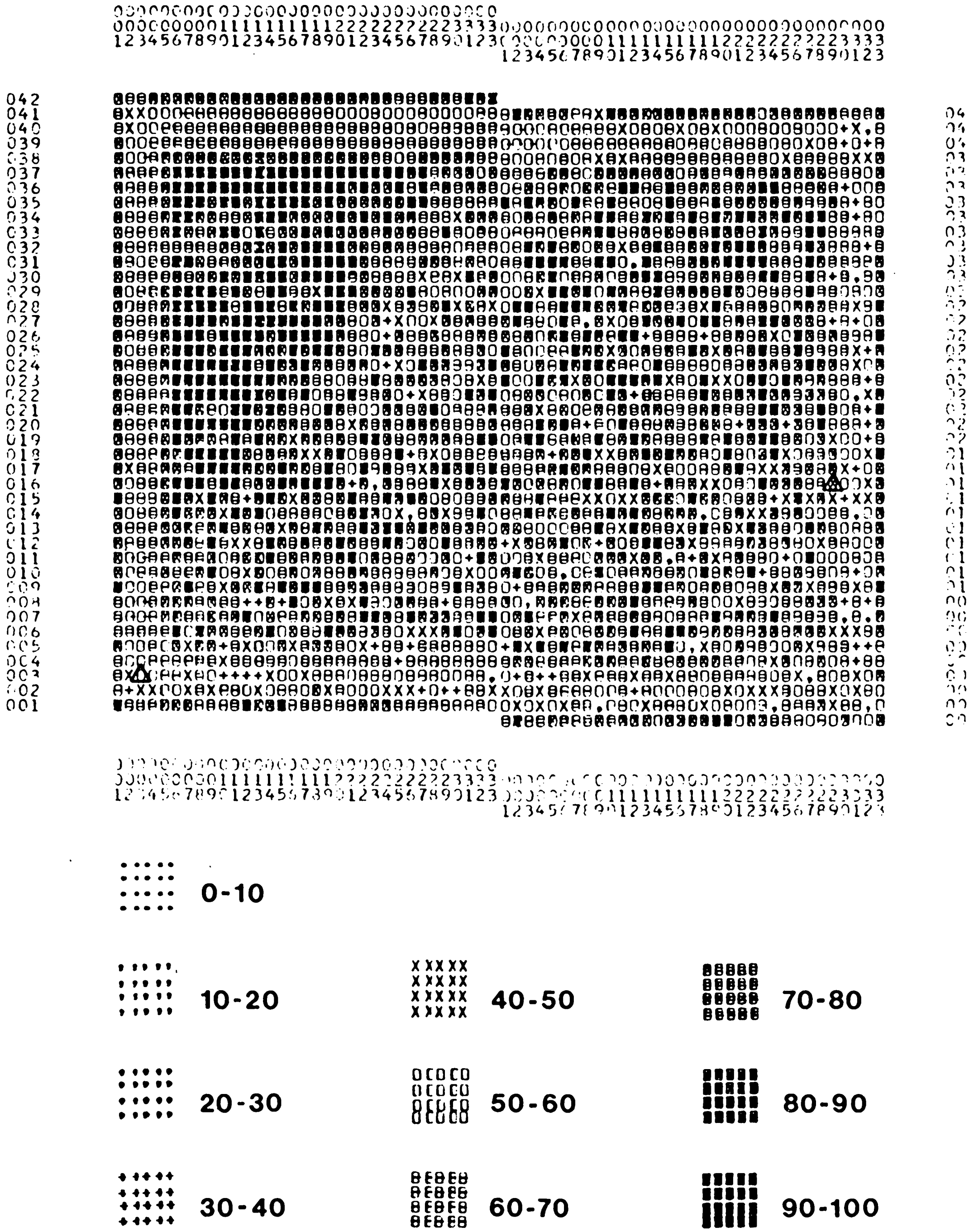


Fig. 27. Computer-generated map of probable aesthetic impact [number of visible cells] in the demonstration subarea.

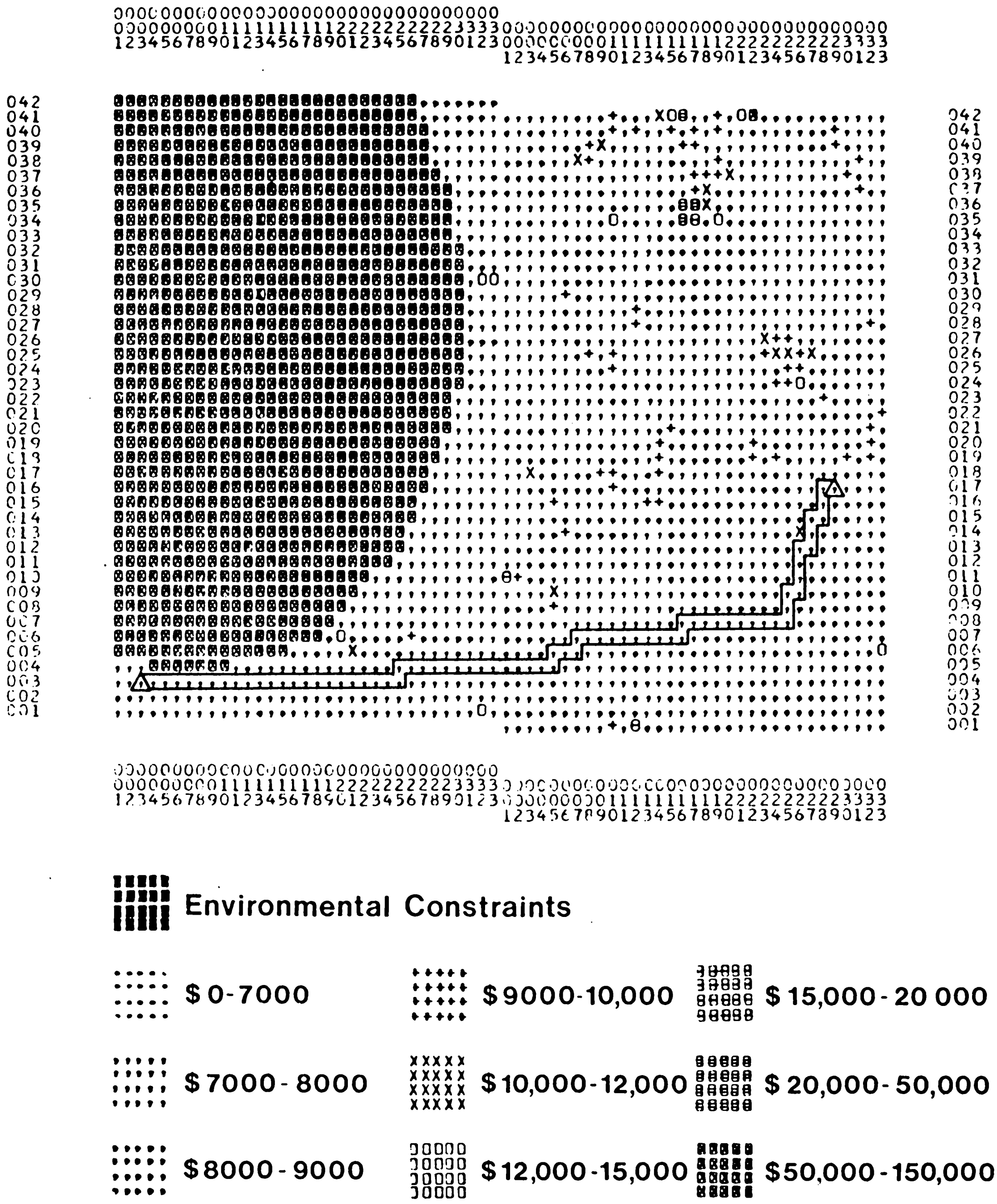


Fig. 28. Computer-generated map of the results of analysis 1 based on constrained present valued costs.

way. Since the shading density at each point is directly related to the present valued sequence of probable expenses incurred if construction were undertaken on that site, the optimum route selection process may be thought of as seeking that chain of printer characters which connect the two end points and which are, generally, lightest in color. Dark, or expensive, cells will be included in a route if necessary, but only if no alternate chain of cells of less total expense can be found. This route may be thought of as the minimum economic impact route, unconstrained by environmental considerations.

Total present valued cost is a derived data parameter dependent primarily upon land acquisition costs and estimated engineering costs. Engineering costs are primarily a function of the slope of the underlying ground (see Table 1). Comparison of the route displayed in Fig. 28 with the data maps in Fig. 20 (slope) and Fig. 26 (land values) demonstrate that the minimum cost solution was sensitive to both parameters. The slope map in Fig. 20 is shaded darkly at steeply sloping sites. Visual inspection of the minimum cost route superimposed on this slope map shows that the route indicated is a compromise between directness of routing and the expense of engineering on steep sites. Only five moderately steep sites were traversed by this route. It is possible to trace routes which traverse fewer steep sites, but a route of greater total length would result. Apparently the increased land and construction cost outweigh any potential cost reduction to be realized by routing through fewer "steep" cells. Comparison of the minimum cost route with the map of land values in Fig.

25 shows that the route traverses an area of uniformly low land prices. The route appears to be most sensitive to land values near its eastern terminus. A ring of relatively expensive sites surrounds that end point and the route seems to cross this "barrier" at its narrowest point, while proceeding westward without backtracking.

Table 7 may be used to compare the results of the alternate right of way routes demonstrated in Analyses 1 through 10. Each route is evaluated on the basis of its length (number of cells traversed), total cost, total index of impact for each of the three stereotypic viewpoints represented in Analyses 8 through 10, aesthetic impact, and number of cells of various characteristics which it traverses.

Of special importance in the economic evaluation of right of way routes are the additional economic costs for required angle towers. The minimum cost routing algorithm contains no penalties for changes in route direction. However, the construction of angle towers entails an economic cost in addition to the cost of standard tangent towers. To reflect adequately the economic costs of any route this additional cost must be considered. Table 8, derived from data presented by Strobl (1973), summarizes the types of angle towers commonly constructed and the additional present valued costs associated with each. It was estimated that two heavy angle towers and one heaviest angle tower would have to be substituted for tangent towers to follow the route designated in Analysis 1. The additional present valued cost would be $24,941, bringing the total estimated cost to $562,454.

Table 7. Comparison of alternate right of way demonstrations.

Characteristic	Analysis No. 1-4	5	6	7	8	9	10
Number of cells	73	73	77	77	75	77	75
Total land acquisition costs	15,007	19,740	30,967	31,302	28,260	30,836	31,438
Total present valued costs	537,513	547,201	599,073	599,458	583,658	597,803	588,362
Total present valued costs (level 2-4 constraints)	537,513	547,201	599,073	599,458	583,658	597,803	588,362
Total present valued costs (level 5 constraints)	3,515,199	1,535,249	1,587,121	1,587,505	4,551,632	4,565,668	4,556,225
Total present valued costs (level 6 constraints)	36,271,520	23,371,456	1,587,121	1,587,505	6,535,672	9,526,687	9,517,245
Total present valued costs (level 7 constraints)	38,256,960	23,371,456	3,572,011	2,579,780	10,503,640	17,465,784	14,477,854
Additional angle tower costs	24,941	40,371	68,435	68,435	40,371	53,610	47,442
Utility industry impact index	14.95	14.17	12.95	12.85	12.39	13.48	12.94
Environmentalist impact index	24.62	23.70	23.58	23.66	22.35	21.27	21.93
Socioecological impact index	21.97	20.74	19.95	19.91	19.63	20.05	19.60
Aesthetic impact (No. cells visible)	4,955	4,782	5,257	5,262	4,360	4,835	4,813
Land use and ownership:							
Miscellaneous forested land	58	60	62	63	57	45	52
Agricultural Land	15	13	15	14	18	32	23
Potential recreation resources:							
Public parks	33	21	0	0	2	4	4
Miscellaneous resources	2	1	1	1	4	4	4
Trails	2	1	2	1	4	9	6
Slope class 0-5 degrees	68	64	57	57	53	58	53
Slope class 5-15 degrees	5	9	20	20	22	19	22
Light duty roads	11	7	7	7	7	8	5

Table 7. Comparison of alternate right of way demonstrations (continued).

Characteristic	Analysis No. 1-4	5	6	7	8	9	10
Highways	2	1	1	1	2	2	2
Proposed historic sites	1	0	0	0	0	0	0
Potential historic sites	0	1	0	0	0	1	1
Water resources:							
Rivers	15	10	10	10	15	18	16
Small streams	24	40	37	37	29	25	26
Ponds	2	-	-	-	-	-	-
Pipelines	3	4	4	4	3	3	3
Soil suitability:							
Good	14	12	31	32	32	40	38
Fair	59	61	46	45	43	37	37

Table 8. Additional present valued costs of angle towers.

Angle Tower Type	Angle	Additional Present Valued Cost
Heaviest	60^0-90^0	$8,935
Heavy	30^0-60^0	8,003
Medium	15^0-30^0	5,563
Light	3^0-15^0	2,016

Constrained Optimization Results

Figs. 29 through 34 display the results of the constrained optimization procedures undertaken in Analyses 2 through 7. In each case the optimum route selection algorithm was used to determine a minimum present valued cost route between the previously defined end points. However, in each case a successively tighter set of environmental "constraints" was placed on the optimization process. The present valued economic costs associated with certain sites were significantly raised if those sites possessed one or more physical characteristics which were judged to make them undesirable as transmission sites. The effect was to force the optimization algorithm to drop these sites from consideration, unless it was absolutely necessary to traverse them. The set of environmental constraints defined for each analysis was always used in conjunction with all the constraints defined by previous analyses.

Analysis 2

For Analysis 2 the constraint set used was designed to represent the legal limitations under which transmission facilities siting is undertaken. The present valued cost of each cell in the demonstration subarea was reset to one million dollars if that cell (1) contained a Federally registered historic site, or (2) was part of an airport or approach zone, or (3) was on the circumference of the previously described Federal transmitter zone. Fig. 29 displays the constrained present valued cost map used for this analysis and the route selected. No registered historic sites or airports were present. Therefore, the only cells for which economic costs were incremented were those on the

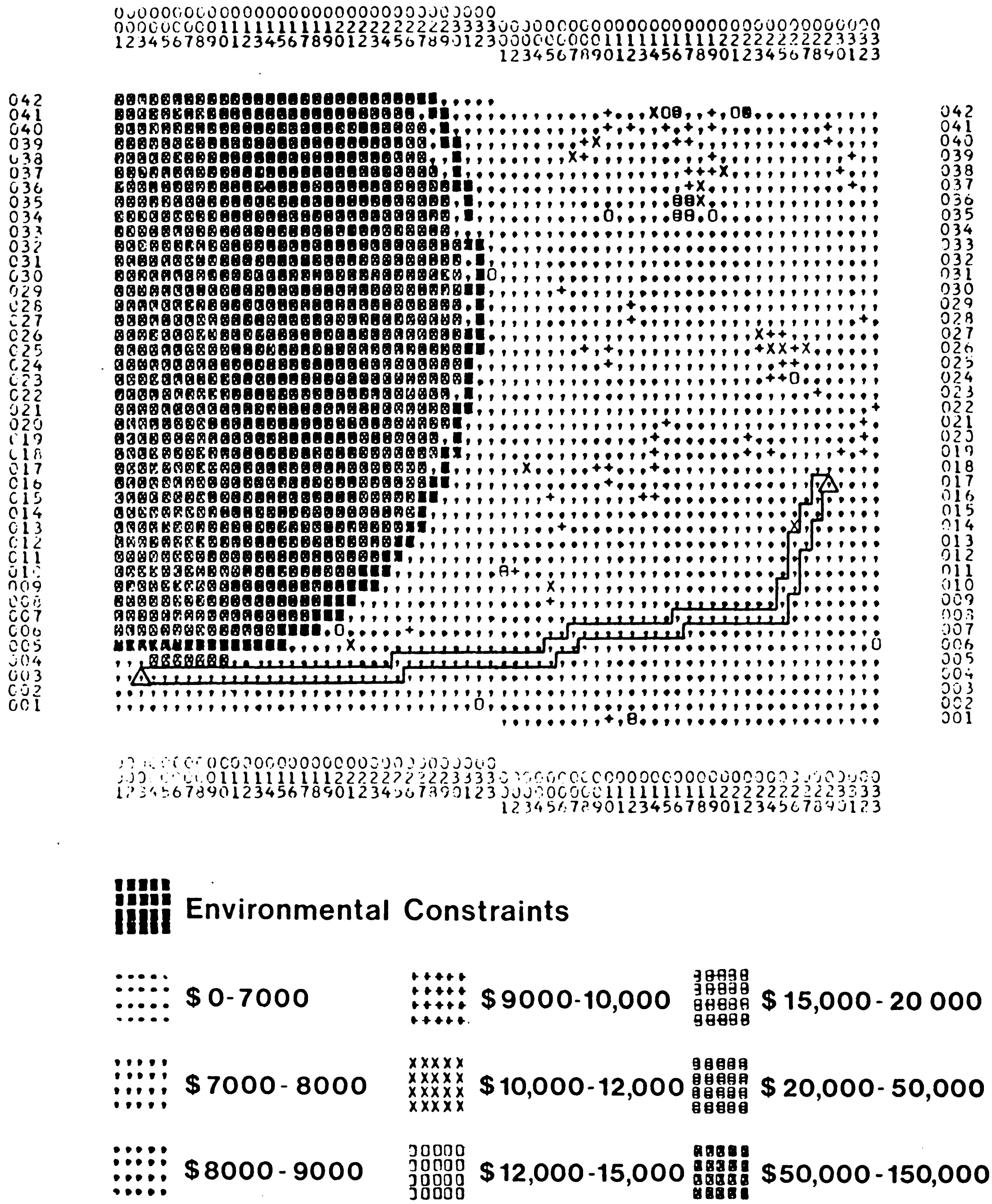


Fig. 29. Computer-generated map of the results of analysis 2 based on constrained present valued costs.

