HISTORIC AIRBOAT USE AND CHANGE ASSESSMENT USING REMOTE SENSING AND GEOGRAPHIC INFORMATION SYSTEM TECHNIQUES IN EVERGLADES NATIONAL PARK

By

LOUIS MANGLASS

(Under the Direction of Marguerite Madden)

ABSTRACT

The National Park Service (NPS) has a mandate of restoration and preservation of the lands for which it is responsible. As part of this mandate, resource managers of Everglades National Park (ENP) must take stock of current commercial and private airboat activities in the East Everglades Expansion Area and assess the impact of airboat use on the Everglades wetlands. Remote sensing and geographic information system (GIS) techniques were used to create digital databases of airboat trails from current and historical aerial photographs. These data were then used to derive statistics and produce trail maps which were used to assess airboat impact over time. Graph theory and GIS network analysis of the temporal trail database provide managers with a set of tools which, when combined with proposed scenarios for future airboat use, provide powerful analysis capabilities to minimize the potential impacts of that use.

INDEX WORDS: Geographic information systems, GIS, Remote sensing, Everglades National Park, ENP, National Park Service, NPS, Airboat, Change assessment, Trail map, Aerial photography, ArcGIS

HISTORIC AIRBOAT USE AND CHANGE ASSESSMENT USING REMOTE SENSING AND GEOGRAPHIC INFORMATION SYSTEM TECHNIQUES IN EVERGLADES NATIONAL PARK

BY

LOUIS MANGLASS

B.S., The University of Georgia, 2002

A Thesis Submitted to the Graduate Faculty of the University of Georgia in Partial Fulfillment of the Requirements for the Degree

MASTER OF SCIENCE

ATHENS, GEORGIA

2006

HISTORIC AIRBOAT USE AND CHANGE ASSESSMENT USING REMOTE SENSING AND GEOGRAPHIC INFORMATION SYSTEM TECHNIQUES IN EVERGLADES NATIONAL PARK

by

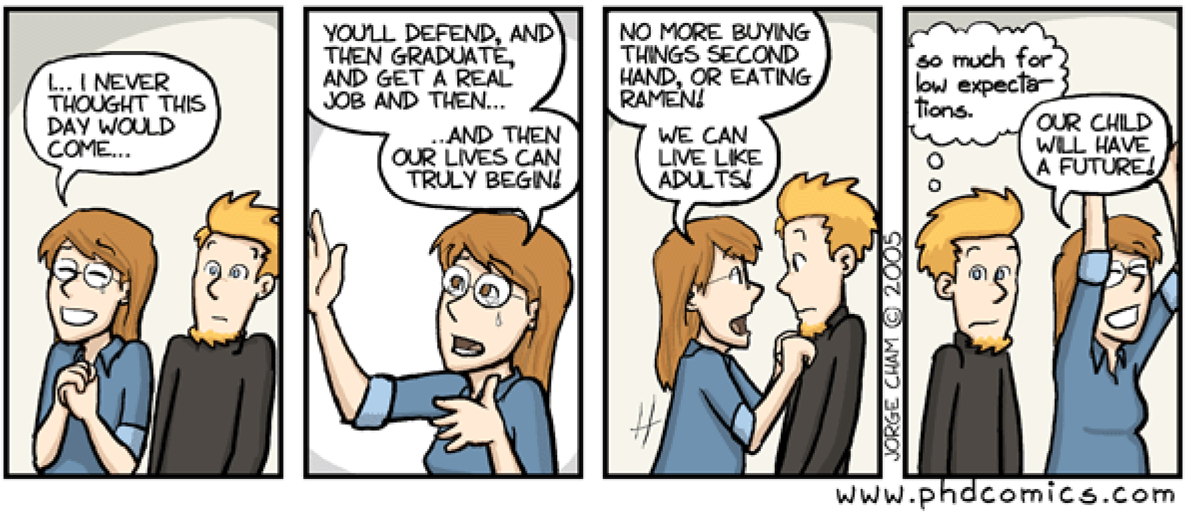
LOUIS MANGLASS

Major Professor: Marguerite Madden

Committee: Thomas R. Jordan
E. Lynn Usery

Electronic Version Approved:

Maureen Grasso
Dean of the Graduate School
The University of Georgia
August 2006



"Piled Higher and Deeper" by Jorge Cham
www.phdcomics.com

ACKNOWLEDGEMENTS

First, I would like to thank my family because they refused to let me quit my master's degree program. I never in my wildest dreams thought I would ever finish this project. This document is proof that I lost that bet.

I would like to thank my advisor, Dr. Marguerite Madden, and my committee members Drs. Thomas Jordan and E. Lynn Usery for their support and comments throughout this project. I would also like to thank the Center for Remote Sensing and Mapping Science (CRMS) and the National Park Service (NPS) for all their help and funding. The scope of this research project would simply have been far too large without their support, especially the ability to perform ground truthing with knowledgeable Park Service personnel. Furthermore, I would like to thank the South Florida Water Management District (SFWMD) for providing the CRMS and myself with access to the 2003 true color photography used in this study. Their support made it much easier to bring the study up to date.

TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

CHAPTER 1

INTRODUCTION

Everglades National Park (ENP) in South Florida is one of the oldest National Parks in the United States. Designated on 6 December 1947, ENP bounds roughly 607,000 hectares of wetlands that are unique in the world and have been designated a World Heritage Site (NPS 2005a). Throughout its history, however, the park has been subject to human encroachment. People have settled around the park, introduced exotics, caused hydrological diversions and pursued recreational activities such as hunting and airboat use that have potential impacts on the natural environment.

In an effort to protect the Everglades ecosystem and provide a buffer between the wetlands and agricultural/developed lands, the Everglades Expansion Act of 1989 legally added the East Everglades Expansion Area to the northeast corner of the ENP. However, the roughly 44,000 hectare area was still held by private and public interests. On 1 October 1991, the State of Florida donated Chekika State Park to the ENP, yet literally several thousand tracts remained in small (a few hectares) private holdings that were mandated to be sold to the National Park Service (NPS). Over the years, individual parcels were thus added to the Expansion Area.

Enforcement of Federal land laws was difficult during this time on these small patches of nonadjacent Park lands because activities such as hunting were technically still legal on the interspersed privately-held lands. Many of these smaller tracts eventually required lengthy and expensive legal action to obtain, including condemnation of the land by the government. By early 2002, nearly 99 percent of the lands finally had been acquired, but some tracts are still awaiting acquisition because of legal proceedings. Today, people who historically pursued cultural activities in the East Everglades Expansion Area such as hunting, camping and piloting airboats are discovering that enforcement of Federal laws is restricting their activities, causing some conflicts of interest and a need for formalized management strategies.

The ENP, as a unit of the NPS, has a mandate for restoration and preservation of the lands for which it is responsible, and part of this mandate for the East Everglades Expansion Area includes taking stock of current commercial and private airboat activities and assessing their impacts on the land. It is up to the NPS resource managers and planners to evaluate the historical practices of airboaters and to determine if those activities can continue without damaging ENP natural areas. Unfortunately, many local people feel their rights as citizens are being restricted, while others believe the NPS is failing to preserve the public trust lands. To this end, human activities such as airboat and off-road vehicle (ORV) use in the East Everglades Expansion Area must be assessed, historically as well as currently, and the relevant data on airboat impacts must be categorized and summarized so appropriate decisions can be made.

Remote sensing and geographic information system (GIS) techniques can be used to create digital databases of airboat use from current and historical aerial photographs flown over the East Everglades, and these data can be used to derive statistics and produce trail maps which can be used to assess airboat impact over time. Such information will allow managers to propose guidelines for future airboat use.

Since ownership and policies have changed as the ENP has acquired the Expansion Area land, assessing the impact of airboat use will require a study of the trends of past use. Furthermore, there must be a baseline to which the changes can be compared. This study will cover a nine year time period at three specific years: 1994, 1999 and 2003. These dates were selected because aerial photographs are available for these years and they satisfy the requirements to measure trends and impacts of historic airboat use in the East Everglades as policies have changed.

These trail databases are part of a cooperative agreement between the Center for Remote Sensing and Mapping Science (CRMS) at the University of Georgia's Department of Geography and the NPS to help ENP resource managers determine the extent of airboat impact and its change over time. To this end, I have been responsible for overseeing the integration of the trail maps digitized by several photointerpreters, have participated in digitizing some of the trails and helped to conduct an accuracy assessment flight over the study area. The objective of this study is to analyze the trail database for trends in historical airboat use and apply graph theory and GIS network procedures to perform an analysis of airboat traffic and impact in the East Everglades Expansion Area.

Specific objectives of this thesis include: 1) Assess changes in airboat use over time from overlay analysis of multitemporal trail data; 2) Use network analysis tools to demonstrate patterns of airboat use, change and patterns that are not immediately evident from the large amount of available data, and; 3) Establish airboat trail scenario networks that can be used by ENP resource managers to compose management policies that will maximize preservation efforts while allowing an acceptable level of airboat use in the park by private and commercial interests.

Study Area

The East Everglades Expansion Area, covering roughly 44,000 hectares, was purchased from many private landholders in the north east corner of the ENP and east of the Big Cypress National Preserve. It is bounded on the north end by US 41/Tamiami Trail and on the east end by various private holdings in Homestead (Figure 1). The north end of the Expansion Area, extending roughly to Grossman's Ridge, is part of the natural flow of water from Lake Okeechobee toward the Gulf of Mexico. This area is characterized by slow-moving

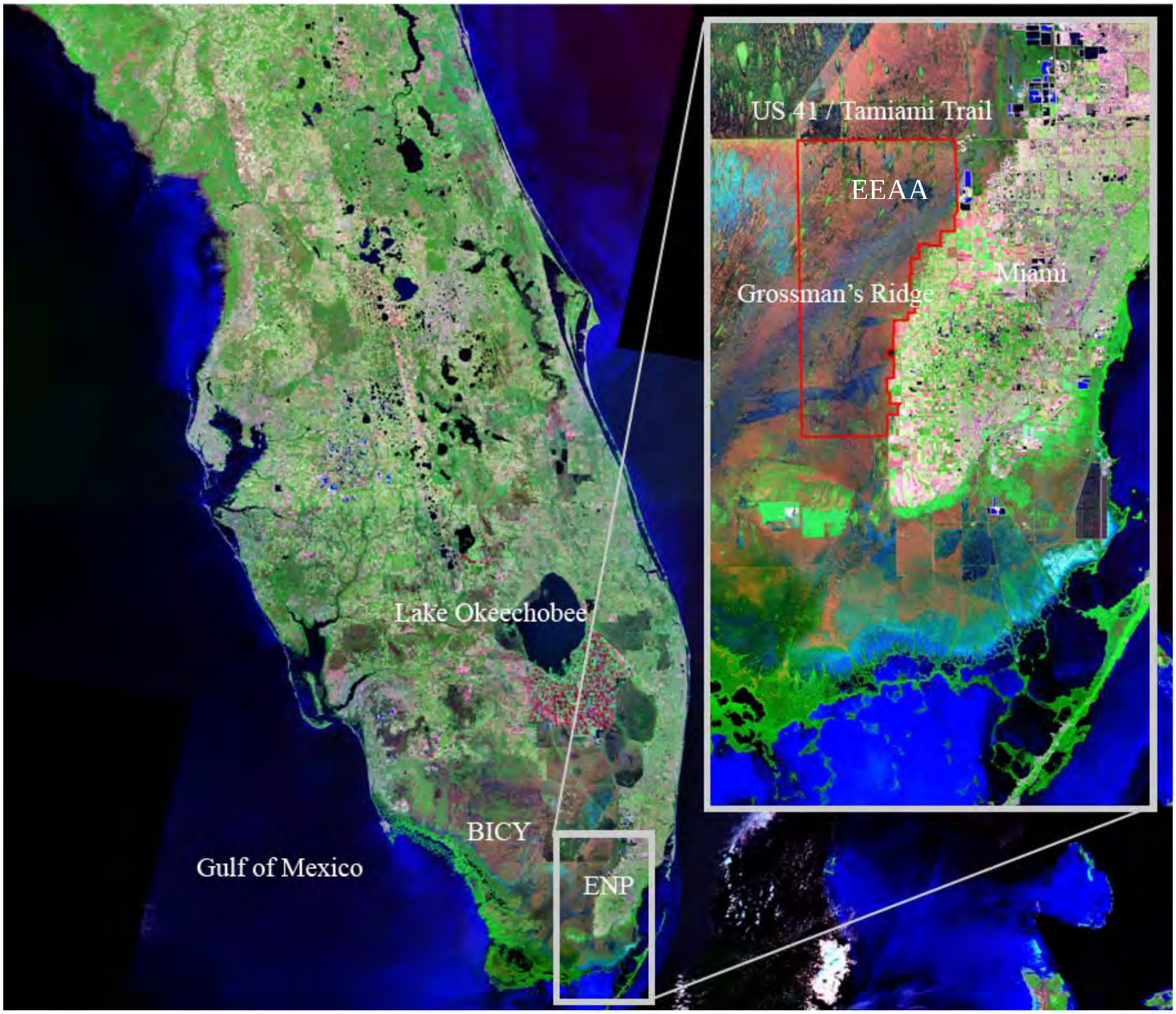


Figure 1: Location of the East Everglades Expansion Area (outlined in red)

water (approximately 30 m per day) from mere centimeters to one meter deep over a bed of limestone and its resulting eroded soils (Myers and Ewel 1991). The water flows through vast areas of wetland, locally known as prairies and marshes. The East Everglades Expansion Area is technically in the temperate climate zone, but is affected by the Gulf Stream, tropical trade winds and its subtropical latitude. As a result, it has near-tropical highs during the warm, wet season from May to November and near-freezing lows in the cold, dry season the rest of the year.

Figure 2: Airboats

Rainfall ranges from roughly 75 to 305 centimeters annually. The land is very flat, roughly three meters above sea level, and it has a very gentle slope of a few cm from the north to the south end of the Expansion Area (Tebeau 1968). The slow-moving water covers much of the soils during the wet season, and the constant cycling provides a rich mucky (25-65 percent organic matter) to peaty (more than 65 percent organic matter) soil that covers a limestone substrate.

