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ACCESS CORRIDOR SELECTION USING AN AUTOMATED
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THE SUSITNA HYDROELECTRIC PROJECT EXAMPLE

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ACCESS CORRIDOR SELECTION USING AN AUTOMATED GEOGRAPHIC INFORMATION SYSTEM: THE SUSITNA HYDROELECTRIC PROJECT EXAMPLE

By

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ABSTRACT

ACCESS CORRIDOR SELECTION USING AN AUTOMATED GEOGRAPHIC INFORMATION SYSTEM: THE SUSITNA HYDROELECTRIC PROJECT EXAMPLE

By

David Lowell Thomas

The objectives of this study were to devise a method for analyzing the relative desirability of three proposed access route corridors to the Susitna Hydroelectric Project's dam sites. An automated geographic information system was used to combine environmental, engineering, and economic factors within a computerized data base. The data base was inserted into the GIS which allowed the spatial georeferencing, analysis, and display of the data in a manner which facilitated the selection of the preferred access corridor.

The display of the data, in color photographs and with statistics, revealed that a combination of access corridors would allow the construction of an access route that avoided critical limiting areas within the Susitna River basin. It was concluded that the use of the GIS was adequate in satisfying the competing economic, environmental, and engineering concerns and provided an efficient, holistic approach that could be used to facilitate the decision process.

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CHAPTER I

INTRODUCTION, STATEMENT OF THE PROBLEM, AND HYPOTHESES

Introduction

The main objective of this study was to devise a method for analyzing the relative desirability of three proposed access route corridors to the Susitna Hydroelectric Project's dam sites. The project is scheduled to be constructed in a remote, inaccessible location in Southcentral Alaska. The adopted methodology utilized environmental, engineering, and economic variables within an automated geographic information system. It identified the access corridors that: 1) maximized the technical ease of construction, 2) minimized environmental impact, 3) minimized cost, and 4) accommodated socioeconomic preferences.

Alaska's Railbelt. The portion of Alaska consisting of Anchorage, Fairbanks, and the sparsely populated transportation corridor connecting them, is commonly called the "Railbelt." This area contains 70% of the state's population. The Railbelt's population is growing rapidly and demand for electrical power is expected to expand at an even greater rate. The electrical energy requirements in the Railbelt are forecasted to increase from 2,808 gigawatts hours (Gwh) in 1983 to 3,737 Gwh in 1990, 4,542 Gwh in 2000, and 5,858 Gwh in 2010.[1]

Power Supply Problems. Several additional potential electrical power sources for the Railbelt have been identified, including natural gas, coal, and the hydroelectric potential of the Susitna River. Natural gas currently generates 75% of the Railbelt's electrical demand. The natural gas sources under consideration include fields in Cook Inlet and on Alaska's North Slope. The Cook Inlet natural gas proven reserves are estimated to contain 3.5 trillion cubic feet. With the present demand for natural gas and estimates of future patterns of consumption, Cook Inlet gas reserves are forecasted to be depleted by 1998.[2] The North Slope gas reserve, which has yet to be exploited, is projected to cost twice that of the 1983 price for Cook Inlet gas. Furthermore, the transmission of the gas would require a substantial capital investment. Consequently, the North Slope generation scenario is not economically attractive and its reliability is considered questionable.[3]

Coal-fired electrical generation is another alternative for the Railbelt. Coal currently generates 13.5% of the electrical energy supplied to the Railbelt region. Three coal fields, the Nenana, Kuparuk, and the Beluga, contain 136 billion tons of coal - the majority of Alaska's coal deposits. However, only the Nenana and Beluga fields can be exploited on a large scale. The Kuparuk field is not considered a viable source for effective large scale production. Coal production in the Nenana field would have to double in order to support future electric power generation. The Beluga field, which currently is not developed, would be required to produce 5 to 10 million tons per year. This quantity would serve both export and domestic markets. However, the lack of infrastructure poses a major risk in developing a large scale Beluga mine. Furthermore, both the Nenana and Beluga coal fields involve serious environmental concerns. Potential problems include impacts on water and air resources, terrestrial and aquatic environments, and aesthetics. Furthermore, the cost associated with the expansion of the coal fields is expected to be high.[4]

In comparison with the alternative electrical power sources of natural gas and coal, the Susitna Project emerges as the most viable electrical generating source for the Railbelt. The project is estimated to have a positive benefit/cost ratio over a planning period of 1993-2050. This estimate indicates that the project will be economically viable. Consequently, it is planned that by the year 2020, the Susitna Hydroelectric Project will supply 80% of the Railbelt area's electricity requirements.[5]

The Susitna Hydroelectric Project. The Susitna River, after flowing for miles over the Copper River Plateau, is channeled through an area bounded by the Alaska Range to the north, and the Talkeetna Mountains to the south. At this point, the river surges through the narrow Devil Canyon. This portion of the river, which runs east to west, has several potential dam sites and was first identified as a possible hydroelectric power source in 1940. A study at that time focused on the lower portion of the river and resulted in a favorable feasibility report. However, the plan was eventually turned down by the Secretary of the Interior who cited detrimental impacts to fish and wildlife habitat. Nevertheless, his report identified the site as one of the several alternative sources for future Railbelt power.[6]

In 1972, the U.S. Bureau of Reclamation investigated the hydroelectric potential of the upper Susitna River and passed the design responsibility to the Army Corps of Engineers. In 1979, the Alaska Power Authority began to seek detailed proposals concerning the feasibility of a hydroelectric project and the current two-dam scheme emerged. This plan calls for two dams: one at Tsusena Creek (the Watana Dam), and one at Devil Canyon. These structures would create two immense reservoirs that would be 1/2 to 3/4 miles at their widest points and nearly 100 miles in total length. The large dams and companion reservoirs are planned to be constructed between 1985 and 2000.

Study Area

The upper Susitna River basin, a relatively roadless wilderness area, is situated midway between Alaska's two main population centers, Anchorage and Fairbanks. The Susitna River, Alaska's third largest river, has its origins in three immense glaciers. Hundreds of tributaries come together to form the swift flowing upper Susitna which winds 200 miles through largely uninhabited country. Visitors to the upper Susitna basin are mainly hunters, fishermen, and whitewater boating enthusiasts.[7] After traveling through its upper valley, the Susitna flows under the Alaska Railroad and the Parks Highway which form the major transportation corridor connecting Anchorage and Fairbanks. From this point, the river flows southward to its terminus at the Gulf of Alaska, not far from the expanding city of Anchorage (Figure 1). The upper Susitna River basin is a pristine subarctic environment. The diverse landscape consists of variable quality spruce forests in the lower protected valleys changing into shrub and tundra vegetation in the uplands. The region also contains many lakes and streams. The upper portion of the basin consists of broad, u-shaped valleys. Further downstream, the river becomes progressively more incised, culminating in the spectacular steep-walled Devil Canyon about 20 miles above the Parks Highway.

The climate is influenced primarily by the cool, dry air of Alaska's interior. As a result, the summer months are mild with light to moderate precipitation. The long and cold winter period, from September to May, is characteristically continental. The climate in the lower western extremity of the upper basin is modified by the marine climate of the Gulf of Alaska.

The soils of the upper Susitna River basin consist primarily of inceptisols and spodosols. Inceptisols are one of the most common soils in Alaska, characterized by poorly developed parent material and little or no horizon development. Inceptisols often include poorly drained soils underlain with permafrost.[8] In the Susitna basin, inceptisols are found in both lowland depressions (poorly drained histic pergelic cryaquepts), and upland elevations (pergelic cryaquepts).[9] Spodosols, another soil common to the upper Susitna basin, are found in forested areas and upland, well-drained areas.[10] Above 4,000 feet in elevation, rough terrain predominates with shallow, gravelly soils.[11]

The vegetation within the upper Susitna River basin is varied. The lowland areas bordering the Susitna River contain dense stands of spruce, poplar, and birch. Higher

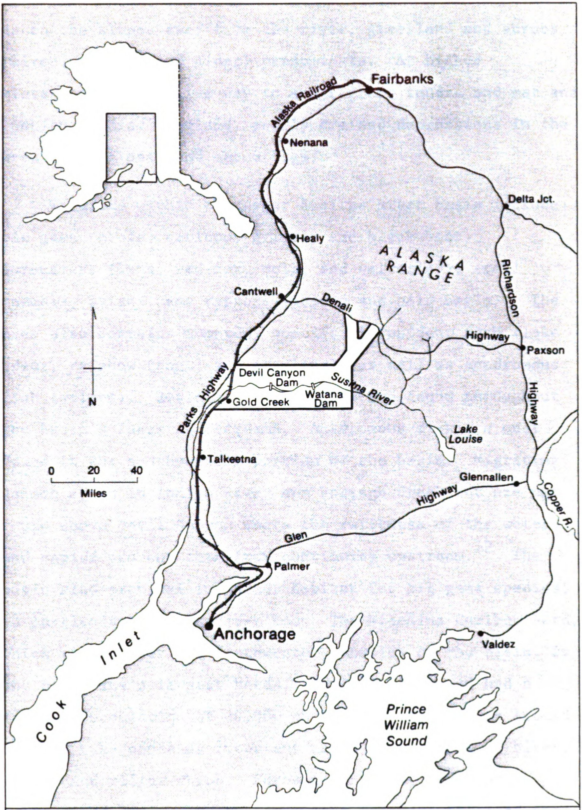

Figure 1. Regional Setting of Study Area.

up on the slopes away from the river, grassland and shrubs (birch, willow, and alder) predominate. At higher elevations, these give way to sedge grass tundra and mat and cushion tundra. Lowland, poorly drained depressions in the area contain peat and shrub bogs.

Wildlife within the upper Susitna River basin include: big game (moose, caribou, grizzly and black bear), furbearers (lynx, red fox, wolf, and wolverine), small mammals, avians, and raptors (golden and bald eagle). The area also contains numerous species of resident fish (lake trout, rainbow trout, and grayling), as well as anadromous fish (salmon). Resident fish species are found throughout the basin's lakes and streams. Anadromous fish are only found in the southwestern portion of the basin. Migrating salmon spawn in Indian River and Portage Creek but are not found above Devil Canyon where the swiftness of the water and rapids prevent them from continuing upstream.[12] The basin also provides important habitat for big game species, in particular moose and caribou. The Nelchina Caribou herd, which ranges over the northwestern portion of the basin, is one of Alaska's largest herds. In 1981, the herd had a reported population of 20,000 animals.[13] The region around Stephan Lake contains important moose browse such as birch, alder, and willow shrub. Furbearer, avian, and raptor habitat are located primarily in the forested areas of the river basin. Small mammals are found in the wetland areas near rivers and lakes.

Statement of the Problem

The proposed Susitna Hydroelectric Project will be located in an isolated, inaccessible area. Before construction of the dams can begin, an access route must be built to support the massive influx of materials and workers. Three access route corridors were identified in a previous investigation by the Alaska Power Authority (Figure 2). Each of the three corridors involves environmental, engineering, and economic limitations. A satisfactory method for selecting the best access corridor must consider all of these limitations in order to minimize construction impacts. Furthermore, the selection method must be cost-efficient to be of value for future land use management decisions.

Access. The proposed Susitna Hydroelectric Project presents many potential problems for geographic investigation due to its magnitude, isolation, and location in the pristine, subarctic environment of Interior Alaska. One problem involves the isolation of the project. The Susitna River Valley, in particular the location of the proposed Watana and Devil Canyon Dams, is located in an area between two widely separated roads, namely, the Parks Highway on the west which connects Anchorage and Fairbanks,

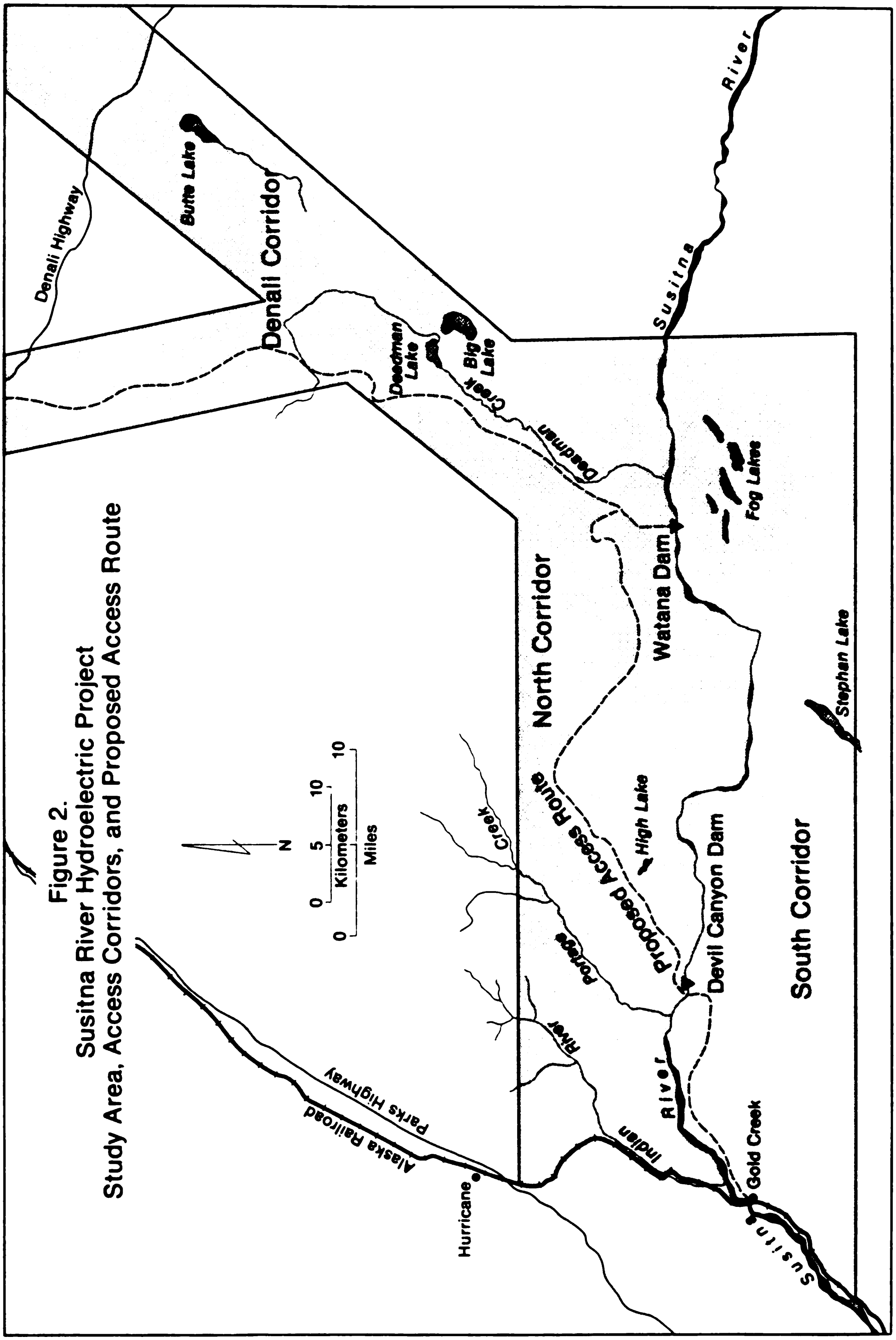

Figure 2.
Susitna River Hydroelectric Project
Study Area, Access Corridors, and Proposed Access Route

and the Denali Highway to the northeast, which connects the Richardson Highway and the Parks Highway. At present, there are no regularly maintained roads penetrating deeply into the region from either highway (Figure 1).