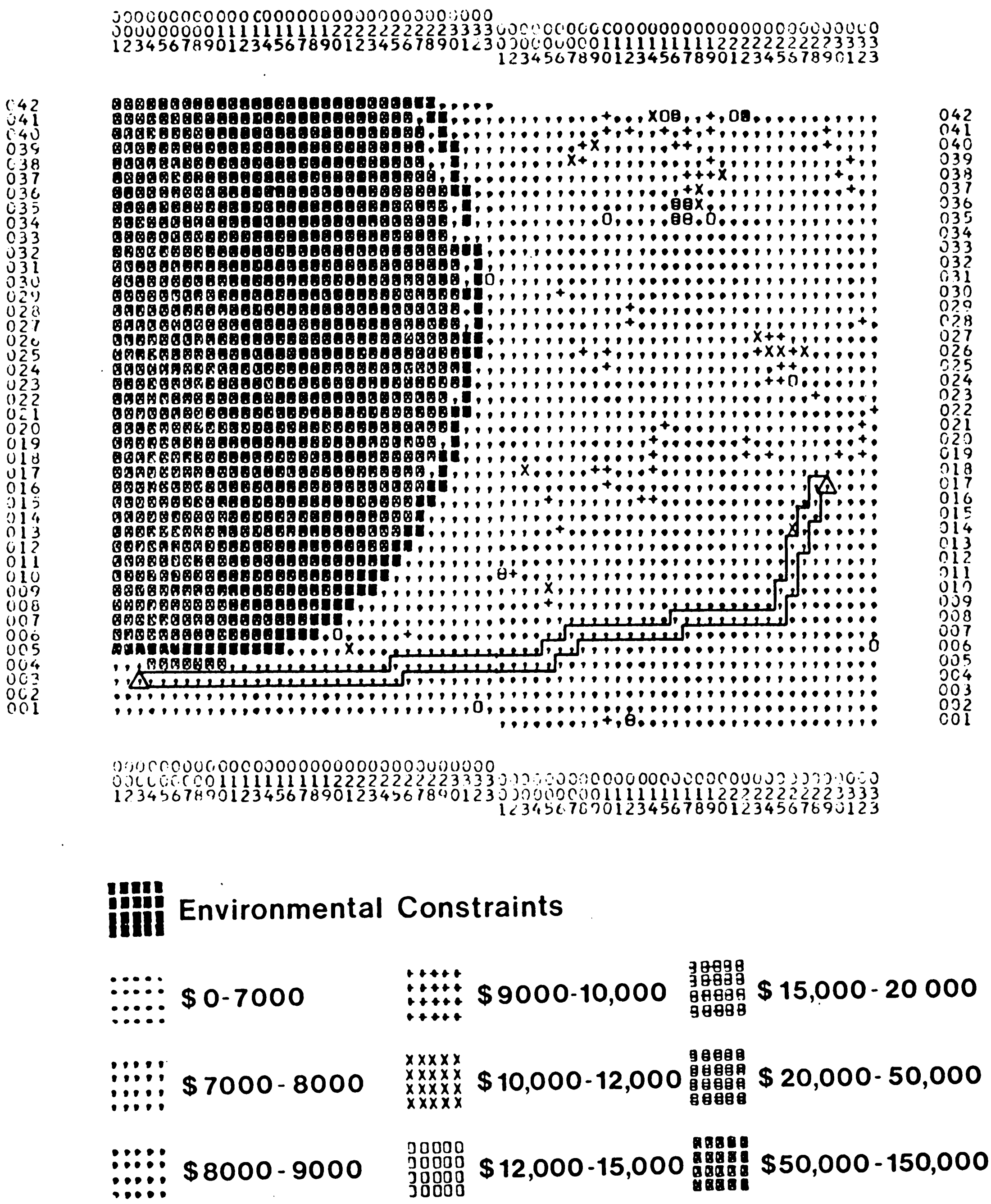


Fig. 30. Computer-generated map of the results of analysis 3 based on constrained present valued costs.

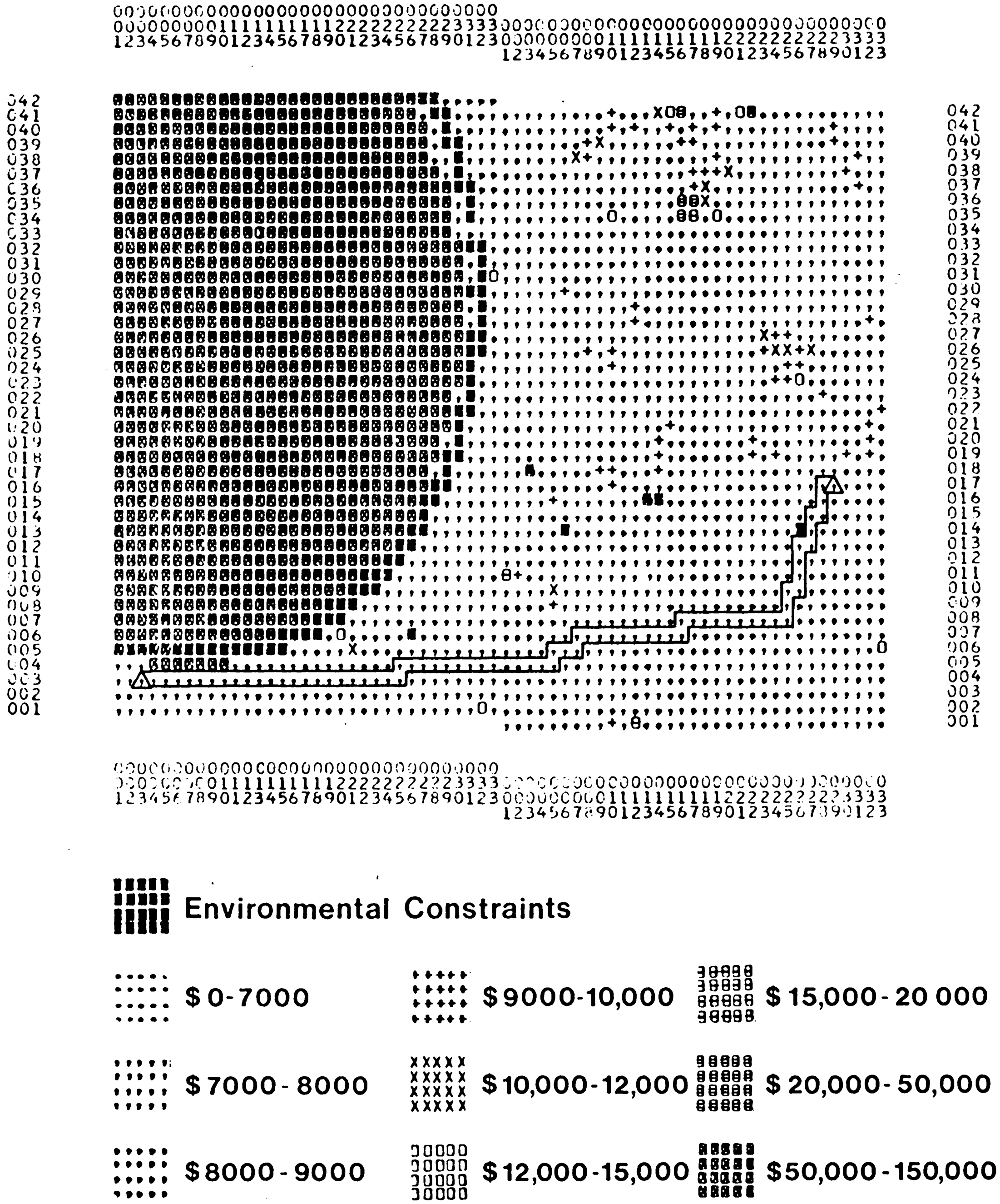


Fig. 31. Computer-generated map of the results of analysis 4 based on constrained present valued costs.

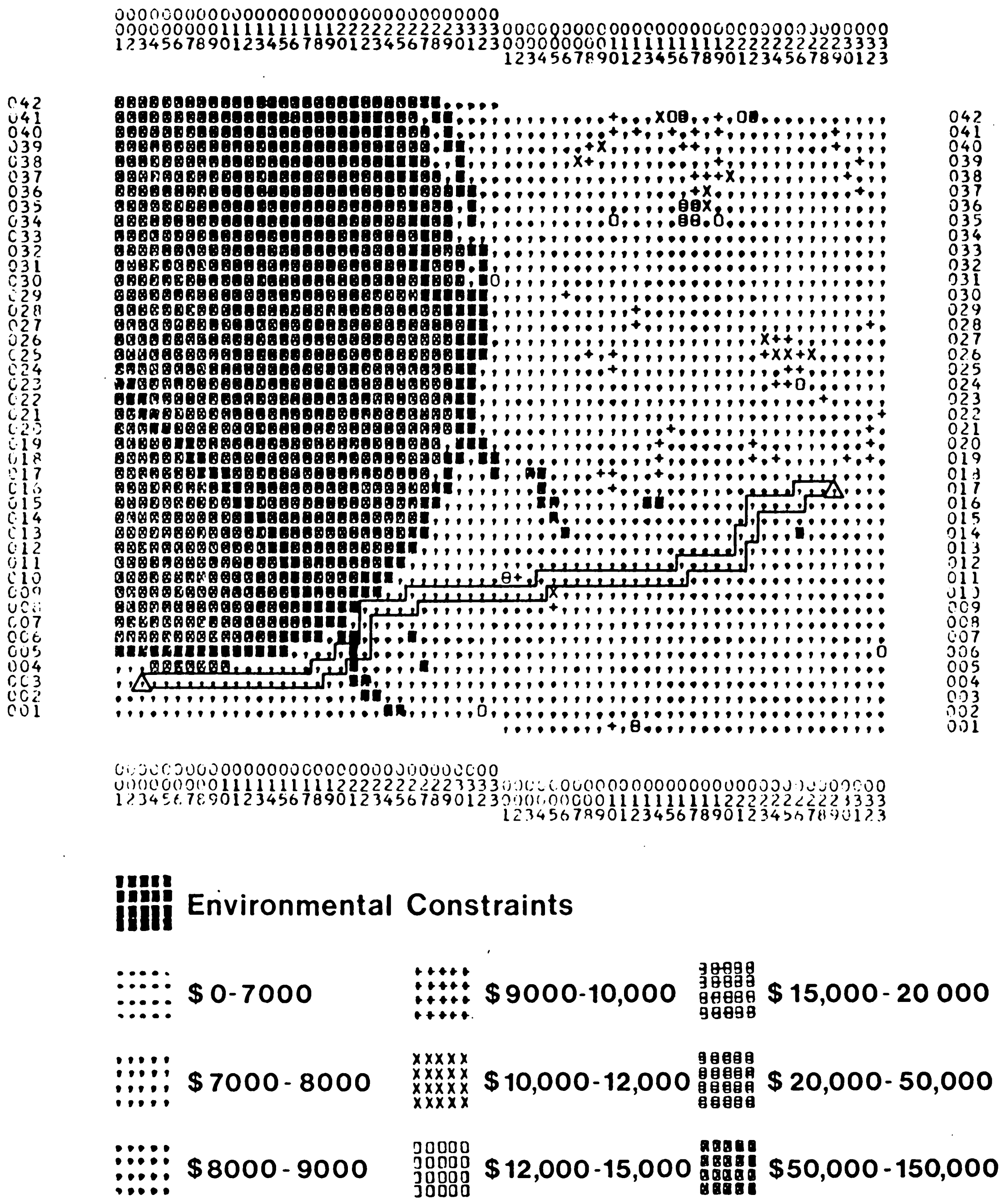


Fig. 32. Computer-generated map of the results of analysis 5 based on constrained present valued costs.

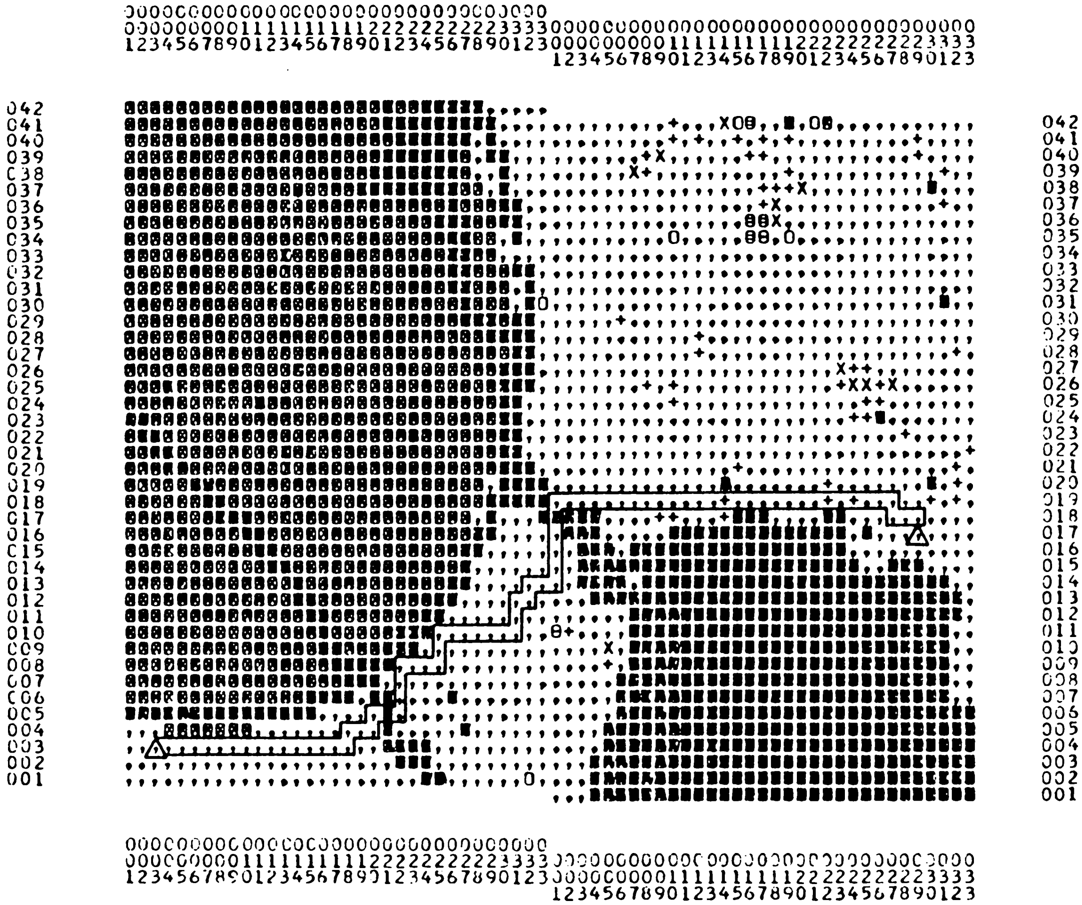
Environmental Constraints

$0-7000 | $9000-10,000 | $15,000-20 000

$7000-8000 | $10,000-12,000 | $20,000-50,000

$8000-9000 | $12,000-15,000 | $50,000-150,000

Fig. 33. Computer-generated map of the results of analysis 6 based on constrained present valued costs.



Environmental Constraints

$ 0-7000

$ 7000-8000

$ 8000-9000

$ 9000-10,000

$ 10,000-12,000

$ 12,000-15,000

$ 15,000-20 000

$ 20,000-50,000

$ 50,000-150,000

Fig. 34. Computer-generated map of the results of analysis 7 based on constrained present valued costs.

border of the transmitter zone. Cells which contained one or more constraint characteristics are represented by completely black printer characters. Since none of the cells effected was part of the unconstrained minimum cost route, that route was still selected as optimum under this constraint set.

Analysis 3

The additional constraint characteristics selected for Analysis 3 were the presence of:

(1) scenic easements to the State of Virginia

(2) national parks

(3) state parks and recreation areas

(4) publicly-owned natural areas

(5) national forests

Examination of Fig. 30 indicates that no additional constraint cells were indentified as a result of this analysis for inclusion with those already reclassified during Analysis 2. The resultant optimum route therefore does not differ from those previously defined.

Analysis 4

During Analysis 4 the optimum economic routing solution was further constrained on sites with one or more of the following characteristics:

(1) state-owned natural resources

(2) private, noncommercial recreation facilities

(3) slope greater than 15 degrees

(4) swamps or marshes

Six additional constraint cells were identified, each because of the presence of steep slopes. However, none of these had any impact on the previously defined minimum cost route (see Fig. 31).

Analysis 5

During this analysis the data cells in the demonstration subarea were scanned for the presence of:

(1) recommended historic sites

(2) proposed scenic easements

(3) existing hiking trails

The map in Fig. 32 displays the additional constraint cells identified in Analysis 5. Note that the minimum cost route selected during this analysis has been shifted somewhat to the north of those previously designated. The reason for this change is the presence of constraint cells, resulting from proposed scenic easements along Route 3, in the western portion of the subarea. To traverse the minimum number of these "sensitive" cells the selected route had to cross Route 3 farther to the north than did provious routes. To accomplish this without backtracking (thereby increasing the total right of way length) the optimization algorithm directed the relocation of the optimum route east of Route 3. Once the new minimum cost constrained route crosses this sensitive zone it quickly converges with the previously defined routes.

Table 7 facilitates an examination of the differences between the minimum present value cost path derived in Analysis 1 and the constrained solution. Both lines are approximately the same length. The constrained route, however, traverses somewhat more expensive land and has a higher estimated total cost. In addition, the constrained route contains several additional directional changes necessitating the inclusion of five angle towers of various form, at a total cost of $40,371. The overall impact of the constrained route, as measured by the three impact indices, was apprpxomately 5 percent less than that of the unconstrained route. The aesthetic impact was reduced by 3 percent. The constrained route crossed fewer roads and potential recreation resource sites than the unconstrained route, but crossed more streams.

<u>Analysis 6</u>

Additional constraint cells were identified at this stage as those data cells which possessed one of the following characteristics:

(1) potential historic sites

(2) residential settlement

(3) proposed public parks and recreation areas

(4) urban areas and industrial sites

As a result of those constraints another significant part of the subarea was effectively removed from consideration for right of way routing. The southeastern section of the area, south of the Rappahannock River, was classified as a proposed public park by the Virginia Outdoor Recreation Commission. This constraint forced the associated minimum cost path in a more northerly direction than did the constraint set used in Analysis 5 (see Fig. 33).

This northern route required some backtracking and resulted in a slightly longer path than was selected in Analyses 1 through 5. Significant increases were realized both in land acquisition costs and total right of way costs. Several additional directional changes were required, increasing the probable costs of angle towers. There was a significant increase in aesthetic impact due to this route selection. In addition, the northern route was forced to traverse a higher number of hilly (slope from 5 degrees to 15 degrees) sites, thereby incurring additional engineering costs.

Analysis 7

The presence of proposed hiking trails was the only level seven constraint characteristic applicable to the demonstration subarea. Proposed trails accounted for the increased width of the constraint area around the Rappahannock River at the center of the subarea, pictured in Figure 34. The resultant minimum cost route differed only slightly from that derived under level six constraints. No significant changes in costs or other measures of impact were realized.

Indices of Overall Impact

Analyses 8 through 10 tested the optimum route selection technique with alternate impact criteria. Instead of the economic impact measures and constraints used as the sole optimization criteria in Analyses 1 through 7, indices of overall right of way impact were formulated. These indices, rather than absolutely forcing right of way routes to avoid certain critical sites, were designed to model more accurately the mix of economic and noneconomic impacts incurred by segments of society if such sites are traversed. The objective was to recognize and deal more realistically with the multidimensional nature of transmission line impacts. For demonstration purposes three dissimilar social value systems were modeled: the utility industry viewpoint, the environmental viewpoint, and the socioeconomic viewpoint. Using the techniques and routes documented in the Procedures chapter each data cell in the demonstration subarea was evaluated as a potential right of way site under each of these three value systems. A minimum impact route was then determined for each social viewpoint, based on the map of impact indices for that value system.