Historically, Lake Okeechobee would overflow its southern banks during the wet season, providing more water to the Everglades system. However, many canals and dams have been constructed throughout the 1900s, and currently the flow of water from Lake Okeechobee through the East Everglades is regulated by the dams along Tamiami Trail. Water delivery totals were set by Congress to mimic natural wet-dry seasons, with water delivery picking up from May through August, reaching their peak in October, and settling back down by January when Lake Okeechobee would have settled to stable levels (Davis and Ogden 1994).

The Shark River slough is the primary source of this slow-moving water to the Everglades National Park. It flows southwards along the northeastern edge of the park and is largely found in the west end of the East Everglades Expansion Area. Throughout the slough are tree islands, where bits of organic matter could not be suspended by the slow-moving water and instead provided an obstruction which collected more organic matter (Myers and Ewel 1991).

Eventually these obstructions developed into areas of slightly higher ground and provided drier substrate for shrubs and trees to grow. Over time, a tear-shaped island whose major axis and elevation grow as the tree island is created. Tree islands in East Everglades are generally on the order of hundreds of meters long and several meters tall, providing a habitat for land mammals such as deer. Archaeological evidence indicates that the north ends of the islands were historically used by Native Americans dating back nearly two thousand years. Since the early 1920s, the islands were purchased and used, sometimes even settled by hunters who built small hunting camps or houses. The area has historically been used by private airboaters for hunting and camping, as well as other recreational purposes, except when low water levels prevent airboat operation (Tebeau 1968). Commercial operators also have used this area, providing ecotourism opportunities with larger versions of the standard private airboats. On the east and southern end of the East Everglades Expansion Area, the water level is lower and the land in the far southeastern end is above water level by a few meters (Myers and Ewel 1991). Airboat use is precluded in this area, though off-road vehicles (ORVs) are used for transportation and recreation.

Figure 3: Airboat trail

Development of South Florida started in the early 1800s when canals were dug in an attempt to drain the lands. However, a lack of understanding prevented the attempts from being successful until the first decade of the 20th century. This new land was used for agriculture and inspired the beginning of an immigration of residents and tourists to South Florida. This led to expanded development operations and even the construction of a railroad to facilitate transportation. Unfortunately, the natural water flow through the wetlands of South Florida was greatly disturbed and there was heavy ecological damage from both the disturbance of the water flow and the development itself. In 1948, the development accelerated even more as Congress created the Central and South Florida Project, overseeing the construction of roads, canals, levees and other water-control structures. The project worked both for and against the ENP as it provided protection and water for certain areas of the park while degrading the natural system and further impeding the natural water flow (Davis and Ogden 1994).

In 1972, the Florida legislature passed several environmental laws including the Land Conservation Act, which allows the sale of bonds to provide a source of funding for the protection of environmentally endangered and recreational lands. This set the stage for recovery efforts. Next, Florida Governor Bob Graham started the “Save Our Everglades program” with the South Florida Water Management District (SFWMD) in 1983. The program, which finished in 2000, restored a 23,300 square kilometer area including both the ENP and some areas which have since been acquired. This was assisted by a set of laws passed in 1985 and the Surface Water Improvement and Management Act (SWIM), passed in 1987, all of which established policies involving the protection and restoration of wetlands and bodies of water. The SWIM plan for the ENP, however, caused the Federal government to initiate litigation against local government bodies. When the lawsuit was settled in the early 1990s, the Federal government took a more active role in the ENP, establishing the South Florida Ecosystem Restoration Task Force in 1993 and expanding it in 1996. Part of this Task Force involved the U.S. Army Corps of Engineers, which was authorized to develop a plan to restore and preserve the natural ecosystem and water flow of South Florida, which was presented to Congress in July 1999 (Davis and Ogden 1994).

These restoration efforts, especially the South Florida Ecosystem Restoration Task Force, were either important to raising awareness for the East Everglades or partially a result of the purchasing program to recover the area. Its heavy use by airboaters for hunting and recreation, coupled with decades of unnatural water management, requires Federal intervention to recover. However, for landscape managers to make appropriate management policies they must be properly informed about the extent of the impact of the activities on the landscape, particularly airboat use. By mapping historic airboat trails and providing an analysis of historic impact patterns, the impacts of airboat use can be analyzed and integrated into the decision process regarding management policies for the East Everglades Expansion Area.

CHAPTER 2

LITERATURE REVIEW

The field of mathematics provides some very foundational ideas upon which every GIS operates. For example, the French mathematician and philosopher of the 17^{th} century, René Descartes, formalized the Cartesian Coordinate system, which is the basis of many coordinate systems used in GIS. Analytic, or coordinate, geometry allows us to define the distance between objects in Cartesian coordinate space. Trigonometry and linear algebra provide us with the necessary tools to rectify aerial photographs and perform photogrammetric measurements. It should come as no surprise, then, to say that mathematics can be applied in new ways to geographic information to organize it, expose new patterns and provide optimal solutions to research questions which would otherwise be infeasible to determine.

Network analysis, however, is not a coordinate-based problem. Instead, it is based on connections between points, or nodes, which may represent endpoints or simply other connections. Many of the problems that network analyses propose to solve can be reduced to traversing this collection of segments and nodes, or a network, in a particular way. In a GIS, this is often done with a vector layer or set of vector layers, where edges and nodes can be assigned values representing the impedance, or cost, of traveling the network. The network analysis tool then usually attempts to minimize these cost factors. Because of the nature of such a network, analysis operations can be understood by examining graph theory.

Graph Theory

Graph theory is the branch of mathematics which formalizes a non-coordinate approach to expressing the connectivity (or adjacency) of objects (known as vertices or nodes) by way of connections (known as edges). This abstract concept can be applied to many things people use every day: road, water and computer networks can all be seen as a collection of points (intersections, pipe junctions, faucets and computers) with connections between them (roads, pipes and network cables). The 19th-century German physicist, Gustav Kirkhhoff, refined graph theory to formalize the concept of trees, or special graphs that have no cycles (no way to go from a vertex **a** to other vertices and back to **a** without traversing some edge **E** more than once) (Harary 1969). He used this concept to develop a set of laws that are still used to analze electrical networks today. Cayley worked on trees at the same time Kirkhhoff did, but applied them to the field of chemistry to enumerate the isomers of saturated hydrocarbons, still an important contribution to organic chemists today (Harary 1969).

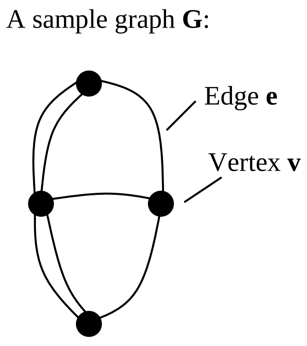


Figure 4: Graph example

While many components of graph theory are important to the study of networks such as the network of airboat trails in the East Everglades Expansion Area, the study of certain trees within this network can help determine how to protect the largest amount of land from airboat impact while permitting airboaters access to the areas they desire. Given that a subgraph **S** of a graph **G** is a graph that has all of its vertices and edges in **G**, a special subgraph of the airboat trail network can be found that has as its vertices all of the points of interest (docks/ramps, tree islands and tour locations, for example) whose edges (airboat trails) are found in the original trail network as well.

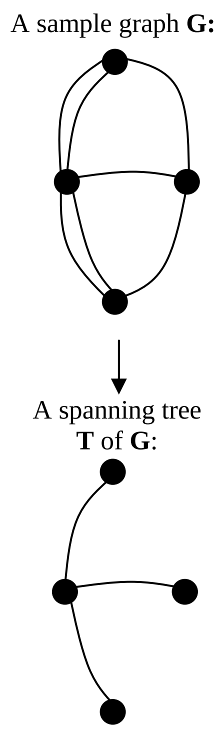


Figure 5: A spanning tree

Furthermore, a tree can be derived from this subgraph that connects every vertex. This tree is known as the spanning tree of the subgraph, and shows us one way to maintain access to the desired locations with as few trails as possible (Harary 1969).

The spanning tree itself is not very interesting, as it only serves to show that the locations of interest are connected, which is trivial to demonstrate. However, certain classes of trails may be preferable to keep open based on their trafficability and the permanence of their impact. It would be useful to determine if a given spanning tree can be generated from just these trails without sacrificing connectivity. In addition, the spanning tree itself is very limiting, since it is a tree and there are no cycles, or loops, and thus no redundant edges. A final trail network may require loops to prevent airboaters from traveling in different directions along the same path, or multiple trails to popular locations to avoid trail congestion. Such a trail network can be built from a spanning tree, balancing connectivity and sufficient traffic capacity with a limited level of impact.

A cut **C** of a graph **G** is a set which contains edges whose removal disconnects two parts of a graph (*i.e.*, segments a graph in such a way that there are two vertices **a** and **b** which are not connected). Similarly, a cutpoint **p** of **G** is a point which if removed will disconnect a graph. This principle can be applied to a set of points, **P**, which is necessary to cut a graph if there is no single cutpoint **p**. Such sets and points define vertices and/or edges which should be removed from a graph **G** to create a new graph **H**. This can be noted **G** - **C** = **H**. This can be used in a minimum-cut analysis, a branch of analyses that attempts to maintain the highest flow

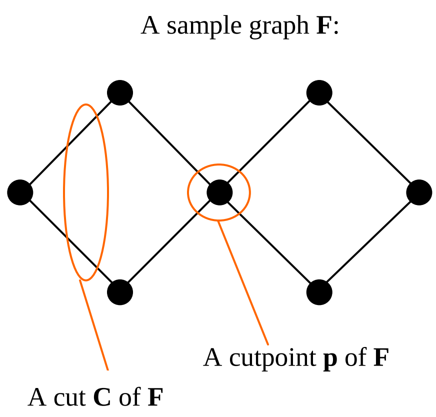


Figure 6: A cut and a cutpoint

rate through a network by cutting the least important edges, and in a cutpoint analysis to preserve crucial points or attempt to find redundancy in the parent graph should the area the point is in require special conservation efforts (Wilson 1996).

The minimum-cut analyses can be paired with the spanning tree to find a network that allows for maximum trafficability by airboaters while protecting the greatest extent of East Everglades Expansion Area wetlands and finding alternate routes around areas that need to be particularly protected. By extension, these techniques can be applied to any of the National Parks which are having issues with land management, such as Everglades National Park.

Motorized Recreational Activities in National Parks

The news is filled with reports of motorized recreational activity in National Parks conflicting with the mandate to protect those same spaces. A popular and well-reported example of this conflict occurs in Yellowstone National Park, where the cold winter climates and heavy snowfall are conducive to the recreational use of snowmobiles. On 6 March 2000, for example, CNN correspondent Natalie Pawelski reported that environmental groups had initiated a lawsuit against Yellowstone National Park which named snowmobiling as an active and intrusive source of noise pollution. Snowmobilers, on the other hand, argued that the sound of fellow snowmobilers instilled, "… an exhilarating feeling" (Pawelski 2000). Furthermore, snowmobile proponents argued that the animals were not bothered by the vehicles. Then Yellowstone National Park Superintendent, Michael Finley, countered that the bison were sometimes unbothered and sometimes disturbed, wasting energy that, "… is so important and valuable for them in the winter." In addition to the air pollution, Natalie Pawelski notes that Yellowstone National Park is a Class 1 "Airshed," a Federal designation indicating that the air quality must be protected (Pawelski 2000).

Ultimately, the problem in Yellowstone was not a small one. Pawelski (2000) estimates that roughly 55,000 snowmobiles enter the park each winter at the West Yellowstone entrance alone, and there were high enough carbon monoxide levels reported at the entrance booths that park personnel became sick and additional mechanical ventilation had to be added. Pawelski further states that 78 percent of the park's carbon monoxide emissions and an amazing 94 percent of its hydrocarbons come from the snowmobiles, "… leaving a smelly blue haze in their wake," and that the Environmental Protection Agency (EPA) said the park should ban all snowmobiles, "… until the air quality situation improves" (Pawelski 2000).

Snowmobiling, however, is not simply a recreational activity that is enjoyed by some park visitors: it is a large part of the economy for bordering towns and a source of income for many entrepreneurs. A search with the popular Internet search engine, Google, using the keywords "yellowstone snowmobile" will return dozens of sites dedicated to recreational activities in Yellowstone including snowmobiling and snowmobiling tours in National Parks. Not only is the issue a large one in Yellowstone, but it also is present in many other National Parks, though their use had been limited at most parks in some fashion. In November 2000, the NPS moved to put a three year phase-out of snowmobiles from Yellowstone and Grand Teton National Parks. It was opposed by local snowmobile operators, and a study estimated that such a ban would cost the region $16.5 million in lost revenue and 400 jobs. The International Snowmobile Manufacturers Association, the state of Wyoming and groups of outdoor enthusiasts filed a suit against this ban soon afterward, and in a settlement the NPS was given until 21 January 2002, "… to publish a supplemental environmental impact statement on snowmobiling," and until 15 March to propose modifications to the ban, with a final revised regulation by 15 November 2002 (AP 2000a). When the final revised regulation was due, the Associated Press

(AP) reported that a compromise would allow a cap of 1100 snowmobiles per day to start in December 2003, with only 550 of those allowed to pass through the West Yellowstone gate. Still, local business owners argued these restrictions would eliminate half their business during busy times (AP 2002). Later, this revised ban was turned over in court (AP 2004)

Not only are these snowmobiles a significant source of the park's air pollution, but they have other significant ecological effects as well. Olliff *et al.* (1999) edited a report derived from the literature on impacts to flora, fauna and open waters from winter recreation, specifically snowmobiles. The report, nearly 200 pages long, details the effects of winter recreation on the ecology of the park, primarily as it affects wildlife. Suggested management guidelines say that in areas where forest regeneration is being encouraged or fragile, or in areas where unique communities are found (such as riparian and wetland habitats), snowmobiling activities should be restricted to permit regeneration and preserve critical habitats. The report summarizes well-documented snowmobiling impacts such as air, snow and noise pollution, litter, and even damage to soils and plants. Bison habits also have been impacted, as they changed their habits to follow snowmobile trails (Olliff *et al.* 1999). In Montana and Wyoming, the report cites several previous studies which document the impact of snowmobiling on the local fauna, and Oliff *et al.* (1999) recognize that similar effects could occur in Yellowstone National Park as the winter conditions can be more severe and the level of snowmobiling activity generally higher. The report does, however, isolate snowmobiling activities in thermally-affected wildlife habitats as the most pressing issue of winter recreation in Yellowstone National Park, and prioritize it for consideration. The final section lists some management guidelines that address the need for different activity levels to maintain park operations while addressing preservation needs by giving sections of the park Opportunity Area ranks and suggesting activity levels commensurate with the preservation needs of that section.