A major limiting factor to development of the Susitna River basin has been the lack of access. Inaccessibility has rendered it economically impractical to exploit the area's resources.[14] The area is not used for agriculture and has very little forestry and mining activity. Consequently, past and present land use in the area has been of extremely low intensity. The only significant land uses at the present are hunting, fishing, and wilderness cabin and small resort-based vacationing.

The construction of the Watana and Devil Canyon Dams will require a significant change in access to the upper Susitna River basin. The Watana Dam will require 350,000 tons of cement, 33,000 tons of reinforcing steel, and 16,000 tons of construction equipment. The Devil Canyon Dam will require 650,000 tons of cement, 22,000 tons of reinforcing steel, and 5,000 tons of construction equipment. The large amount of materials and equipment will require an estimated 108 truck loads per week for Watana and 132 truck loads for Devil Canyon. Furthermore, the construction activities related to the dams will require 4,500 people for Watana and 3,100 people for Devil Canyon.[15] An access route must be constructed to the dam sites in order to allow the transport of these construction materials and workers.

Project Schedule Constraints. Another feature of project access is the projected schedule of construction. R and M Consultants and the Alaska Power Authority base the project schedule on the estimated power requirements of the Railbelt. Their study shows that power from the Watana Dam will be required on line in 1993. A period of eight years is required to build the facility, thus requiring construction to begin in 1985. The Federal Energy Regulatory Commission license is expected in late 1984, necessitating mobilization of construction crews and equipment immediately thereafter.[16] It is estimated that a delay of the project by one year would result in an increase of cost by 100 to 200 million dollars.[17] Consequently, it is essential that a suitable access route to the dam sites be established as soon as possible.

The Proposed Access Corridors. Clearly, the problem of access to the Susitna Hydroelectric Project is an important issue that must be resolved early in the project planning process. The Alaska Power Authority initiated the access corridor analysis in 1980. At that time, three potential corridors were identified. The APA used general engineering criteria (maximum grade of 6%, maximum curvature of 5 degrees, and load factors for during and post construction), to determine three broad corridors. Within these corridors, the agency then identified 18 potential access routes. These were evaluated using the following specific criteria: 1) minimize environmental impact, 2) minimize total project costs and initial investment, 3) provide transportation flexibility in order to minimize costs and schedule risks, 4) provide for ease of operations and maintenance, 5) provide initial access within one year, and 6) accommodate native, local community, and public preferences. This process resulted in the selection of three preferred access corridors and a potential access route (Figure 2).[18] Two corridors, the North Corridor and the South Corridor, both enter the valley from the west via the Parks Highway. A third corridor, the Denali, connects the upper Susitna River with the Denali Highway to the northeast. The corridor finally selected will eventually contain a dirt, gravel, or asphalt access road which will provide both the Devil Canyon Dam and the Watana Dam with a transportation system to support the construction activities and schedule.[19]

The Previous APA Investigations. The APA analysis involved the consideration of engineering, environmental, and economic factors. All three of the proposed corridors involve numerous engineering problems. The area is essentially a subarctic environment consisting of permafrost, bog, tundra, and relatively poor drainage. Also, the corridors contain fragile fish and wildlife habitat such as streams containing anadromous fish and fragile raptor habitat. Economic problems shared by the three corridors consist of land acquisition costs, construction and logistic costs, and native, local community, and public preferences. The large size of the study area also complicates the analysis. The terrain to be evaluated for the access corridors is 8,208 square kilometers in area and contains 323 kilometers of river. Although only long, narrow corridors need be located, large areas must be analyzed in order to select the best and most economical routes.[20] Consequently, the analysis of access corridors has to consider large areas and requires a substantial investment of time and money.

The problem faced by the APA in selecting an access corridor was one of satisfying all interests. From an engineering standpoint, the Denali Corridor afforded the greatest ease in construction. From the environmental viewpoint, the North Corridor was a better choice. Economically, the Denali Corridor was less expensive but the majority of the Native Alaskan corporations (who own three-fourths of the land bordering the Susitna River), prefer access to their lands along the South Corridor. Consequently, the APA had to select an access corridor that provided the least obstacles for road construction, minimized environmental impact, was economically feasible, and also satisfied public preferences. The APA eventually selected a route that passed through the Denali Corridor and the South Corridor in 1983 (Figure 2), but concluded that due to these diverse considerations cited above, no route would satisfy all requirements.[21]

The APA analysis of the access corridors was lengthy and multi-faceted. The selection of the final corridor and access plan (a road from the Denali Highway to the Watana Dam site and a railroad from Gold Creek to the Devil Canyon Dam site) required three years and nine separate studies. Furthermore, the economic, environmental, and engineering analyses were all done by separate consultants. Consequently, the decision process was time consuming and costly.

Objectives

The Proposed Method. The objective of this thesis investigation was to develop a method of analyzing the proposed Susitna access corridors that would integrate the diverse factors investigated in the Alaska Power Authority studies in one study. The methodology that evolved utilizes an automated geographic information system and considers engineering factors (terrain units, slope, and land cover), environmental factors (wildlife habitat, land cover, and cultural resources), and economic factors (construction costs, land ownership, and socioeconomic preferences). The research employed the data supplied to the APA by the various consultants and agencies, and integrated them into one analysis. The goal was to simplify the decision making process and select the optimum corridor in a shorter time span with less cost. Furthermore, by integrating the data into one analysis, the final selection will better conform to the various economic, engineering, and environmental constraints.

The evaluation of potential transportation corridors has been a common problem for engineering projects. The task often proves to be difficult because several of the constraints involved may be in opposition, i.e., the least cost route may be the worst environmentally. Several methods have been used to determine the influence of the various factors involved in corridor selection. Basically, these methods consist of: 1) reducing the various factors to a common level (equal scale base maps), 2) establishing a relative ranking of each factor's components, and 3) developing a methodology for quantifying and displaying the data in order to compare the various factors.[22]

Geographic Information Systems. One of the most efficient means of achieving these goals is by means of a computer-assisted geographic information system (GIS). A GIS is a georeferenced system for the specification, acquisition, storage, retrieval, and analysis of data.[23] The georeferencing aspect of the GIS distinguishes the system from other information systems in that it enables the data to be referenced in a manner which permits retrieval, analysis, and display on spatial criteria. This allows the system, which consists of descriptive parameters such as points, lines, or grids, to describe accurately and systematically the geographical location of natural, cultural, or socioeconomic variables.[24] Consequently, an analysis of access corridors (which involves assessing environmental, engineering, and economic factors) can be facilitated using a GIS based method.

Analysis of the Susitna Hydroelectric Project access corridors was well suited to a computer-assisted GIS approach. The large size of the study area and data sets are easily incorporated within the GIS. Furthermore, the system can make rapid comparisons of two or more types of data in order to measure the extent of their limitations. Since the investigation of an entire corridor involves hundreds of square kilometers, this rapid analysis is highly beneficial to project planners.

Once the various data types are referenced to a common system (typically a base map), they are entered into the GIS. The computer then compares data sets (on the basis of specified criteria), produces new overlay combinations, and subsequently permits more ready assessment of the influence or interaction of the different variables.

The output of a computer-assisted GIS is also well suited to corridor analysis. Maps containing the original data types and combinations of transformed data types are produced in alphanumeric form on line printers, plotters, or CRTs. The maps, produced rapidly, can then be utilized by project planners and engineers for assessment of the corridors.

The number, form, and complexity of analyses possible with georeferenced data are virtually limitless. Furthermore, the flexibility of the computer-assisted geographic information system make it ideal for applications such as land capability/suitability analysis, environmental impact assessment, and particularly transportation route location.[25]

Summary of the Objectives. The objective of this research was to develop a method for access corridor selection that integrated all the factors involved in the APA study in one analysis. An analysis of this type, aided by a computer-assisted geographic information system, can incorporate diverse elements as well as "screen" the study area to identify potential limiting factors. The analysis eliminates much field work, reduces the length of time required for route selection, and is less costly. Furthermore, the methodology developed in this investigation must also identify the access corridor(s) that:
1) maximized the technical ease of construction (the

engineering preferred corridor), 2) minimized environmental impact (the environmentally preferred corridor), 3) minimized cost and accommodated socioeconomic preferences (the economically preferred corridor), and 4) represented the overall preferred corridor.

Hypotheses

The analysis and investigation of access corridors is characteristically geographic in nature. Evaluating the three proposed corridors includes the spatial aspects of the engineering, environmental, and economic factors. Geography provides for the inclusion of a variety of fields. Thus, geography deals not only with natural features of the earth and their distribution, but also with climate and people. As Navas pointed out:

> "To cover a wide range of fields, the geographer has turned into a generalist in order to interpret the specialists' contributions. Or, from another point of view, he has become an expert exercising the very important function of interpreting the closely associated fields of geology, physiography, mineralology, climatology, plant geography, and many other sectors of the physical base of geography, while at the same time being a student of history, economics, sociology, even finance."[26]

The analysis of access corridors requires the synthesis of a variety of elements. All three of the proposed access corridors share similar conditions: a fragile subarctic environment, valuable wildlife habitat, and similar economic-socioeconomic factors. Geographic analysis allows the combination of these elements into a more holistic approach.

The following general hypothesis was tested in order to investigate the ability of the proposed method to accurately evaluate access corridors and satisfy competing interests.

- The proposed computer-assisted GIS method of analysis of the Susitna access corridors will incorporate all competing environmental, engineering, and economic constraints in one study. In so doing, the methodology will provide a more efficient (less time and cost), holistic approach to access corridor selection than the previous APA studies.

In addition to the general hypothesis, three specific and testable sub-hypotheses were set forth:

1. The use of the GIS for access corridor location for the Susitna Hydroelectric Project will readily identify:
   - The economically preferred corridor.
   - The environmentally preferred corridor.
   - The engineering preferred corridor.
   - The overall preferred corridor.

2. The use of a GIS for access corridor location will provide output that will display the study area, the

problem, and the various solutions in a manner that will facilitate the decision process.

3. The use of a GIS for access corridor location will be less costly and less time consuming in comparison to the previous APA analysis.

The sub-hypotheses were tested in order to establish the validity of the main hypothesis. Because of the nature of the hypotheses, the "tests" were comparative rather than analytical. It is postulated that if these tests produced results that supported the sub-hypotheses, then the proposed method for analyzing the Susitna Hydroelectric Project access corridors could be considered:

- An analysis that incorporates all competing economic, environmental, and engineering constraints in one study.

- An analysis that provides a more efficient and holistic approach capable of an accurate and comprehensive corridor evaluation in less time and with less cost than the previous APA investigation.

CHAPTER II

LITERATURE REVIEW

Introduction

A literature review shows that few studies have used a geographic information system to address the problem of access corridor location. However, much research has been done on highway location analysis, geographic information systems, highway construction and design, and also on the environmental aspects of road construction. Many studies have also examined the role of remote sensing techniques in road corridor location.

The use of a GIS in the analysis of the proposed Susitna access corridors requires the quantification of economic, environmental, and engineering criteria. In order to assign relative weights or importance to these criteria, literature was reviewed which involved highway construction impacts on northern environments and their economic and engineering implications. By establishing these impacts, the assignment of relative importance to criteria within the analysis was a more objective process.

The majority of the literature reviewed for this investigation was outside the field of geography. A great many of the previous studies were in the field of engineering, geology, and remote sensing. However, as Navas pointed out, the geographer has become a generalist, interpreting closely related fields.[27] Consequently, the geographer is interested in the spatial aspects of engineering, environmental, and economic factors. The literature review for a geographic analysis of the Susitna access corridors must therefore consider these closely related fields.

Access Corridor Selection

Much of the related literature deals with the problem of access corridor selection. Rasmussen et al. (1980) investigated a computer-assisted approach to selecting forest roads locations. Geographic techniques were used to store, analyze, and display economic and aesthetic criteria in order to develop a better planning method. The resulting analysis included environmental constraints that previously were left out of the planning process. Their research is one of several that deals with the problem of combining physical and economic constraints with the various components of the ecosystem.

Perhaps one of the earliest applications of computer-assisted analysis in highway location was by Roberts and Suhrbier (1962). Their investigation incorporated a digital terrain model for the preliminary location of a highway. The objective of the model was to produce a graphic representation of certain design constraints that could be utilized by engineers.

Frazier et al. (1979) also used computer planning techniques for corridor selection. The study concentrated on procedures for subjectively weighting various criteria involved in routing a corridor through agricultural areas. They concluded that even though the weightings were subjective, they represented the various interests involved in corridor selection and allowed an adequate numerical emphasis. The study suggested that, if evaluated simultaneously, this type of data could be used effectively to make regional planning decisions. Consequently, they concluded that computer planning techniques provided the tools necessary to handle the large volume of data needed to solve complex land use problems.

Several studies examine the problem of highway corridor location with conventional, non-computerized techniques. Parker (1977) dealt with fundamental route location problems and their implications for engineering. Hufstader (1979) examined the use of criteria to determine an environmentally acceptable corridor for a power transmission line. Hufstader's analysis involved the mapping of alternative corridors on a constraints map in order to avoid non-compatible areas. Colwell (1983) provided an overview of the general analysis and evaluation of the factors involved in route selection. He outlined the methodology commonly used in corridor selection and highway planning. McHarq (1969) applied a method of overlaying engineering, natural and social values, and life threatening criteria (flood susceptibility), in order to select an alternative highway route. McHarq manually overlaid the resulting maps in order to illustrate an optimum alignment.

Schroeder and Daniel (1980) also utilized overlay mapping techniques in their investigation of the scenic quality of forest road corridors. Their study incorporated economic, engineering, and environmental factors in a method for determining road location and design. The analysis involved overlay mapping techniques that combined environmental sensitivity, terrain suitability, and economic costs. The final composite map represented a weighted sum of the individual variables, and displayed the overall desirability of each point in the area for road construction.

Geographic Information Systems

Many studies explore the utility of geographic information systems. However, few specifically examine the role of GIS in access corridor selection. One study, undertaken by the Environmental Systems Research Institute (ESRI 1981), utilized an automated geographic information system to conduct a systematic land capability/suitability analysis for a subbasin of the lower Susitna River. The area, the Willow subbasin, is south of the area that contains the proposed Susitna Hydroelectric Project. ESRI designed a GIS to compile land resource inventory data. The method facilitated selection of land for timber harvest, agriculture, mining, and urban/rural residential development. It also included transportation corridors and critical areas such as wetlands, ecological hazards, and fragile wildlife habitat. The methodology utilized by ESRI consisted of creating a stable base for all data types (mylar base maps), entering the data into a GIS utilizing this common base, and developing computer models which used ranked, prioritized factors to produce capability/ suitability overlay maps.

Several studies have investigated the potential of a geographic information system for a variety of planning applications. Wood and Beck (1982) illustrated the use of a GIS for land use planning in Colusa County, California. Baxter et al. (1982) described the use of a GIS by the Tennessee Valley Authority in a land use analysis system. Three other studies, McFarland (1982), Tomlinson (1968), and Colwell (1983), investigated the utility of geographic data bases for natural resource planning and regional development. Anderson and Beavers (1976) investigated the potential of a reconnaissance level GIS for identifying natural resource critical areas. Their study developed a method of identifying geographic areas which contained natural resource characteristics such as geologic hazards (degree of slope, erosion rate, etc.). Their methodology consisted of mapping various criteria on a reconnaissance level and inserting the data into a computer based land information system. The goal of their study was to identify potential critical areas by "screening" a large area utilizing general resource data in a GIS.