Analysis 8 - utility industry viewpoint

Fig. 35 is a map of the impact indices calculated for the demonstration subarea using the hypothetical utility industry value system. The ring of nonclassified cells around the Federal transmitter zone indicate that this zone was considered an absolute constraint to right of way routing. The impact index calculated for the utility industry value system summarized in Table 3 is most sensitive to economic costs, potential scenic impacts, and conflicts with industrial, agricultural, and recreational land uses. Fig. 35 reflects this sensitivity in its southeast corner. Here land values are relatively low and few conflicting land uses exist. However, because of the recreation potential of this region, the associated data cells have been assigned slightly elevated indices of potential impact, represented by a darker shading pattern. Those sites where this recreation potential occurs in conjunction with high land values and potential significant aesthetic impact are represented by plus signs. The existing transmission right of way at the northwest corner of the subarea is plainly evident in this impact map, indicating that the construction of parallel

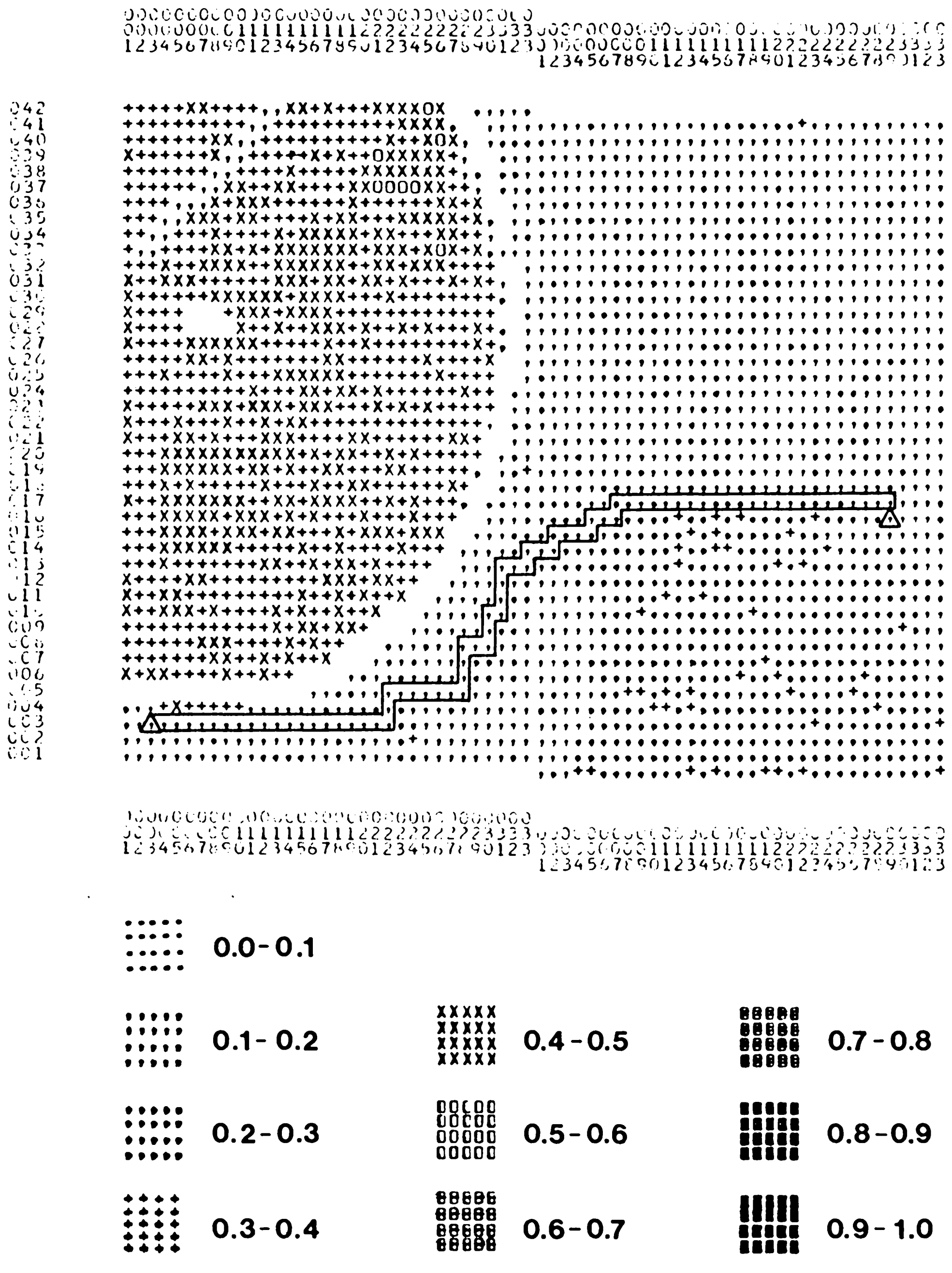


Fig. 35. Computer-generated map of the results of analysis 8 based on the utility industry viewpoint index of overall impact.

transmission facilities is an attractive option under the value system being modeled. However, this existing corridor is not close to the end points of the hypothetical right of way. In addition, it is within the constraint zone of the Federal radio transmitter. Artificially high land values recorded for all neighboring sites effectively eliminate the possibility of any minimum impact route paralleling this facility.

The minimum impact route determined through this map of probable impact indices is similar in location to the heavily constrained economic optima derived in Analyses 6 and 7. However, the "utility industry" route is somewhat more direct, requiring the construction of five angle towers, at an additional cost of $40,371.

Analysis 9 - environmentalist viewpoint

The "environmentalist" impact index is most sensitive to probable aesthetic impacts, changes in natural communities (terrestrial and aquatic), and conflicts with recreational land uses. Fig. 36 is a map of the environmentalist impact index calculated for the demonstation subarea. The shading of this map is generally darker than that of the utility industry impact map, indicating that the value system being modeled in this analysis is sensitive to impact dimensions which are related to a wider variety of critical site characteristics. The result is that fewer sites of outstandingly low potential impact can be identified.

The minimum impact route identified during this analysis appears to be most sensitive to sites having one or more of the following critical

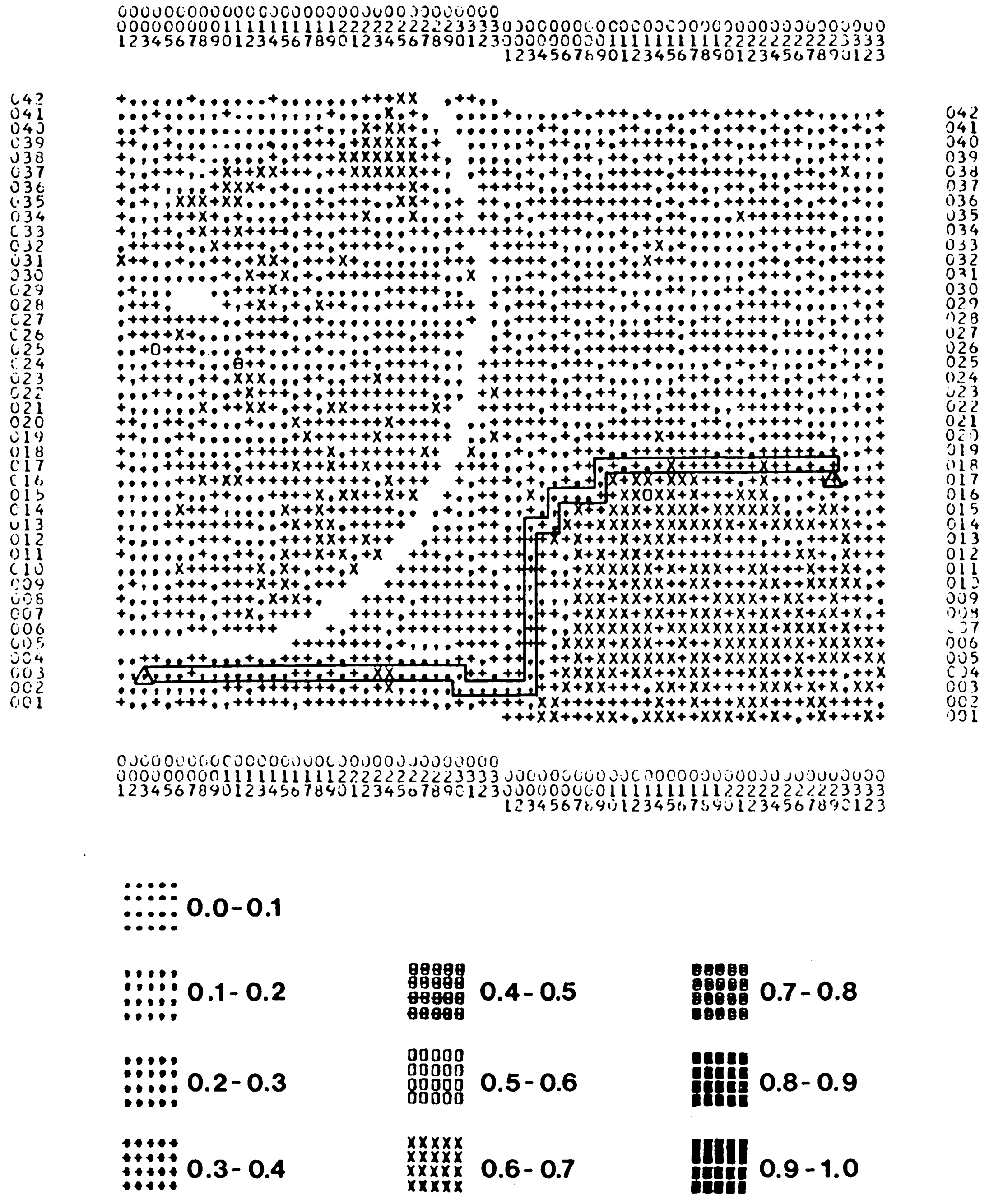


Fig. 36. Computer-generated map of the results of analysis 9 based on the environmentalist viewpoint index of overall impact.

characteristics: severe aesthetic impact, potential recreation resources, and the presence of forest communities. It appears less sentitive to the aquatic ecosystem impacts associated with construction distrubance near large streams than was intuitively expected. The route incorporated significant directional changes, necessitating the installation of six heaviest angle towers, at an additional cost of $53,610.

Analysis 10 - socioeconomic viewpoint

The socioeconomic impact index is responsive to a greater variety of impact dimensions than the indices calculated for Analyses 8 and 9. In particular, it is sensitive to land-use conflicts with agricultural residential and forestry activities, adverse impact to aquatic ecosystems and vegetative communities, and potential aesthetic impacts. This diversity of "concern" resulted in a relatively homogeneous map of impact indices (see Fig. 37). The minimum impact route specified is similar to that indicated in the "environmentalist" analysis (Analysis 9). However, the less distinct differentiation of "high impact" sites allowed for a more direct route, shorter in total length. Fewer additional heavy angle towers would be required to construct transmission facilities on this route.

Mount Storm - North Anna Transmission Line

An analysis of the probable impacts resulting from the construction of a proposed transmission network between Mount Storm and the North Anna Nuclear Plant was conducted on behalf of the staff of the Virginia State Corporation Commission. The routes proposed by the utility

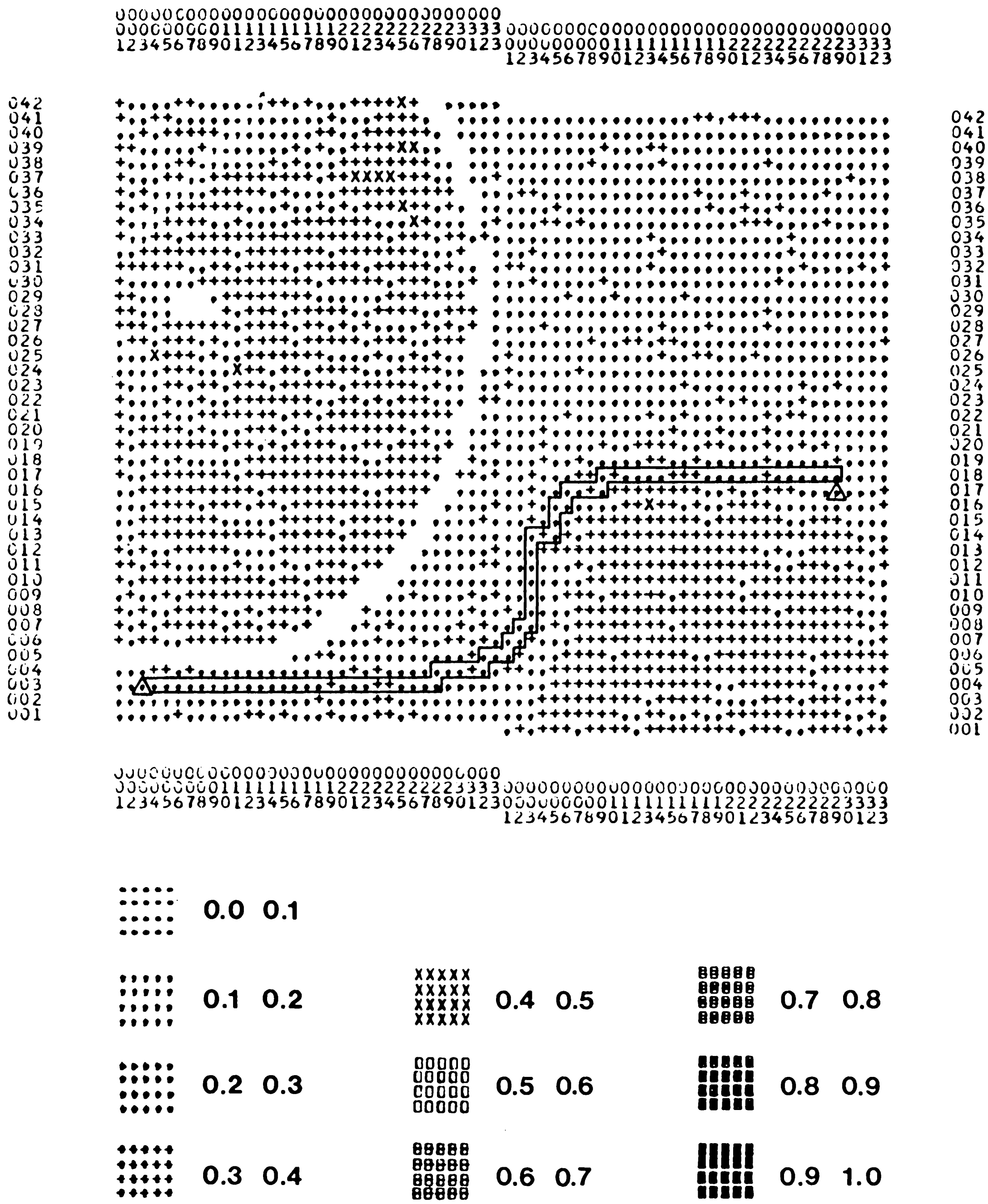


Fig. 37. Computer-generated map of the results of analysis 10 based on the socioeconomic viewpoint of overall impact.

industry and those suggested by intervenor organizations were evaluated in economic and environmental dimensions. In addition the least cost route selection algorithm was applied to the problem in order to supply to the Commission information about alternate routes which tend to minimize the overall adverse impacts resulting from transmission facilities construction.

Unconstrained economic analyses were conducted, based on land value data gathered by personnel of Technical Associates, Incorporated, and the previously discussed engineering criteria. The detailed economic analysis of the proposed routes and the determination of a minimum cost route are documented by Ileo (1973) and Strobl (1973). Fig. 38 is a schematic representation of the results of those economic analyses. The indicated costs are total present valued costs, including the costs of the construction of additional angle towers. The total estimated cost of constructing the intervenor-proposed facilities was $43,725,585. The estimated cost of the industry-proposed route was $35,281,500, while that of the least cost, computer-selected route was $33,643,045.

Few significant differences were noted between the spatial location of the industry-proposed route and the least cost route. In the 70-mile span of the Mount Storm-Morrisville segment the least cost route was never more than five miles distant from the industry proposal. Both routes paralleled an existing right of way for several miles north of Front Royal, Virginia. The least cost route for the Bristers-Morrisville segment paralleled a short stretch of existing right of way south of Bristers. It then proceeded generally west to

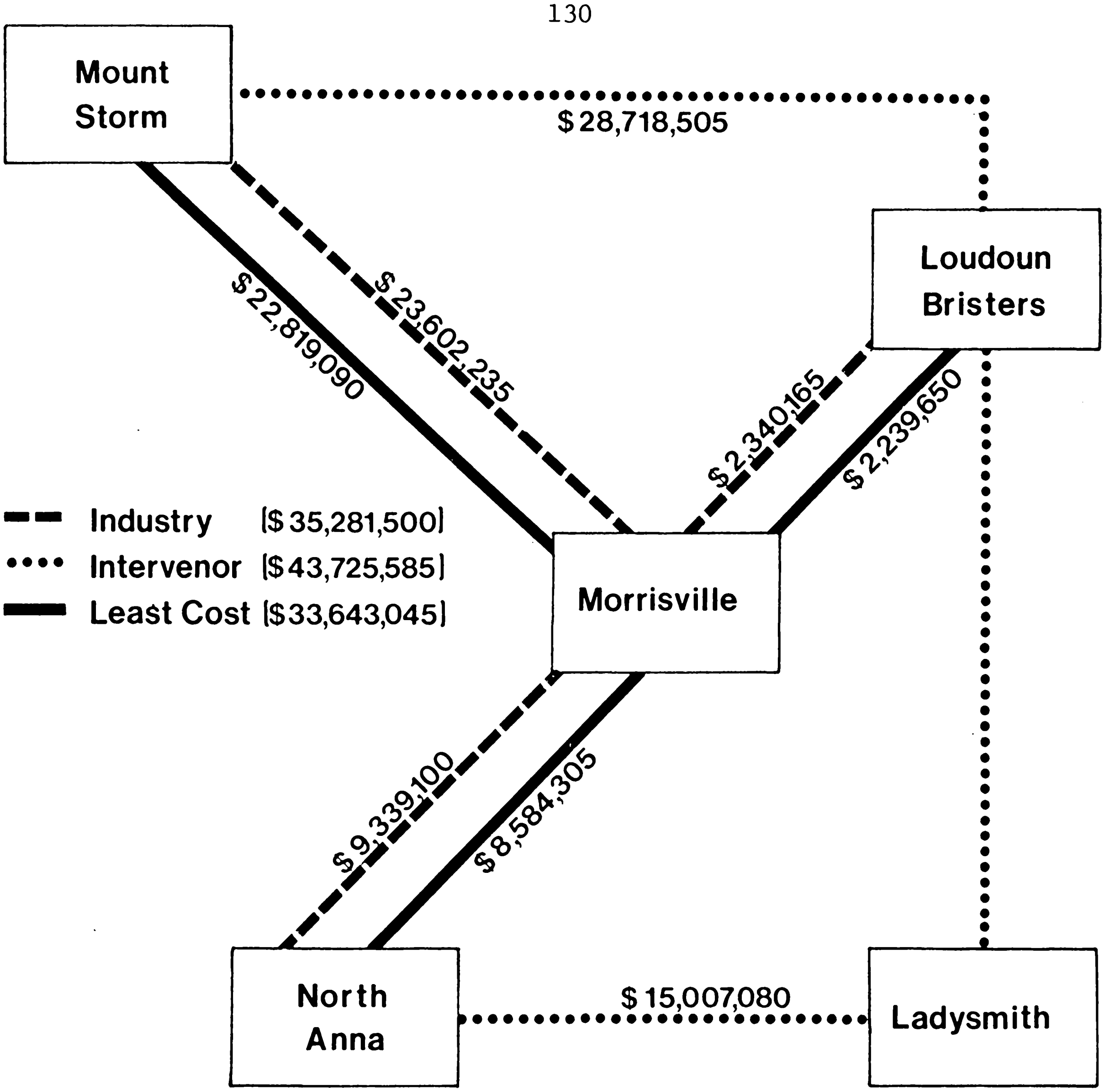


Fig. 38. Economic analysis of the Mount Storm – North Anna transmission network. Data source: Ileo 1973.