These issues are pandemic across National Parks impacted by motorized recreational activities, and those parks are experiencing changes in the flora, fauna and ecological processes. The Center for Wetlands, University of Florida and the Ecosystem Research Unit of the National Audubon Society published a report on the Big Cypress National Preserve which documented the park's natural inventory, its history and the activities in and near the park, as well as their impacts on the park lands (Duever *et al.* 1986). They mention off-road vehicles (ORVs) in their section on land use and document specific impacts such as rutting, soil disturbance, injuring or killing of vegetation and changing floral communities. The vehicles have different impacts on different soil compositions, but the report seems to conclude that all soil types, once the root mat is damaged, are subject to displacement and erosion from not only ORVs but natural sources such as rain (Duever *et al.* 1986).

Studies have been done in many parks across the world to measure the ecological impact of visitors and other influences (Cole, 1981, Griffiths and Van Schaick, 1993, Ingle *et. al.* 2003). Brodhead and Godfrey (1997), for example, have written of a methodology to measure the disruption of dune vegetation in Cape Cod national seashore under controlled conditions. After selecting certain dunes within the study area based on their flora, they repeatedly drove over them with ORVs at varying angles and under varying conditions such as slope and prevailing wind direction. This seems to be one of many similar studies conducted over a long span of time. A similar study, undertaken by Anders and Leatherman in 1987, used Fire Island, New York as their study area (Anders and Leatherman 1987). There have been many more studies of coastal areas, and a brief survey of ORV impacts on coastal areas over the last 25 years was undertaken by Ingle *et al.* in 2003. Off-road vehicles are used recreationally, just like airboats, but the concern of these studies was oriented towards impacts on biomass and as such their studies could take place on a large scale under controlled conditions. In the East Everglades Expansion Area, even the notion of a controlled condition is humorous because it would be incredibly hard to delineate a protected space and enforce that delineation while permitting unrestricted use in the rest of the EEEA.

Concerns about trail impacts are not limited to the United States of America, and it is not strictly mechanical recreation impacts that are studied. In the Sumatran rain forest, for example, the impact of human traffic on forest wildlife was monitored by “camera traps,” or motion-activated digital cameras that monitor activity in a field of view (Griffiths and Van Schaik 1993). In addition, there have been attempts to map ORV trails in other parks as a measure of human impact. One such study, conducted by Clarus Technologies/Integrated Concepts and Research Corporation (ICRC), provides many resources to park managers who wish to measure the extent of their trails with the Global Positioning System (GPS) (Bruehler 2004). Unfortunately, due to the immense number and length of the trails through the Everglades East Expansion Area, their sometimes ephemeral nature and the need to study change through historical data, these techniques are not adequate for this study. However, they do show that others have faced the problem of measuring impact.

Further studies have been conducted to document trails and infer the impacts of ORVs in Big Cypress National Preserve (BICY) by the Center for Remote Sensing and Mapping Science (CRMS), Department of Geography at the University of Georgia (UGA). Welch *et al.* (1999, 2002) documented the trails through photointerpretation and GIS techniques, providing more in-depth information about the length and width of trails created by ORVs. The CRMS classified trails by width as primary, secondary or tertiary, and classified areas of high-density trails as high-impact areas, later interpreting evident trails and establishing a conversion factor to trail length. Primary trails are 20 m to 30 m wide, Secondary trails are 10 m to less than 20 m wide, and Tertiary trails are 3 m to less than 10 m wide (Welch 1998). The results of this study indicate the Tertiary class of trails represents by far the greatest trail length in the Big Cypress National Preserve (Welch 1998). Since Tertiary trails are the narrowest trail, they correspond directly to individuals or small groups of ORV operators, and the magnitude of impact of this type of operator is massive in the Preserve. The impact of airboat use in the ENP East Everglades Expansion Area can be measured in a similar fashion, and it is a far less documented phenomenon.

CHAPTER 3

METHODOLOGY

Datasets

In order to compile spatial datasets depicting trends in airboat use over time and to assess potential impacts of airboats on the natural vegetation of ENP, historical and current information on trails and vegetation and water levels are required. This information is available in the form of aerial photographs recorded by the U.S. Geological Survey (USGS).

The primary sources of data for this project are aerial photographs from 1994, 1999 and 2003 (Figure 7). The 1:40,000-scale USGS National Aerial Photography Program (NAPP) color infrared (CIR) 1994 and 1999 photographs are available as USGS Digital Orthophoto Quarter Quadrangle (DOQQs) at 1-m resolution. The 2003 photographs are 1:24,000-scale true color, scanned at 0.5-m pixel size and were made available by the Southern Florida Water Management District (SFWMD). The 2003 photographs were flown by the private company Woolpert and Associates, based in Cincinnati, Ohio. Table 1 provides a summary of the aerial photography information.

Trail Mapping and Ground Truth Methodology

Management guidelines for the East Everglades Expansion Area must be based on solid historical airboat use and impact data that provide an objective basis for making decisions about the continued public availability and types of airboat use in the ENP. To accomplish this,

Table 1: Aerial Photograph Information

	1994	**1999**	**2003**
Source	USGS	USGS	SFWMD
Scale	1:40,000	1:40,000	1:24,000
Film Type	CIR	CIR	True Color

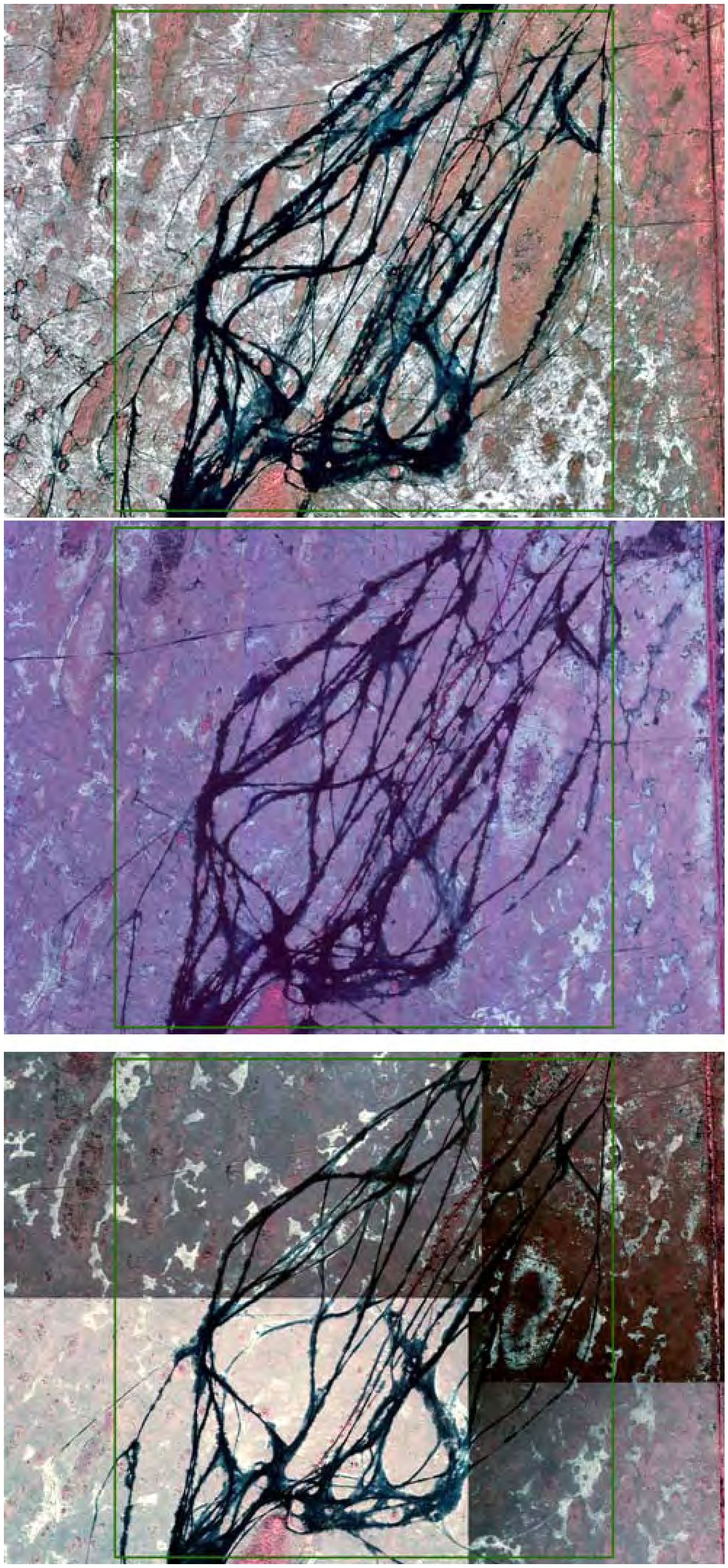


Figure 7: 1994, 1999 and 2003 photos (top to bottom) of a portion of the East Everglades Expansion Area

a database of historic airboat trails was compiled for the years 1994, 1999 and 2003, covering nearly 10 years of airboat use in the study area (Jordan *et al.* 2006). Evident trails can vary in width, so trails are classified as either narrow (< 3 m), medium (≥ 3 m, < 10 m) or wide (≥ 10 m). It is assumed that wider trails impact a wider swath of vegetation and may prove to have a greater, more permanent impact on the ecology of the Everglades. Large swaths of dense, intertwined narrow trails can be categorized by a high trail density polygon. These polygons signify areas where intense airboat activity is evident. Open-water polygons represent areas that either: 1) appear to be naturally open or cannot be attributed solely to airboat activity; or 2) are areas that have undergone such intensive and repeated airboat use that the substrate has been disturbed, the water is deep and vegetation is sparse. These areas are considered separately because if airboats use these areas the impact may not be directly measured from one year of aerial photography. However, this permits change analysis between years.

To create these data, aerial photographs were collected for the appropriate dates. For 1994 and 1999, CIR DOQQs were readily available, which are orthorectified products with a horizontal accuracy of approximately ± 3 m. The 2003 true color images were provided to the project by the South Florida Water Management District (SFWMD) and came unrectified. These photos were rectified to the 1999 DOQQs. Orthorectification was not necessary due to the constant elevation of the area. The rectification process achieved an RMSE of ± 1 m, which provides a product with horizontal accuracy commensurate to that of the 1994 and 1999 DOQQs.

The trails and areas of dense trails and open water were manually delineated in ArcGIS 9.1 (ESRI, 2005) using heads-up digitizing and the component programs ArcMap 9.1 and ArcCatalog 9.1. In this way, a personal geodatabase was created with a feature dataset bounding the extent of the East Everglades Expansion Area and feature classes that represent evident trails classified by width, areas of high trail density and open-water areas.

Everglades National Park was visited two times (November 2004 and March 2005) for the purpose of conducting ground truth surveys. In the first trip, two airboats driven by Park Rangers were employed to observe many of the major airboat trials and tree islands frequented by commercial and private airboats. Goals of this orientation airboat tour included: 1) observation of trails leading to and surrounding camps and structures; 2) discussion of social/physical history of airboat trail use in the area, and; 3) inspection of different types of airboat trails to develop a trail classification system for airboat trails observed in ground and helicopter surveys. Observations during the tour were recorded with digital ground photos and a Garmin V handheld GPS receiver, accurate to approximately ± 9 m.

Field observations identified three general trail-type classes based on vegetation community (*i.e.*, open water, wet prairie and sawgrass) with trail width subclasses (*i.e.*, ≥ 10 m, 3 – 10 m and ≤ 3 m), as well as game trails and canals. High density areas consisted of areas with so many individual trails that they would be difficult to delineate individually. Each airboat trail reference class was assigned a number for use in identifying trails during the helicopter surveys. These ground truth data were used to verify the linear features visible from aerial photographs that corresponded to airboat trails visible from a helicopter and from the ground.

Viewing the region from the air was the most appropriate and efficient way to conduct a ground truth survey in the East Everglades Expansion Area and determine classes of airboat trails that were most likely to be visible and discernable from the aerial photographs. After CRMS personnel participated in an eight-hour helicopter safety training class held at the ENP

Daniel Beard Research Center during the November 2004 field visit, helicopter surveys were conducted over a three-day period.

A series of 18 parallel, east-west flight lines were defined *a priori* to best cover the area within a four-hour flight day. Latitude-Longitude GPS coordinates for the flight line end points were provided to the pilot who flew the aircraft at an average speed of approximately 70-80 kph (45-50 mph) and altitude of 152.4 m (500 ft) above ground level. The doors were removed to increase visibility of the landscape by the observers. The crew on-board the helicopter consisted of the pilot, two CRMS personnel and one NPS personnel. The CRMS trail observer (Madden) sat in the front left-side seat to observe the trails below and on the left side of the helicopter, the NPS trail observer sat in the right rear seat to observe trails on the right side of the helicopter and the GIS specialist (Jordan or Manglass) sat in the left rear seat with a laptop computer connected to a Trimble Pro XRS GPS (Figure 8). The GPS antenna was placed in the front left portion of the windshield for optimal visibility of satellites.

Figure 8: Helicopter survey seating configuration.

As the helicopter flew along the transect flight line, Madden would observe a trail beneath the helicopter and call out a class number (1-12). The GIS specialist in the back seat would monitor the progress of the survey using real-time display of the aircraft GPS position on a map of the region displayed in ArcGIS software and the NPS observer could confirm Madden's observation. When a trail was identified, its location would be marked by entering a point feature and the class number into the database. A total of 600 points were collected in this manner during the November 2004 field trip (Figures 9 and 10). The survey along the east-west transects required two flight days to complete. On the third day, north-south flight lines were flown and trail data were collected as an independent check of helicopter observations. In addition, we visited specific points of interest in order to obtain photographs from the air of features such as hunting camps, tree islands and commercial airboat enterprises.