Several studies investigate the effectiveness of the GIS and the quality of the final products produced. Mead (1982) assessed the data quality in geographic information systems. Mead concluded that data quality depends not only on accuracy and precision but also is related to the usability and versatility of the data. Mooneyhan (1982) investigated the overall effectiveness of geographically based information systems for resource management. He concluded that if natural resource information is readily accessible in a GIS, resource managers would have the ability to make better and more timely decisions. Furthermore, Mooneyhan concluded that geo-based data can be used by numerous individuals and agencies for a variety of purposes without being re-entered into the GIS. This feature minimizes cost and facilitates updating the data.

Two studies which provide general descriptions of geographic information systems are Lillesand and Kiefer (1979), and Campbell (1982). Lillesand and Kiefer discuss the development of land information systems and the methodology involved in developing a GIS. Campbell provides a training module for a GIS which includes data management systems, spatial data handling, and remotely sensed data.

Environmental Aspects of Road Construction

Two studies were reviewed that investigated the impact of transportation routes on wildlife. Horejsi (1981) examined the behavioral response of barren ground caribou to moving vehicles. His study determined that abrupt changes in the physical environment can act as behavioral and ecological barriers. Horejsi reported that caribou exhibited signs of fear and anxiety when encountering a moving vehicle and that 88% of the animals encountered ran away. Wolfe (1978) investigated the impacts of habitat changes due to road construction. Wolfe found that road construction has both positive and negative implications for big game. Forest road systems can have positive impacts by facilitating movement of big game to grazing areas created by logging. However, the increased access provided by the roads to vehicles increases the vulnerability of game to hunting pressure. Wolfe concluded that the more negative impacts of road construction on big game habitat included effects on migration routes, the separation and isolation of contiguous habitats, and more ready access to remote natural areas by recreationists.

Sparrow et al. (1978) investigated the effects of off-road vehicle traffic on soils and vegetation in the region around the Denali Highway. Part of this region includes the Denali access corridor for the Susitna Hydroelectric Project. The area around the Denali Highway is popular among recreation participants. They found that the tundra environment was extremely sensitive to disturbances because of low temperatures, short growing seasons, and a lack of species diversity. Surface damage in an environment of this type may take a considerable amount of time to re-vegetate and scars can last as long as 25-30 years. The study found that the impact from vehicle traffic is dependent on certain soil and terrain characteristics. The most important factors influencing long-term impact on soils are soil depth, drainage, slope, vegetation type, and the amount of use. The study concluded that the most disturbed regions were wet areas composed of moss and organic materials. It recommended that routes avoid wet areas, boggy areas, and areas with highly erodible soils in order to minimize damage.

Engineering Aspects of Road Construction

A considerable amount of research has been done on highway construction and engineering. However, because the study area is located in a subarctic environment, the literature reviewed for the thesis concentrated on studies in northern regions similar to Alaska. Many investigations deal with highway design in northern climates. Baker and Johnston (1981) studied cold regions earthwork and concluded that careful preplanning of earthwork operations in permafrost areas was essential, particularly for large-scale operations. Their research also indicated that the selection of methods, suitable equipment, time of year, and scheduling of the work, are the most important variables in northern road construction. Boyd et al. (1981) investigated several basic considerations of northern engineering. They found that permafrost problems are basically the same, regardless of what type of project is undertaken. In particular, removal of ground cover in tundra areas can cause uncontrolled permafrost degradation and erosion. Drainage is also of special importance in permafrost areas, where the frozen ground acts as an impermeable barrier to surface water. This can result in extensive surface water accumulation during the summer months. The study concluded that a significant amount of time is required during construction to mitigate permafrost problems.

Two studies deal specifically with permafrost and highway engineering. Brown et al. (1981) studied terrain characteristics and their effects on permafrost distribution. They concluded that four terrain factors influence permafrost location: relief, vegetation, snow cover, and water. The study also showed that any human lowering of the permafrost table in areas of frozen soil could result in a thermokarst topography of depressions, solifluction, and landslides. Johnston et al. (1981) also studied the engineering characteristics of frozen and thawing soils. Their study identified problems related to the strength and deformation behavior of frozen soils, settlement of thawing soils, and heave of frozen soils. They found that the behavior of frozen soils under a load was quite different from that of unfrozen soils because of the presence of ice and unfrozen water. Their study concluded that many of the problems caused by frozen soils depend greatly on the soil particle size. Silt and clay silts are the most susceptible to frost action and can give rise to large thaw settlements while sands and gravelly sands are somewhat less affected.

Three studies involving highway construction materials were reviewed. Krebbs and Walker (1971) provided a good overview of the soil types necessary for the foundations and subgrade of roads. Their study also investigated soil drainage characteristics and their implications for road construction. Oglesby (1975) provided a summary of the basic engineering practices in road construction including preliminary reconnaissance, highway design, and surveying. Argue et al. (1981) and Wallace and Williams (1974) provided summaries of northern construction practices for roads, railroads, and airport runways. Both studies focused on design problems associated with permafrost.

A large body of literature has been published by the National Cooperative Highway Research Program (NCHRP). Four studies in particular are associated with road construction in northern climates. NCHRP no. 33 (1976) investigates the acquisition and use of geotechnical data. This study summarizes the accepted stages of development in road construction, namely, corridor studies, route selection, preliminary and final design, bidding, and construction. The study stresses the importance of geotechnical data such as soils, drainage, geological maps, and aerial photographs in the corridor study phase of analysis. The NCHRP considers this stage as the most important in the road construction process. Other NCHRP studies include: roadway design in seasonal frost areas (no. 26, 1974), erosion control on highway construction (no. 18, 1973), and the effects of weather on highway construction (no. 47, 1978). The latter study concluded that the adverse conditions which most affect highway construction are rain and snow combined with wind and cold. These conditions are common in the Susitna River basin.

Three studies involving terrain evaluation and northern construction projects were done by Kreig and Reger (1976), Kreig (1977), and Rutter (1977). Kreig and Reger investigated preconstruction terrain evaluation for the Trans-Alaska Pipeline Project. The project was a massive construction endeavor which traversed 590 miles of permafrost terrain and three major mountain ranges. Kreig and Reger incorporated field reconnaissance data, airphoto interpretation information, and computer analysis to evaluate terrain conditions over large areas where acquisition of ground-truth data was limited by difficult access and high cost. The resulting information was incorporated in terrain unit maps which were then used for designing pipeline structural parameters and for determining construction techniques for each landform. Kreig and Reger concluded that their method of evaluating terrain conditions was well suited for large areas with limited ground-truth information. They also concluded that the landform approach allowed timely construction planning which, because of the magnitude of the project, would not have been possible using conventional field work procedures. Kreig (1977), in a related article, further discussed the airphoto analysis techniques and computer data bank utilized in the previous study of the Trans-Alaska Pipeline Project. Kreig concluded that a combination of airphoto analysis and landform mapping can be very useful to engineers who must predict terrain conditions over large areas with limited field reconnaissance.

Rutter (1977) also utilized terrain evaluation methodology in construction planning. His study investigated the utility of terrain evaluation for the MacKenzie Transportation Corridor in Canada's Northwest

Territories. Rutter's study consisted of a reconnaissance-scale terrain inventory of the corridor. The inventory consisted of surficial geologic mapping, engineering studies, investigations of geomorphological processes in permafrost areas, and the definition of terrain units. Rutter constructed terrain unit maps utilizing airphotos and geotechnical data. The maps were then incorporated in the transportation corridor design.

Hunter et al. (1981) investigated site and route studies in northern permafrost environments. They stressed the importance of proper selection and investigation of sites and routes in permafrost areas. Their study concluded that environmental factors must be considered as well as reconnaissance and detailed site and route studies be made if unsatisfactory engineering performance is to be avoided. They also stated that environmental and social concerns, in addition to the more obvious terrain and geotechnical aspects, can be indicated on a map depicting a wide corridor. This procedure is frequently done before commencing selection and detailed study of a route along a much narrower corridor. The study also showed that the more desirable locations for roads in permafrost regions usually consist of the shortest distances, gentle slopes, a minimum of sidehill, a minimum number of river crossings, and sandy/gravelly soils underlain at a shallow depth by bedrock. The study identified the areas that the terrain analyst working in permafrost regions should avoid: stratified fine-grained deposits, hummocky moraines with moderate to high relief, poorly drained depressions in till plains, frozen or thawed peatlands, and thermokarst terrain. They concluded that the main objective of terrain analysis for engineering projects includes the delineation of landforms and the recognition of surface materials. These characteristics determine the best location for new building sites and access routes.

Remote Sensing Inputs for Highway Corridor Location and Geographic Information Systems

Remote sensing has had an important role in highway corridor location. Remotely sensed data is often used as an input for geographic information systems. The preliminary reconnaissance stage in the road construction process frequently involves the "screening" of large areas in order to identify the critical limiting factors (Anderson and Beavers, 1976). Often the areas to be screened are so large, that ground-truth information is limited. Kreig and Reger (1976), Kreig (1977), Rutter (1977), and Hunter et al. (1981) all document the use of airphoto interpretation for large areas with limited ground-truth data. The use of airphotos allows the estimate of terrain characteristics and the subsequent location and assessment of potential routes. This procedure is very useful and cost-effective for engineers involved with large projects. Hunter et al.

(1981) states that the use of airphotos in terrain analysis is almost universal.

Remote sensing inputs to highway corridor location consist primarily of data interpreted from airphotos. However, Landsat satellite images are also possible inputs to the process as well. Landsat data, at a smaller scale than airphotos, is used extensively in resource development. Gatto et al. (1980) used Landsat imagery to undertake an environmental analysis of the upper Susitna River basin. The area covered in their investigation included the location of the proposed Susitna Hydroelectric Project and the access routes. The study evaluated the utility of the environmental data derived from a Landsat image. The goal was to provide information adequate for preconstruction planning and design for the hydroelectric project. The information consisted of a map showing the distribution of surficial geologic materials and poorly drained areas. They concluded that the use of the Landsat imagery provided general geologic information for a remote area quickly and cost-effectively. They also concluded that the imagery could not supply the detailed site-specific data required for design. However, the study reaffirmed the notion that remotely sensed data can be an effective input to a large-scale construction project such as the access corridors for the Susitna Hydroelectric Project.

Krebs (1982) also dealt with the cost-effectiveness of remotely sensed data. Her study investigated the utility of remote sensing technology, particularly aerial photography and Landsat data, for a multiresource inventory of Alaska's wildlands. Krebs stated that a major problem for Alaskan resource managers was the nonexistent or insufficient inventory data for large, remote areas. Krebs utilized a computer-aided information management system which incorporated Landsat data, digital terrain data, and aerial photography. The investigation included land cover, slope, aspect, and elevation criteria. Krebs concluded that remote sensing technology provided a cost-effective approach for systematic and integrated resource inventories.

The Environmental Systems Research Institute (ESRI, 1981) also documented the use of remote sensing data in transportation corridor location. ESRI conducted a land capability/suitability analysis of the Willow subbasin in Alaska. The study used airphoto information to make interpretations and delineations of environmental phenomena including stream and road networks, watershed boundaries, and average slope gradients. This information was then incorporated on mylar base maps with collateral data, and then input into a geographic information system. The ESRI study concluded that the information derived from aerial imagery was important in verifying, rectifying, and clarifying the distribution and aerial extent of the regions phenomena.

Use of remote sensing techniques in highway construction include route surveying and design (Snow, 1969), estimating soil erosion (Fenton, 1982), and general highway engineering (Chaves and Schuster, 1968). Snow documented the advantages of aerial photography in route surveying. The advantages included greater flexibility in route location with better ground coverage of wider routes, less elapsed time between starting the survey work and construction, and a more uniform accuracy provided by maps made from photogrammetric methods. Fenton investigated the use of remote sensing techniques by soil scientists for estimating soil erosion. Fenton stated that aerial photography has been used by soil scientists in the U.S. since the mid 1930's. Fenton concluded that remote sensing techniques have been used extensively to increase the speed and accuracy of soil mapping. Fenton also concluded that the computerization of soil data bases provided an efficient means for storing, retrieving, and analyzing data concerning soil erosion problems. Chaves and Schuster investigated the use of color photography for highway engineering. Their study concluded that aerial color photography has been of considerable use in highway materials surveys. Other related uses of remote sensing techniques for resource development and geographic analysis include transmission line routing (Plitz, 1982), outdoor recreation site inventories (Dill, 1963), and land and water resource management (Hardy, 1982 and McFarland, 1982).

Several studies provide general information on remote sensing inputs for geographic information systems and corridor analysis. Colwell (1983) provided an excellent summary of remote sensing inputs for route corridor selection and geo-based information systems. Colwell stated that remote sensing data, when combined with ground-acquired data, provided a composite data base that is second to none for the selection of urban development sites and for regional land use planning purposes. Colwell also stated that aerial photographic interpretation for locating transportation systems has been in use for over 35 years. Colwell concluded that the major areas of highway engineering that utilize image interpretation techniques include highway planning and inventory surveys, highway location surveys, highway corridor evaluation, environmental analysis, and construction surveys.

Two other sources that provide general information on remote sensing and its utility in construction and geo-based information systems include Lillesand and Kiefer (1979) and Avery (1977). Lillesand and Kiefer provide information pertaining to land information systems and the process of integrating airphoto information. Avery provides an in-depth review of aerial photographic interpretation techniques.

Agency Data

The most important information for this study originated from the Alaska Power Authority and their earlier investigation of the proposed Susitna Hydroelectric Project. In 1979, the APA began to seek detailed proposals concerning the feasibility of a hydroelectric project in the upper Susitna River basin. Since that time, several different studies have been done on various aspects of the project. Several of the studies were undertaken by other consultants under contract with the power authority.

Acres American, Inc., completed several studies, three of which were reviewed for this research: the Susitna Hydroelectric Project Feasibility Report Supplement (1983); the Susitna Recommendation Report (1982); and the Susitna Access Route Selection Report (1982). All of the reports deal specifically with the proposed access routes to the Devil Canyon and Watana Dam sites. The Feasibility Report Supplement was the most recent study and incorporated the conclusions of the earlier reports.

Terrestrial Environmental Specialists, Inc., (TES, 1981) investigated the environmental implications of the alternative access plans. Their analyses included tabulation of the environmental impacts which were expected to result from the construction of the Susitna access routes.

Three other investigations of the Susitna access routes were done by R and M Consultants (1982), Jones and Jones (1975), and Jubenville et al. (1981). R and M Consultants studied the design and logistic requirements for the dams and access corridors. Their study included an in-depth evaluation of the engineering requirements for the access corridors. Jones and Jones did an inventory and evaluation of the environmental, aesthetic, and recreational resources of the Susitna River basin. Jubenville et al. did a land use analysis for the study area. Their study involved the past, present, and future land use patterns in the river basin and the probable impacts of the hydroelectric project.

Several studies done by the Alaska Power Authority were also reviewed. The Economic and Financial Update (1983) takes into account the most current data on key economic variables affecting the project's feasibility. This report also includes an estimate of current and future electricity demands for the Railbelt and a report on the availability of alternative fuels. The second APA document reviewed was the Susitna Hydroelectric Project Plan of Study (1980). This report is the original plan that prefaced the feasibility studies. The report provided the guidelines and schedules for all the subsequent investigations.