Morrisville, necessitating the construction of more angle towers than did the industry route. The Morrisville-North Anna segments differed only in the vicinity of Pigeon Run. This proposed state park was crossed by the industry-proposed route, but avoided by the least cost route.

Environmental impact analysis was conducted by means of the successive addition of the constraints, listed in Table 2, to the predicted economic costs. The least cost route previously identified remained unchanged, even after the application of the most stringent (level 7) constraint set. Upon careful examination it became apparent that all of the constraints operative in the vicinity of this route had already been reflected in the economic cost estimates used for the initial unconstrained routing search, either as increased engineering costs associated with topography or artificially high land values representing the unavailability of assessments for publicly-owned resources. The implication of this somewhat unexpected result is that the analysis conducted on the basis of predicted economic costs alone (Analysis 1) was not strictly unconstrainted. During the collection of land value estimates certain assumptions had been implicitly made with respect to the infeasibility of building transmission facilities on sites of recognized social significance. State and national parks, historic sites, and other tax exempt properties typify such sites. If the unavailability of tax assessments is accepted as a condition sufficient to render a site infeasible, then the specific inclusion of characteristics which typically render sites untaxable in the constraint lists of future analyses will be little more than a check on already active constraints. If, however, tax exempt status is not a sufficient condition to define constraint sites than more effort will be required to appropriately estimate land acquisition costs of such sites.

As stated earlier, the industry-proposed route traversed a proposed state park near Pigeon Run. The intervenor-proposed route was judged to violate several of the environmental constraints. It traversed one area of steeply sloping terrain near the Potomac River, a characteristic indicating significant engineering costs as well as potentially severe ecological impacts. In addition, that route was likely to impact one residential development and numerous historic resources in northern Virginia.

The overall recommendation submitted to the Virginia State Corporation Commission was that the industry-proposed route, if relocated to avoid Pigeon Run Park, was not significantly different from the minimum impact route and should not be rejected on economic or environmental grounds.

DISCUSSION

Evaluation of the Technique

The procedures for the analysis and design of minimum impact transmission rights of way described in this dissertation have potential for significantly increasing the responsiveness of the site selection process to ecological, social, and aesthetic values. In particular, the technique provides a vehicle for simultaneously considering the probable economic and environmental costs of rights of way construction. Application of the technique to future transmission systems routing can effectively encourage the protection of fragile ecosystems and natural communities. It can help the planner to minimize unnecessary adverse impacts of rights of way on wildlife habitat. The indices of overall impact serve to include natural resource impacts in the planning process explicitly. The objective is not to emphasize environmental impacts at the expense of engineering considerations or economics, but to ensure that each type of impact is appropriately represented in the siting decision.

The Value of Explicitness

The minimum cost route determination algorithm provides a very objective solution (a route) in a highly subjective decision-making environment. The explicitness with which the constraints and impact indices are defined and the mathematical definition of the route selection algorithm can be of significant value to the utility system planner. A right of way route selected with the aid of this technique can be more confidently defended as an optimum choice than can a route planned via a less structured approach. The reasons for routing decisions, which may be questioned by utility management or regulatory agencies, can be rationally explained in relation to the physical characteristics of the sites traversed and the other available sites. Even if a route selected for implementation is not coincident with the computer-generated path, the technique can be of explanatory value. The "optimum" route can serve as a standard against which the likely impacts of any proposed route may be compared.

The rights of way location technique is not completely automated. Instead it is computer-assisted. It is designed to take advantage of the computational capabilities of computers to complement, not replace, the activities of human decision makers. The computer programs incorporated in the system are capable of quickly examining the probable impact of a very large set of alternate routes. In addition, computers are capable of simultaneously incorporating a complex set of resource characteristics and dimensions, including changes over time, into rational indices of impact. Access to these efficient computational powers helps the planner to make specifically defined, realistic trade offs between conflicting values and to examine the probable impacts of his decisions.

The computerized nature of this process encourages explicitness in the route planning process, but not at the expense of analysis flexibility. Computer support of the route design process actually fosters dynamic analysis capabilities. The impact index calculations are programmed to accept changes in any of the numeric weights and values used. The speed with which computer processing may be accomplished can ensure the performance of this feedback function in a timely manner. The dynamic nature of social values has been recognized and provided for by designing a system which allows for their periodic reassessment. Although initially developed for regulatory purposes, the right of way location technique described herein should be attractive for use by utility industry planners. The capability for explicitly incorporating noneconomic values in a route optimization process may encourage the environmental design of right of way routes, rather than the environmental analysis of already designed routes. The process is economically efficient. The entire task of system development, data capture, and route determination in the defined analysis area was completed in a period of 6 months, at a total cost of $25,000. Much of this cost must be incurred only once. The computer programs are written for the general case and the data already encoded is suitable for any route selection analysis within the mapped area. Depending on the configuration of any other route to be selected in that portion of Virginia, the costs for update of the data files and computer-aided route selection would not be likely to exceed $5,000.

The optimum route selection technique documented in this thesis is not a completely deterministic process. The optimization algorithm will determine the minimum impact route through any matrix of possible transmission right of way routes. However, the technique is a model of the transmission facilities construction process. It involves the abstraction of the many economic and environmental processes and interactions which are associated with right of way construction. The network formulation artificially limits the number of possible links from which a right of way route may be constructed and the indices used to describe economic and multidimensional impacts are essentially abstractions, always subject to a set of limiting assumptions. However, such simplification is necessary for the computer implementation of the model and the human comprehension of its meaning. The explicitness of the solution is a result of this simplification.

The model cannot be used in isolation to route transmission rights of way. It is but one of the tools available. It can provide a powerful technique for selecting an appropriate right of way corridor, but the final site selection process must be accomplished in conjunction with field investigations. The corridor selection process serves to limit the amount of fieldwork necessary to a relatively narrow strip of land. Adoption of such a computerized site selection process does not eliminate the role of field personnel. Instead it fosters a man-machine interaction, using the computational powers of the computer in conjunction with the integrative powers of the human planner.

Value Systems, Constraints, and Index Construction

Much discussion has been devoted to the fact that this technique is designed to seek an optimum transmission right of way route. Some care must be exercised in the use of the term "optimum." Because it is inherently an abstraction, the minimum impact route defined is an operational optimum, not a social optimum. In other words, the route selected is a function of the resource characteristics included in the data base and the values attributed to these characteristics by the user of the model. At the time this analysis was performed the included characteristics were considered to provide the most information about the quality of potential sites, while being sufficiently well defined to allow recording of the data in computer format within the monetary and time constraints of the associated decision processes of the State Corporation Commission. The social values of the probable impacts were not gathered by any poll of the population of Virginia. Rather, they were chosen by the investigator to represent (to the best of his ability and knowledge) the value systems of several segments of society. Alternate value systems are undoubtedly operational. Such systems may respond to site characteristics not included in the model presented. The values and characteristics employed in this analysis were deemed the most appropriate at that time. However, the route selection system is not inflexible. The impact information is designed specifically to be modified or supplemented. If other value systems seem more appropriate or if alternate critical characteristics are important, future users have the option of changing the criteria by which the system calculates the index of probable impact.

In light of the imperfect nature of the model of impact and the uncertainty associated with the estimation of the social value of various impact dimensions, the optimum route selection technique is best used as a comparative, rather than a predictive model. The economic cost calculated for any route evaluations is unlikely to match exactly the cost which would actually result from right of way construction. The overall impact, even if directly measurable, would probably not match the computer-derived estimate. However, since these estimates are the result of an explicitly stated set of weighting rules applied equally to all cells (hence, all routes) they may be used to compare the relative probable impacts of any pair of routes. The assumption is, of course, that the weighting rules used for any analysis relate the computed cellular impacts directly, if not completely accurately, to the actual social impacts realized due to construction. The validity of this assumption can never be ensured absolutely, but it can be protected by subjecting the weighting rules to maximum possible public scrutiny.

The Involvement of Decision Makers

The procedure for constructing indices of overall impact is designed to incorporate inputs from two separate sets of participants. Experts in environmental and socieconomic affairs are the appropriate sources of a comprehensive list of critical characteristics and the numeric impact measures (c_{ij}) which make up the impact matrix. However, it is the decision maker (or panel of decision makers) who should supply the list of impact dimensions and their associated weights for each analysis. Such a division assigns the responsibilities of the total analysis to the most appropriate parties. Technical experts are the most knowledgeable of the two groups, with respect to the physical, biological, and social processes which relate to transmission facilities construction. They can best estimate the severity of impacts in physical units. However, it is the decision maker, be he a member of a regulatory commission, a utility industry manager, or a public representative, who is best equipped to enumerate and weigh the various dimensions of impact. Whether aided by technical information or not, the job of the people who ultimately make and implement routing decisions is one of considering all relevant social impacts in two respects: (1) their probable severity, and (2) their relative importance. Individual decision makers, of course, differ with respect to their definition of the term "relevant."

Active participation in the weighing process can change the role of a regulatory agency, such as the Virginia State Corporation Commission. By their initial support for the development of a minimum impact corridor selection procedure, the members of the Commission indicated a desire to shift from an essentially passive role, reacting to the routing proposals of others, to an innovative role. This has been confirmed by continued Commission use of the procedure as one input to their decision process. Since the charge of the Commission is to protect the interests of the people of Virginia, assumption of an even more active role in the iterative specification of impacts and weights would not seem to be inconsistent with their responsibilities.

Future System Development

Development of the minimum impact corridor selection system is not complete. The system will be evolutionary in nature. The procedures documented in this dissertation are the first attempt at implementing a viable aid to the rights of way routing decision process. The present system was developed under a necessary set of resource and time constraints. Future iterations in the development process are the feedback functions which will ensure the continued viability of the system. The following are future developments which may prove fruitful.

Data Capture and Coding

All the resource data which were acquired and converted to computer readable format during this study were obtained via the manual methods outlined in the Procedures chapter. It is likely that major efficiencies could be realized in the data acquisition process if full advantage were taken of currently available automated techniques. Specifically an investigation of LANDSAT satellite imagery stored on computer compatible tapes (CCT's) should be undertaken. Use of such data, already in computer readable form, could eliminate the need to manually digitize land cover information. Land cover patterns are dynamic in nature and may change rapidly as land use changes. Satellite imagery may be one of the few practical means of updating a regional land cover data file efficiently.

Semiautomated digitization, using X-Y digitization tables to record data directly on computer readable media, should be investigated for potential utility in the capture of information recorded on maps. Adoption of machine-assisted digitization techniques would convert the current two step data coding-keypunching process to a single step. This could result in significant time savings for data capture, as well as a reduction in the probability of data transcription errors.

It seems likely that future computer programs could be developed to eliminate the need to digitize topographic characteristics, such as slope and aspect directly. Since cell centroid elevation is currently digitized and entered in the computer data base, an algorithm, such as that proposed by Sharpnack and Akin (1969), could be easily implemented to calculate the slope associated with each data cell, as well as its direction.

Improved precision is desirable in the digitizing several site characteristics. The investigator encountered extreme difficult in making meaningful interpretations of the engineering characteristics of soil associations. If more precise soils data (soil type or phase) were available for future analysis areas, it could provide much more information about the physical characteristics of the land. Interpretations of probable ecological site characteristics could be more confidently made. Greater precision in specifying the characteristics of existing transmission facilities would also be desirable. The present data base for existing rights of way simply recognizes the presence or absence of transmission facilities in each cell. Any reduction of total impact resulting from parallel construction near existing transmission lines could be more meaningfully modeled if the characteristics of the existing rights of way are more precisely specified.

If available in mapped form, additional data base parameters would be useful in future analyses. Of particular value in the process of site screening and route selection would be data base information on the confirmed or probable presence of critical natural phenomena. Moyseenko et al. (1976) have implemented a computer information system for recording the spatial distribution of endangered species and critical habitats. The interface of such information with the corridor selection process could serve to reduce significantly the probability of adverse impacts to natural systems.

Data Management Procedures

One product of this investigation is a permanent natural resources data base for a significant portion of the Commonwealth of Virginia. However, the procedures for the storage, retrieval, and update of the massive amounts of cellular information involved were developed hurriedly under several economic and temporal constraints. It is probable that major efficiencies could be realized if the data management procedures were redesigned. Adoption of a generalized data base management package available from one of several commercial vendors might prove fruitful.

In retrospect, it seems that the choice of a cellular data structure was appropriate for this geographic data system. The inherent simplicity of registering two or more files of spatial data recorded in regularly shaped cells far outweighs the cartographic precision to be gained by recording data in irregular polygons. It also appears that the 27-acre cell size selected was an appropriate compromise between spatial data precision and digitization efficiency. However, alternate coordinate systems should be investigated for defining cell boundaries in future analyses. The Universal Transverse Mercator system has two prominent deficiencies when used to reference a regional data system as in this study. First, the UTM reference system does not coincide exactly with the boundaries of the data source documents selected, 7.5-minute quadrangle maps. These maps are bounded by geodetic (latitude and longitude) coordinates and their incompatibility with the UTM system led to numerous instances of data coding duplication, as well as failure to digitize data for certain cells. Second, the orientation of the UTM coordinate system is altered at specific meridians every six degrees of longitude around the equator. When dealing with regional data bases the effects of this shift in coordinates is profound. Cells in the neighborhood of one of these meridians assume triangular shapes of various sizes and are exceedingly difficult to deal with analytically. A viable alternative to UTM referenced cells is the use of geodetic referencing. Geodetically bounded cells are not equal in size, but the areal changes related to latitude are predictable. The value of geodetically-referenced cells is that, although they are not true geometic rectangles, they do not deviate from a quadrilateral shape, which can be approximated by rectangular display hardware.

Optimization Processes

As is the case with many of the computerized modules in the minimum impact corridor selection technique, the optimization algorithm itself could benefit from redesign and reprogramming. In its present form it can use significant segments of computer processing time to solve for least cost routes through analysis areas large enough to encompass regional transmission facilities. Particular attention should be devoted to implementing alternate data management techniques within the algorithm itself, as well as adopting improved computational operations.

One important deficiency of the present minimum impact route selection algorithm is its inability to model those engineering and economic impacts which result from routing nonlinearities. The present process performs a least cost path search without assessing penalties for changes in the direction of the right of way route. Only after optimization is completed are the economic penalties of angle tower construction assessed against the route. The danger is that a "least cost" route may entail so many turns that, after the addition of angle tower costs, it may not be the optimum route. Future development of the route selection process should seek to incorporate the costs of directional change directly in the optimization algorithm.

It would be desirable to incorporate the possibility of selecting diagonal paths between cells during the optimization process. The network model of the route selection problem presented in the "Procedures" chapter allows only orthogonal paths into and out of each cell. Such a restriction can lead to several distortions of estimated right of way lengths. The example in Figure 39 demonstrates this phenomenon. This example shows two possible paths between diagonally opposed end points. Examination of these alternatives reveals that both traverse exactly nine cells, indicating that both routes are the same in total length. Actually the lower, stairstep-like route is only

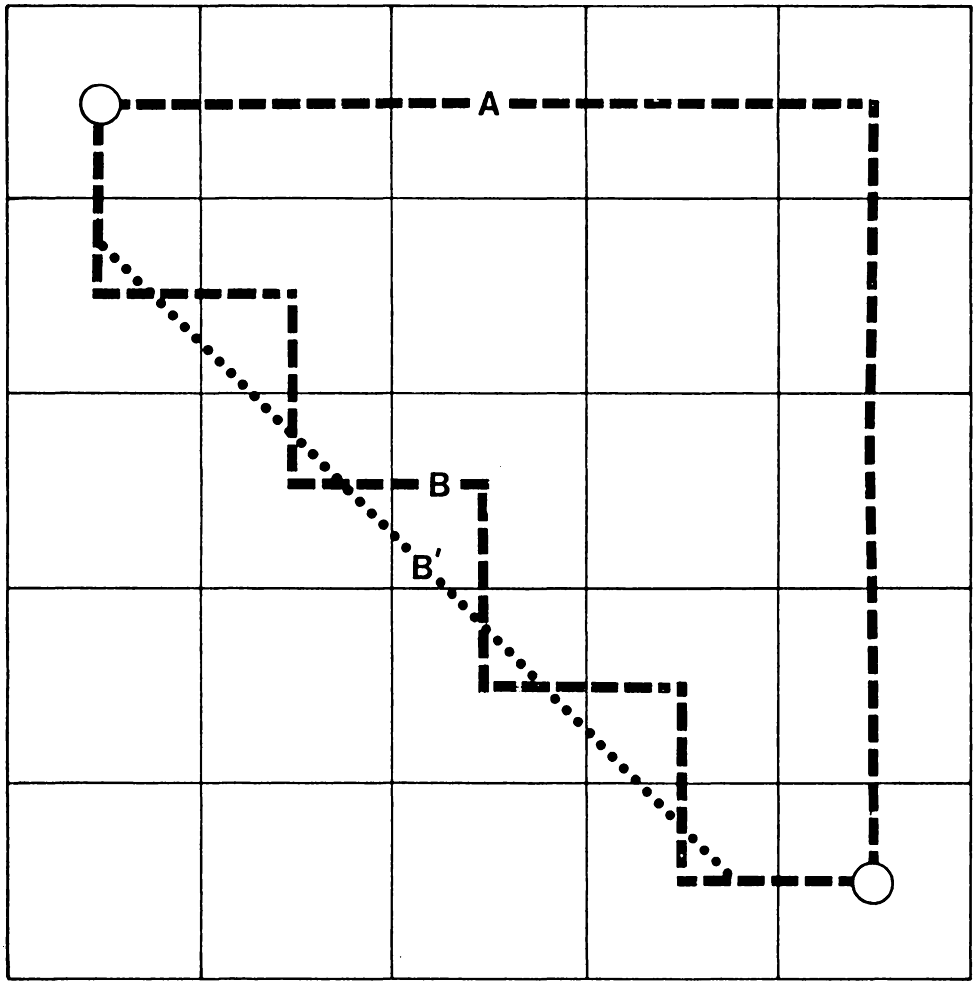


Fig. 39. Example of potential distortions of right of way length estimates. Because only orthogonal intercellular paths are included in the minimum impact search routes A and B are considered to be equal in length. Route B, however, could be approximated by a more direct route, B'.

an abstract representation of a much more linear diagonal route which could be designed within the corridor of associated cells. Such a route would be significantly shorter than the upper route. However if all cells in this map had been assigned identical indices of impact, the current algorithm would be indifferent between the two routes shown as candidates for the minimum impact solution. Future development should seek to model more adequately the length of rights of way. Incorporation of the possibility of diagonal paths between cells should be examined as one alternative solution to the length distortion problem. Such a solution would have to recognize the longer lengths (and greater total impacts) of diagonal paths versus orthogonal paths.