Although a considerable amount of valuable information was recorded during the first helicopter data collection mission, several problems with the procedures were initially identified including difficulties in seeing the computer screen in the glare of the sunlight, the awkwardness of operating the computer mouse and keyboard while wearing fireproof gloves and the speed with which a point could be entered into the database. Entering a point required three steps: 1) monitoring the location of the aircraft on the computer screen and marking the point indicated by the GPS cursor location; 2) opening the attribute table and entering the correct class number; and 3) saving the point to the database. This operation required about 6-9 seconds per point and was frequently too slow for areas with very dense trail networks. At an air speed of 70 kph (45 mph), the aircraft is moving over the ground at a speed of 20 meters per second. Thus, the time lag between the observation and recording could potentially introduce a positional error of up to about 200 m. To abrogate this, the GIS specialist would track the GPS position of the aircraft on the map using the mouse and record the position immediately upon hearing the observation called out. The trail class value would then be entered into the database. Even with this technique, however, there was typically a one to three second delay between the observation call and recording of the point, leading to potential error of up to 60 m. In addition, because of the time required to record each point, it was extremely difficult to record every point that was observed in areas of very dense trails. In these areas, it was not unusual to cross an airboat trail at a rate of up to one trail per second.

These problems were addressed during the second field visit and helicopter survey in March 2005. A new computer program for data collection was written specifically for this purpose in which the GPS coordinates were read directly into the program and saved as a record of the flight path. The user interface was designed to fill the computer screen and consisted of 18 programmable buttons with large numbers that could easily and quickly be selected using the mouse.

Upon clicking the button for a given airboat trail class, the coordinate, class number and class name were recorded directly into a database file. This new method was extremely successful and permitted the helicopter to fly faster, resulting in over 950 points being recorded in one flight day during the second survey. The accuracy of the positional locations of observations was tested against 22 points where the helicopter flight line crossed a road. For the 22 test points, the average positional accuracy was ± 37.8 m, which is approximately equivalent to the forward motion of the aircraft of 35.6 m/sec (80 mph) as measured from the GPS track log recorded during the second survey.

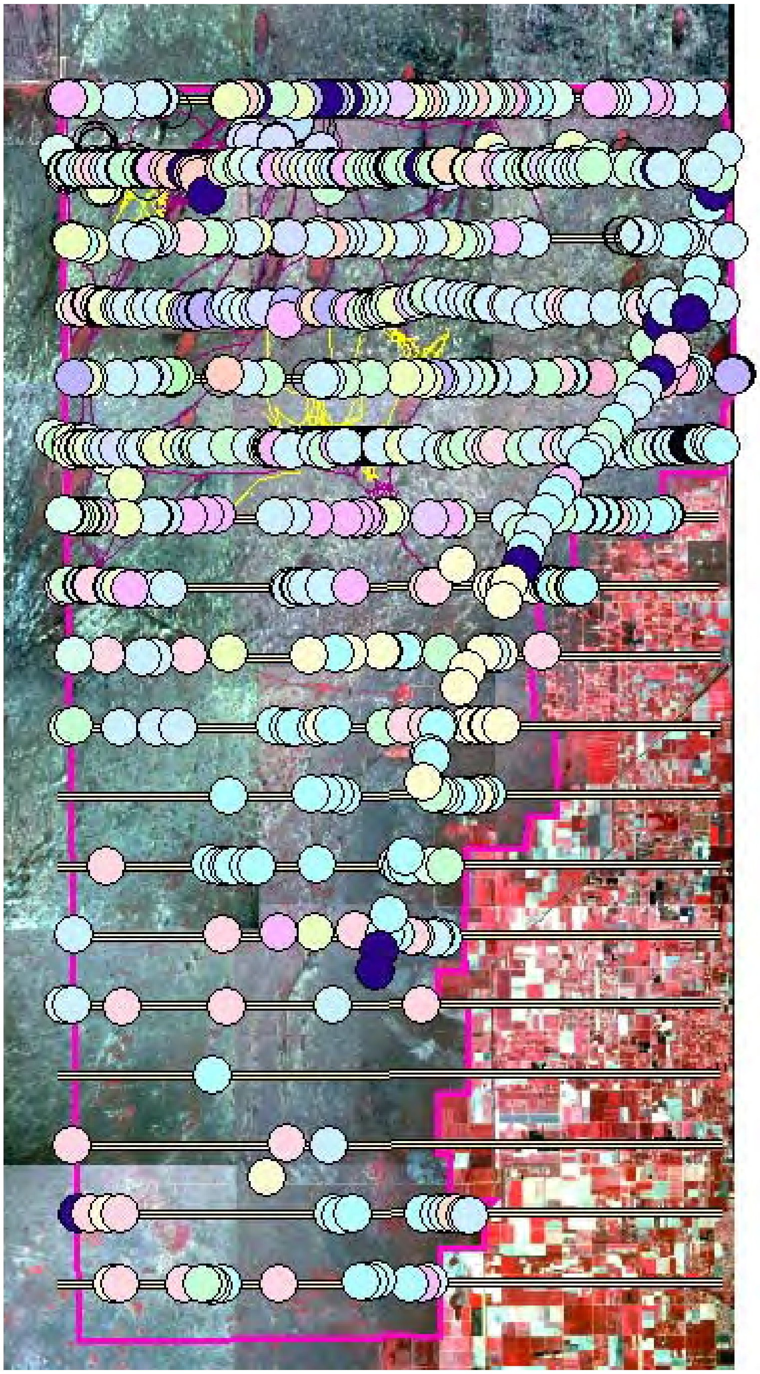


Figure 9: East Everglades Expansion Area helicopter survey showing 18 parallel flight lines and approximately 600 observations from the November 2004 field visit.

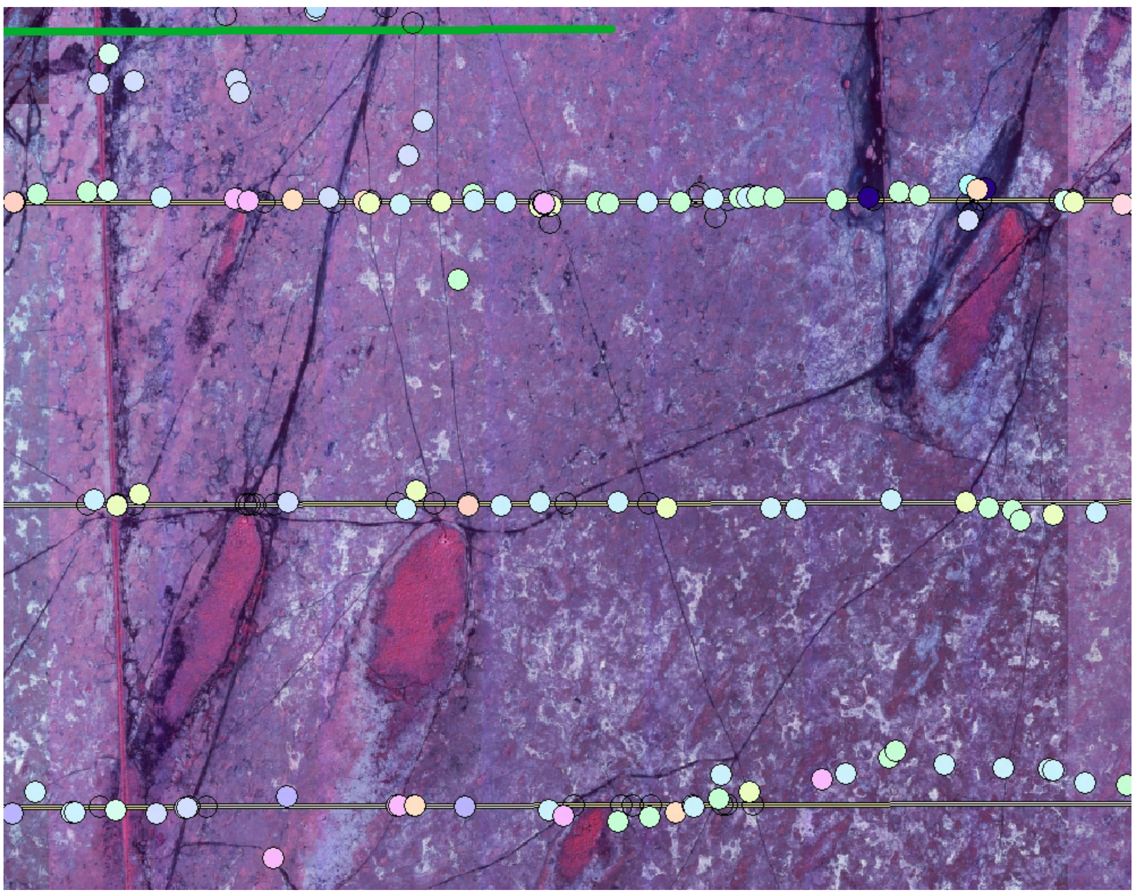


Figure 10: Closeup of a portion of the helicopter survey record.

This positional error could be reduced further by flying more slowly (e.g. 70-80 kph (40-50 mph) as was done during the first survey), but it would also result in extended flight time to cover the study area.

Summary statistics of trail lengths were generated in ArcToolbox 9.1 and divided by year and trail classification. Quality control was implemented upon the trail data, and all trail data were edgematched and edited for consistency. This provided a powerful summary of trail information that has been checked for quality and can be used to establish trends in airboat use over the 9 – year period.

Network Analysis

With the data showing an acceptable level of accuracy and trends pointing toward recovery, network analyses can proceed to find more efficient ways to target specific recovery areas and augment the recovery that is currently occurring. The next step involved creating a database of static trails, or trails that appear in all of the 1994, 1999 and 2003 geodatabases. To do so the 1999 trail feature class arcs were buffered at 10 m to account for possible variations in position due to geometric errors in the aerial photograph rectification and digitizing between years. This buffered trail feature class was unioned with the open water and high-density polygon areas to create polygons of trafficked areas in 1999. The same was done with the 2003 trail feature class.

Next, the trail feature class from 1994 was clipped by the 1999 and 2003 trafficked polygons from the previous step. The result was a feature class of static trails, or trails that appear stable in the 1994, 1999 and 2003 aerial photographs. As expected, many of the Class 1 and Class 2 trails, especially in the areas frequented by commercial air boats, carried over into the stable trail feature class. Surprisingly, many Class 3 trails in the same areas also carried over, and many of the Class 3 trails were completely intact strictly from the trail buffers and not from the open water/high-density polygons. There were, as expected, many small fractions of Class 3 trails in outlying areas that were consistently trafficked over the study period but have different paths or only small, shared components. These small segments, measuring from meters to, in a few rare cases, a hundred or so meters, were considered noise and were removed from the stable trail feature dataset.

The high-density and open water polygons from 1994 were unioned to give a set of polygons that provided evidence of heavy airboat use. The same was done for 1999 and 2003, and these unioned polygons were intersected to provide a set of polygons that reflected areas which were subject to heavy impact throughout the time period. These polygons are considered to have a lower cost of travel (*i.e.*, they contain “low-cost” routes) than areas outside of these polygons because the areas have been subject to consistent and heavy impact. This reasoning makes the assumption that unless they become specifically targeted for recovery, it is preferable to have airboats traveling across these already damaged areas than into areas which are relatively intact and currently less damaged. The static trail feature class was then clipped by this high impact polygon set and a field was added to reflect that these trails lay inside of low-cost areas. Next, the static trails were erased and the resulting trails again flagged by a field that indicated they were outside these low-cost areas. These two trail datasets were then merged to provide a connected static trail network with low-cost routes identified.

This trail network was placed into a feature dataset in a geodatabase set to the extent of southern Florida. A point feature class, Destinations, was added to reflect all the required locations in the network: docks, ramps, other ingress /egress points and points of interest such as the heads of tree islands. The trail network feature class and the destinations feature class were organized in a topology which enforced the fact that destinations should be placed on vertices of trail segments and that trail segments should not overlap or self-intersect. The planarize tool in the Topology Editor toolbar assures that self-intersecting segments get split and vertices are added at the intersection for all offending trail segments. If overlaps occur, they can be fixed by splitting trail segments and removing the redundant information. The topology was loaded to enforce these rules as destinations were added, assuring all destinations are located on trail vertices and should either the destination or its corresponding trail vertex move the other will follow.

The components (destinations and trails) were next placed into a network dataset in which the destinations were considered valid stops and the trail segments were considered valid paths of travel. Cost fields were added to the network, including trail segment length, trail segment width, low-cost trail segment modifiers and a composite field which was calculated based on the selected parameters. Note that although the network dataset must be rebuilt after every edit session, it allows the Network Analyst tool from ESRI to be used to analyze airboat traffic along the trail database.

With these criteria, graph theoretical concepts were applied to the airboat trail network, where all destinations are considered terminal vertices and all intermediate vertices (where trail segments meet) are considered intermediate vertices. Furthermore, noise and dead-ends were cleared from the network with relative ease using topological distinctions and graph characteristics. When placing destinations, some locations have multiple trails which end at the point of interest. In this case, a short leader of appropriate width class is attached to the vertex of the former point of interest and the destination is located at the other end. This permits the terminal vertices to split into several directions while maintaining the topological distinction of a logical endpoint within the network.

CHAPTER 4

RESULTS AND DISCUSSION

The East Everglades Expansion Area airboat trail database was completed and compiled as a feature database in an ArcGIS personal geodatabase. For each study year (1994, 1999, 2003) there is a corresponding feature class containing all of the trails for that study year. Each of the trails stored in the database has attributes for class number and length. The areas of all polygon features (High Impact and Open Water areas) also are calculated and stored in the database. These attributes permit the trails to be summarized in terms of total length and class. In order to derive a conversion factor for calculating effective Class 3 trail length per area of High Impact polygons, all of the visible Class 3 trails evident within four 500 x 500 m sample areas of high impact were delineated. The total length of trails within the polygons was then converted to a length per unit area for deriving the linear summary statistics. This conversion factor is 0.113886 linear meters for every 1 square meter of High Impact area polygon, or 1138.86 m per ha.

East Everglades Trail Summary Statistics – 1994

The summary statistics for the 1994 trail database for the East Everglades Expansion Area are given in Table 2. It can be seen that the vast majority of trails are Class 3 trails, with 8,651 km of individually delineated Class 3 trails and 8,828 km of Class 3 trails within 7,752 ha of High Impact areas. The combined length of Class 3 trails is 17,479 km. There also were 169 km of Class 1 trails and 185 km of Class 2 trails. Open Water represented 256 ha of the total area. The total length of all trails mapped in East Everglades from the 1994 photographs was 17,833 km, of which 98.0 percent were Class 3-type trails.