Two other agency studies concern the soils of the Susitna River basin and nearby areas. The Exploratory Soil Survey of Alaska (1979) provided general soils information useful for large-scale planning. The study contained predictions of soil behavior for selected land uses and identified limitations and hazards. The study included the upper Susitna River basin and the region contained in the proposed access corridors. Another study which provided general soils information was the Soil Survey of the Susitna Valley Area, Alaska (1973). The study concentrated on the soils of the lower Susitna River basin. Although the report did not include the thesis study area, the collateral soils information it provided were important for the analysis of the access corridors.

CHAPTER III

METHODOLOGY

Developing the GIS Data Base

The objective of this investigation was to provide a method of analyzing the alternative Susitna access corridors which incorporated the many diverse factors encountered in previous studies within one study. The method developed in this thesis research uses a geographic information system which allowed the screening of the large area within the upper Susitna River basin in order to identify potential limiting factors. The problem of selecting an optimum access corridor for the Susitna Hydroelectric Project involved engineering factors (terrain units, slope, and land cover), environmental factors (wildlife habitat, land cover, and cultural resources), and economic factors (construction costs, socioeconomic preferences, and land ownership). Consequently, in order to identify limiting factors, these data types were incorporated into three separate data bases; environmental, engineering, and economic, which were then input into a geographic information system. The geo-based data then allowed the selection of the feasible access corridors that: 1) minimized critical wildlife habitat destruction, 2) avoided undesirable impacts on cultural resources, 3) maximized the technical ease of construction, 4) minimized costs, and 5) satisfied socioeconomic preferences.

Environmental Data Base. The environmental data base consisted of data generated by Terrestrial Environmental Specialists, Inc., (TES, 1981). This information included wildlife habitat, land cover, and cultural resource data. The wildlife habitat data included the various habitats in the access corridors (fish, big game, raptors, furbearers, avians, and small mammals). The information was contained on a series of 1:24,000 scale maps. The land cover information consisted of 23 vegetation types contained in the Susitna River basin (Appendix A). Because the analysis of the access corridors was on a reconnaissance level and covered a large area, the vegetation types were classified at Level I of the Anderson Classification System.[28] The categories included forest, shrub, tundra, water, grassland, wetlands, and rock/snow. This information was mapped on three 1:63,360 scale maps. The cultural resource information considered the potential of the Susitna River basin for archaeological resources. Several archaeological sites, as well as potential sites, have been identified in the study area. This information was mapped on a series of 1:24,000 scale maps.

Engineering Data Base. The engineering data base input into the GIS consisted partly of information developed by

R and M Consultants (1982). This information included terrain units which were mapped on a series of 23 maps at a scale of 1:48,000. Terrain units are commonly used for evaluating landform units over large areas where acquisition of ground-truth data is limited (Kreig and Reger, 1976; Kreig, 1977; and Rutter, 1977). The terrain units mapped by the R and M study covered the area within the three proposed access corridors. The units identified landforms that were expected to occur from the ground surface to a depth of 25 feet.[29] The terrain units mapped by R and M Consultants represented 24 different landform types (Appendix B). Each unit contained nine engineering characteristics that allowed the qualitative assessment of the various river basin soils and the determination of their engineering suitability for access road construction. The assessments (Appendix C), included soil type, drainage, erosion potential, depth to the ground water table, probable permafrost distribution, frost heave potential, thaw settlement potential, bearing strength, and slope stability. Each terrain unit was then assessed in terms of its suitability for access road construction.

Economic Data Base. The economic data base consisted of construction cost, socioeconomic preference (native and community), and land ownership (federal, state, native, private, and state park). The economic data were in tabular form and originated from two sources: R and M Consultants

(1982) and the Alaska Power Authority (1983, 1984). The construction costs (Appendix D) considered the total cost of building an access road through each of the three corridors; the North, South, and the Denali (Figure 2). For the purpose of this study, construction costs were represented by engineering limitations. The limitations included steep slopes, poor soils, wetlands, and permafrost. The presence of these limitations will result in increased construction costs.

Socioeconomic preference takes into account the preference of the Alaska native corporations and the other land owners in the river basin for a particular access route. The native corporations which own three-fourths of the land along the Susitna River and south of the proposed Watana Dam, are major landholders in the study area. The choice of an optimum access corridor should be responsive to their desires. Data representing socioeconomic preference was not spatial (i.e., was not mappable information) and could not be easily digitized. However, data representing land ownership was contained on an APA map and was easily digitized for the GIS. Consequently, landownership was used in the analysis to represent socioeconomic preference. This component of the economic data base considered the major landholders in the Susitna River basin: the federal government, state government, native corporations, and private landowners. The location of the three proposed access corridors will have an impact on all of these properties due to increased access and development. Several landholders, particularly the native corporations and the various private landowners, have expressed strong opinions on access corridor location. The native corporations have a strong preference for access to their landholdings bordering the Susitna River. However, many of the private landowners have a strong preference for limiting access to their areas. Consequently, these opinions were considered in the choice of an access corridor.

Aerial Photography. Remotely sensed data, in particular aerial photography, is often used as an input for geographic information systems (Anderson and Beavers, 1976; ESRI, 1981; Krebs, 1982). Reconnaissance surveys frequently involve large areas without extensive ground-truth information. Aerial photos can be used to estimate terrain characteristics and assist in locating routes without incurring prohibitive costs (Kreig and Reger, 1976; Kreig, 1977; Rutter, 1977; Hunter, 1981). In the current study, the environmental data base and the engineering data base were supplemented and verified using aerial photos. The imagery used was obtained from North Pacific Aerial Surveys of Anchorage. It consisted of 8 flight lines and 130 frames covering the proposed Susitna access corridors. The film used was color panchromatic and the scale was 1:24,000. Interpretation of this imagery contributed to: 1) the verification and supplementation of the land cover information supplied by TES, 2) the verification of the wildlife habitat information from TES and R and M Consultants, and 3) the verification of the terrain units delineated by R and M Consultants.

Stages of the Analysis. The method for access corridor selection developed in this study included the use of a geographic information system. The analysis consisted of five steps: 1) the reduction of the data sources to a common scale (1:250,000 mylar base maps), 2) GIS data input, 3) data entry modification, 4) computer analysis, and 5) image display and annotation.

Data Reduction

The first step in the development of the GIS was the creation of a set of mylar base maps of the study area. The various data types (terrain units, slope, landcover, wildlife habitat, cultural resources, hydrologic data, and land ownership) were originally mapped at different scales with varying detail. Each had to be transferred to 1:250,000 scale base maps for the analysis phase. The re-scaling of the diverse data types to a common scale was done to standardize the data and facilitate data input into the GIS - a common practice with geo-based data.[30]

Scale. A base scale of 1:250,000 was chosen for three reasons. First, the entire study area consisting of the upper Susitna River basin and the access corridors (8,208 square kilometers), could be contained only on a map with a scale of 1:250,000. This choice of scale facilitated GIS data input by allowing the study area to be dealt with as one unit. Base maps at a larger scale would have required the division of the area into smaller subsections. The subsections would then have to be treated separately and composited at the last stage in the analysis. Secondly, a primary goal in developing the access corridor selection methodology was to minimize time and cost. Developing the GIS at a larger scale would have required considerably more time and resources. A larger scale data base would contain more information. This would require more time in GIS data input and analysis as well as place limitations on computer memory. The third justification for the choice of small scale was the nature of the analysis itself. The optimum analysis of the Susitna access corridors developed in this study was at a reconnaissance level. Reconnaissance level surveys are used to "screen" large areas such as counties (Wood and Beck, 1982), or states (ESRI, 1981), and to provide a framework into which more detailed inventories are placed.[31] Consequently, a small scale is frequently the choice for large area inventories and transportation corridor studies (Tomlinson, 1968 and ESRI, 1982).

Data Classes. The data types mapped on the 1:250,000 mylar base maps included: slope, wildlife habitat, cultural resources, land ownership, hydrologic information, terrain units, and land cover.

1. Study Area: The study area consisted of the three wide access corridors proposed by the APA and Acres American, Inc.[32] The South Corridor begins at Gold Creek in the west and follows the south side of the Susitna River eastward to Watana Creek (a distance of 66 kilometers). The North Corridor begins at the Parks Highway in the west and extends east to Watana Creek on the north side of the Susitna River (66 kms.). The Denali Corridor begins in the northeast at the Denali Highway and follows Deadman Creek until it reaches the North Corridor. The Denali Corridor also contains two spurs: the west spur reaches the Denali Highway via Deadman Creek (39 kms.) while the east spur follows a route past Butte Lake (36 kms.). The width of the three corridors (11 kms.) was determined by the APA and was a result of topographic limitations within the river basin. Consequently, the terrain unit data, land cover data, wildlife habitat, and cultural resources data were only available in strips 11 kilometers wide.

2. Slope: The slope data was interpreted from two 1:250,000 USGS topographic sheets that contained the study area (Healy and the Talkeetna Mountain sheets). Slope was mapped in seven classes representing a percentage: <5%, 5, 10, 20, 30, 40, and >40%. The

values were estimated by marking a mylar template with a measured distance of 2,000 feet (at 1:250,000). The template was then overlayed on the study area base map at numerous test points. The number of 200 foot contour intervals within the measured 2,000 feet were then counted. The calculation of slope was made using "rise" divided by "run," or the number of contours divided by 2,000 feet. This number was then converted to a percentage. An example would be an area with a "rise" of 600 feet (3 contour intervals) within the measured distance of 2,000 feet (the "run"). The resulting percentage of slope is 600'/2000' = .3 or 30% slope. This procedure was done for the entire study area.

3. Wildlife Habitat: The wildlife habitat data was interpreted from 1:24,000 scale R and M Consultants maps. This information consisted of boundary lines drawn around the various habitat areas. The procedure for transferring the information was to simply re-draw the boundaries on a 1:250,000 base map. However, the areas delineated by R and M Consultants were rather subjective. Consequently, collateral data (previous research concerning wildlife habitat, land cover data, and aerial photos), was used to verify the boundaries. The combination of this information helped to establish the habitat areas in a more objective manner.

4. Cultural Resources: The cultural resource data consisted of several R and M Consultants 1:24,000 scale maps. This information identified areas within the upper Susitna River basin that contained archaeological sites. These areas were re-drawn on a 1:250,000 base map.

5. Economic Data: The economic data base consisted of socioeconomic preference and land ownership. The land ownership data consisted of one APA 1:250,000 scale map. This information was traced on a 1:250,000 mylar base map.

6. Hydrological Data: The hydrological information consisted of the major streams, rivers, and lakes in the basin, as well as the Susitna River. This data was traced onto a 1:250,000 mylar base map from the USGS topographic sheets.

7. Terrain Units: The R and M Consultants terrain unit data was very detailed and originally mapped at a large scale (1:48,000). In order to convert the mapped terrain unit data to a 1:250,000 base map, a Bausch and Lomb Zoom Transfer Scope was used. The Zoom Transfer Scope allowed the exact transfer of the original large scale data to the smaller scaled base map. However, the scale reduction resulted in resolution that was too fine for the GIS computer analysis. The terrain unit

polygons were considered too small for the computer to resolve. The ERDAS 400 system used for the analysis was only able to "recognize" polygons 1/8th of an inch in diameter or larger. Polygons smaller than this are simply ignored and data is lost. Hence, the data was aggregated in larger classes. Consequently, the terrain units, which represented 24 different landform types, were aggregated into four classes: no limitations, moderate limitations, severe limitations, and unsuitable for access corridor route construction. These categories were based on the engineering performance expected for each landform type. R and M Consultants included nine different engineering characteristics. These characteristics allowed the qualitative assessment of the landform units in terms of their suitability for access route construction. The assignment of the landform types to the four suitability classes was based on previously cited literature (Krebs and Walker, 1971; R and M Consultants, 1982; and the Soil Conservation Service, 1979), and considered the number of limitations each landform type had in the nine engineering categories. Thus, because the terrain unit Bxu (bedrock) had no limitations in any of the nine categories, it was classified as having "no limitations" for access route construction. The terrain unit C/Bxu + Bxu (colluvium over bedrock and bedrock exposures), had one limitation - moderate to high erosion potential, and was classified as "moderate limitations." This process continued for all the terrain units, grouping units without limitations in the "no limitations" category; types with one limitation were classified as "moderate limitations," types with two limitations were considered "severe limitations," and units with more than two limitations were classified as "unsuitable." Consequently, a terrain unit map of 23 different classes was transformed to a map of four suitability classes. This procedure reduced the detail of the terrain unit data polygons and facilitated the digitizing process.

8. Land Cover: The land cover data was reduced to a base map in the same fashion as the terrain unit data. The original land cover data was detailed and mapped on a relatively large scale (1:63,360). Consequently, the data was transferred to a 1:250,000 base map with the Zoom Transfer Scope. The scale reduction again resulted in excessive detail for digitizing. Furthermore, the 21 original land cover categories provided a level of detail that was not necessary for the reconnaissance level "screening" of the Susitna River basin. Thus, the classes were aggregated into vegetation classes based on the Anderson Classification System. This classification system establishes nine

categories for Level I, the top level of the classification hierarchy. The classes include urban, agricultural land, rangeland, forest land, water, wetlands, barren, tundra, and permanent snow/ice. The classification system was subsequently adopted for the Susitna River basin by dropping the classes that did not apply (agricultural land, rangeland, urban, and barren), and by adding two classes of vegetation that were prevalent in the study area (grassland and shrub). The final land cover classes consisted of: forest, shrub, tundra, water, grassland, wetlands, and rock/snow.

GIS Data Input

Before being entered into the GIS, the data types (economic, environmental, and engineering) had to be converted into a computer compatible digital format. This procedure was done by digitizing the data types, which were contained on 1:250,000 mylar base maps, on a Calcomp 9000 digitizer, and an IBM XT personal computer. The digitizer, which consists of an electronic grid, converted the polygonal boundaries of the data classes to a number of x-y points. Descriptive information about the data classes (i.e., 20% slope, caribou habitat, native land, etc.), were specified by a key number. The x-y grid of the digitizer then formed cells which were superimposed over the data classes. Once the base maps with the data classes were digitized, the relative positions of the classes were referenced by the grid cell system. This procedure then enabled the computer to compare data sets, produce overlay combinations, assess the influence and interaction of the different variables, and subsequently provided input to the access corridor selection methodology.

Cell Size. An important decision in the digitizing process concerned the size of the cells which were superimposed over the data classes. The cell size chosen determines the resolution of the final data base and maps. Every feature within a cell is assigned the same value. Larger cells will likely contain a greater variety of information. However, all of this information is then assigned to one value and consequently detail is usually lost. Smaller cells contain less information but will contribute to an overall increase in resolution. However, a map made up of smaller cells will also contain much more data. This creates larger data files and requires a significantly greater amount of computer memory and digitization time.

Two factors must be considered when choosing the cell size: 1) the amount of data to be digitized, and 2) the resolution of the data to be digitized. The amount of data for the Susitna access corridor GIS was considerable. Seven maps had to be digitized with each map representing large amounts of information. Furthermore, the resolution of several data types was quite fine. The land cover map and the terrain unit map contained hundreds of minute polygons. The smallest polygons were roughly 1/8th of an inch in size. Consequently, a cell size of 1 cell = 1 kilometer was chosen (1/8th of an inch = 1 kilometer at a scale of 1:250,000). Hence, the smallest area resolved in the analysis was 1 square kilometer. The resolution afforded by this choice was fine enough to capture the detailed terrain unit and land cover data without requiring a prohibitive amount of time and cost in digitizing the maps. This choice was also consistent with the level of detail required by a reconnaissance level "screening" of the proposed access corridors.