Additional display capabilities should be developed to aid analysis of route optimization results. The present mapping capabilities of the route selection system should be augmented to enable the graphic display of the minimum impact route. The optimization program determines more options than the least impact route between the specified origin and destination points. When the route selection process is complete, the computer files actually contain a description of the minimum impact "tree," the set of minimum impact routes from the origin cell to all other cells in the analysis area. It should be feasible to display a map of this entire set of optimal paths. This feature would allow the transmission system planner to consider the relocation of substations and the associated changes in overall impact.

Alternate Uses of the Technique

The utility of the technique developed during this investigation is not limited solely to the siting of electricity transmission rights of way. Perhaps the most significant product of this work is the establishment of a regional geographic information system. The objective was to develop a data file and associated computer procedures which could be of aid in the design of transmission networks within the Commonwealth of Virginia. However, the product is neither state-specific nor problem-specific. The data base structure has been designed to accept not only data for the remainder of Virginia, but also information for as large a region as desired. Increased data volumes will necessitate future development in the data processing techniques employed, but will not invalidate the data storage and retrieval structure. Additional resource parameters can be incorporated into the existing data base if they are required for the analysis of other types of resource development.

Minimum impact path search algorithm could conceivably be applied to the process of planning other types of linear facilities. If the relevant site characteristics and appropriate sets of impacts can be defined, the technique should be useful in the process of planning and siting interstate highways and other roads. The technique might contribute to the development of hiking trails in national parks or forests.

In addition, a regional data base of this nature can provide important information about the spatial distribution and coincidence of significant site characteristics to designers of other developments. The availability of regionally comprehensive data is most valuable during the early phases of planning for development projects. Logically, the process of siting such projects is sequential in nature, narrowing the focus of the analysis from the enumeration of many potential sites within a region to the screening of these candidate sites for that area with the most suitable characteristics for the development under consideration. Detailed, on-site investigations serve to confirm the suitability of the site selected. Regional data bases can contribute most to the siting process at the site enumeration phase. Computer-assisted mapping can be used to focus attention on the areas within a region which have physical characteristics compatible with the proposed development. Within these areas the candidate sites can be identified with the aid of maps expressing their relative suitability. The data which are stored in a regional data base to facilitate site enumeration and screening should include all the physical characteristics which tend to make any site either attractive or undesirable for development. Of special importance are those characteristics which, for economic, engineering, ecological, or political reasons, are constraints to development.

SUMMARY

A computer-assisted system was developed for use by the State Corporation Commission of the Commonwealth of Virginia in the process of evaluating and licensing electric transmission right of way construction. The system was designed to analyze objectively the probable impacts of proposed construction activities and to provide insights into the location of routes which tend to minimize the overall adverse impacts incurred by society. The system effectively relates the probability of adverse impact to precisely definable characteristics of the land which any right of way traverses. Ecological, sociological, and economic dimensions of overall impact are explicitly recognized.

Providing inputs to the system required designing and establishing a regional geographic information system . A cellular data structure was devised and a standardized data acquisition methodology was designed. Information about the spatial distribution of 17 basic land characteristics was collected on maps for an analysis area 5,000 square miles in size. Information about economic, ecological, topographic, land-use and political characteristics was included. This information was converted to computer readable format and stored on permanent magnetic files. Data management procedures were developed to facilitate the access to logical subunits of the data.

The processes involved in the system include formulating indices of impact, evaluating proposed right of way routes, and designing alternative, minimum impact routes. The index of probable economic impact relates land values and terrain characteristics to the total

economic cost of land acquisition, facilities construction and maintenance on any site. A discounting procedure is used to include time explicitly as an economic factor. The index of aesthetic impact examines the topographic relationship of any site and the surrounding terrain to predict the visual impact of transmission facilities construction. Two indices of overall impact were formulated: constrained economic costs and subjective weights. The constrained economic cost formulation is a simplistic opportunity cost model. The weighing technique is a more complex model which specifically recognizes the multidimensional nature of transmission right of way impacts and the divergent values which segments of society may apply to each. A time-dependent "impact function" serves to relate critical physical site characteristics to each impact dimension.

The evaluation of proposed right of way routes is accomplished by summing any selected index of impact for all data cells included in the proposed corridor. The number of times a route crosses sites with particular critical characteristics may be tabulated.

The design of alternate right of way routes which tend to minimize a selected index of impact is accomplished by a minimum flow search algorithm. The set of all possible routes between two substantions is modeled as a network of intercellular paths, each with an associated impact (or cost). A computer version of the Dijkstra minimum cost path search is used to select that set of paths which connects the substations with minimum total impact.

The outputs of the route selection system are tabular and graphic. Tabular outputs include a list of the geographic coordinates of all cells included on any minimum impact alternative route determined by the search algorithm. For any route, computer-selected or not, a table of resource impacts is available. Computer generated maps are produced by the system to provide the user a visual display of the spatial distribution of resource characteristics and calculated impact indices in the vicinity of the right of way under analysis. Graphic display provides information about the regional context of a route and its proximity to critical features. It can facilitate the identification of modifications which would cause little or no change to the total impact of any route.

Feedback may be incorporated in the future. The computer programs are modular in nature and substitute impact index calculations. optimization procedures and display products may be easily incorporated. The capability to update information stored in the data base is available for resource parameters which are likely to change over time. The present index construction models are not absolutely locked to the data inputs documented in this dissertation. The numeric weights, impact dimensions, critical site characteristics, and impact functions cited were considered to model appropriately the impacts likely at the time of this investigation. Many of these relationships involved are not precisely defined and subjective judgment was used liberally in their quantification. However, if more precise knowledge of these phenomena becomes available in the future, it may be easily incorporated in the analysis.

The computer-assisted right of way selection system does not "make" right of way siting decisions. Decision-making is a human function. The system does, however, provide the decision maker with a practical technique for modeling the necessary trade-offs between economic, sociological, and ecological impacts. It is a rational structure for the multidimensional evaluation of proposed rights of way and the design of minimum impact alternatives.

LITERATURE CITED

Amidon, E. L. 1964. A computer-oriented system for assembling and displaying land management information. U.S. Forest Service Research Paper PSW-17.

Anon. 1950. Section 56-265.2. Utility Facilities Act. pp. 599-601 of the Code of Virginia.

Anon. 1972a. Article 6, Chapter 1, Title 56, Section 56-46.1 of the Code of Virginia.

Anon. 1972b. New way to plant rights of way. Electrical World 178(9):149.

Anon. 1973. Right of way acquisition requires new attitudes. Electrical World 179(11):41-43.

Applegate, L. J. 1968. HVDC has little hazard for piping. Power (May):82-84.

Arner, D. H. 1960. Effects of rights of way techniques on vegetation. Trans. N. Amer. Wildl. Conf. 25:378-386.

Barrett, S. 1971. Transmission right of way: multiple use pays dividends! Electric Light and Power, Aug. 1971:59-61.

Bonham, C. D. 1971. ECOMAP: A computer program for mapping ecological data. Science Series No. 9. Range Science Dept. Colorado State University. 30 pp.

Bramble, W. C., W. R. Byrnes, and D. F. Worley. 1957. Effects of certain common brush control techniques on game food and cover on a powerline right of way. No. 4. Pa. Agr. Expt. Sta. Progress Rept. 175. 7 pp.

Chang, D. R. 1967. Tapered steel poles put 230 kV line on narrow R/W. Electrical World 167(26):55-58.

Churchman, C. W., and R. L. Ackoff. 1954. An approximate measure of value. J. Operations Res. Soc. of Amer. 2:172-187.

Clawson, M. 1959. Methods for measuring the demand for and value of outdoor recreation. Resources for the Future, Inc. Reprint No. 10.

Commonwealth Associates. 1973. Environmental report, proposed ± 250 kV DC transmission, Duluth, Minnesota/Center, North Dakota. Square Butte Electric Cooperative. 110 pp.

Coomber, N. H., and A. K. Biswas. 1973. Evaluation of environmental intangibles. Genera Press. Bronxville, New York. 77 pp.

Curran Associates, Inc. 1973. Evaluation of power facilities: a planner's handbook. Berkshire County Regional Planning Commission. Pittsfield, Massachusetts. Unpubl. Manuscript.

Dijkstra, E. W. 1959. A note on two problems in connection with graphs. Numer. Math. 1:269-271.

Dohrenwend, R. 1973. Environmental management during power transmission line construction: operational considerations. pp. 58-71 In R. Goodland (ed.). Powerlines and the environment. The Cary Arboretum of the New York Botanical Gardens. Millbrook, New York. 170 pp.

Dreyfuss, H. 1972. Aesthetic guidelines for electric transmission-design guide. Southern California Edison. Rosemead, California. 82 pp.

Edison Electric Institute. 1968. Summaries: EII Library of land economic studies. A report of the Edison Electric Institute Committee on the Environment. No. 68-44, New York. 55 pp.

Egler, F. E. 1953. Our disregarded rights of way - ten million unused wildlife acres. Trans. N. Amer. Wildl. Conf. 18:147-158.

Egler, F. E. 1954. Right of way vegetation management studies. I Old Saybrook, Middlesex County, Connecticut. Amer. Museum Natural History Committee for Rights of Way. Tech. Rept. No. 1. 4 pp.

Egler, F. E. 1957. Rights of way and wildlife habitat: a progress report. Trans. N. Amer. Wildl. Conf. 22:133-144.

Egler, F. E. 1960. Human ecology and Connecticut's two roadside bulletins. Ecology 41:820-822.

Energy Policy Staff. 1970. Electric power and the environment. Office of Science and Technology, Washington, D.C. 71 pp.

Fales, R. R. 1969. Some applications of computer-generated maps to wildlife management. M.S. thesis. Va. Polytechnic Inst., Blacksburg. 83 pp.

Fisher, A. C., J. V. Krutilla, and C. J. Cicchetti. n.d. The economics of environmental preservation: a theoretical and empirical analysis. mimeo. 39 pp.

Frederick, C. J., Jr., and J. J. Luty. 1972. Problem recognition study: Central New Hampshire planning region. Regional Field Service, Harvard Graduate School of Design. 339 pp.

Giles, R. H., Jr. 1971. A preliminary report: the illusive wildlife benefit unit. mimeo. 16 pp.

Goodland, R. 1973. Ecological perspectives of power transmission. pp. 1-35, In R. Goodland (ed.) Power lines and the environment. The Cary Arboretum of the New York Botanical Gardens. Millbrook, New York. 170 pp.

Gosselink, J. G., E. P. Odum, and R. M. Pope. 1973. The value of the tidal marsh. mimeo. 32 pp.

Herrington, L. P., and G. M. Heisler. 1973. Microclimate modification due to power transmission rights of way. pp. 36-37. In R. Goodland (ed.). Powerlines and the environment. The Cary Arboretum of the New York Botanical Gardens. Millbrook, New York. 170 pp.

Hill, J. C. 1972. Shared transmission corridors aid grid growth. Electric Light and Power Transmission and Distribution (March): 49-52.

Ileo, M. J. 1973. Direct testimony and exhibits, Technical Associates, Inc. Part I-III SCC Case No. 11655. State Corporation Commission of Virginia 73 pp.

Johnson, R. L. 1966. The current status of beautility. Public Utilities Fornightly 78(4):15-23.

Jones, A. B. III, C. W. Smart, and R. H. Giles, Jr. 1976. Operating manual for POWER: a computer system for corridor location and land use decisions. Virginia Polytechnic Institute and State University, Blacksburg. 325 pp. (In review).

Jordon, E. M. 1972. Memorandum to all electric utilities: procedures under the Utility Facilities Act and House Bill 967. State Corporation Commission of Virginia. mimeo. 5 pp.

Knetch, J. L. 1963. Outdoor recreation demand and benefits. Land Economics 39:387-396.

Krauskopf, T. M., and D. C. Bunde. 1972. Evaluation of environmental impact through a computer modeling process. pp. 107-125. In R. B. Ditton, and T. I. Goodale (eds.) Environmental impact analysis: philosophy and methods. Univ. of Wisconsin Sea Grant Program, Madison. 171 pp.

Krutilla, J. V. 1970. On the economics of preservation on development of the lower portion of the Hells Canyon: Hearings transcript. U.S. Federal Power Commission. Washington, D.C. March 13, 1970. pp. 5821-5885.

Leopold, L. B. 1971. A procedure for evaluating environmental impact. U.S. Geological Survey. Washington, D.C. Circular 645.

Lobdell, C. H. 1971. A deterministic model for evaluating long-term effects of wildlife management decisions on public benefits. Unpublished M.S. thesis, Virginia Polytechnic Institute and State University. 94 pp.

Lobdell, C. H. 1972. MAST: a budget allocation system for wildlife management. Unpublished Ph.D. dissertation. Virginia Polytechnic Institute and State University, Blacksburg, Virginia. 227 pp.

McHarg, I. L. 1969. Design with nature. Doubleday and Co., Inc. Garden City, New York. 197 pp.

Michener, H. 1928. Where engineer and ornithologist meet: transmission line troubles caused by birds. The Condor 30(3):169-175.

Moyseenko, H. P., D. F. Furney, R. E. Jenkins, and L. A. Miller. 1976. Lowest common denominator element file: an information management system. The Nature Conservancy. Washington, D.C. 100 pp.

Murray, T., P. Rogers, D. Sinton, C. Steinitz, R. Toth, and D. Way. 1971. Honey Hill: A system analysis for planning the multiple use of controlled water areas. Report to U.S. Army Engineer Institute for Water Resources. IWR71-9. The National Technical Information Service. AD736-343. 725 pp.

Nez, G. 1970. A composite mapping system for practical location research. U.S. Department of Commerce. Economic Development Admin. 31 pp. mimeo.

Niemann, B. J., Jr., and A. H. Miller. 1973. EDAP: environmental decision alignment process. Landscapes Limited. Madison, Wisconsin. 246 pp.

Niemann, B. J., Jr., and B. H. Murray. 1972. TIMELES: Transmission implementation and management of environmental location of energy systems. Aware 21:3-6.

Permar, D. H. 1971. A legal solution to the electric power crisis: controlling demand through regulation of advertising, promotion, and rate structure. Environmental Affairs 1(3):670-693.

Randall, W. E. 1973. Multiple use potential along power transmission rights of way. pp. 89-113. In R. Goodland (ed.). Power lines and the environment. The Cary Arboretum of the New York Botanical Gardens. Millbrook, New York. 170 pp.

Richards, N. A. 1973. Old field vegetation as an inhibitor of tree vegetation. pp. 78-88. In R. Goodland (ed.). Powerlines and the environment. The Cary Arboretum of the New York Botanical Gardens. Millbrook, New York. 170 pp.

Rose, P. H. 1970. Underground power transmission. Science 170:267-273.

Schall, H. R. 1972. Constraint maps - the newest tool in R/W selection. Transmission and Distribution. April, 1972. 6 pp.

Scherer, H. N., B. J. Ware, and C. H. Shih. 1972. Gaseous effluents due to EHV transmission line carona. IEEE Transaction Paper T72, 550-2:1-9.

Sharpnack, D. A., and G. Akin. 1969. An algorithm for computing slope and aspect from elevations. Photogrammetric Eng. 35:247-248.

Sibley, S. L. 1966. Case example - the economics of aesthetics: industry must take the initiative. Edison Electric Institute Bulletin 34(1):10-14.

Sinton, D., and C. Steintz. 1971. GRID Manual, version 3. Laboratory for Computer Graphics and Spatial Analysis. Harvard University, Cambridge, Massachusetts, 33 pp.

Snowden, D. P. 1972. Superconductors for power transmission. Scientific Amer. 226(4):84-91.

Statler, R. 1973. Preparing environmental impact statements. pp. 132-149. In R. Goodland (ed.). Powerlines and the environment. The Cary Arboretum of the New York Botanical Gardens. Millbrook, New York. 170 pp.

Strobl, K. C. 1973. Direct testimony and exhibits, Technical Associates, Inc. Part I-III SCC Case No. 11655. State Corporation Commission of Virginia. 68 pp.

Swanson, R. A. 1969. The land use and natural resource inventory of New York state. New York State Office of Planning Coordination, Albany. 20 pp.

Turban, E. and M. L. Metersky. 1971. Utility theory applied to multivariable system effectiveness evaluation. Management Sci. 17(12):817-828.

U.S. Department of Interior and Agriculture. 1971. Environmental criteria for electric transmission systems. U.S. Government Printing Office. Washington, D.C. 52 pp.

U.S. Federal Power Commission. 1971. The 1970 national power survey. U.S. Government Printing Office. Washington, D.C.

U.S. Federal Power Commission. n.d. Electric power transmission and the environment. U.S. Government Printing Office. Washington, D.C. 22 pp.

Voelker, A. H. 1973. Regional analysis data system. pp. 131-178. In Regional environmental analysis progress report, June 15, 1971 - June 15, 1972. ORNL-NSF-EP-12. Oak Ridge National Laboratory. 264 pp.

Von Bertalanffy, L. 1968. General system theory. George Braziller, Inc. New York. 289 pp.

Young, L. B. 1973. Power over people. Oxford University Press. New York. 216 pp.

Zieman, J. C., H. H. Shugart, G. A. Bramlet, A. Ike, J. R. Champlin, and E. P. Odum. 1971. Optimum pathway matrix analysis approach to the environmental decision making process. Testcase: relative impact of proposed highway alternatives. Institute of Ecology, University of Georgia, Athens. 31 pp.

APPENDICES

Appendix I. Virginia right of way routing system data parameters and codes.