Table 2: Summary Statistics for East Everglades Airboat Trails: 1994

Feature Type	Total Length/Area
Class 1: >10 m wide	169 km
Class 2: 3 – 10 m wide	185 km
Class 3: < 3 m wide	8,651 km
High Density: < 3m wide	8,828 km
Total Class 3	17,479 km
Total Trails	17,833 km
High Density polygons (1138.86 m/ha)	7,752 ha
Open Water area	256 ha

East Everglades Trail Summary Statistics -- 1999

Summary statistics for the 1999 trail database for the East Everglades Expansion Area are given in Table 3. The vast majority of trails are again Class 3 trails, with 2,845 km of individually delineated Class 3 trails and 7,523 km of Class 3 trails within 6,606 ha of High Impact areas. The combined length of Class 3 trails is 10,368 km. There also were 88 km of Class 1 trails, 183 km of Class 2 trails and 233 ha of Open Water area. The total length of 1999 trails was 10,639 km, of which 97.4 percent were Class 3-type trails.

Table 3: Summary Statistics for East Everglades Airboat Trails: 1999

Feature Type	Total Length/Area
Class 1: >10 m wide	88 km
Class 2: 3 – 10 m wide	183 km
Class 3: < 3 m wide	2,845 km
High Density: < 3m wide	7,523 km
Total Class 3	10,368 km
Total Trails	10,639 km
High Density polygons (1138.86 m/ha)	6,606 ha
Open Water area	233 ha

East Everglades Trail Summary Statistics – 2003

The 2003 trail summary statistics show although the vast majority of trails are again Class 3 trails, with 1,926 km of individually delineated Class 3 trails, there were only 79 km of Class 3 trails within 70 ha of High Impact areas (Table 4). The combined length of Class 3 trails is 2,005 km. There also were 73 km of Class 1 trails and 164 km of Class 2 trails. Open Water represented 60 ha of the total area. The total length of all 2003 trails was 2,242 km, of which 89.4 percent were Class 3-type trails.

Table 4: Summary Statistics for East Everglades Airboat Trails: 2003

Feature Type	Total Length/Area
Class 1: >10 m wide	73 km
Class 2: 3 – 10 m wide	164 km
Class 3: < 3 m wide	1,926 km
High Density: < 3m wide	79 km
Total Class 3	2,005 km
Total Trails	2,242 km
High Density polygons (1138.86 m/ha)	70 ha
Open Water area	60 ha

Accuracy Assessment

Helicopter survey information from missions flown in 2005 provided reference data to assess the accuracy of the 2003 interpreted trail data. Points to consider when comparing helicopter observations to mapped trails include: 1) a total of 9 classes were used to identify trails observed from the helicopter while 3 trail width classes were interpreted from the aerial photos; 2) helicopter observations and photo interpreted trails are subjective and may contain small errors; 3) the aerial photographs were recorded two years before the reference helicopter data were collected. All of these considerations withstanding, the reference trail data showed acceptable agreement with mapped data.

Based on the airboat survey, an initial trail classification system was developed with 9 impact classes used to identify trails in the helicopter survey. These classes, summarized in Table 5, are defined not only by width but by vegetation type and in some cases by particular uses. The data available from the helicopter survey were far more detailed than the three width-based classes available from interpretation of the aerial photographs in order to provide possible reasons for any missed or misidentified mapped trails. However, in many cases the reference data can be reclassified by their widths and a correspondence can be created between the collapsed reference data classes and the aerial photograph-based mapped trail data reclassed. The width classes (1, 2 and 3) for each reference class are listed in Table 5.

Table 5: Class Types and Descriptions

Reference Class	**Description**	**Reclassified Width Classes**
1	Open Water: > 10 m	1
2	Open Water: 3-10 m	2
3	Open Water: < 3 m	3
4	Wet Prairie: 3-10 m	2,3
5	Sawgrass Medium: < 3 m	2,3
6	Sawgrass Tall: < 3 m	3
7	Game Trail	--
8	High Density	2,3
9	Canal	1,2

All of the reference data were collected and clipped to the study area. A total of 459 data points were spatially linked to the 2003 trail database based on a buffer of 60 m surrounding each helicopter observation, as ± 60 m is the estimated geographic accuracy of the helicopter observations. The nearest trail neighbor that fell within 60 m of a reference data observation point was considered a match. The data from these points were converted into an Excel table and summarized to demonstrate the accuracy of the 2003 trail database.

Tables 6 and 7 show the accuracy assessment results. In Table 6, the reference data points were divided by reference class as observed in the helicopter and the corresponding 2003 heads-up interpreted width class that fell within 60 m of the reference point. The grey shaded boxes indicate correctly identified width class trails for a given reference class. Table 7 shows the actual percent of heads-up digitized trail data that correctly matched the reference data, broken down by width class and reference class.

Table 6: Classification Matrix

Reference Class	Width Class 1	2	3	Total
1	7	9	14	**30**
2	3	13	22	**38**
3			4	**4**
4		2	15	**17**
5	2	5	63	**70**
6		6	213	**219**
7	1	2	25	**28**
8	1	6	31	**38**
9	5	3	7	**15**
Grand Total	**19**	**46**	**394**	**459**

Table 7: Heads-up Accuracy Summary

Width Class	Correct	Incorrect	Total	%Correct
1	12	7	19	**63.2**
2	29	17	46	**63.0**
3	326	68	394	**82.7**
Total	**367**	**92**	**459**	**80.0**

Reference Class	Correct	Incorrect	Total	%Correct
1	7	23	30	**23.3**
2	13	25	38	**34.2**
3	4	0	4	**100**
4	17	0	17	**100**
5	68	2	70	**97.1**
6	213	6	219	**97.3**
7	0	28	28	**0**
8	37	1	38	**97.4**
9	8	7	15	**53.3**
Total	**367**	**92**	**459**	**80.0**

The results appear variable, with an overall accuracy of 80 percent and 63 percent accuracy of width Class 1 and 2 trails and 83 percent accuracy of width Class 3 trails. Table 7 demonstrates that the largest errors are in reference Classes 1, 2, 7 and 9. Reference Classes 1 and 2 are Open Water classes measured by width. There may have been some confusion in the identification of width Class 1 (open water > 10 m wide) and width Class 2 (open water 3 – 10 m wide) trails during the helicopter surveys because it is difficult to determine the width of wide trails as the helicopter passes over, especially trails that are around 10 m wide. In addition, wide airboat trails are variable in width along their length by nature of their formation by multiple passes of airboats. The same trail may be a width Class 2 in one section, expand to a width Class 1 and then constrict again to a width Class 2. This also can lead to confusion in an accuracy assessment. Reference Class 7 is reserved for game trails, and since game trails should not have been included in this airboat mapping study, all 28 mapped trails that fell within 60 m of a helicopter reference point were incorrect. Reference Class 9 is the class for canals, which 53 percent of the time were misidentified as airboat trials. Since canals are heavily used by airboats, this error does not seriously affect conclusions on airboat trail trends. Reference Classes 5, 6 and 8 (trails through sawgrass and high-density trails) have very respectable accuracy with over 97 percent correct, and reference points of Classes 3 and 4, small open water trails and wet prairie, though small, correlate completely with 100 percent of the trails correctly classified. Given the probability of confusion between width Class 1 and width Class 2 trails, it would also be beneficial to consider the potential for overlap in the reference interpretation, since many trails are close to the breakpoints of 10 m and 3 m as defined by reference Classes 1, 2 and 3.

Tables 8 and 9 show the results of leniency in determining the accuracy of reference Classes 1 and 2. These accuracies improved to 63 percent and 82 percent, respectively, and the overall accuracy increased to 86.7 percent. These results appear promising, and indicate the fuzzy nature of airboat features, along with problems in subjective interpretation of objective measurements such as width. However, there is still a 100 percent error for the 28 mapped trails that correspond to reference points which were recorded as game trails.

The overall accuracy of the mapped trails is 80 percent and relaxing the strict definition of reference Classes 1 and 2 improves the overall accuracy to 87 percent. Factors to remember include the possibility of reference error, the ephemeral nature of width Class 3 trails and the two

Table 8: Classification Matrix with margins subsumed

Reference Class	Width class 1	2	3	Grand Total
1	7	9	14	**30**
2	3	13	22	**38**
3			4	**4**
4		2	15	**17**
5	2	5	63	**70**
6		6	213	**219**
7	1	2	25	**28**
8	1	6	31	**38**
9	5	3	7	**15**
Grand Total	**19**	**46**	**394**	**459**

Table 9: Heads-up accuracy summary with margins subsumed

Width Class	Correct	Incorrect	Total	%Correct
1	12	7	19	**63.2**
2	38	8	46	**82.6**
3	348	46	394	**88.3**
Total	**398**	**61**	**459**	**86.7**

Reference Class	Correct	Incorrect	Total	%Correct
1	16	14	30	**53.3**
2	35	3	38	**92.1**
3	4	0	4	**100**
4	17	0	17	**100**
5	68	2	70	**97.1**
6	213	6	219	**97.3**
7	0	28	28	**0**
8	37	1	38	**97.4**
9	8	7	15	**53.3**
Total	**398**	**61**	**459**	**86.7**

years of time between the 2003 aerial photographs used to map trails and the 2005 reference data flight. With an accuracy of 80 percent to 86.7 percent, the methodology for mapping airboat trails appears adequate and managers can be confident that the airboat trail features mapped from the aerial photographs are, indeed, present and visible. Narrow trails were, in general, far more accurately mapped with respect to the reference data while the speed and distance factors present in helicopter surveys result in wider trails being harder to categorize by width. Also, width Class

1 and width Class 2 trails are often varied in width and a single wide trail may change categories along its entire length. The narrow trails, on the other hand, were consistently roughly the width of an airboat and so were easy to distinguish from the wider Class 2 trails. When the differences between these trails is acknowledged, the general accuracy level of Class 1 and Class 2 trails rises to acceptable levels. In light of these results, the data should be considered accurate and further study of trends in East Everglade trails can continue.

Trends and Impacts from 1994 – 2003

As indicated in Table 10, the total length of trail in every category decreased every time period between 1994 and 2003. This indicates a dramatic rate of recovery of evident airboat trails in the East Everglades Acquisition Area over the nine year period. Most of the recovery in mapped trails actually occurred from 1994 to 1999, and areas experiencing a heavy impact also recovered nearly six times more area from 1999 to 2003. Width Class 1 and width Class 2 trails made modest recoveries, with 43.2 percent and 88.9 percent of the 1994 trail length remaining in 2003. Only 22.2 percent of the Class 3 trail length from 1994 remained in 2003 while high-density polygons, when converted to trail length, had only 0.1 percent of the 1994 trail length remaining in 2003. In all, the total length of Class 3 trails in 2003 was 11.5 percent of the 1994

Table 10: Trail statistics summary, 1994 - 2003

	Total Length (km)			**Change (km)**		
Feature Type	**1994**	**1999**	**2003**	**'94-'99**	**'99-'03**	**'94-'03**
Class 1	169	88	73	-81	-15	-96
Class 2	185	183	164	-2	-19	-21
Class 3	8,651	2,845	1,926	-5,806	-919	-6,725
High Density	8,828	7,523	79	-1,305	-7,444	-8,749
Total Class 3	17,479	10,368	2,005	-7,111	-8,363	-15,474
Total Trails	17,833	10,639	2,242	-7,194	-8,397	-15,591
	Total Area (ha)			**Change (ha)**		
High Density Polygons	7,752	6,606	70	-1,146	-6,536	-7,682
Open Water area	256	233	60	-23	-173	-196

total length of Class 3 trails, a decrease of 15,474 km. The total decrease in all trails between 1994 and 2003 was 15,591 km.

This decrease in evidence of airboat trails is apparent from a visual inspection of the images from each year, but the summary statistics are impressive. Obviously, Class 3 trails have been disappearing in far greater number and percentage than wider trails. In addition, high-density polygons not only make up a larger proportion of Total Class 3 trail reduction, but are one of two classes (Open Water comprises the other) which decreased more between 1999 and 2003 than from 1994 to 1999. This may be partially attributed to the ban on hunting in 1999, as hunting methods often involve sequential passes of airboats across shallower areas, especially around tree islands, to flush wildlife that may be hiding.

Regardless of the specific circumstances, the decrease in evidence of airboat trails indicates successful restoration efforts in the park potentially related in part to changes in hunting laws and federal purchase of private parcels in the East Everglades Expansion Area. Still, 2,242 km of trails exist in the East Everglades Expansion Area, a 44,000 ha site. Furthermore, the vast majority of these trails are located in the northern half of the East Everglades Expansion Area, increasing the stress on a smaller portion of the ENP. Since Class 3 trails have shown very promising rates of recovery and 2,005 km of the 2,242 km of remaining trails are Class 3 trails (or 89.4 percent), it stands to reason that there is still much more recovery possible with proper trail management. While private and commercial use must be balanced, 2,242 km is a great length of trail and it may be possible to analyze the trail data and find areas that do not need to absorb traffic to protect and recover.

Network Analyses

With the airboat network dataset completed and rebuilt, Network Analyst can be used to perform several types of analyses. Perhaps most importantly, the route finder can help create a spanning tree with minimal effort and no custom programming. Given a network dataset, the route finder will traverse edges from the first point, or stop, to the second, then the second to the third, and so on sequentially through pairs of stops until it connects either the last two points or the last point and the first point, depending on the parameters. The route will traverse only one edge per vertex, much like a vehicle can only go in one direction at an intersection. By avoiding loops and minimizing travel cost, the route finder is essentially finding a spanning tree between a pair of points for every pair of points in the sequence of specified stops. Because the route finder is not restricted from using roads it has already traveled, the end result is not necessarily a spanning tree. However, if each trail segment is traversed once with respect to each pair of stops, then the final route can be simplified by considering only the trail segments traversed and not the number of times the trail segments are traversed. The route finder was capable of finding routes among the 22 destination points after a bit of cleaning and rebuilding the dataset using trail length as the cost of travel and attempting to minimize cost.

To improve the solution of the route finder, a composite cost was computed from multiple fields. All trail segments contained in a low-cost area are marked with a 1 for low-cost travel, and those located outside the low-cost areas are marked with a 0 in the same field. For each trail segment, the width class (1, 2 or 3) less the value of the low-cost marker was multiplied by trail length to calculate travel cost per trail segment. This gives narrower trails, those with more evidence of recovery, a higher cost of travel, and a trail in a low-cost marker will act as if it were one width class wider. For width Class 1 trails in low-cost areas, the cost of travel is considered to be zero: trails that show evidence of wide impact in areas that have shown evidence of heavy impact throughout the time period are considered entrenched, least likely to recover and heavily favored by airboaters. Unless there is a specific reason to target these areas for recovery, they are well established trails possessing minimal promise of recovery and can be considered a safe concession. The resulting route (Figure 11) is efficient and again can be minimized to a spanning tree by considering the edges traversed and not how many times the edges are traversed. The result is a graph such that (terminal vertices + internal vertices) = total vertices = trail segments + 1.