Data Types. The data types were divided into separate classes as they were digitized. The terrain units were digitized in four classes: no limitations, moderate limitations, severe limitations, and unsuitable. Each polygon received a key number which specified the information within that class. The wildlife habitat data was digitized in five classes representing the different habitats in the study area: avians and small mammals, furbearers, big game, fish, and raptors. The land cover data were digitized into six classes: rock/snow, tundra, grassland, wetlands, forest, and shrub. The cultural resources data were digitized with only one class which represented the areas containing archaeological sites. The slope data were digitized in seven classes: less than 5%, 5, 10, 20, 30, 40, and greater than 40% slope. The land ownership data were digitized in five classes: federal, state, native, private, and state park. Each class represented the major landowners in the Susitna River basin. The last map digitized consisted of the Susitna study area. This file was digitized in eight classes: major lakes, major streams and rivers, existing roads, the Alaska Railroad, the Susitna River, the Denali Corridor, the North Corridor, and the South Corridor. This file provided the study area boundaries and the major features within. The file also contained the three proposed access corridors which were under consideration.

ERDAS File Transfer. The data files, once entered into the geographic information system, were then analyzed using the software routines of an ERDAS 400 microcomputer (Earth Resources Data Analysis System). The ERDAS is a microcomputer-based GIS which was designed for planning and resource analysis applications. The software packages it provides allows the user to integrate multiple sources of digital data (such as land cover, terrain units, slope, etc.), into a consistent format for display, analysis, and mapping.[33]

After the various base maps were digitized, the data was transferred to the ERDAS 400. The transfer process consisted of copying the digitized data from IBM 5 1/4-inch floppy disks to ERDAS magnetic tapes. The tape data was then transferred to 8-inch floppy disks which were used for the duration of the analysis. The data, once placed on computer floppy disks, can be used repeatedly. Updating and expanding the data base becomes a simple procedure of copying files onto the disks.

The GIS Files. At this point in the analysis, the data base consisted of seven digitized files: slope, wildlife habitat, cultural resources, land ownership, terrain units, land cover, and the general study area. These files were converted into GIS files using three programs: IMCREATE, BUILDH, and GRDPOL. The IMCREATE program was used to create the framework of the new GIS files. Each digitized file was converted into a matrix of columns and rows. IMCREATE builds an empty GIS file of "n" columns and "m" rows. The columns and rows are determined by the size of the study area (108 kilometers east-west and 78 kilometers north-south), and the cell size (1 cell = 1 kilometer). Thus, the columns and rows of the GIS files numbered 108 and 78 respectively. BUILDH was the program that contained the "header" information for each GIS file. The header information included the cell size (1 km.), the map reference coordinate system (Universal Transverse Mercator), and the units of area to be used in the analysis (acres). This information, along with the empty GIS file created by IMCREATE, was utilized by the third program - GRDPOL.

GRDPOL accepted the digitized data and inserted it into the newly created GIS file. The digitized data was then contained in individual GIS files consisting of a 108 row by 78 column matrix.

The three programs: IMCREATE, BUILDH, and GRDPOL, were used for all six of the digitized files. However, three of the files: land cover, slope, and the terrain units required an additional program. The GRDPOL program converts the digitized data, which is in the form of polygons, and inserts it into the cells of the GIS file. This process is simple when a polygon is small enough to fit into one whole grid cell or if the polygon has a shape that doesn't split the grid cells and share them with other polygons. If three different polygons share a portion of the same grid cell, a decision must be made as to which data type will represent that cell. The computer solves this problem by processing the digitized data sequentially - in the same order they were digitized. If two digitized polygons share the same grid cell, the last polygon digitized will determine the value of that cell. This procedure is adequate when the polygons are large enough and the conflicts are infrequent. However, if the polygons are small or have a convoluted shape and several do share a grid cell, the decision process may provide misleading results. An example of this problem would be if an unsuitable terrain unit (extensive permafrost), an unsuitable land cover value (wetland), and a

suitable land ownership value all shared a portion of the same grid cell. The computer would then assign the value of the last polygon digitized to the grid cell. If this happened to be a suitable classification (native owned land), then the limiting variables of permafrost and wetlands would be concealed. This could produce misleading conclusions concerning the distribution of limitations and would be unsuitable for access route selection. Hence, the decision process must be modified to reflect the greater emphasis of the unsuitable, limiting factors.

The land cover, slope, and terrain unit files were composed of many small and convoluted polygons. The decision process was then modified in order to avoid misinterpreting the original data. Hence, a program called AGGREGAT was used. This program enabled the specification of certain data values in the conflict/decision process. In the case of the land cover, slope, and terrain unit data files, the class that represented the greatest limitations to access route construction was specified as the priority value. These classes consisted of: "wetlands," slope of ">40%," and "unsuitable." The AGGREGAT program then ranked the rest of the class values in terms of the second, third, and fourth degree of limitation. If a conflict occurred in the assignment of a grid cell value, AGGREGAT assigned the highest degree of limitation present in the cell as the cell value. This procedure then enabled GRDPOL to insert the digitized data into the GIS files without creating misleading results.

Editing. The last step before entry modification and the analysis routines consisted of editing the GIS files. All seven GIS files: slope, wildlife habitat, cultural resources, land ownership, terrain units, land cover, and the study area, were displayed on the ERDAS monitor and edited using a program called PUPDATE. PUPDATE is a polygon update utility that allows the user to rectify any errors that occurred in the digitization process. Occasionally when a new GIS file is displayed, several pixels or elements in the matrix may have been mis-classified. PUPDATE allowed the interactive editing of the GIS files before the analysis routines were run.

Data Entry Modification

One advantage of a computer-assisted geographic information system is its ability to modify and weight the various data types. Each variable is assigned a numerical value that corresponds to the importance that variable has in the analysis. Consequently, each variable is assigned a number (1,2,3, etc.) and ranked according to its limitations for access route construction. An example is land cover. One of the greatest limitations in road construction is the existence of wetlands (Krebs and Walker, 1971; Oglesby, 1975; Johnston, 1981; and Sparrow, et al., 1978). Thus, in the analysis, wetlands were considered an overriding limitation and received a weight greater than other variables (i.e., ranked at #1, the variable with the greatest limitations). The weight reflected the degree of limitation the variable had in the analysis.

The weighting and ranking of input GIS files is a subjective process. However, in this study, the process was based on related literature and agency standards determined by the Alaska Power Authority and the various agencies concerned with access corridor development. Ranking the data based on literature and previous research enabled the process to be more objective and thus accurately represent the access corridor situation. The data types in the seven GIS files were weighted and ranked in order to reflect the objectives of the investigation. The objectives were: 1) maximize the technical ease of construction, 2) minimize the environmental impact, 3) minimize overall cost, and 4) accommodate socioeconomic preference.

Maximizing the Technical Ease of Construction. The first objective, maximizing the technical ease of construction, utilized the engineering data base. The elements necessary for satisfying this objective were: the optimum terrain units for road construction, minimal slope, and the avoidance of difficult land cover. To identify areas that maximized the technical ease of construction, the classes of terrain units that were suitable for road construction were identified and given preference ("no limitations"), areas of slope less than or equal to 5% were identified, and areas containing wetlands were identified. The weightings of these various categories were based on engineering and agency literature, which recommended the avoidance of wetlands, areas with steep slopes, and areas of unsuitable terrain characteristics (poor soil and drainage, high potential for erosion, high ground water table, continuous permafrost, high frost heave potential, high potential for thaw settlement, low bearing strength, and low slope stability). Consequently, upon display of the data file, the engineering suitability of all areas within the access corridors for route construction was established.

Minimizing Environmental Impact. The second objective, minimizing the environmental impact, utilized the environmental data base. The elements necessary for meeting this objective were: the location of critical wildlife habitat, the location of areas with a high potential for impact to cultural resources, and the location of fragile land cover. The identification of a suitable access route corridor that would minimize environmental impact required the identification and avoidance of: 1) fish, raptor, and big game habitat; 2) areas with a high potential for impact to cultural resources (existing and potential archaeological sites); and 3) areas of fragile land cover (wetlands and tundra).

The avoidance of fish habitat (anadromous and resident), was given the highest priority in the environmental analysis. Following fish habitat, the second and third ranking priorities were assigned to raptor and big game habitat. Initially, it was thought that big game habitat, in particular caribou habitat, should receive the highest priority. However, a review of the literature involving road impacts to caribou and several interviews revealed that the impact to the Nelchina Caribou herd in the northern portion of the Susitna basin would not be the greatest problem for access corridor selection. The impacts to caribou would include road kill, calf mortality, unnecessary expenditures of energy while in flight, and increased hunting pressure. All of these impacts can be mitigated by careful control and management. Horejsi (1981) indicated that 80% of the caribou encountered along the Dempster Highway in the Yukon Territory ran away from a moving vehicle. However, Horejsi also stated that the speed of the approaching vehicle had more bearing on the caribou flight than the movement of the vehicle or the size of the threatening object.[34] Consequently, if the speed of vehicles traveling the access corridors in the Susitna River basin are controlled, the impact of road kill and unnecessary flight could be mitigated.

Wolfe (1978) indicated that road corridors can actually facilitate game movement to their habitat.[35] However, he indicated that hunting pressure can increase with the greater access the road provides. The impact of increased hunting can be mitigated in the Susitna River Valley by controlling access and with strict management guidelines. If these practices are followed, the problem of increased hunting pressure could be mitigated.

Furthermore, the disturbance to the caribou and their calving grounds also may not be as important as first thought. Interviews with Dr. Richard Fleming (Deputy Susitna Project Manager - Environmental), and Dr. Ronald Skoog (former Director of the Alaska Department of Fish and Game), indicated that the impacts on caribou may be secondary to potential fish impacts. Dr. Fleming indicated that while caribou impacts can be mitigated relatively easily, the impacts on anadromous and resident fish populations would be considerably more difficult.[36] These impacts include river bank erosion, siltation, and loss of spawning grounds. Furthermore, Dr. Skoog indicated that the Nelchina Caribou herd ranges over a very large area in the northern portion of the Susitna basin. He indicated that their response to increased noise and activity from the hydroelectric project access roads and construction would likely be movement of the herd to another portion of their existing range.[37] This occurrence would not overly stress the caribou nor their calves and is not considered a severe impact.

Minimizing Overall Cost. The third objective, minimizing overall cost, included the technical ease of construction. The objective of minimizing cost required maximizing the technical ease of construction (the optimal terrain units, low percentage of slope, and the avoidance of wetlands). Satisfying these criteria enables the total cost of construction to be kept to a minimum.

Accommodating Socioeconomic Preference. The fourth objective, accommodating socioeconomic preference, included native corporation preferences, private landowner preferences, and land ownership (state, federal, private, native, and state park). In order to satisfy socioeconomic preference, these factors were considered. Each corridor is favored by a different group: the native land owners prefer access to their land holdings south of the Susitna River and the proposed Watana Dam, the state and federal agencies involved in the project all prefer an access corridor that minimizes environmental impact, and the private landholders prefer to maintain the limited access that exists at the present. The socioeconomic data, in part, is represented in the ERDAS analysis by the land ownership data file. In this file, native owned land is given preference. The native corporations, who own 75% of the land along the Susitna River, prefer access to their lands. Thus, the native land is weighted accordingly, and is considered a better location for the access corridor rather than private, federal, and state owned land.

Computer Analysis

The digitized data files, once transformed into GIS files and given the appropriate weightings, were then analyzed using the software routines of the ERDAS 400. The routines used in the study (MATRIX and OVERLAY) were performed on the GIS files in order to illustrate areas in the upper Susitna River basin that would: 1) minimize environmental impact, 2) maximize the technical ease of construction, and 3) minimize economic cost and satisfy socioeconomic preference for access route construction.

Analysis Routines. The MATRIX routine compared the occurrences between two input GIS files and created an output GIS file that contained the coincidences between their sets of classes. The routine creates a matrix where one input file is assigned to the columns of the matrix and the other input file is assigned to the rows. The values that occur in the cells of the matrix represent the coincidence of the two files. The values within the matrix are then assigned to the new output GIS file. MATRIX was used for two purposes: 1) create a common boundary or outline for each of the seven GIS files, and 2) generate statistics which represented the occurrence of each variable within the files and in each of the three proposed access route corridors (the Denali, North, and South Corridors).

A common border was needed for each of the seven GIS files (slope, wildlife habitat, cultural resources, land ownership, terrain units, land cover, and the study area). This was necessary because each data file, when digitized, was not the same shape as the specific study area. The differing shapes of the files resulted from the nature of the different data types. Slope was mapped on the USGS topographic sheets and covered more area than just the access corridors. In contrast, the terrain unit data was contained in only the access corridors. Consequently, MATRIX was used to combine the study area data file, which consisted of the exact boundaries of the study area with each of the other six files. Any data values that fell outside the study area were then assigned a background value and dropped out of the analysis. Hence, each of the GIS files consisted of exactly the same study area and outline. This enabled the second software routine, OVERLAY, to overlay the data files and maintain common boundaries.

MATRIX was also used to generate statistics for each GIS file variable. The statistics (Tables 1-10), were created by combining each data file with the study area file in a MATRIX. The outcome thus showed the coincidence of each variable (shrub, fish habitat, 30% slope, etc.), with each corridor (Denali, North, and South). By studying the statistics, it was possible to determine the percentage and acreage of each variable in each corridor. These figures provided a statistical basis for the access corridor selection process. After generating statistics, the MATRIX output files were then used with OVERLAY to produce the final displays for the analysis.

The OVERLAY program created a new GIS data file by combining two to five specified GIS files. OVERLAY took the highest value for any grid cell from the old variables and assigned it to a new data value.[38] Thus, input GIS files were "overlaid" to produce new output files. The variables input were specified so that only certain characteristics appeared in the final output file (effectively "masking" out certain conditions). In the analysis, the critical limiting factors were assigned the highest priority. During the overlay procedure, the highest values then masked out any other values that occurred in the same geographic location.

OVERLAY was used in the GIS analysis to identify areas of environmental limitations, engineering limitations, and economic limitations. In each case, the GIS data files representing the environmental, economic, and engineering data were overlaid in order to produce an output GIS file that identified the optimum corridor for access route construction. In each data file, the class with the greatest limitation was assigned the highest number and priority. The other classes were then ranked in terms of their degree of limitation for access corridor construction.

Environmental Limitations. For the environmental limitations GIS file, three input GIS files were overlaid to produce the output file: land cover, wildlife habitat, and cultural resource potential.

The cultural resources data file, which initially only contained the existing archaeological sites in the study area, was transformed by OVERLAY into a "Cultural Resources Potential" file. This was done by overlaying slope, terrain units, and land cover with the file containing the actual archaeological sites. The purpose of this overlay was to not only illustrate the current archaeological sites but to also delineate areas with a good potential to include sites. The study by Terrestrial Environmental Specialists, Inc., (TES 1981, p. 2-9), outlined several criteria necessary for delineating zones of high, moderate, and low archaeological potential. High potential areas contain areas of moderate slope (natural topographic constrictions, lake and stream margins), well drained areas subject to repeated use (the optimum terrain units), and non-forested areas. Areas of moderate potential consisted of rolling topography, moderate terrain units, and tundra/grassland areas. Areas of low potential contained extreme topography, severe or unsuitable terrain units, and unsuitable land cover (such as wetlands, forest, and rock/snow). The resulting overlay of land cover, terrain units, slope, and existing archaeological sites, provided a GIS file that illustrated the cultural resource potential of the upper Susitna River basin. This file was then incorporated with land cover and wildlife habitat in order to identify environmental limitations.