1. Roads:

   0 = none
   1 = light duty
   2 = secondary
   3 = highway

2. Counties:

   FIPS code

3. Planning Districts:

   Virginia state code

4. Water Resources:

   0 = none
   1 = large streams and rivers
   2 = intermittent and small streams
   3 = ponds
   5 = sewage disposal
   6 = swamp
   7 = wooded marsh
   8 = submerged marsh
   9 = mangrove

5. Pre-existing Powerlines:

   0 = none
   1 = present

6. Other Existing Utilities:

   0 = none
   1 = railroad
   2 = pipeline
   3 = telephone cable
   4 = railroad and pipeline
   5 = railroad and telephone
   6 = pipeline and telephone
   7 = railroad, pipeline and telephone

Appendix I. Virginia right of way routing system data parameters and codes (continued).

---

7 and 8. Land Use and Ownership:

0 = miscellaneous
1 = National Park
2 = National Forest
3 = miscellaneous forested
4 = state-owned natural resources
5 = orchard
6 = airport (originally coded as a separate variable)
7 = agricultural field and pasture
8 = residential
9 = urban
10 = military and U.S. government installations

9. Federal Transmitter Zones (coded only for Mt. Storm to N. Anna line):

0 = none
1 = present

10. Elevation:

centroid cell elevation (to nearest 10 feet)

11. Slope:

1 = less than 5 degrees
2 = 5 to 15 degrees
3 = greater than 15 degrees

12. Aspect:

1 = north
2 = northeast
3 = east
4 = southeast
5 = south
6 = southwest
7 = west
8 = northwest
9 = ridge top
0 = bottom land

Appendix I. Virginia right of way routing system data parameters and codes (continued).

13. Soil Association:

decimal number aaa.bb
where: aaa = FIPS county code
bb = code on county soil map

14. Precipitation:

number of inches of annual rainfall

15. Historic Landmarks:

0 = none
1 = registered
2 = recommended
3 = potential

16. Recreation Resources:

decimal number aa.b
where: aa = code for resource type

b = 0 for existing facilities
2 for potential resources

Type codes:

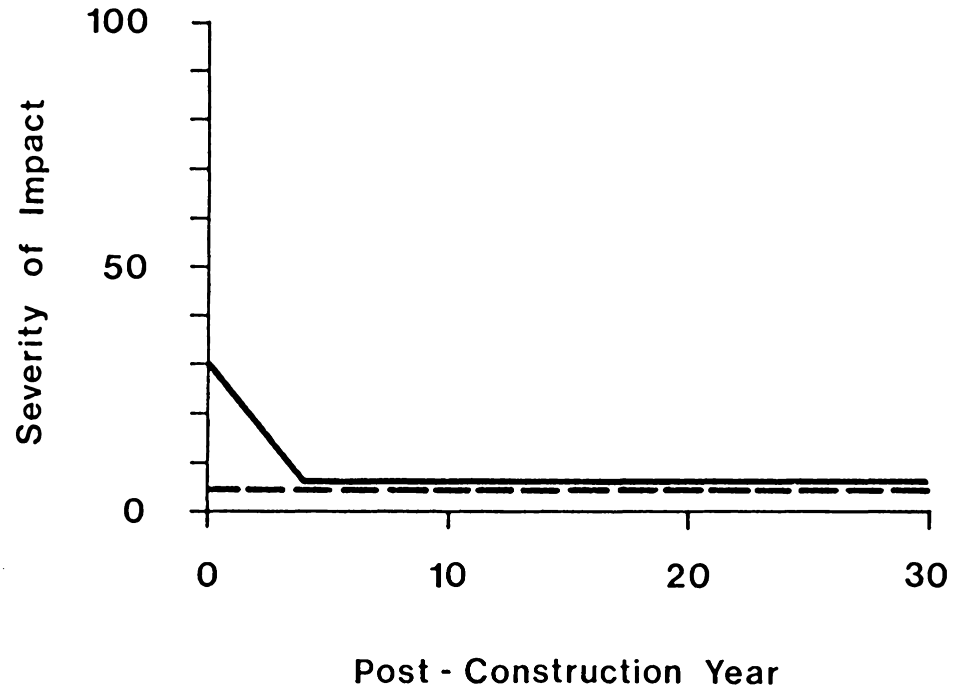
1 = public and semipublic parks and recreation areas
2 = public forests and natural areas
3 = private, noncommercial recreation areas
4 = commercial recreation areas
5 = scenic and other easements
6 = potential resources (miscellaneous)
9 = trails
10 = miscellaneous public lands
11 = boat landings
12 = beaches

17. Assessed Per Acre Land Values (collected by Technical Association, Incorporated, for Mt. Storm line):

dollar values

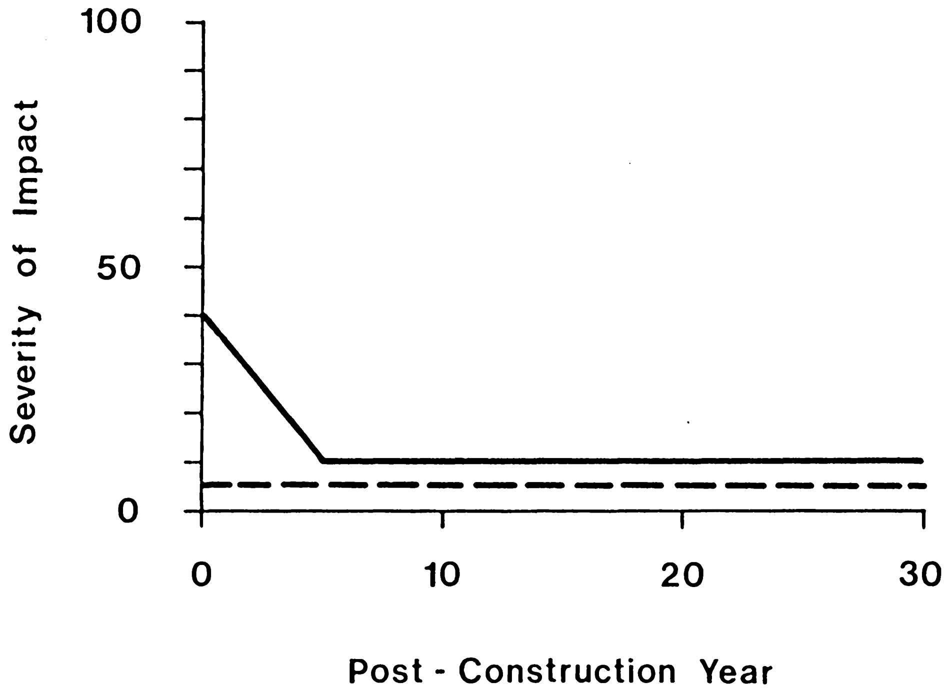
Appendix II. Impact functions formulated for use in the Virginia right of way routing system.

The contents of this appendix are graphic representations of the impact functions formulated by the investigator to portray the relationships between critical site characteristics and the probable, multidimensional impacts realized if right of way construction were to be undertaken. Each figure represents a functional relationship between one critical characteristic and one dimension of impact over time. The vertical axis is a relative scale of impact severity and the horizontal axis is a scale of time elapsed since right of way construction. The impact function for sites without pre-existing transmission facilities is shown as a solid line. If incremental impacts are likely on sites which are already occupied by such facilities, a dotted line is used to display this relationship. The contents of Tables 5 and 6 are the sums of the probable annual impacts for each combination of impact dimension and critical characteristic.