The spanning tree generated is 62.41 km in length, which is less than three percent of the total trail length in 2003. However, length is only one factor to be considered in planning efficient routes. The width of the trail and the severity of the impact inflicted upon traversed areas are also considered in the metric, so to properly assess the true ecological impact these routes may cost it is beneficial to consider the actual network cost of each route segment as calculated above. For this, the Network Analyst O/D (Origin/Destination) tool provides a table with traversal costs between all permutations of vertices in the Origin set to vertices in the Destination set. By adding all terminal vertices to both the Origin and Destination sets the O/D tool will provide the cost to traverse every permutation of routes, 484 in total. These can be arranged into a table, or matrix, from which visual analysis of the results will be more efficient. Furthermore, since all trails are two-way and the cost to traverse a trail segment in one given direction and the cost to traverse that same trail segment in the reverse direction are equal, it should be straightforward to see that the O/D cost matrix will be a square matrix that is symmetric (where for a square matrix **A** with dimension n, $a_{ij} = a_{ji}$ for all $1 \leq i,j \leq n$). In addition, it should also be straightforward to see that its diagonal will contain the cost to travel from a

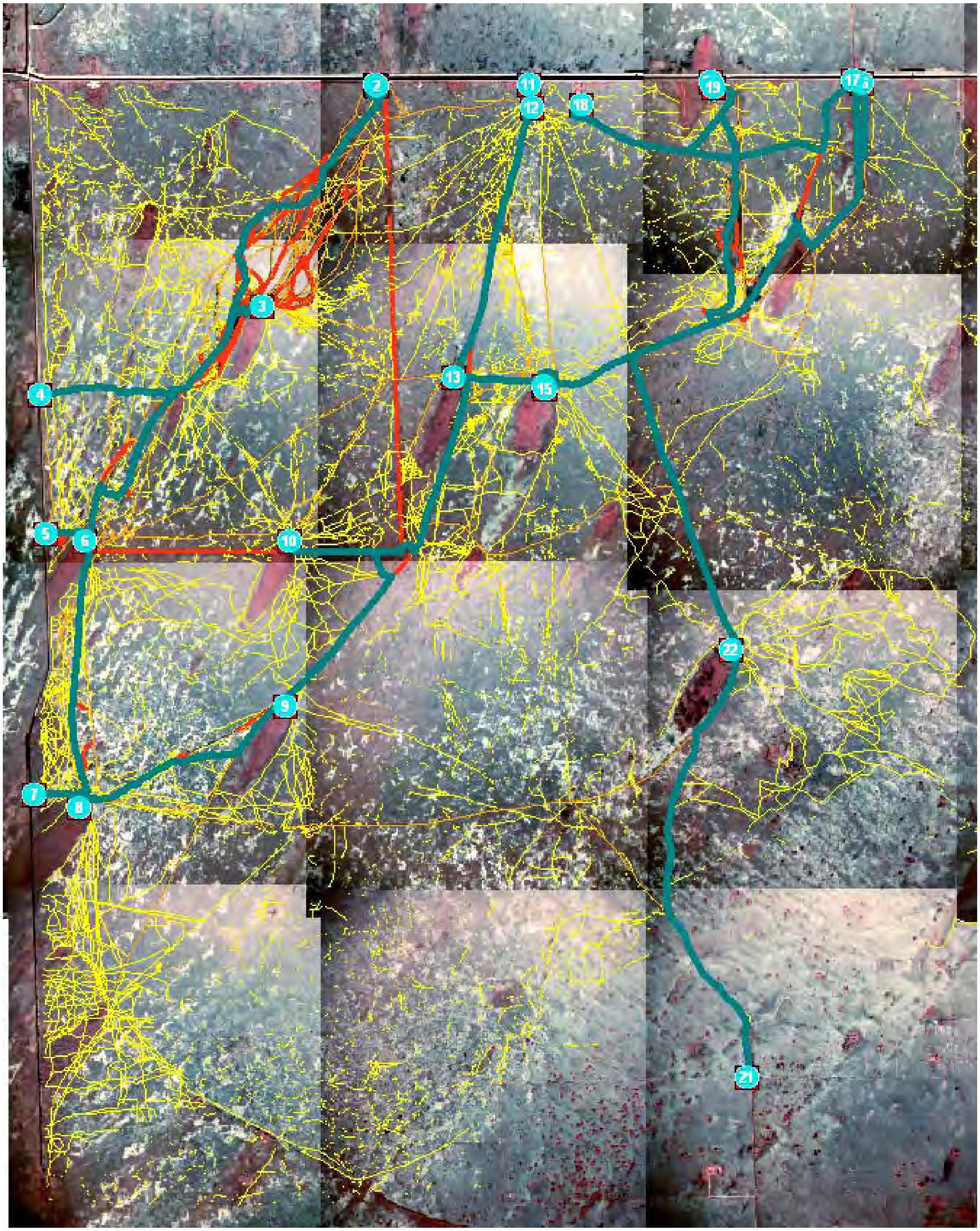


Figure 11: Spanning tree route.

terminal vertex to itself, a trivial operation, and so should be filled with zeros (where $a_{ij} = 0$ for all $1 \leq i,j \leq n$, i=j).

The resulting O/D matrices for both total length and network cost across the entire static network are included in the appendix. Their summary statistics are presented below in Tables 11 and 12. Table 13 contains the values for network cost included in Table 12 divided by the total length of each trail in Table 11, providing an average width class factoring in low-cost areas. The values in Table 13 will vary between 0 and 3, depending on the width class of the trail segments that make up the route between each terminal vertex and whether or not it travels through low-cost areas. Tables 14, 15 and 16 contain this same information for the spanning tree, a simple network which minimally guarantees connectivity.

By comparing these sets of tables, one can see average travel length and cost change by limiting travel and the rough impact level in terms of width class along such trails. It also can be seen that the average length from a given destination to another given destination (not counting trivial trips from a terminal vertex to itself) changes from 9,508 m to 14,292 m, an increase in length by 50 percent. It is reasonable to assume that travel time will increase in a roughly commensurate way. Figure 11 shows where the destinations are located and a quick look at the charts confirms that neighboring destinations are usually a direct, short route away while for some destinations airboats have to travel nearly the entire spanning tree to connect them, resulting in a maximum trip length increase from 19,731 m to 35,039 m, an increase of 78 percent. The spanning tree does, however, have a slightly smaller average cost across its trails and a slightly smaller maximum cost. It stands to reason that, with additional scenario analyses, average cost may be able to be reduced, or at least stay in roughly the same range, while average trip length can be reduced.

Table 11: Summary statistics for length between terminal vertices along the network

Average:	9507.815 m
Max:	19731.1 m
Min:	99.9 m

Table 12: Summary statistics for network cost between terminal vertices along the network

Average:	14979.3
Max:	36297.98
Min:	199.86

Table 13: Average width class accounting for traversing low-cost areas along the network

Average:	1.57
Max:	2.52
Min:	0.58

Table 14: Summary statistics for length between terminal vertices along the spanning tree

Average:	14291.56 m
Max:	35039.0 m
Min:	99.9 m

Table 15: Summary statistics for network cost between terminal vertices along the spanning tree

Average:	14979.3
Max:	36297.98
Min:	199.86

Table 16: Average width class accounting for traversing low-cost areas along the spanning tree

Average:	1.44
Max:	2.47
Min:	0.58

Scenarios and Additional Network Analyses

The spanning tree permits travel between all of the terminal vertices at the cost of trip length. This increased cost and trail limits restrict the number of trails that can be traversed and may cause traffic problems and a reduced sense of isolation, which is critical for the setting of commercial airboat operations. Therefore, additional scenarios can be considered which will result in a subset of trails that should remain open. These subsets, as well as others, can be added to the spanning tree, if justified, and the resulting proposed network can be analyzed for cost factors in the same way the whole network and spanning tree was previously analyzed.

First, consider the commercial airboat operations, in this case Everglades Safari. Everglades Safari has a number of designated routes to avoid airboats traveling within sight of one another and interfering with its own sense of isolation. Their tours are in heavily trafficked areas, so they cannot completely maintain isolation from private airboat operators, but providing them with a network of additional routes, such as in Figure 12, will permit them the same degrees of freedom currently available, while only opening wide trail classes that in large part go through low-cost areas. These trails can simply be added to the spanning tree to form the beginning of the proposed network.

Another scenario to consider is the heritage that some trails possess. Private airboat operators have strong cultural ties to certain trails, such as the wide Class 1 trail, nicknamed the Autobahn, from the Airboat Association inholding. While private airboats are relatively small in size, these trails often show evidence of heavy impact because private airboater users prefer to travel repeatedly across them. Many of these trails are preferred because they are efficient or scenic routes or they are resilient to low water levels. As a result, they also often occur in areas of high impact, evidenced by low-cost polygons, and since they are often wider from frequent travel they are also preferential to trails which show more promise of recovery with respect to the proposed network. A sampling of potential trails for this scenario is shown in Figure 13.

These scenarios do not strictly need to add trails to the proposed network. Specific trails or whole areas also can be denied to non-NPS airboat operators. These trails or polygons can be removed from consideration by declaring all network segments that fall along these trails or partially within these polygons obstructed in the Route Finder tool, and any such trails that appear either within a denied polygon or within a buffer of a denied trail can be flagged as an

Figure 12: Scenario 1, potential trails that Everglades Safari may wish to use. Spanning tree is in green, desired trails in blue.

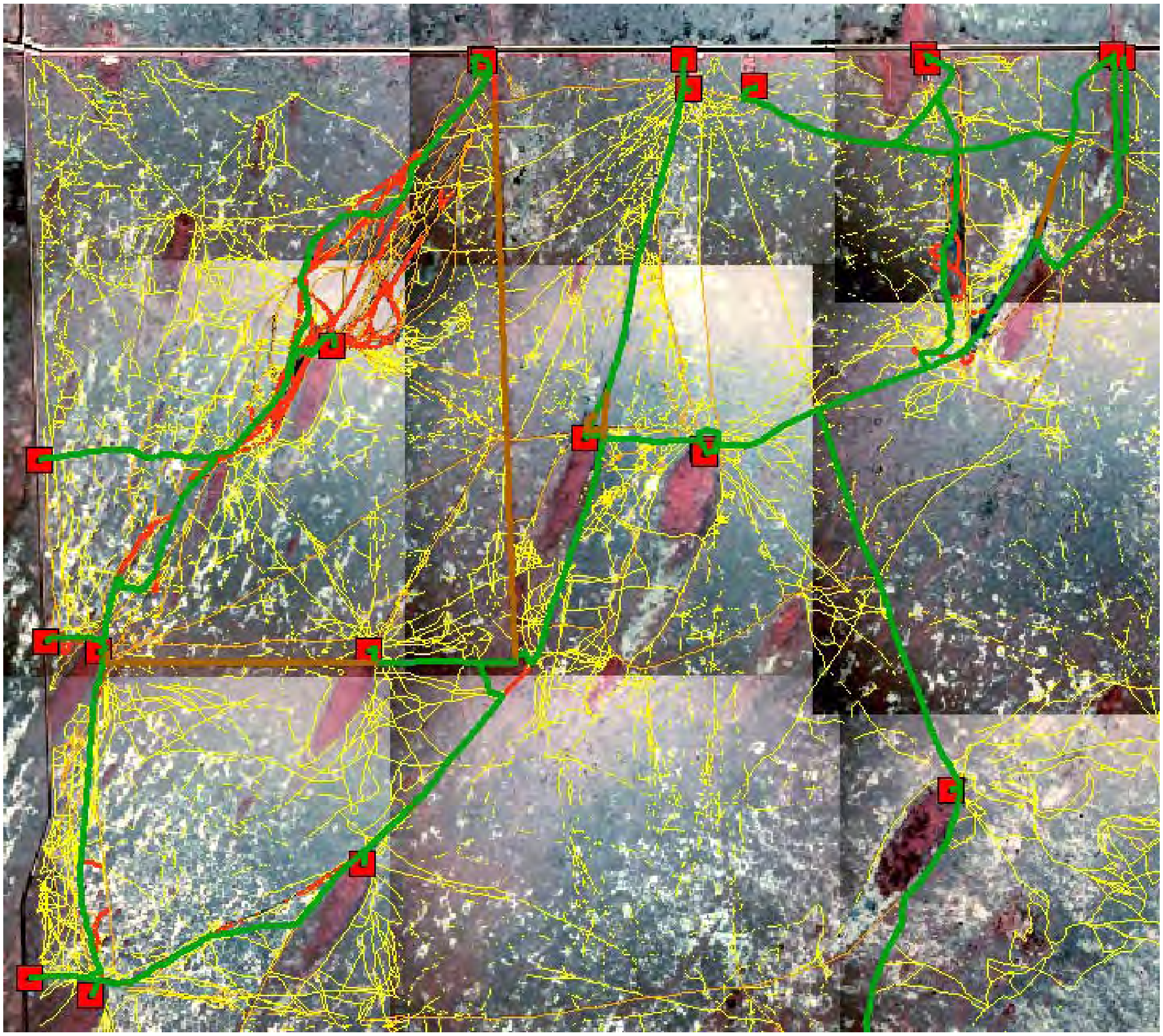


Figure 13: Scenario 2, potential trails that private airboat operators may wish to use. Spanning tree is in green, desired trails in brown.

error with proper topology tools. Figure 14 proposes several denied areas and a few denied trails for the purposes of demonstrating a potential denial scenario.