For the OVERLAY of environmental limitations, the data within each input file were ranked in four classes reflecting the greatest limitation ("unsuitable") to the least limitation for access route construction ("no limitations"). The data classes in the land cover file were ranked: wetlands, tundra and rock/snow, forest, and shrub. The wildlife habitat classes were ranked: fish, big game, raptor/furbearers, and avians/small mammal habitat. The cultural resource classes were ranked: areas of existing archaeological sites, areas with a high potential for site occurrence, areas with a moderate potential, and areas with a low potential for site occurrence. The OVERLAY of the three files then produced an output GIS file with four environmental limitations categories: unsuitable (a combination of the greatest limitations in all three files), severe limitations (a combination of the second greatest limitations), moderate limitations (a combination of the third ranking limitations), and no limitations (a combination of the suitable areas in all three files).

Engineering Limitations. The engineering limitations output GIS file consisted of overlaying three input GIS files: integrated terrain units, land cover, and slope. The classes in each file were ranked (greatest limitation to least): terrain units - unsuitable, severe, moderate, and no limitations; land cover - wetlands, tundra and rock/snow, forest and shrub, and grassland; slope - greater than 40%, 40%, 30%, 20-10%, and 5 to less than 5%. The output GIS file thus contained four classes: unsuitable, severe limitations, moderate limitations, and no limitations. These data classes then represented the degree of engineering limitations the three proposed access corridors would have for access route construction.

Economic Limitations. The economic limitations output GIS file consisted of overlaying two input GIS files: land ownership and the output file "Engineering Limitations" which represented the technical ease of construction. The classes in the land ownership input file were ranked (greatest to least limitation): state park and private land holdings, federal land, state land, and native land. These rankings reflected, in part, the desire to accommodate native, state, federal, and private access corridor preference. The classes in the "Engineering Limitations" GIS file were already ranked as unsuitable, severe, moderate, and no limitations. The resulting output GIS file, "Economic Limitations," contained four classes: unsuitable, severe, moderate, and no limitations. These classes represented the suitability of land in the river basin for access corridor construction based on land ownership and socioeconomic preference.

Optimum Access Corridor Location. An output GIS file that illustrated the optimum corridor for access route location was created by overlaying the "Environmental Limitations" GIS file with the "Engineering Limitations" and "Economic Limitations" data files. In this OVERLAY, the rankings were: unsuitable, severe limitations, moderate limitations, and no limitations. Each class in the output file represented the best to worst location for an access route from an environmental, engineering, and economic/socioeconomic point of view. This output file thus provided the optimum solution to the access corridor location problem based on the manipulation of engineering factors (terrain units, slope, and land cover), environmental factors (wildlife habitat, land cover, and cultural resources), and economic factors (land ownership and technical ease of construction), from within a geographic information system. The reconnaissance level data, in effect, has "screened" the upper Susitna River basin in order to identify potential limiting factors. The final output file from the GIS can now be applied to other information (economic data containing construction cost, logistics cost, and schedule costs), in order to select the optimum access route corridor.

Display

Color and Annotation. The four GIS files; "Environmental Limitations," "Economic Limitations," "Engineering Limitations," "Optimum Access Corridor Location," and the original seven GIS input files, were displayed on the ERDAS color monitor. Several programs within the GIS software then allowed the addition of colors, legends, and titles to the various files. The colors were chosen so that they provided optimum differentiation between classes: red was assigned to unsuitable, orange to severe limitations, blue to moderate limitations, and green to areas with no limitations.

Access Route Location. After the files were assigned colors and annotated, an access route was "drawn" through each of the final four files. The access route was located in order to illustrate the optimum access corridors. The route was placed through areas providing the least limitations. If possible, areas of moderate to no limitations were linked. The route was drawn using the PUPDATE (polygon update) utility. This program allowed the change of existing data elements (unsuitable, severe limitations, moderate limitations, and no limitations) to an element that represented the access route. A line of data elements were changed to the new access route classification and assigned the color black. Hence, the hypothetical access route appears as a black line on the images.

Photography. All eleven of the GIS file images were displayed on the ERDAS monitor and photographed. The images included the seven GIS files used as the data base as well as the final four images "Environmental Limitations," "Economic Limitations," "Engineering Limitations," and the "Optimum Access Corridor Location." A special hood was attached to the monitor's cathode ray tube which blocked all light except that from the tube. A Nikon F 35mm camera with a 55mm Micro 1:2.8 lens was used. Several exposures (f 5.6, speed 1/4 second), were taken of each image using Kodacolor 400 VR color print film.

CHAPTER IV

RESULTS

The Automated Geographic Information System

The objective of this study was to provide a geographic approach for analyzing the Susitna access corridors. The methodology utilized an automated geographic information system to analyze the large areas within the access corridors and identify potential environmental, engineering, and economic factors. These factors were combined within the computer assisted GIS to produce maps and statistics which illustrated the optimum access corridors.

The problem of selecting an optimum access corridor involved engineering factors (terrain units, slope, and land cover), environmental factors (wildlife habitat, land cover, and cultural resources), and economic factors (construction costs, socioeconomic preferences, and land ownership). The use of an automated GIS allowed the integration of the diverse data types into one analysis. Consequently, the multi-faceted problem was addressed in a more holistic, geographic manner which identified the access corridors that: 1) maximized the technical ease of construction,

2) minimized environmental impact, 3) minimized cost, and 4) accommodated socioeconomic preference.

In considering the sub-hypothesis that a geographic approach to access corridor location would provide concise output displaying the study area, the problem, and the various solutions in a manner that would facilitate the decision process, an important conclusion can be drawn. The reduction and input of the diverse data types within the automated GIS created an easily retrievable data base that can be used by a wide range of agencies in long-term land inventory, planning, and management in the upper Susitna River basin. The output from the GIS analysis included eleven color maps and statistics. The first seven maps represent the data base that was used in the analysis (Figures 3-9). These maps consist of land cover, slope, integrated terrain units, cultural resource potential, wildlife habitat, land ownership, and the study area. Each map contains four to seven classes of information. The maps clearly depict the complexity and diversity of the upper Susitna River basin as well as the problems involved in access corridor selection. In previous studies, each data type was analyzed and illustrated separately.

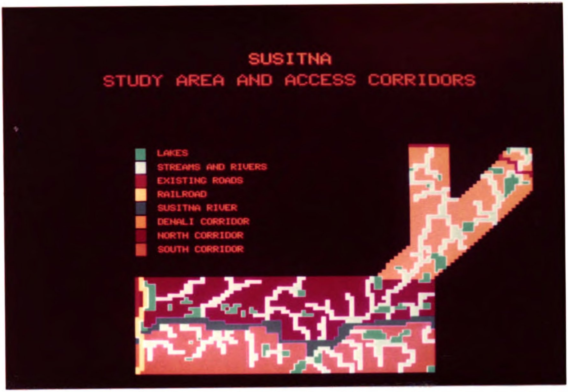

FIGURE 3. STUDY AREA GIS FILE

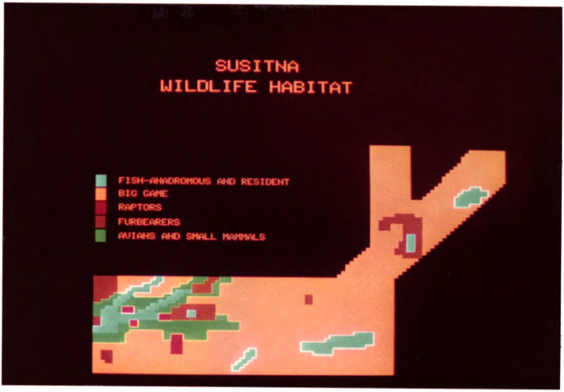

FIGURE 4. WILDLIFE HABITAT

FIGURE 5. CULTURAL RESOURCE POTENTIAL

FIGURE 6. INTEGRATED TERRAIN UNITS

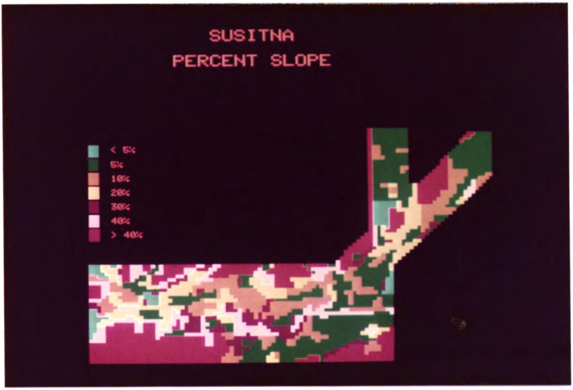

FIGURE 7. PERCENT SLOPE

FIGURE 8. LAND OWNERSHIP

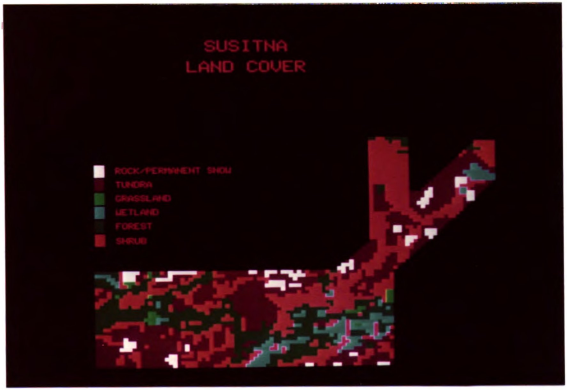

FIGURE 9. LAND COVER

In order to assess the access corridor situation, it was necessary to collect the various documents and study them individually. The output from this study represents a synthesis of the previous studies and illustrates the optimum solution in one map. Thus, the review of the color maps aids the decision process by presenting the study area, the problem, and the solution in a more cohesive, holistic manner.

Corridor Limitations and Route Location. Consideration of the sub-hypothesis that a geographic approach to access corridor location will readily identify the economically, environmentally, engineering, and subsequently the overall preferred corridor, involves the review of the final four color maps produced by the GIS. These maps consist of the environmental, engineering, and economic limitations in the study area as well as the final optimum access route location.

Environmental Limitations. The environmental limitations GIS file was a result of combining land cover limitations, wildlife habitat limitations, and cultural resource limitations. In order to select an access route corridor based on these limitations, Figure 10 was produced and statistics generated. The map graphically depicts the environmental suitability of the proposed access corridors (the Denali, North, and South). Environmental suitability was divided into four classes: no limitations, moderate limitations, severe limitations, and unsuitable. Each class represents a composite of land cover, wildlife habitat, and cultural resource limitations. The optimum access corridor contains the least of these limitations.

Review of the statistics generated for Figure 10 (Table 1) reveals that there are no areas without environmental limitations. Furthermore, only 4% of the study area contains "moderate limitations."

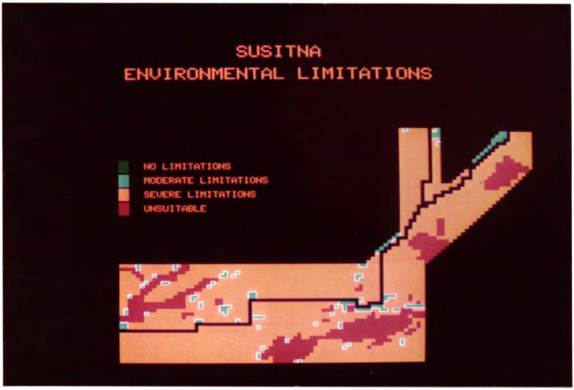

FIGURE 10. ENVIRONMENTAL LIMITATIONS

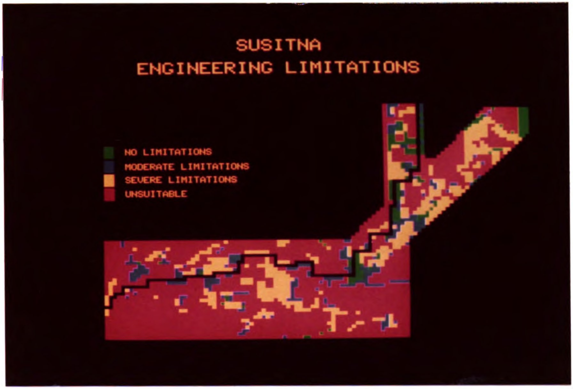

FIGURE 11. ENGINEERING LIMITATIONS

The majority of the study area (73.7%), is classified as having "severe limitations" for access route construction. The reason for this is twofold. First, most of the upper Susitna River basin contains fragile big game habitat including caribou, moose, and bear habitat. The caribou habitat in particular, covers the entire eastern half of the study area. The second factor contributing to the area's severe environmental limitations is the distribution of cultural resources. A large portion of the river basin contains areas with a high potential for cultural resources. These regions consist of well drained, non-forested areas that are expected to contain archaeological sites.

Consequently, from an environmental standpoint, the upper Susitna River basin is not a good area in which to construct roads. However, it is possible to minimize the environmental impact by identifying and avoiding the most critical areas. These areas include Indian River and Portage Creek (anadromous fish habitat), and Stephan Lake, Fog Lakes, Deadman Lake, and Butte Lake (resident fish habitat, archaeological sites, and wetlands). The georeferencing and display of the critical limitations by the GIS assisted in locating an access route which avoids these areas.

TABLE 1: ENVIRONMENTAL LIMITATIONS

Data Value	Number of Points	Number of Acres	%	Description
0	5423	1340096.2	0.0	Background
1	0	0.0	0.0	No Limitations
2	11	29406.5	4.0	Moderate Limitations
3	2211	546367.8	73.7	Severe Limitations
4	490	121085.6	16.3	Unsuitable
5	181	44727.5	6.0	Potential Route

TOTAL NON-ZERO POINTS = 3001
TOTAL NON-ZERO ACREAGE = 741587.5
(Percentages are based on NON-ZERO points.)

TABLE 2: LAND COVER

Data Value	Number of Points	%	Description
0	5479	39.5	Background
1	49	1.0	Denali Corridor/Rock/Snow
2	312	6.4	Denali Corridor/Tundra
3	0	0.0	Denali Corridor/Grassland
4	31	.6	Denali Corridor/Wetland
5	27	.5	Denali Corridor/Forest
6	395	8.1	Denali Corridor/Shrub
7	50	1.0	North Corridor/Rock/Snow
8	335	6.9	North Corridor/Tundra
9	22	.5	North Corridor/Grassland
10	27	.5	North Corridor/Wetland
11	300	6.2	North Corridor/Forest
12	329	6.8	North Corridor/Shrub
13	29	.6	South Corridor/Rock/Snow
14	377	7.7	South Corridor/Tundra
15	12	.3	South Corridor/Grassland
16	128	2.6	South Corridor/Wetland
17	301	6.2	South Corridor/Shrub

TOTAL NON-ZERO POINTS = 4870
(Percentages are based on NON-ZERO points.)

TABLE 3: WILDLIFE HABITAT

Data Value	Number of Points	%	Description
0	5754	50.8	Background
1	36	.7	Denali Corridor/Fish
2	746	13.7	Denali Corridor/Big Game
3	0	0.0	Denali Corridor/Raptors
4	88	1.6	Denali Corridor/Furbearers
5	0	0.0	Denali Corridor/Avians
6	90	1.7	North Corridor/Fish
7	586	10.8	North Corridor/Big Game
8	10	.2	North Corridor/Raptors
9	121	2.2	North Corridor/Furbearers
10	125	2.3	North Corridor/Avians
11	99	1.8	South Corridor/Fish
12	622	11.4	South Corridor/Big Game
13	24	.4	South Corridor/Raptors
14	0	0.0	South Corridor/Furbearers
15	123	2.3	South Corridor/Avians

TOTAL NON-ZERO POINTS = 5445
(Percentages are based on NON-ZERO points.)