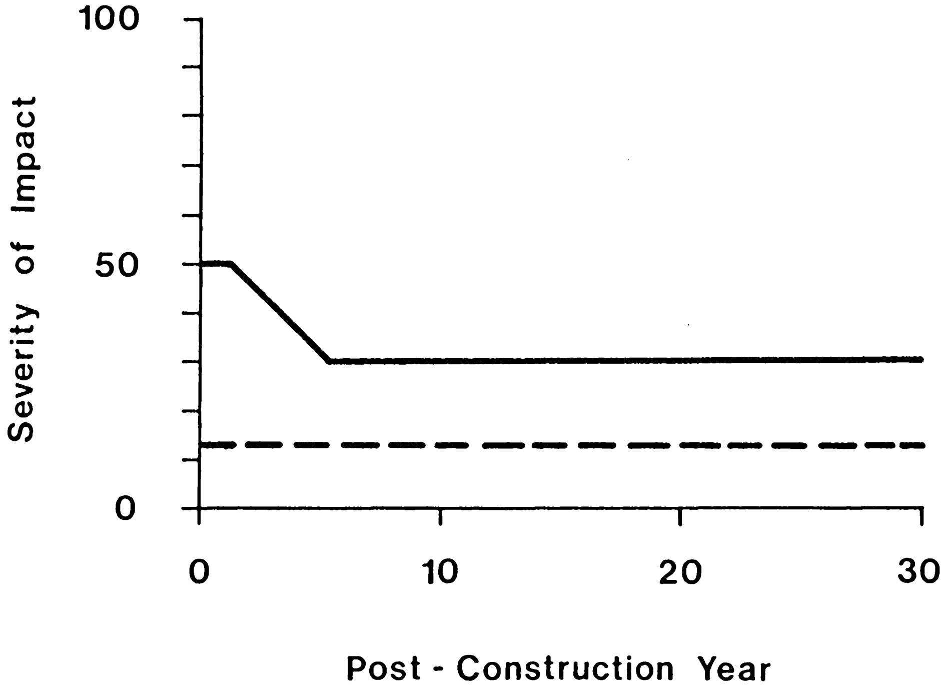
Impact Dimension : 3

Critical Characteristic : 6, 8



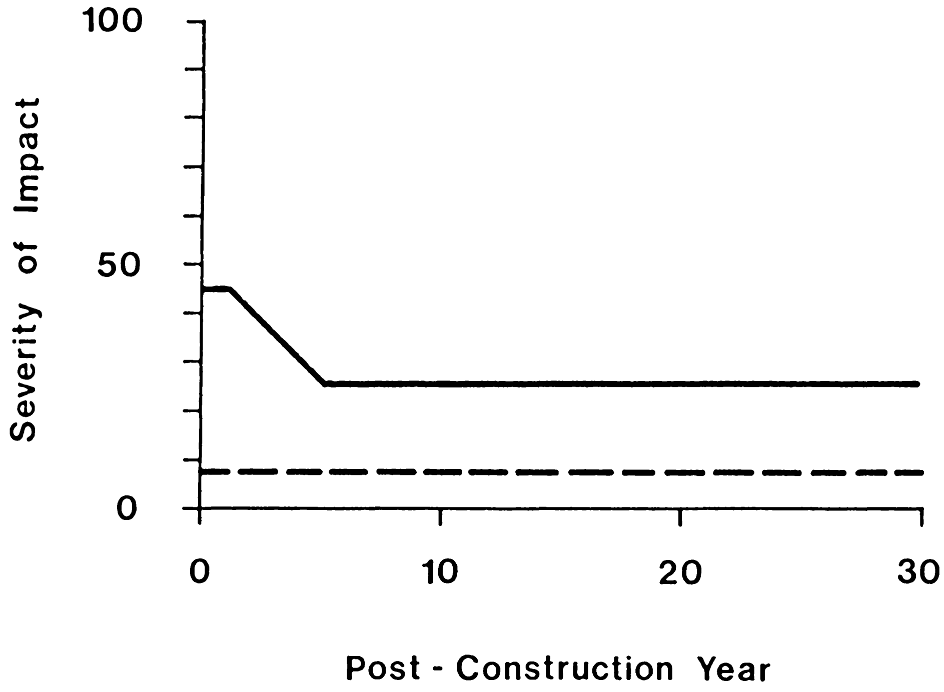
Impact Dimension : 3

Critical Characteristic : 7



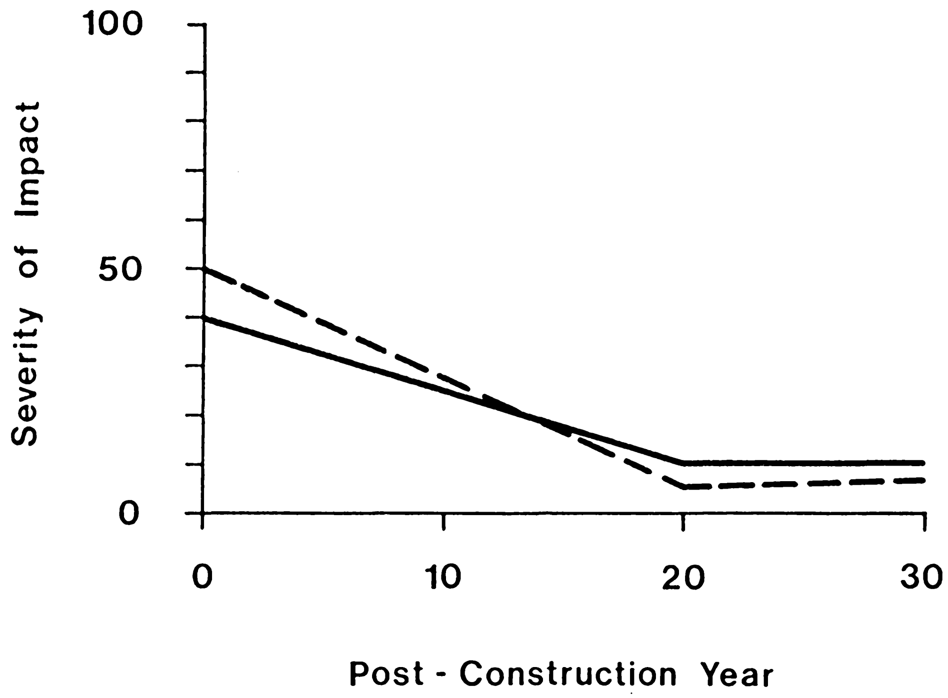
Impact Dimension : 3

Critical Characteristic : 9



Impact Dimension : 3

Critical Characteristic : 10, 11

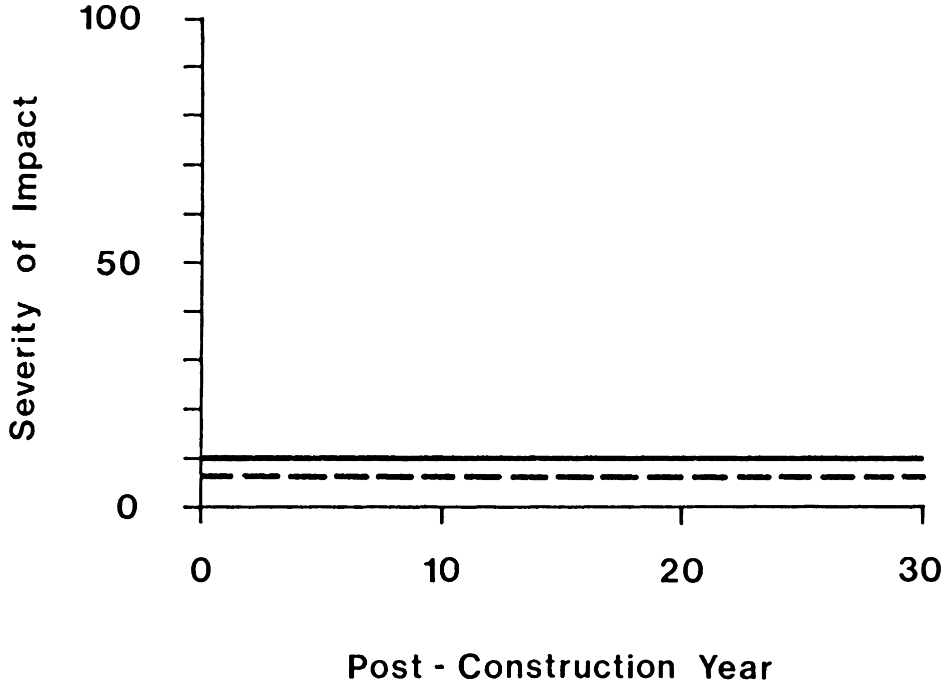


Impact Dimension : 3

Critical Characteristic : 17

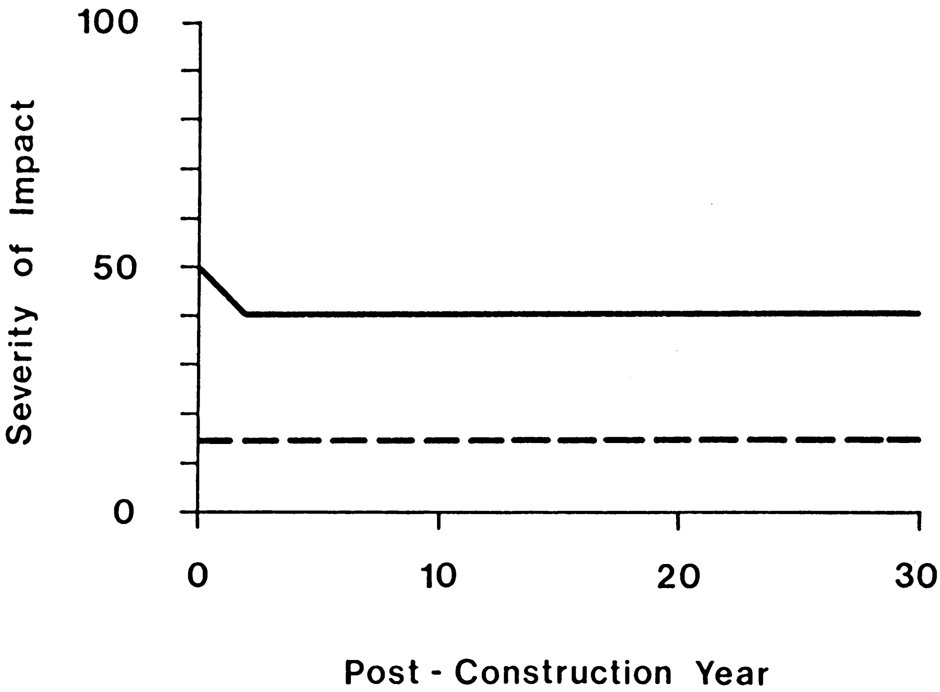
Impact Dimension : 3

Critical Characteristic : 37, 38, 39



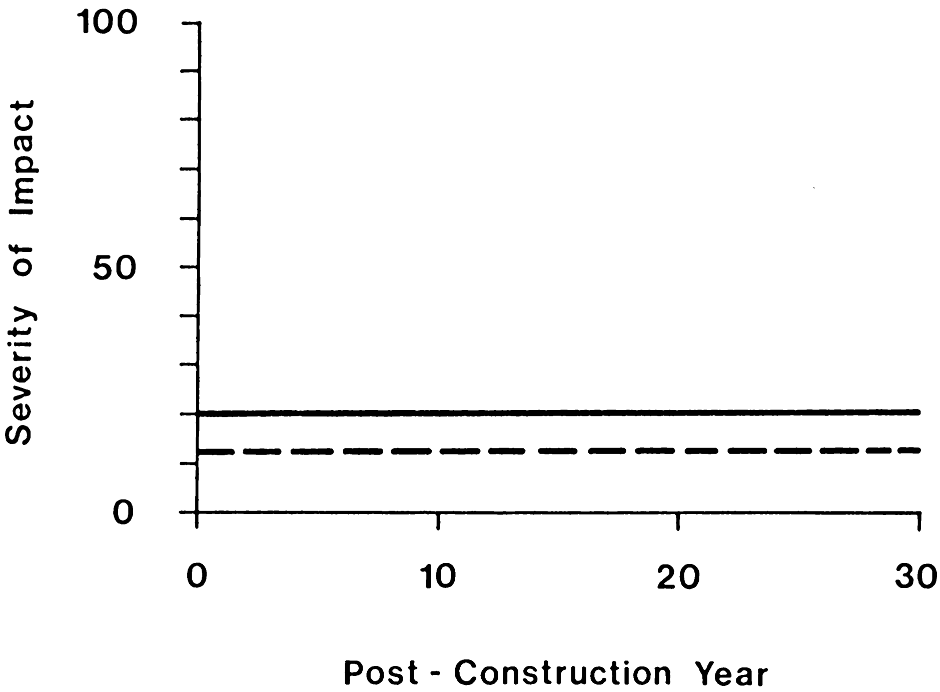
Impact Dimension : 3

Critical Characteristic : 40, 41



Impact Dimension : 4

Critical Characteristic : 6, 7, 8

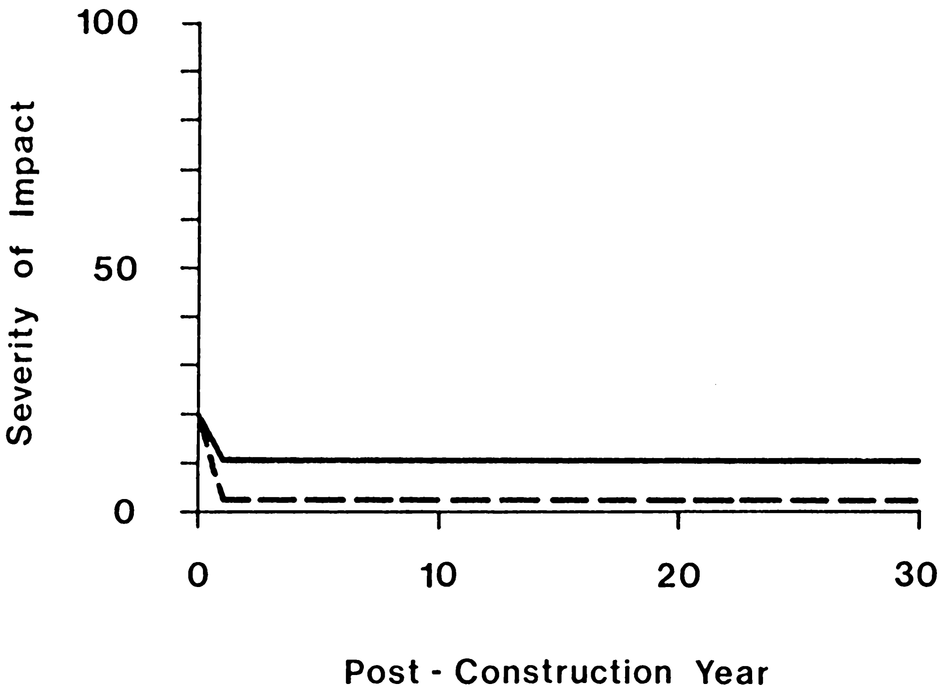


Impact Dimension : 4

Critical Characteristic : 9, 10

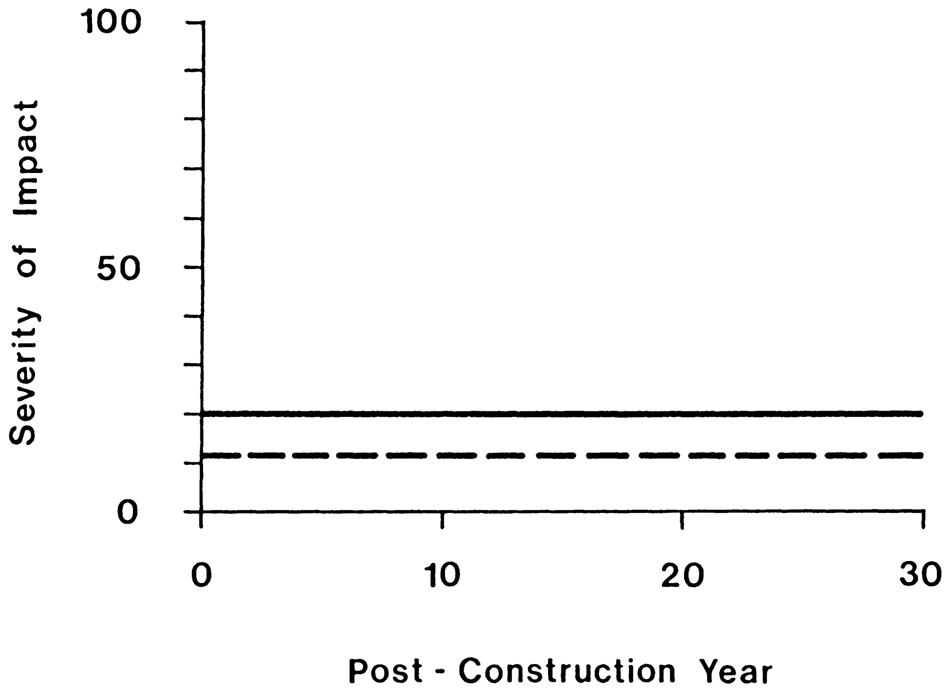
Impact Dimension : 4

Critical Characteristic : 42



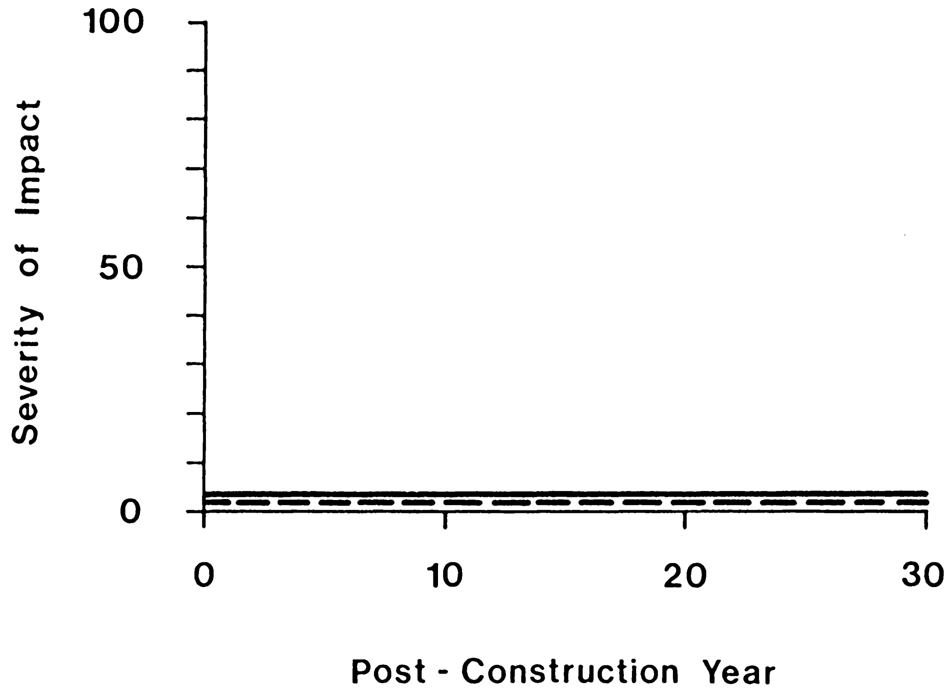
Impact Dimension : 5

Critical Characteristic : 3, 4, 5



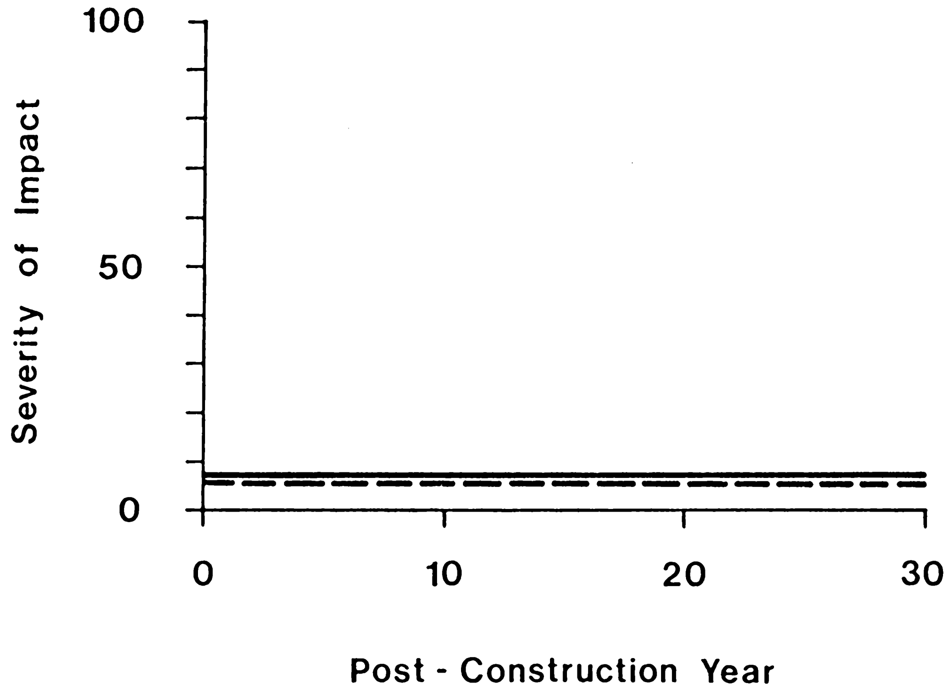
Impact Dimension : 5

Critical Characteristic : 6, 7, 8



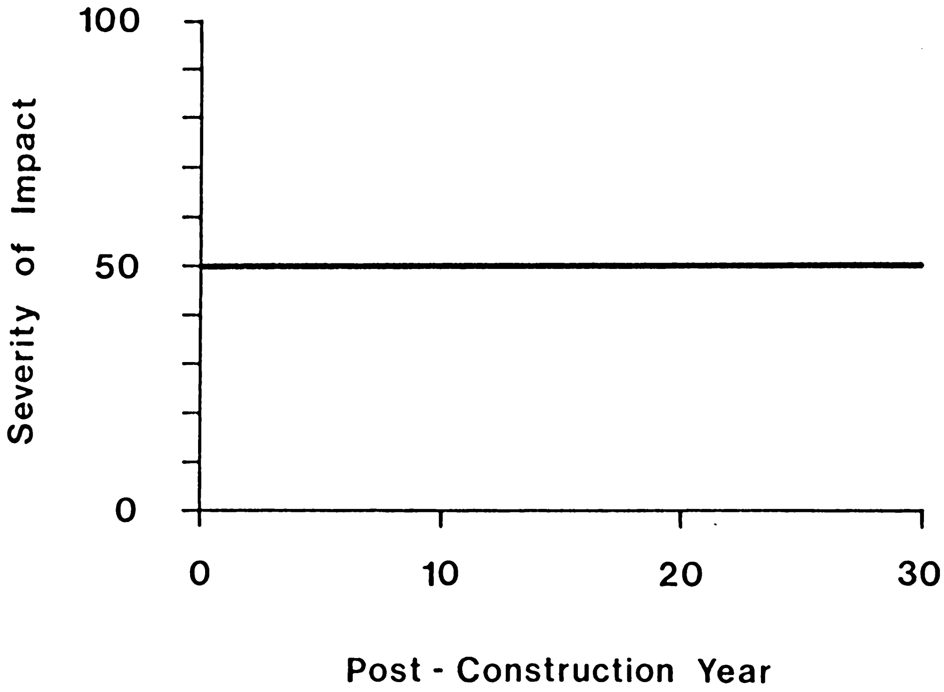
Impact Dimension : 5

Critical Characteristic : 16, 37, 38, 39



Impact Dimension : 5

Critical Characteristic : 17

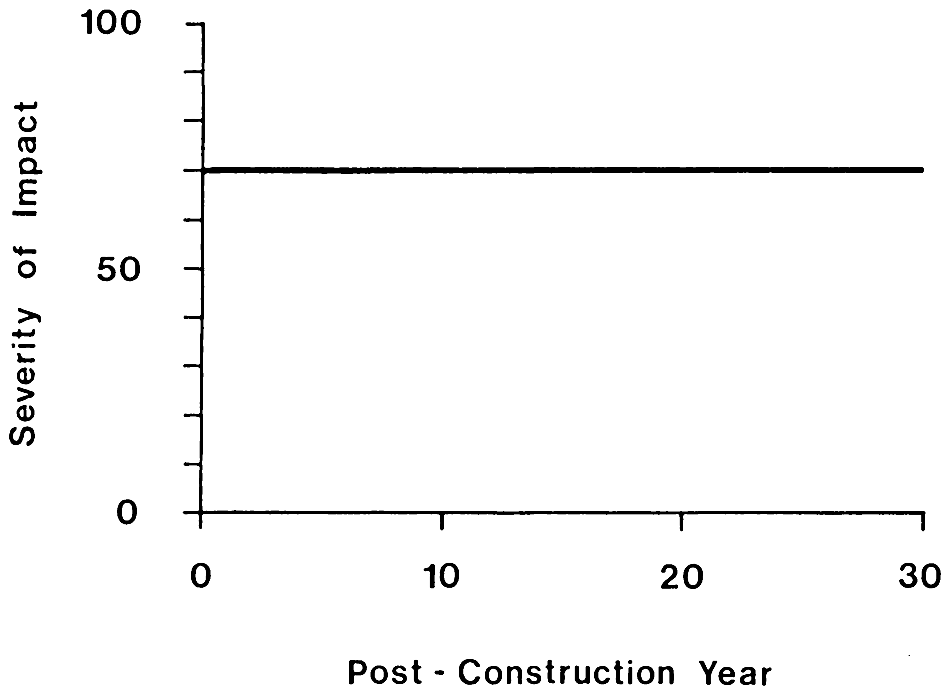


Impact Dimension : 6

Critical Characteristic : 21, 23, 25, 27, 31, 32, 33, 34, 36

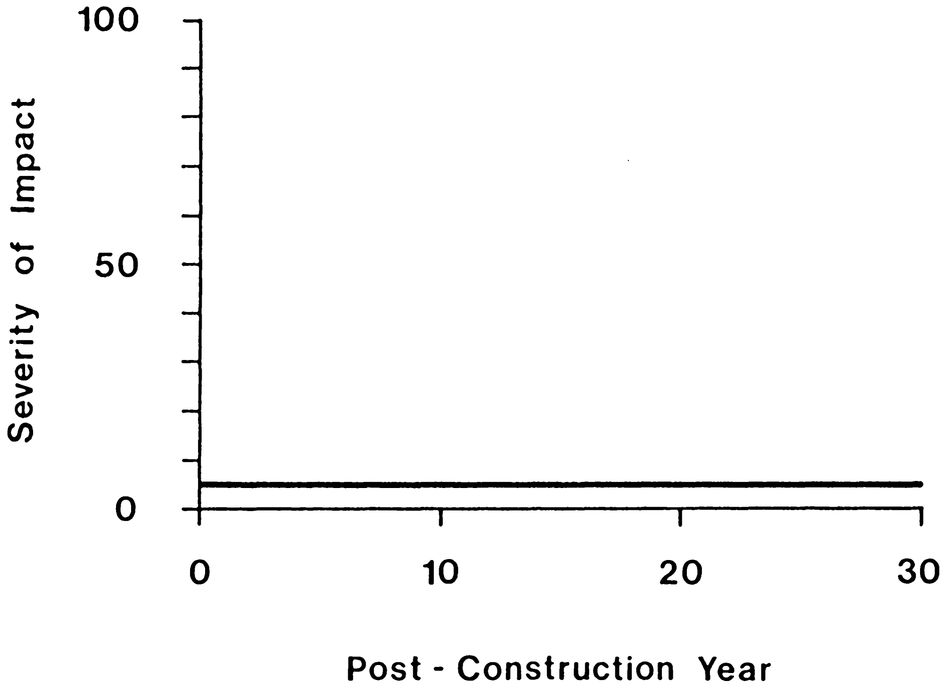
Impact Dimension : 6

Critical Characteristic : 22, 24, 29, 30



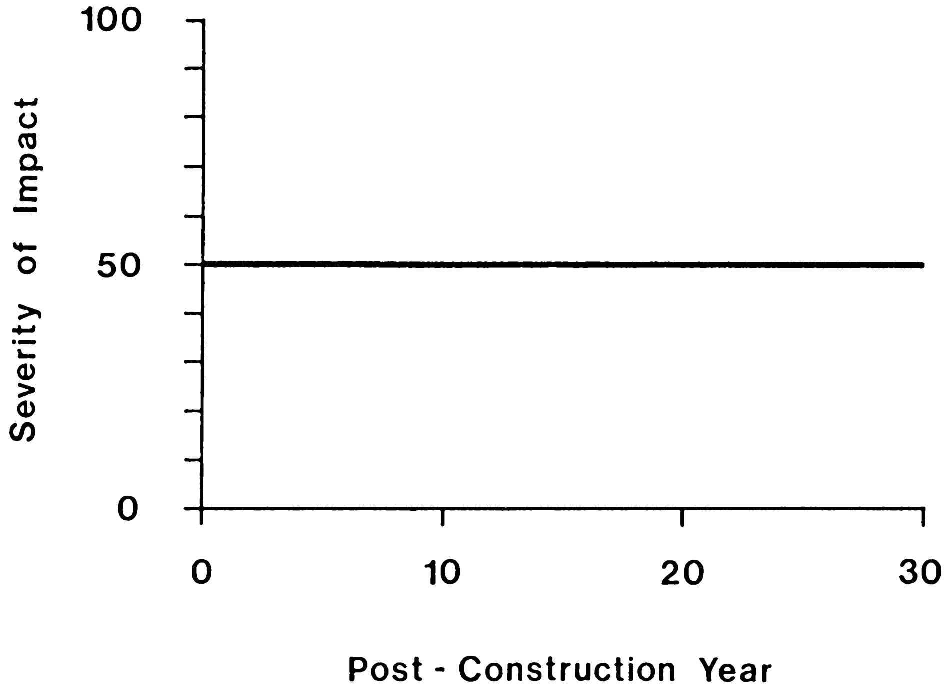
Impact Dimension : 6

Critical Characteristic : 35



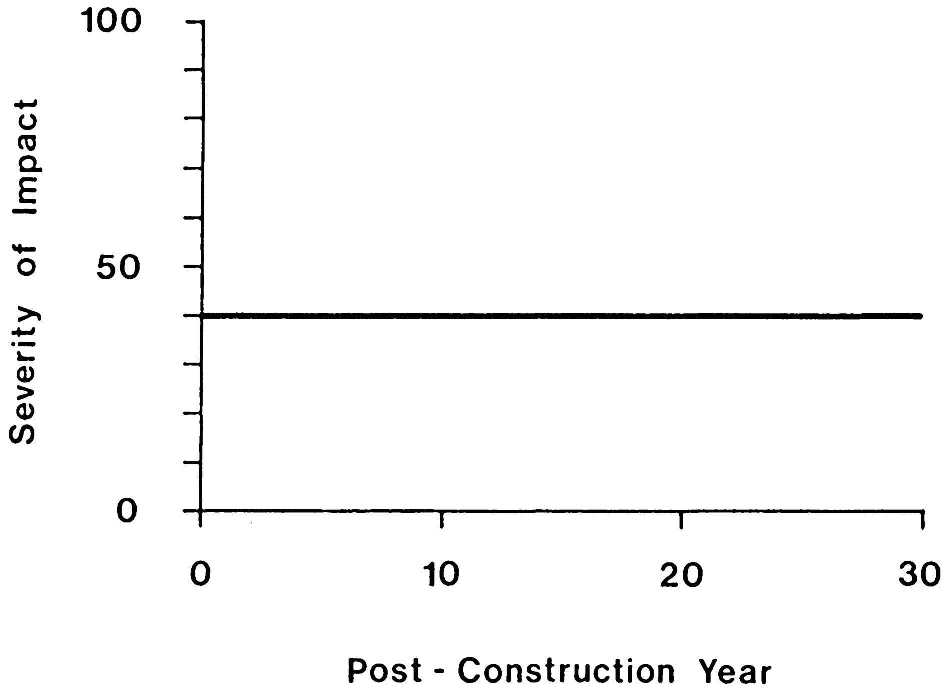
Impact Dimension : 6

Critical Characteristic : 26, 28



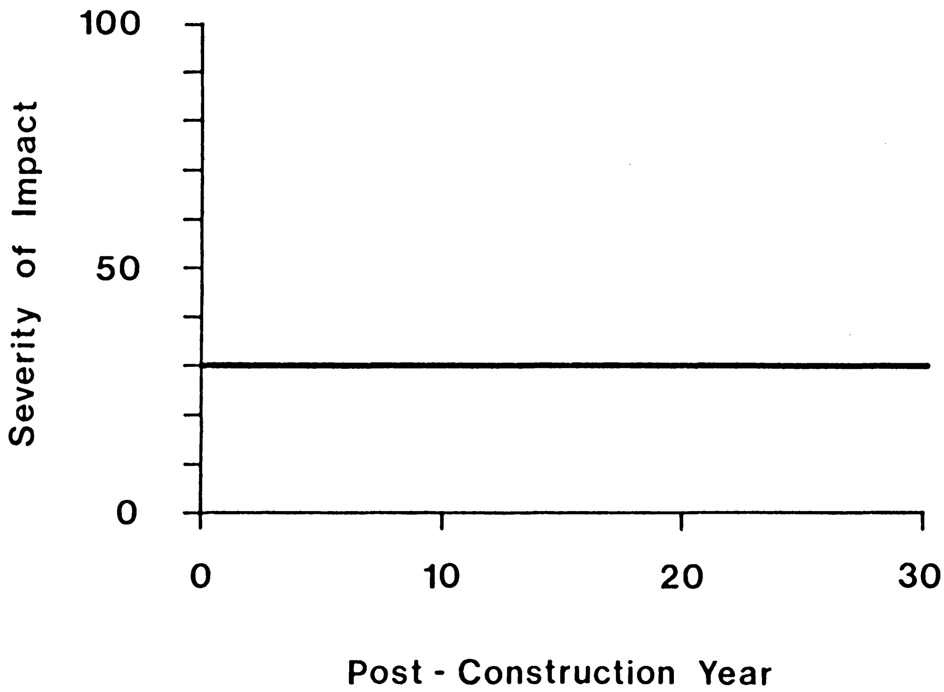
Impact Dimension : 7

Critical Characteristic : 18



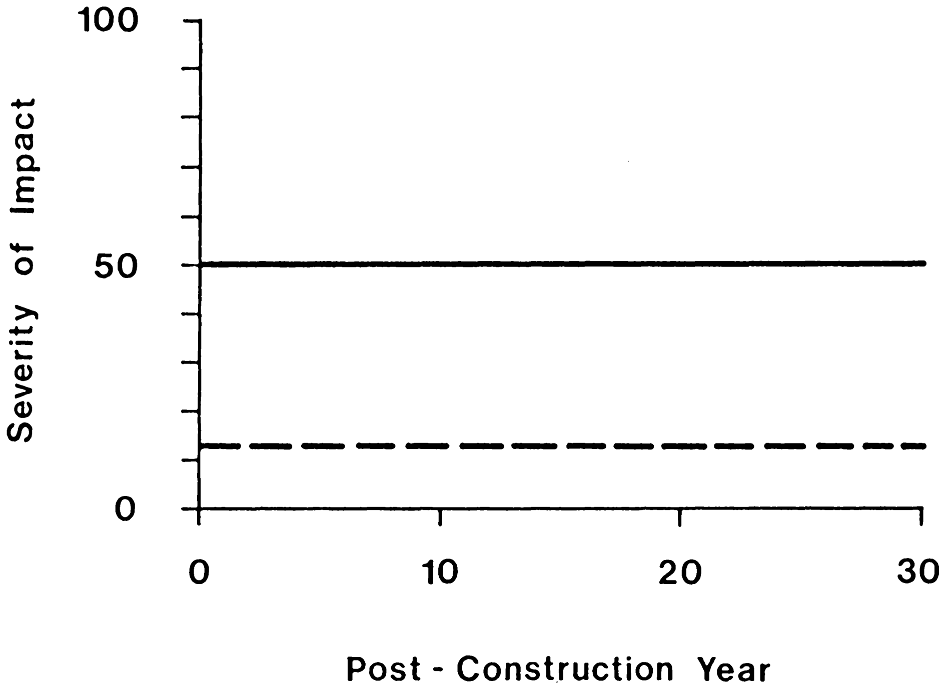
Impact Dimension : 7

Critical Characteristic : 19



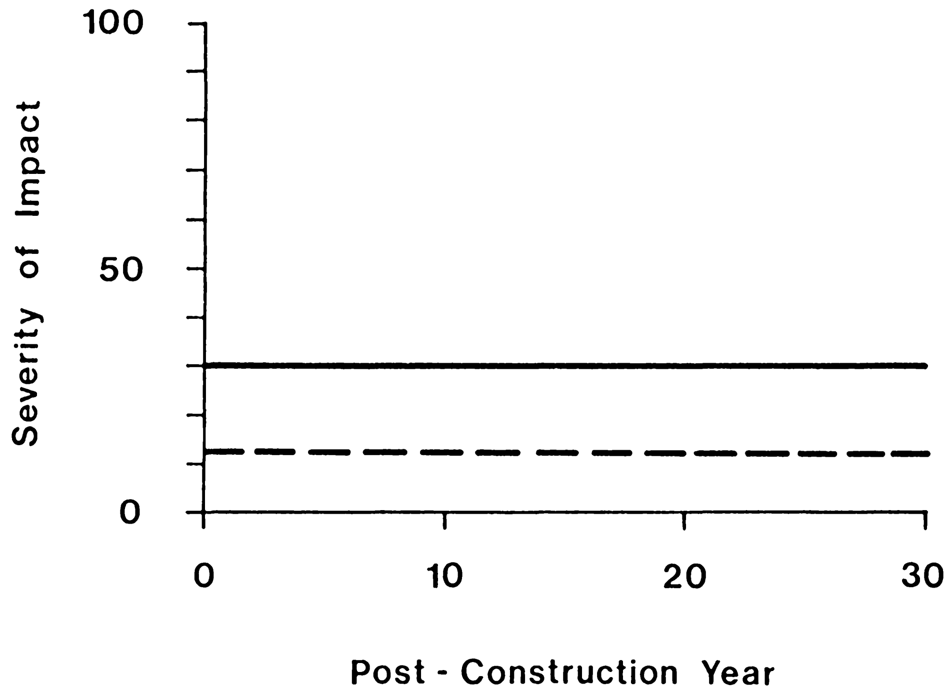
Impact Dimension : 7

Critical Characteristic : 20



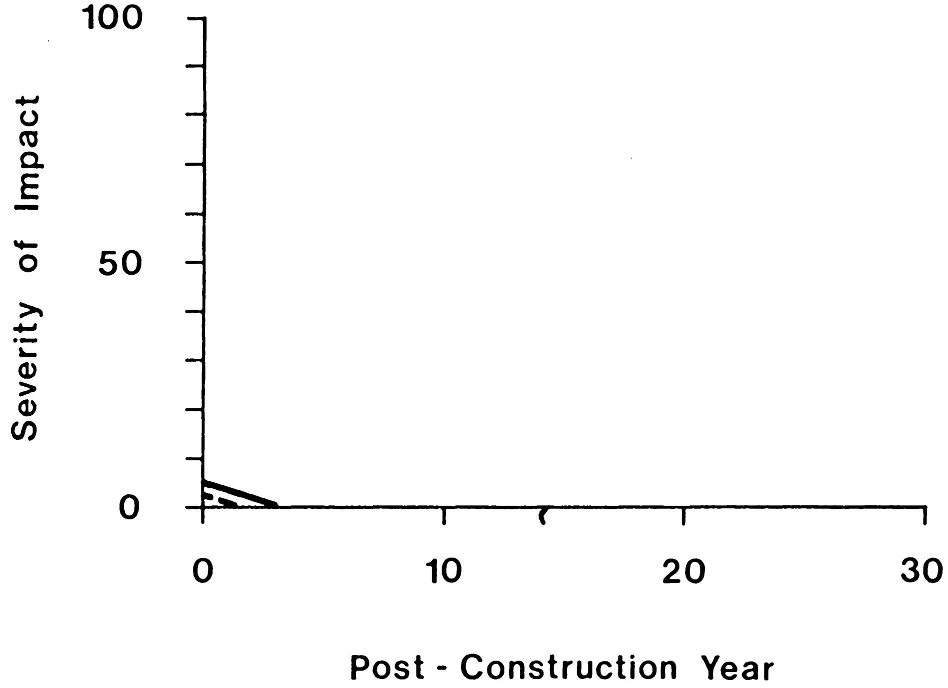
Impact Dimension : 8

Critical Characteristic : 14



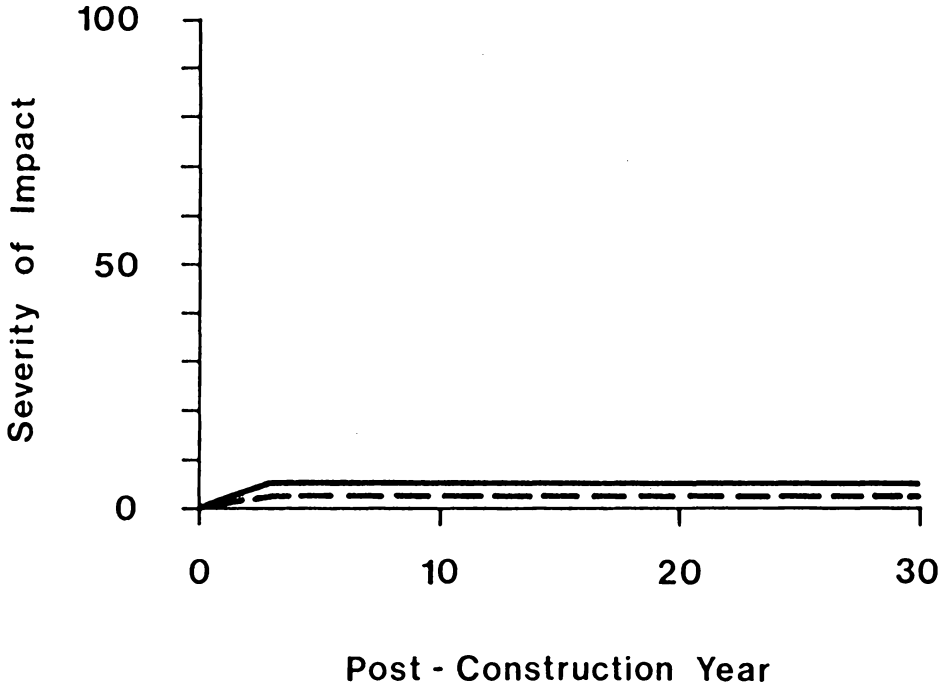
Impact Dimension : 8

Critical Characteristic : 15



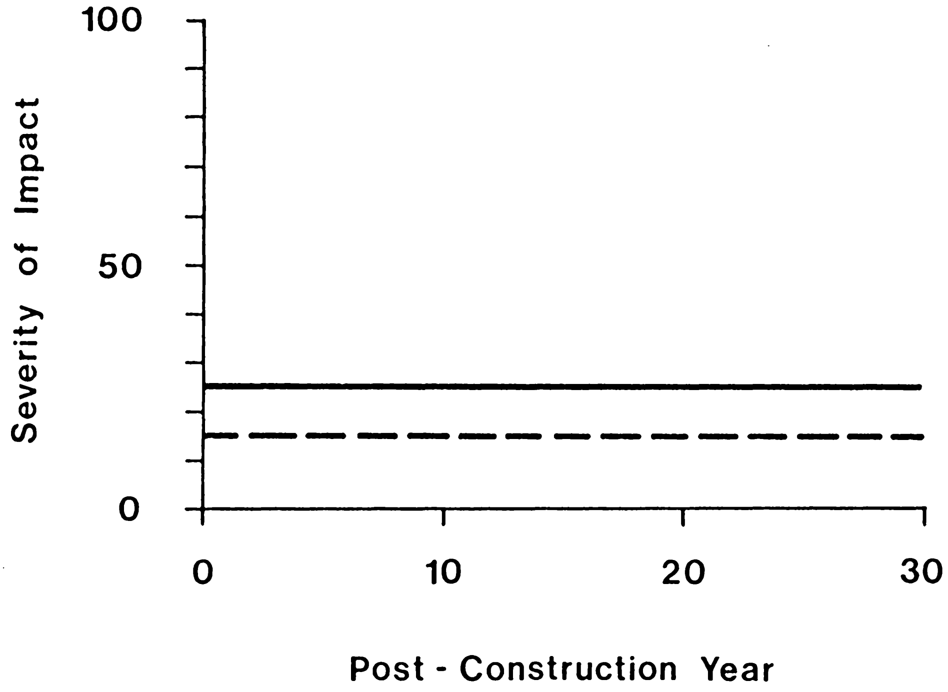
Impact Dimension : 9

Critical Characteristic : 12



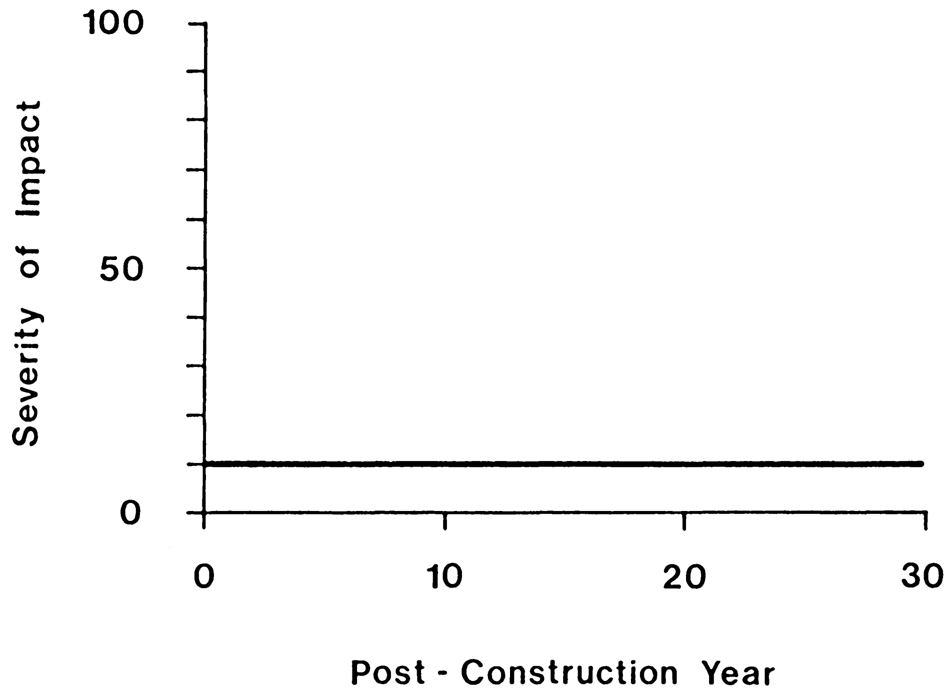
Impact Dimension : 9

Critical Characteristic : 13



Impact Dimension : 10