In addition, it is not necessary for scenarios to be based only on human or ecological needs. Scenarios also can be added which operate strictly upon the metrics used to determine travel cost and environmental impact. For example, a final scenario was added to the proposed network such that any terminal vertex pairs that have a spanning tree route length of 26,000 m or

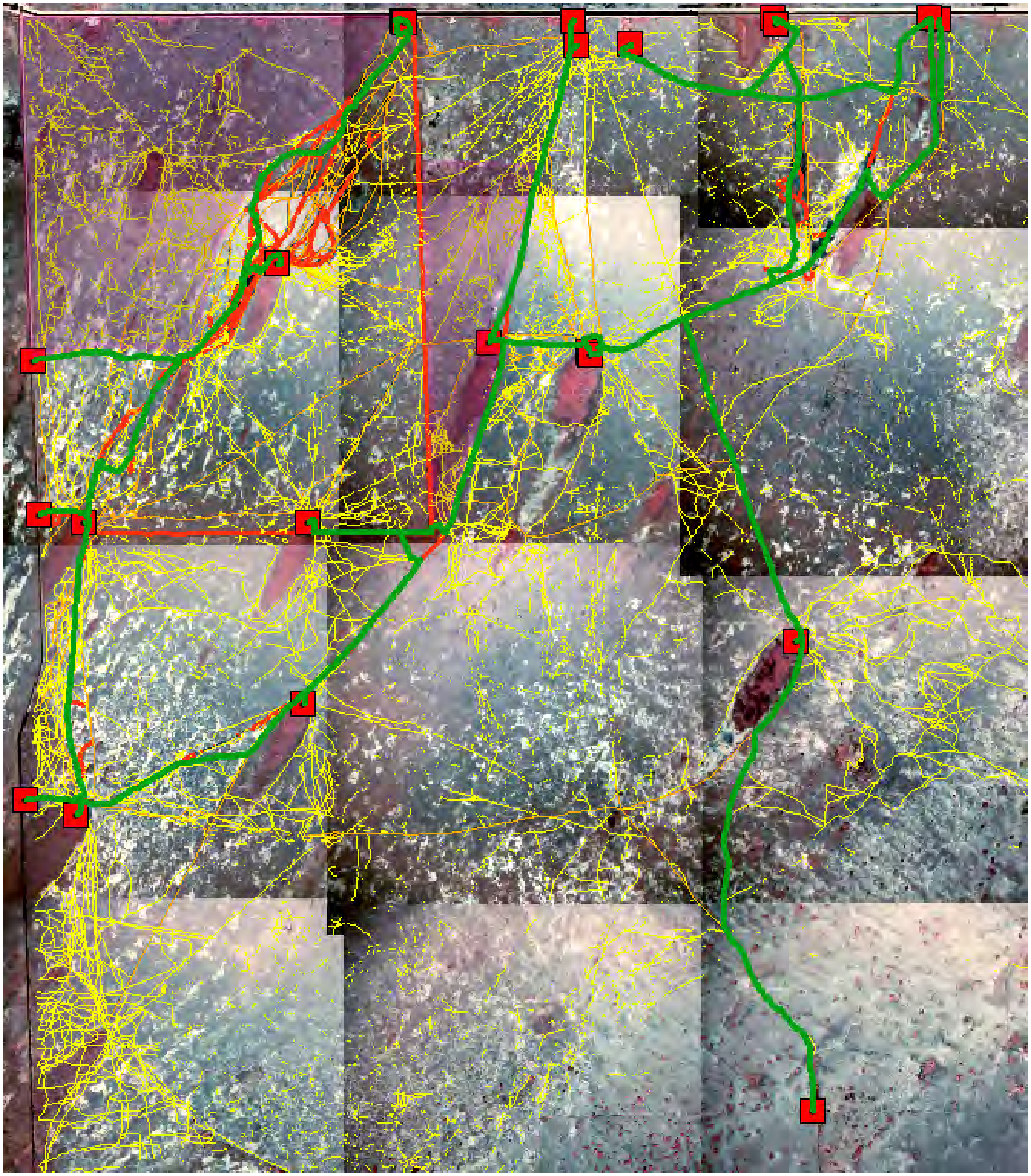


Figure 14: Scenario 3, targeted protection areas. Spanning tree is in green, areas to protect are shaded purple.

more will have an additional route generated across the static trail network with consideration for minimal cost between those vertices. This will reduce the network cost to travel between terminal vertices which are far away topologically along the spanning tree, thus reducing the overall travel cost and length of the proposed network and possibly lowering the average travel cost as well. A total of 50 route pairs, which corresponds to 25 distinct routes (two ways each route) were found in the O/D Matrix. The new routes generated from vertex pairs are included in Figure 15.

These new scenarios were combined with the spanning tree graph as seen in Figure 16, and the results are summarized in Tables 17, 18 and 19 as above for comparison. The results have improved significantly over the spanning tree alone. The average distance between two terminal vertices in the proposed network is 10,975 m, a mere 15 percent longer than in the entire network and only 78 percent of the average spanning tree distance. Furthermore, the maximum trip length is only 20,643 m, 5 percent further than the maximum trip length in the full network and only 59 percent of the longest trip along the spanning tree. Best of all, the total trail length of the proposed network is only 124,509 m, roughly 6 percent of the total trail length in 2003. This proposed network connects all of the desired locations while providing the necessary trafficability, route redundancy and other specifics of four potential scenarios in roughly 1/20th of the total length of trails evident in 2003.

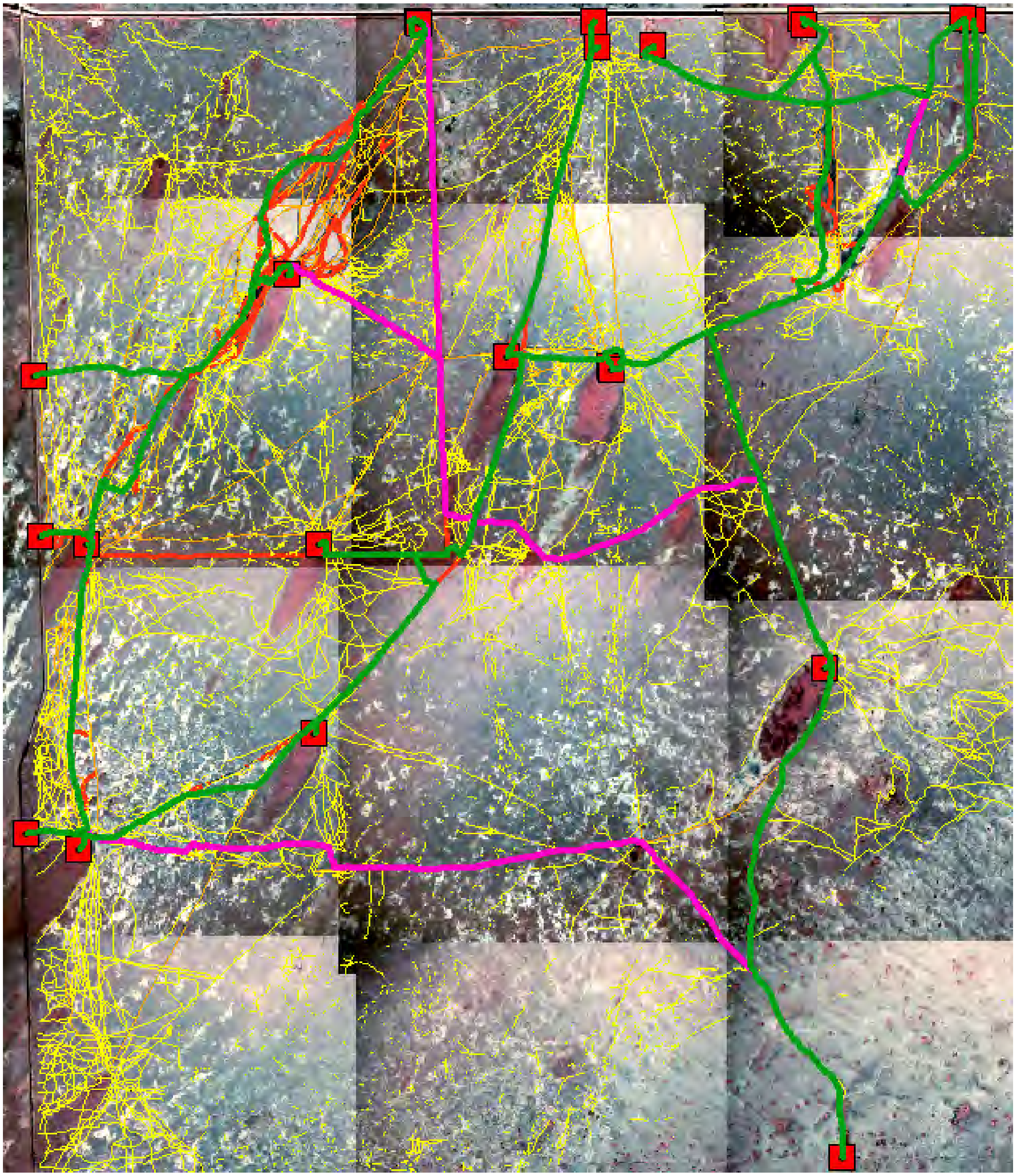


Figure 15: Scenario 4, improve route efficiency. Spanning tree is in green, additional routes are in pink.

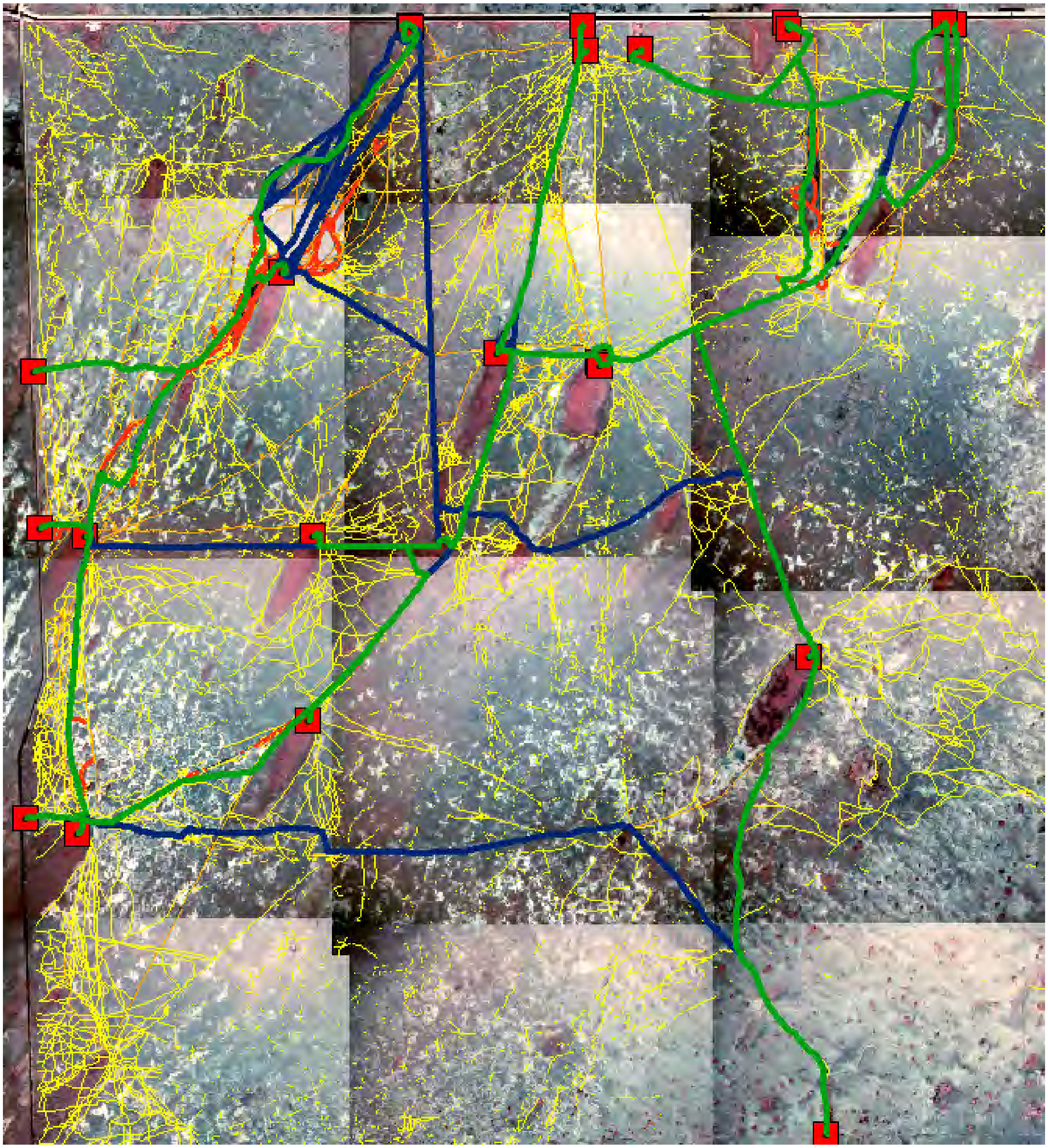


Figure 16: Proposed routes. The proposed route will consist of the spanning tree, in green, and the blue trails. In this case, the other trails visible will no longer be traveled.

Table 17: Summary statistics for length between terminal vertices along the proposed network

Average:	10975.02 m
Max:	20642.7 m
Min:	99.9 m

Table 18: Summary statistics for network cost between terminal vertices along the proposed network

Average:	16181.39
Max:	42223.42
Min:	199.86

Table 19: Average width class accounting for traversing low-cost areas along the proposed network

Average:	1.46
Max:	2.70
Min:	0.58

CHAPTER 5

SUMMARY AND CONCLUSION

The National Park Service has acquired the vast majority of the lands in the East Everglades Expansion Area and is completing litigation to seize the remaining few parcels. Its interim management plan has proven to be effective, as there is definite evidence of large reductions in overall airboat impact, including trail length and density, throughout the East Everglades area during the period from 1994 through 2003. In particular, Class 3 Trails (<3 m wide) have declined significantly from almost 17,479 km to just over 2,005 km (a decrease of 15,474 km, or 89 percent). This reduction indicates that as private airboat use has declined in the East Everglades, the vegetation is able to recover from occasional, dispersed use such that previous airboat trails are no longer evident on large scale aerial photographs.

Class 1 trails (>10 m wide) also have declined from 169 km to 73 km (a decrease of 96 km, or 57 percent), even while the commercial airboat business has been growing. In addition, open water areas mostly in the vicinity of commercial airboat operations (*i.e.*, polygons representing deep water areas of high airboat use) have declined from 256 ha to 60 ha (77 percent reduction). This implies airboat tour companies are following more consistent routes. Class 2 trails (3-10 m wide) have remained fairly static (185 km down to 164 km between 1994 and 2003, a decrease of 21 km, or 11 percent) in location and length, indicating that these trails are subject to persistent use by private and limited commercial tours. These trails are thought to be the most widely used private airboat trails.