TABLE 4: CULTURAL RESOURCE POTENTIAL

Data Value	Number of Points	%	Description
0	5423	0.0	Background
1	74	2.5	Denali Corridor/Low Potential
2	250	8.3	Denali Corridor/Moderate
3	474	15.8	Denali Corridor/High
4	72	2.4	Denali Corridor/Existing Sites
5	79	2.6	North Corridor/Low Potential
6	257	8.6	North Corridor/Moderate
7	727	24.2	North Corridor/High
8	0	0.0	North Corridor/Existing Sites
9	55	1.8	South Corridor/Low Potential
10	294	9.8	South Corridor/Moderate
11	596	19.9	South Corridor/High
12	123	4.1	South Corridor/Existing Sites

TOTAL NON-ZERO POINTS = 3001
(Percentages are based on NON-ZERO points.)

The statistics generated in the GIS analysis (Tables 2, 3, and 4), were also used to identify an access corridor that minimizes environmental impact.

Based on the statistics generated, the best corridor for an access route is the North Corridor. The North Corridor contains the least amount of wetlands (6,669 acres compared to 7,657 acres in the Denali Corridor and 31,616 acres in the South Corridor), the second best in terms of limiting fish habitat (22,230 acres compared to 8,892 acres in the Denali Corridor and 24,453 acres in the South Corridor), and no archaeological sites (compared to 17,784 acres in the Denali Corridor and 30,381 acres in the South Corridor). Furthermore, the Denali Corridor is second best in terms of minimizing wetlands (7,657 acres), the best in terms of fish habitat (8,892 acres), and the second best in terms of fewer archaeological sites (17,784 acres). The worst choice for access route construction is the South Corridor which contains 31,616 acres of wetlands, 24,453 acres of fish habitat, and 30,381 acres of archaeological sites. These statistics support the choice of the North Corridor as the environmentally optimum corridor for a potential access route.

To further illustrate the environmentally optimum corridor, a hypothetical access route was "drawn" through the areas with least limitations. The route was drawn with the PUPDATE (polygon update) program. The program allowed the change of existing data elements (unsuitable, severe limitations, moderate limitations, and no limitations) to elements that represented an access route. A line of data elements, which passed through the more suitable regions, were changed to the new access route classification and assigned the color black. The route passes through the South Corridor to the Devil Canyon Dam site, the North Corridor to the Watana Dam site, and through the Denali Corridor to the Denali Highway. Within the Denali Corridor, the route could pass through either the west spur or the east spur. The east spur, however, contains a large area around Butte Lake of critical wildlife habitat, wetlands, and archaeological sites. Hence, the west spur would probably involve less environmental impact.

The statistics generated by the ERDAS 400 cannot be used to spatially delineate the critical limiting areas within each corridor. Hence, the access route that appears in Figure 10 diverges partially from the statistically preferred North Corridor. The automated GIS, however, allows the display and georeferencing of the limiting factors and the subsequent alignment of the access route to avoid critical fish habitat within Portage Creek and Indian River. Consequently, the environmentally optimum corridors include the South Corridor from Gold Creek to Devil Canyon and the North Corridor from Devil Canyon to Watana. The

Denali Corridor is the second choice for access to Watana and also provides access to the Denali Highway.

Engineering Limitations. The engineering limitations GIS file resulted from combining land cover, integrated terrain units, and slope limitations. To facilitate the selection of an access route corridor that maximized the technical ease of construction, Figure 11 was produced and statistics generated (Table 5). Figure 11 graphically depicts the engineering suitability of the Denali, North, and South corridors. The engineering suitability of the area was divided into four classes: no limitations, moderate limitations, severe limitations, and unsuitable for access route construction. Each class was a composite of land cover, terrain units, and slope limitations. Statistics generated for the GIS file indicated that the study area was primarily unsuitable for access route construction (64.7%). Furthermore, only 4.9% of the river basin contains areas of "no limitations" and 8.4% consisted of "moderate limitations."

TABLE 5: ENGINEERING LIMITATIONS

Data Value	Number of Points	Number of Acres	%	Description
0	5423	1340096.2	0.0	Background
1	148	36572.8	4.9	No Limitations
2	253	62519.7	8.4	Moderate Limitations
3	509	125780.7	17.0	Severe Limitations
4	1942	479894.3	64.7	Unsuitable
5	149	36819.9	5.0	Potential Route

TOTAL NON-ZERO POINTS = 3001
TOTAL NON-ZERO ACREAGE = 741587.5
(Percentages are based on NON-ZERO points.)

Clearly, the upper Susitna River basin will provide difficulties for access route construction. The difficulties include excessive slope, tundra and wetlands, poor drainage, permafrost, and soils with a high potential for erosion.

However, it is possible to minimize the technical difficulties of the engineering limitations by identifying and avoiding the most critical areas. These areas include Indian River and Portage Creek (excessive slope), Stephan Lake and the Fog Lakes (wetlands, extensive permafrost, and poor drainage), and Butte Lake (wetlands and permafrost). The georeferencing and display of the critical limitations assisted in locating an access route which avoided these areas.

Based on the statistics generated, the best corridor for the location of an access route from an engineering point of view is the North Corridor, with the Denali Corridor a close second (Tables 2, 6, and 7). The North Corridor contains the most acreage of terrain units containing "no limitations" (75,829 acres), while the Denali Corridor is ranked second with 59,774 acres and the South Corridor third with 45,942 acres. The North Corridor also contains the least amount of wetlands (6,669 acres compared to 7,657 acres in the Denali Corridor and 31,616 acres in the South Corridor). The Denali Corridor, however, contains only .09% more wetland acreage than the North Corridor and ranks a close second.

TABLE 6: INTEGRATED TERRAIN UNITS

Data Value	Number of Points	%	Description
0	5811	29.0	Background
1	215	5.8	Denali Corridor/Unsuitable
2	61	1.7	Denali/Severe Limitations
3	210	5.7	Denali/Moderate Limitations
4	242	6.6	Denali/No Limitations
5	421	11.4	North Corridor/Unsuitable
6	56	1.5	North/Severe Limitations
7	216	5.9	North/Moderate Limitations
8	307	8.3	North/No Limitations
9	475	12.9	South Corridor/Unsuitable
10	55	1.5	South/Severe Limitations
11	169	4.6	South/Moderate Limitations
12	186	5.1	South/No Limitations

TOTAL NON-ZERO POINTS = 3680
(Percentages are based on NON-ZERO points.)

TABLE 7: PERCENT SLOPE

Data Value	Number of Points	%	Description
0	5423	24.8	Background
1	33	.8	Denali Corridor/<5%
2	423	10.6	Denali Corridor/5%
3	112	2.8	Denali Corridor/10%
4	100	2.5	Denali Corridor/20%
5	24	.6	Denali Corridor/30%
6	17	.4	Denali Corridor/40%
7	161	4.0	Denali Corridor/>40%
8	47	1.2	North Corridor/<5%
9	246	6.2	North Corridor/5%
10	258	6.5	North Corridor/10%
11	156	3.9	North Corridor/20%
12	89	2.2	North Corridor/30%
13	119	3.0	North Corridor/40%
14	148	3.7	North Corridor/>40%
15	13	.3	South Corridor/<5%
16	288	7.2	South Corridor/5%
17	77	1.9	South Corridor/10%
18	73	1.8	South Corridor/20%
19	89	2.2	South Corridor/30%
20	146	3.7	South Corridor/40%
21	382	9.6	South Corridor/>40%

TOTAL NON-ZERO POINTS = 3989
(Percentages are based on NON-ZERO points.)

In terms of slope, the Denali Corridor contains the least amount of slope greater than 5% (102,258 acres compared to 189,449 acres in the South Corridor and 190,190 acres in the North Corridor). Consequently, the North Corridor is the optimum location for an access route in terms of land cover limitations and terrain unit limitations. In terms of slope, however, the Denali Corridor is the clear choice. Hence, the preferred corridor for access to the Susitna River basin from the west is the North Corridor. The Denali Corridor, with relatively flat terrain highly suitable for road construction, provides the best means for access from the north.

To further illustrate the preferred engineering corridor, a hypothetical access route was "drawn" through the areas of least limitations. The route enters the study area at Gold Creek in the South Corridor. At a point just past Indian River and Portage Creek, the route passes into the North Corridor and continues on to the Watana Dam site. From Watana, the route exits the study area at the Denali Highway.

The access route that appears in Figure 11 diverges partially from the statistically preferred North Corridor. This situation was similar to the Engineering Limitations data file where the statistics did not allow the spatial georeferencing of the limitations. Examining Figure 11 reveals that the North Corridor has a concentration of engineering limitations around Portage Creek and Indian River (the northwest corner of the study area). This is due primarily to the steep-walled canyons of the two rivers. Access route construction through this area would be very difficult, requiring significant amounts of blasting and earthwork. The South Corridor, although statistically the worst corridor from an engineering aspect, concentrates its limitations in the Fog Lakes-Stephan Lake region (the southeast corner of the study area). Hence, the South Corridor provides the optimum access route location from

Gold Creek in the west to a point past the Portage and Indian River Valleys. The route then travels into the North Corridor for the section between Devil Canyon and the Watana Dam site. The Denali Corridor, which statistically ranked second to the North Corridor, provides a suitable route to the Denali Highway in the North.

Consequently, the GIS, in georeferencing the critical limiting factors, allowed an alignment of the access route that takes advantage of the preferred North Corridor, the second-ranking Denali Corridor, and also the suitable western section of the South Corridor. The engineering preferred corridors were: the South Corridor from Gold Creek to Portage Creek, the North Corridor from Portage Creek to Watana, and the west spur of the Denali Corridor to the Denali Highway.

Economic Limitations. The economic limitations GIS file resulted from combining engineering limitations (terrain units, slope, and land cover), and land ownership limitations (private, native, state, and federal preferences). Areas of economic limitations were considered to contain: 1) unsuitable engineering limitations requiring expensive construction techniques, and 2) areas that did not satisfy the various land owners and their preference for access route location.

Figure 12 depicts the economic suitability of the proposed access corridors. The GIS file contains four limitation classes: no limitations, moderate limitations, severe limitations, and unsuitable for access route construction. The statistics (Table 8), produced from the file are similar to the engineering limitations GIS file with only 1.8% (13,344 acres) of the area being classified as having "no limitations." The majority of the area (64%, 477,917 acres) is classified as "unsuitable" for access route construction. This is a result of the extensive engineering limitations within the study area.

TABLE 8: ECONOMIC LIMITATIONS

Data Value	Number of Points	Number of Acres	%	Description
0	5423	1340096.2	0.0	Background
1	54	13344.1	1.8	No Limitations
2	392	96868.5	13.1	Moderate Limitations
3	477	117873.1	15.9	Severe Limitations
4	1934	477917.4	64.5	Unsuitable
5	144	35584.3	4.8	Potential Route

TOTAL NON-ZERO POINTS = 3001
TOTAL NON-ZERO ACREAGE = 741587.5
(Percentages are based on NON-ZERO points.)

Based on the statistics generated, the optimum corridor for engineering purposes was the North Corridor. However, the addition of land ownership variables and socioeconomic preference modifies the selection of the optimum corridor. The most important landownership variables consisted of private land holdings, native land holdings, and the Denali

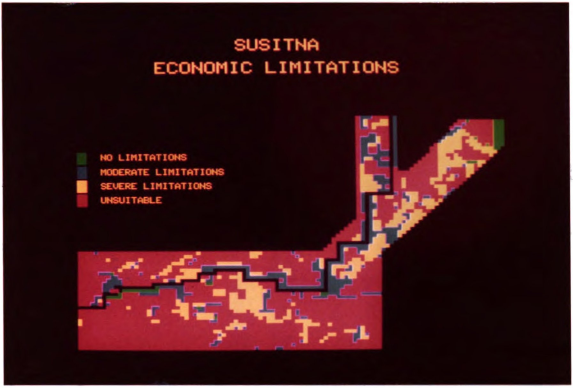

FIGURE 12. ECONOMIC LIMITATIONS

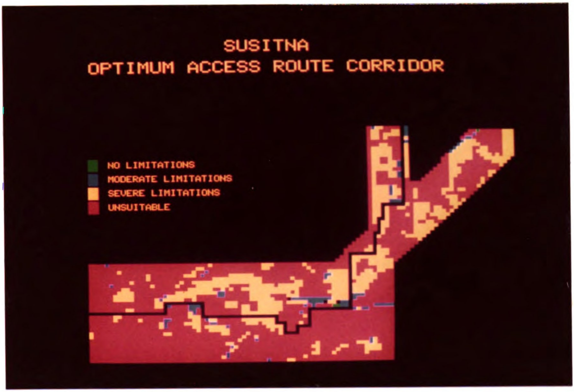

FIGURE 13. OPTIMUM ACCESS ROUTE CORRIDOR

State Park. The private landowners in the river basin have expressed a strong preference for maintaining their present limited access and do not want an access route in close proximity. Furthermore, the state wishes to avoid any construction impacts in the Denali State Park. A third consideration concerns the native corporations preference for access to their extensive land holdings along the south side of the Susitna River. All of these factors were considered in the GIS.

The optimum access corridor from a land ownership perspective was one that contained the least private and state park land as well as providing access to native land. Table 9 illustrated that the Denali Corridor had the least private land (741 acres compared to 11,115 acres in the South Corridor and 14,573 acres in the North Corridor). Also, both the Denali Corridor and the South Corridor contained no land within Denali State Park (the North Corridor contains 13,585 acres).

TABLE 9: LAND OWNERSHIP

Data Value	Number of Points	%	Description
0	5557	53.1	Background
1	652	15.2	Denali Corridor/Federal
2	81	1.9	Denali Corridor/State
3	0	0.0	Denali Corridor/Native
4	3	0.1	Denali Corridor/Private
5	0	0.0	Denali Corridor/Park Land
6	3	0.1	North Corridor/Federal
7	747	17.4	North Corridor/State
8	199	4.6	North Corridor/Native
9	59	1.4	North Corridor/Private
10	55	1.3	North Corridor/Park Land
11	0	0.0	South Corridor/Federal
12	524	12.2	South Corridor/State
13	499	11.6	South Corridor/Native
14	45	1.1	South Corridor/Private
15	0	0.0	South Corridor/Park Land

TOTAL NON-ZERO POINTS = 4288
(Percentages are based on NON-ZERO points.)

The South Corridor, which contained 123,253 acres of native owned land (compared to 49,153 acres in the North Corridor and zero in the Denali Corridor), provided maximum accessibility to the native land. Consequently, the preferred economic corridors were the Denali Corridor, for limiting impacts to private and state land; and the South Corridor for providing access to native land.

However, the display of Figure 12 and the hypothetical access route indicated that the preferred corridors were the North and the Denali. Hence, the route again diverged from the statistical optimum. In Figure 12, the hypothetical access route passes from Portage Creek to the Watana Dam site in the North Corridor. This was a result of the engineering difficulties in the Fog Lakes-Stephan Lake region (the southeast corner of the study area). The route, however, travels along the border of the Susitna River and the South Corridor. This would provide relatively easy access to native land on the south side of the Susitna River. Consequently, the georeferencing and display of the limiting factors has allowed an improved alignment of the access route. The final alignment is more sensitive to the various limiting factors of landownership and slope then the statistics would allow. The visual aspect of the GIS assisted in the selection of the optimum access route corridors.