Critical Characteristic : 9, 10



Impact Dimension : 11, 12

Critical Characteristic : 15

The two page vita has been removed from the scanned document. Page 1 of 2

The two page vita has been removed from the scanned document. Page 2 of 2

A COMPUTER-ASSISTED SYSTEM FOR PLANNING MINIMUM IMPACT TRANSMISSION RIGHT OF WAY ROUTES

by

Charles Willard Smart

(ABSTRACT)

A computer-assisted system was developed as an aid in the process of planning and evaluating the impact of electric transmission rights of way. The system was designed to facilitate the objective analysis of proposed construction activities and to provide insights into the location of routes which tend to minimize the overall adverse impacts incurred by society.

The system includes a series of processes for acquiring regional information on economic, social and environmental site characteristics in a computer readable form. Procedures for the creation and maintenance of a computerized data base of this resource information were developed.

Two indices were formulated to relate the probable multidimensional impact of right of way construction to the physical characteristics of the associated site. The index of economic impact relates probable, discounted construction and maintenance costs to the topographic characteristics of any site. This basic cost may be incremented to make sites with critical environmental characateristics appear less attractive for right of way installation. The index of overall impact uses the subjective judgment of the decision maker and technical experts to

construct a single weighted measure of the probable multidimensional impacts which would result over time from construction activities on critical sites.

Computer programs were developed to evaluate the potential impact of any proposed right of way in tabular and cartographic form. A minimum flow search algorithm was programmed to facilitate the design of alternate routes which minimize total potential impacts.

A data base of 17 basic land characteristics was compiled for a 5,000 square mile study area in northern Virginia. The evaluative and design capabilities of the system were demonstrated in detail on a hypothetical right of way in an 80,000-acre subarea. The same techniques were then applied to the evaluation of a series of three industry-proposed rights of way totaling over 100 miles in length.