Optimum Access Route Corridor. The final GIS file illustrates the overall preferred access corridor (Figure 13). The file is a combination of environmental limitations (land cover, wildlife habitat, and cultural resources), engineering limitations (integrated terrain units, slope, and land cover), and economic limitations (land ownership and engineering limitations). The data is divided into four classes: no limitations, moderate limitations, severe limitations, and unsuitable for access route construction.

Based on Table 10, the majority of the study area is unsuitable for access route construction (68%). This is a result of the severe environmental limitations (anadromous fish habitat and wetlands), the unsuitable terrain units (permafrost, poor drainage, high erosion potential, and poor soils), and the unsuitable cultural resource limitations (existing archaeological sites).

TABLE 10: OPTIMUM ACCESS CORRIDOR

Data Value	Number of Points	Number of Acres	%	Description
0	5426	1340837.6	0.0	Background
1	3	741.3	0.1	No Limitations
2	90	22240.2	3.0	Moderate Limitations
3	717	177180.3	23.9	Severe Limitations
4	2040	504111.4	68.0	Unsuitable
5	148	36572.8	4.9	Potential Route

TOTAL NON-ZERO POINTS = 2998
TOTAL NON-ZERO ACREAGE = 740846.1
(Percentages are based on NON-ZERO points.)

The objective of the analysis was to select a corridor that provided the least limitations and minimized construction impacts. Hence, the hypothetical access route in Figure 13 passes through areas of least limitations. However, the route appears to deviate and pass through areas of severe limitations. This is a result of some areas of moderate limitations being only one cell in diameter. When the access route (which was one cell in diameter) passed through these cells, the original data classification was concealed. Thus, the black access route appears to deviate and pass through unsuitable regions when in reality, the route actually passed through data cells of "moderate limitations."

The route mapped in Figure 13 enters the study area at Gold Creek in the South Corridor, then follows the Susitna River to a point past Portage Creek. Once past the severe topography of Portage Creek, the route crosses into the North Corridor. At this point, the route closely follows the Susitna River to the Devil Canyon Dam site and then on to the Watana Dam site. From Watana, the route heads north through the west spur of the Denali Corridor to the Denali Highway.

The route identified in the "Optimum Access Corridor Location" GIS file closely resembles the routes in the environmental, engineering, and economic limitations GIS files. In all files, the areas around Indian River and Portage Creek were avoided, as was the Fog Lakes-Stephan Lake region. These areas represented the worst limitations in the study area, including anadromous and resident fish habitat, wetlands, and archaeological sites. The Portage Creek and Indian River Valleys also contain the greatest relief in the study area. The route mapped in Figure 13 also avoids the critical areas around Deadman and Butte Lake. These regions contain a high concentration of archaeological sites and resident fish habitat. Land ownership variables were also accommodated, with the final access route location in close proximity to the south side of the Susitna River and the native landholdings.

Based on the statistics generated and Figure 13, it is apparent that the Susitna River basin is not a suitable location for an access route. Much of the area consists of limitations unsuitable for road construction. However, if roads are to be constructed for the Susitna Hydroelectric Project, it is essential that the worst areas be avoided. The spatial georeferencing and combination of the various engineering, environmental, and economic limitations allowed the location of an access route that avoided the critical areas and illustrated the optimum combination of corridors.

CHAPTER V

SUMMARY AND CONCLUSIONS

Summary of the Research

The objective of this study was to provide an optimal method of analyzing the proposed Susitna access corridors which incorporated the diverse factors encountered in the previous Alaska Power Authority investigation. The study utilized an automated geographic information system to combine environmental, engineering, and economic factors within a computerized data base. The data base was inserted into a GIS which allowed the spatial georeferencing, analysis, and display of the data in a manner which facilitated the selection of the preferred access corridor.

Alaska's Railbelt region contains a rapidly growing population with an equally increasing demand for electric power. The waters of the upper Susitna River were first identified as a potential hydroelectric power source in 1940. By 1979, the Alaska Power Authority had begun detailed studies investigating the feasibility of the project. At the present, the plan calls for two dams: the Watana Dam and the Devil Canyon Dam. Both structures will require the introduction of massive amounts of cement, reinforcing steel, and hundreds of construction workers into the previously inaccessible upper Susitna River basin.

A major limiting factor to the development of the Susitna River basin has been access. Historically, inaccessibility has rendered it economically impractical to exploit the area's resource base.[39] The construction of the Watana and Devil Canyon Dams will require a significant change in access to the river valley. The vast amount of construction materials, workers, and the strict schedule require that access be provided to the dam sites as soon as possible. Hence, the Alaska Power Authority began detailed studies of the basin's access potential and three potential corridors were identified. The task was then selecting an access corridor which would provide a minimum of cost and impacts for the construction of an access road. The APA analysis of the access corridors was lengthy and complex. The study was complicated by the large size of the area and by conflicting interests. The APA eventually selected the Denali and South Corridors but concluded that due to the diverse factors involves, no one plan would satisfy all the requirements.

The length of the APA study and the number of various agencies involved contributed to a time consuming and costly decision process. In consideration of these factors and the characteristics of the access corridor situation, the general hypothesis of this study stated that:

1. The proposed computer-assisted GIS method of analysis of the Susitna access corridors will incorporate all competing environmental, engineering, and economic constraints in one study. In so doing, the methodology will provide a more efficient (less time and cost), holistic approach to access corridor selection than the previous APA studies.

Conclusions

One component of the general hypothesis in this study examined the ability of the automated GIS to satisfy the various competing interests encountered in the APA investigation. In order to test the hypothesis, several sub-hypotheses were set forth. The first examined the ability of the GIS to readily identify the environmentally preferred corridor, the engineering preferred corridor, the economically preferred corridor, and the overall preferred corridor. A series of color maps were produced on the ERDAS 400 as well as statistics generated. Each map represented the best access route corridor for each of the competing interests. As a result, it was possible to "draw" a hypothetical access route through the corridors in a manner that minimized environmental, engineering, and economic impacts.

The final map and photograph illustrated the optimum combinations of corridors necessary for access route location. The route included the southwest portion of the

South Corridor, the eastern half of the North Corridor, and the west spur of the Denali Corridor. Although the study area as a whole was found to be not suitable for access road construction, the statistics generated and the georeferencing of the data allowed the final access route to avoid the critical limiting areas in the river basin. Consequently, the use of the GIS was determined to be adequate in satisfying the competing economic, environmental, and engineering concerns.

A second component of the general hypothesis tested the ability of the automated GIS to be a more efficient, holistic approach to access corridor selection. A sub-hypothesis was set forth in order to test the ability of the GIS analysis output to facilitate the decision process. The previous APA study culminated in the selection of an access route. However, the investigation concluded that due to the diverse factors, no one plan would satisfy all the requirements.

The access corridor selected by this study was similar to the optimum corridor selected by the APA. However, the methodology used to arrive at this conclusion was quite different. The APA investigation included various sub-contractors and required roughly three years to be completed. As a result of this investigation, nine separate studies and volumes of data were produced, each concerning a different aspect of the access corridor problem. The objective of this study was to design a method of access corridor selection that synthesized the large volume of data and produced graphic output that could assist in the decision process. Previous research (Frazier et al., 1979) has recognized the effectiveness of simultaneously evaluating georeferenced data in regional planning decisions. Consequently, this method presents, in one study, the optimum access corridor for each competing economic, environmental, and engineering interest. The automated GIS allows the display of each interest individually, a feature valuable in the decision process. Hence, the synthesis of environmental, engineering, and economic factors in this study has resulted in a more efficient, holistic approach to access corridor selection.

A third sub-hypothesis was set forth in order to test the method's ability to provide a cost-efficient means of access corridor analysis. Krebs (1982) has stated that a major problem for resource managers in Alaska was the nonexistent or insufficient inventory data for large, remote areas. Krebs also stated that the means for achieving this data was often expensive and time consuming.[40] The APA investigation of the Susitna access corridors was time intensive and costly.[41] Hence, this study was designed to be cost and time efficient. Although comparisons with the previous studies are invariably subjective, conclusions can be drawn as to the length and relative cost of the studies.

The GIS analysis of the Susitna access corridor required eight weeks to complete. Each stage of the analysis required an average of 1.5 weeks for one person. Furthermore, the use of an automated GIS is generally not expensive. The analysis required 51 hours on a digitizer, an IBM XT personal computer, and the ERDAS 400 microcomputer. The hourly rate for the computer facilities brought the total computer cost to $130.00. Other costs involved in the analysis included mylar for the base maps, eight inch computer disks, and film processing. The total cost of the analysis excluding personnel time was under $300.00.

Comparisons of this study's cost to that of the APA is entirely subjective. Many factors are not accounted for, such as the cost of acquiring the computer equipment and the cost of data acquisition. However, it is clear that the use of an automated GIS can be cost-efficient and not time-intensive.

Areas for Further Research

The methodology outlined in this study was designed for access corridor selection. One goal for continuing research would be to refine the methodology in order to investigate the specific access routes themselves (subsequent to the corridor investigation). To accomplish this, several areas within the GIS analysis should be improved. The first involves the selection of scale. The base scale of

1:250,000 for this study was chosen for two reasons: 1) to provide a reconnaissance level "screening" of the Susitna access corridors, and 2) to provide a framework into which more detailed inventories can be placed. Further refinement of this methodology to include access route selection would require a larger scale (1:63,360 or greater). A study of this nature would contain the more detailed information necessary for access route analysis. A second refinement to the study would be the choice of a smaller cell size. This study utilized a cell size of 1 cell = 1 kilometer. Hence, the smallest area distinguished in the analysis was one square kilometer. This relatively large size was appropriate for the scale and detail of the information. However, a larger base scale and its resulting increase in information would be better represented by a smaller cell size (1 acre or hectare). This would entail dividing the digitization and analysis of the data into subsections in order to incorporate the greater amounts in information. However, the detail afforded by this level of data would be necessary for an analysis of specific access routes.

Another portion of the study which might be expanded is the ERDAS analysis. The software routines utilized in this study (MATRIX and OVERLAY) were adequate for identifying and displaying potential economic, environmental, and engineering factors. However, several other routines are available which could be used to expand the analysis. These programs include SEARCH (performs a proximity analysis of specified variables), and INDEX (which allows the specific weighting of the variables in analysis combinations). SEARCH would be valuable in a larger scale analysis such as access route analysis, where zones of avoidance could be established around anadromous fish streams. INDEX would be valuable in various overlay combinations where the specific weights of certain variables are required. The weights assigned, however, would require extensive, detailed research in support.

Investigating the potential of an automated geographic information system for access corridor selection is an important area of research. The use of an automated GIS allows the integration of large, complex data sets into a computerized data base which can serve both as a "superstructure" for the efficient storage and retrieval of data as well as for systematic applications to land planning and management functions.[42] Establishing the utility of the GIS in assessing route location can be of help to other areas of research such as transmission line routing, recreation trail location, and pipeline location. The decision process in selecting a transportation route can be time consuming and involve large quantities of data. Often, the analysis of transportation corridors involves conflicting characteristics such as environmental, engineering, and economic variables. The geographic information system can provide the means for synthesizing the diverse data and spatially georeferencing it into a solution that can facilitate the decision process. Furthermore, geographic information systems are frequently used as a framework into which more detailed inventories are placed. Consequently, this study will facilitate further analysis of the Susitna access corridors by accepting more detailed information.

FOOTNOTES

FOOTNOTES

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APPENDICES

APPENDIX A

LAND COVER CATEGORIES

1.	FOREST	Open mixed forest Closed mixed forest Open birch forest Closed birch forest Woodland white spruce Woodland black spruce Open white spruce Balsam poplar
2.	SHRUB	Willow shrub Low shrub Birch shrub Tall shrub
3.	TUNDRA	Sedge grass tundra Mat and cushion tundra
4.	WATER	Lake River
5.	GRASSLAND	Grassland
6.	WETLANDS	Open black spruce Wet sedge grass
7.	ROCK/SNOW	Rock Snow/ice

Source: Terrestrial Environmental Specialists, *Susitna Hydroelectric Project - Environmental Studies, Subtask 7.14*, *Environmental Analysis of Alternative Access Plans*, prepared for Acres American, Inc., and the Alaska Power Authority, October 1981.

APPENDIX B

TERRAIN UNITS

SYMBOL		NAME
1.	BXU	consolidated, unweathered bedrock
2.	C	colluvial deposits
3.	Cl	landslide deposits
4.	Cs-f	solifluction deposits
5.	Ffg	granular alluvial fan
6.	Fp	floodplain deposits
7.	Fpt	terrace
8.	GFo	outwash deposits
9.	GFe	esker deposits
10.	GFk	kame deposits
11.	Gta	ablation till
12.	Gtb-f	basal till (frozen)
13.	O	organic deposits
14.	L-f	lacustrine (frozen)
15.	L/Gta	lacustrine sediments over ablation till
16.	L/Gtb-f	lacustrine deposits over basal till
17.	Cs-f/Gtb-f	solifluction (frozen) over basal till
18.	Cs-f/Gta	solifluction (frozen) over ablation till
19.	Cs-f/Fpt	solifluction (frozen) over terrace sediments
20.	Cs-f/Bxu	solifluction deposits (frozen) over bedrock
21.	Gta-f/Bxu	frozen basal till over bedrock
22.	Gta/Bxu	ablation till over un-weathered bedrock
23.	C/Bxu + Bxu	colluvium over bedrock
24.	C/Bxu + Bxw	colluvium over weathered, unconsolidated bedrock

Source: R and M Consultants, Inc., Susitna Hydroelectric Project, Access Planning Study, prepared for Acres American, Inc., and the Alaska Power Authority, January 1982.

APPENDIX C

TERRAIN UNIT CHARACTERISTICS

1. Probable unified soil types: GP, GW, GM, SW, SM, ML, SP, PT, and OL.
2. Drainage and permeability in unfrozen soils: High, Good, Mod., Low, Poor, and Frozen.
3. Erosion potential: High, Moderate, and Low.
4. Ground water table: Deep, Mod. deep, Shallow, and Very shallow.
5. Probable permafrost distribution: Continuous, Discontinuous, Sporadic, and Unfrozen.
6. Frost heave potential: High, Moderate, Low, and Nil.
7. Thaw settlement potential: High, Moderate, Low, and Nil.
8. Bearing strength: Very high, High, Moderate, Low, and Very low.
9. Slope stability: High, Moderate, and Low.

Source: R and M Consultants, Inc., Susitna Hydroelectric Project, Access Planning Study, prepared for Acres American, Inc., and the Alaska Power Authority, January 1982.

APPENDIX D

ESTIMATED TOTAL CONSTRUCTION COST (1982)

Construction Cost: ($ x 1,000,000)

North Corridor	- road to Watana site = $ 241	
	- road to Devil Canyon site = $ 127	
	total cost = $ 368	
South Corridor	- road to Watana site = $ 312	
	- road to Devil Canyon site = $ 104	
	total cost = $ 416	
Denali Corridor	- road to Watana site = $ 224	
	- road to Devil Canyon site = $ 213	
	total cost = $ 437	

Note: Costs are in terms of 1982 dollars and include all costs associated with design, construction, maintenance, and logistics.

Source: Acres American, Inc., Susitna Hydroelectric Project - Feasibility Report Supplement, Final draft prepared for the Alaska Power Authority, March 1983, p. 4-7.

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