These conclusions, drawn upon analyses of the trail database developed during this project, can be stated with confidence because the accuracy assessment has shown that the data digitizing methods are acceptable and so the condition of the East Everglades Expansion Area in each year of study should be accurately reflected in the corresponding database. With an overall accuracy of 80 percent, the methods used in this study are considered to be quite acceptable. Furthermore, with the considerations of helicopter speed and other factors that are part of positional accuracy and the ability to accurately discern trails by width which are near the class breaks, the overall accuracy is closer to 87 percent, a result that instills considerable confidence in the accuracy of the results.

By using standard GIS overlay operations, a network of static trails, or trails that exist in 1994, 1999 and 2003, can be readily generated. This network can become a transit network with enforceable connectivity and adjacency rules. Network travel costs can be computed for each segment based upon several factors, in this case trail width, trail length and the criteria that the passes through an area that has consistently shown a high level of impact throughout the study period. This network also can support special nodes (*i.e.* terminal nodes) which reflect docks or other locations to which airboat operators wish to travel. These terminal nodes can be maintained in a separate feature class but linked to the network with topology rules, allowing them to be imported directly as points of interest for route finding and O/D matrix generation. The resulting O/D matrices for both total length and cost are included in Appendicecs 1 to 9.

Using these same tools, a spanning tree can be generated that connects all potential destinations airboat operators may want to visit. Given additional scenarios for necessary routes of travel, targeted protection areas (through which there should be no travel) and other network weight factors, a final proposed network can be generated in which desirability can be ranked with the information generated. The result can be compared to the static network to determine how much of an improvement the proposed network is from the static and/or most recent trail networks and how effectively it addresses the scenario requirements. A proposed network was generated with four sample scenarios: 1) a commercial airboat operator requiring a large array of redundant trails in one region; 2) historical trails desirable to private operators; 3) areas targeted for recovery and; 4) a mathematical stricture on the length of travel between any two potential destinations. This route required only 6 percent of the total 2003 trail length yet connected every desired destination with an average length between destinations of only 15 percent longer and a maximum length between destinations only 5 percent longer than the entire static network. The average class Width, at 1.46, is slightly lower as well, indicating that the proposed network utilizes routes that will have a minimal ecological impact.

The procedures used in this study provided an unmitigated success in finding a redundant set of connected routes that can service several needs while minimizing ecological impact and permitting specific targeted recovery areas. This methodology has been demonstrated flexible and extensible. Scenarios are completely modular, not only considering additional management needs but adjusting to maximize their potential among parameters other than the cost parameter used in these scenarios. Furthermore, customized programming or the use of other transportation analysis packages can allow advanced traffic analyses such as how much simultaneous traffic can flow from point to point given several nonidentical routes. The procedure can even be abstracted for use with many other preservation projects in the National Park Service, which makes these findings a valuable tool for ecological resource planners.

BIBLIOGRAPHY

Anders, F. J. and S. P. Leatherman, 1987. "Effects of off-road vehicles on coastal foredunes at Fire Island, New York, USA." Environmental Management. 11:1: 45-52

Associated Press. 2000a "Park Service to phase out snowmobiles over three years." CNN. 22 November 2000, Accessed February 2006: <http://archives.cnn.com/2000/US/11/22/parks.snowmobiles.ap/>

Associated Press. 2000 "Few happy with personal watercraft rules." CNN. 27 March 2000, Accessed February 2006: <http://archives.cnn.com/2000/NATURE/08/10/snowmobiles.enn/index.html>

Associated Press. 2000 "Snowmobile groups sue NPS over Denali ban." CNN. 10 August 2000, Accessed February 2006: <http://archives.cnn.com/2000/NATURE/08/10/snowmobiles.enn/index.html>

Associated Press. 2001 "Interior Department settles lawsuit over snowmobiling." CNN. 29 June 2001, Accessed February 2006: <http://archives.cnn.com/2001/ALLPOLITICS/06/29/us.snowmobiling/index.html>

Associated Press. 2002 "Snowmobile Rules Rankle in Yellowstone." CNN. Tuesday 12 November 2002, Accessed February 2006: <http://archives.cnn.com/2002/TRAVEL/ADVISOR/11/12/snowmobile.rules.ap>

Associated Press. 2004 "Yellowstone snowmobile ban overturned." CNN. 15 October 2004, Accessed February 2006: <http://www.cnn.com/2004/LAW/10/15/yellowstone.snowmobile.ap/>

ArcGIS. 2005, Environmental Systems Research Institute (ESRI): <http://www.esri.com/software/arcgis/index.html>

Brodhead, J. M. and P. J. Godfrey, 1997. "Off road vehicle impact in Cape Cod national seashore: Disruption and recovery of dune vegetation." International Journal of Biometeorology. 21:3: 299-306.

Bruehler, G., 2004. GIS/GPS Trail Condition Inventories: A Virtual Toolbox for Trail Managers. Final Report to the U.S. Department of Interior, National Park Service, Clarus Technologies / Integrated Concepts and Research (ICRC), Eagle River, AK, 13 pp.

Clemens, J. and M.H. Franklin. "A Description of Coastal Health at North Head, Sydney Harbour National Park : Impact of Recreation and other Disturbance Since 1951." Australian Journal of Botany. 28:4: 463-478.

Cole, N., 1981. “Visitor Dispersal and Campsite Closure.” Journal of Forestry. 79:2: 86-89.

Davis, S. M. and J. C. Ogden, eds. 1994. Everglades: The Ecosystem and Its Restoration. DelRay Beach: St. Lucie Press. 826 pp.

Doren, R. F., K. Rutchy and R. Welch. 1999. “The Everglades: A Perspective on the Requirements and Applications for Vegetation Map and Database Products.” Photogrammetric Engineering and Remote Sensing 65:2: 155-161.

Dressler, W.H., 2006. “Co-opting Conservation: Migrant Resource Control and Access to National Park Management in the Philippine Uplands.” Development and Change. 37:2: 401-426.

Duever, M. J., J. E. Carlson, J. F. Meeder, L. C. Duever, L. H. Gunderson, L. A. Riopelle, T. R. Alexander, R. L. Myers and D. P. Spangler. 1986. The Big Cypress National Preserve. New York: National Audubon Society. 444 pp.

Griffiths, M. and Van Schaik, C.P., 1993. “The Impact of Human Traffic on the Abundance and Activity Periods of Sumatran Rain Forest Wildlife.” Conservation Biology. 7:3: 623-630.

Hamilton, J.A., 1978. Effects of Off-Road Vehicles on the Sediments of Hatches Harbor, Cape Cod National Seashore. Massachusetts University National Park Service Cooperative Research Unit Report No 30, 23 pp.

Hamburger, R., 2005. “Real Ultimate Power.” Accessed July 2006. <http://www.realultimatepower.net/>

Harary, F. 1969. Graph Theory. Reading: Addison-Wesley. 274 pp.

Hu, S. 1999. “Utilization of an Everglades Vegetation Database.” Photogrammetric Engineering and Remote Sensing. 65:2: 193-198.

Ingle, C., Y. Leung, C. Monz and H. Bauman, 2003. “Monitoring Visitor Impacts in Coastal National Parks: A Review of Techniques.” Protecting Oceans and Their Coasts. pp 228-232.

Jordan, T., M. Madden and L. Manglass, 2006. Airboat/ORV Trail Inventory for the East Everglades Addition Lands, Final Report to the U.S. Department of Interior, National Park Service, Cooperative Agreement Number H5000-03-5040, Center for Remote Sensing and Mapping Science, The University of Georgia, Athens, Georgia, 25 pp.

Kaiser, J. V. Jr., D. A. Stow and L. Cao. 2004. “Evaluation of Remote Sensing Techniques for Mapping Transborder Trails.” Photogrammetric Engineering and Remote Sensing. 70.12: 1441-1447.

Lodge, T. E. 1994. The Everglades Handbook: Understanding the Ecosystem. Delray Beach: St. Lucie Press. 228 pp.

Madden, M. 2004. "Remote Sensing and Geographic Information System Operations for Vegetation Mapping of Invasive Exotics." Weed Technology. 18: 1457-1463.

Madden, M., D. Jones and L. Vilchek. 1999. "Photointerpretation Key for the Everglades Vegetation Classification System." Photogrammetric Engineeric and Remote Sensing. 65:2: 171-177.

Mapstone, B.D., 1995. "Scalable Decision Rules for Environmental Impact Studies: Effect Size, Type I and Type II Errors." Ecological Applications. 5:2: 401-410.

Monz, C. and Leung, Y., 2003. Phase 1 Project Report: National Park Service Coastal Visitor Impact Monitoring, Phase 1 Report to the National Park Service, March 2003.

Myers R.L. and J.J Ewel. 1991. "Ecosystems of Florida." University of Central Florida Press, Orlando, FL. 765 pp.

National Park Service, 2005a: Everglades National Park (National Park Service). Accessed February 2006: http://www.nps.gov/ever/

National Park Service, 2005b: The Everglades: Early Development. Accessed February 2006: <http://www.nps.gov/ever/eco/develop.htm>

National Park Service, 2005c: The Everglades: Restoration Efforts. Accessed February 2006: <http://www.nps.gov/ever/eco/restore.htm>

Olliff, T., K. Legg, and B. Kaeding, editors. 1999. "Effects of winter recreation on wildlife of the Greater Yellowstone Area". Yellowstone National Park, Wyoming. 315 pp. Accessed February 2006: <http://www.nps.gov/yell/publications/pdfs/wildlifewint.pdf>

Pawelski, N. 2000. "Smog-Choked Yellowstone mulls snowmobile ban." CNN. 6 March 2000, Accessed February 2006: <http://archives.cnn.com/2000/NATURE/03/06/yellowstone.snow.fight/index.html>

Tebeau, C. W. 1968. Man in the Everglades: 2000 Years of Human History in the Everglades National Park. Coral Gables: University of Miami Press. 192 pp.

Welch, R., M. Madden and R. F. Doren. 1999. "Mapping the Everglades." Photogrammetric Engineering and Remote Sensing. 65:2: 163-170.

Welch, R., M. Madden and R. F. Doren, 2002. "Maps and GIS databases for environmental studies of the Everglades," Chapter 9. In, J. Porter and K. Porter (Eds.) The Everglades, Florida Bay and Coral Reefs of the Florida Keys: An Ecosystem Sourcebook, CRC Press, Boca Raton, Florida: 259-279.

Welch, R., M. Remillard and R. F. Doren. 1995. "GIS Database Development for South Florida's National Parks and Preserves." Photogrammetric Engineering and Remote Sensing. 61:11: 1371-1381.

Welch, R., M. Madden and T. Litts, 2001. Off-Road Vehicle Trail Accuracy Assessment: Big Cypress National Preserve (BICY), Final Report to the U.S. Dept. of Interior, National Park Service, Cooperative Agreement Number 5120-00-001, Center for Remote Sensing and Mapping Science, The University of Georgia, Athens, Georgia, 35 pp.

Welch, R. and M. Madden, 1998. Off-Road Vehicle Trail Database for Big Cypress National Preserve. Final Report to the U.S. Dept. of Interior, National Park Service, Cooperative Agreement Number 5280-7-9002, Center for Remote Sensing and Mapping Science, The University of Georgia, Athens, Georgia: 30 pp.

Welch, R. and M. Madden, 1999. Vegetation Map and Digital Database of South Florida National Park Service Lands to Assess Long-Term Effects of Hurricane Andrew. Final Report to the U.S. Dept. of Interior, National Park Service, Cooperative Agreement Number 5280-4-9006, Center for Remote Sensing and Mapping Science, The University of Georgia, Athens, Georgia: 43 pp.

Wilson, R. J. 1996. Introduction to Graph Theory. Essex: Pearson Education Limited. 171 pp.

APPENDIX

Appendix 1a: Total length between terminal vertices along the network
Lengths are in meters

	1	2	3	4	5	6	7	8	9	10	11
1	0.00	589.38	5863.30	5649.35	13764.53	14493.92	14504.99	15209.69	14825.87	11453.89	8124.82
2	589.38	0.00	5696.68	5482.72	13597.91	14327.30	14338.37	15043.07	14659.25	11389.93	8060.85
3	5863.30	5696.68	0.00	399.29	9779.33	10508.73	10519.80	11224.50	10840.68	13214.59	9885.52
4	5649.35	5482.72	399.29	0.00	9565.38	10294.78	10305.85	11010.54	10626.72	13000.64	9671.56
5	13764.53	13597.91	9779.33	9565.38	0.00	3217.85	3228.92	6895.38	4830.91	15475.04	14234.75
6	14493.92	14327.30	10508.73	10294.78	3217.85	0.00	99.93	5127.48	3063.00	16204.44	14964.14
7	14504.99	14338.37	10519.80	10305.85	3228.92	99.93	0.00	5138.55	3074.08	16215.51	14975.21
8	15209.69	15043.07	11224.50	11010.54	6895.38	5127.48	5138.55	0.00	2133.40	16920.21	15679.91
9	14825.87	14659.25	10840.68	10626.72	4830.91	3063.00	3074.08	2133.40	0.00	16536.39	15296.09
10	11453.89	11389.93	13214.59	13000.64	15475.04	16204.44	16215.51	16920.21	16536.39	0.00	4398.44
11	8124.82	8060.85	9885.52	9671.56	14234.75	14964.14	14975.21	15679.91	15296.09	4398.44	0.00
12	6976.36	6948.27	9012.57	8798.62	15489.89	16219.29	16230.36	16935.06	16551.24	7960.80	4631.72
13	19731.10	19564.47	15745.90	15531.95	15041.01	15717.85	15728.92	15998.22	15951.68	12297.49	15773.43
14	3704.83	3573.10	5357.04	5143.09	12632.27	13361.66	13372.73	14077.43	13693.61	8061.53	4732.46
15	8175.91	8009.29	4190.72	3976.77	6975.87	7705.26	7716.33	8421.03	8037.21	9350.91	8110.61
16	8308.92	8142.30	4323.72	4109.77	5850.74	6580.14	6591.21	7295.91	6912.09	9868.31	8628.01
17	8673.48	8506.85	4688.28	4474.33	5565.35	6294.75	6305.82	7010.52	6626.70	10383.99	9143.69
18	7845.76	7781.80	9606.46	9392.50	13701.78	14431.17	14442.24	15146.94	14763.12	3745.54	790.31
19	7593.77	7529.80	8551.67	8337.72	10782.49	11511.89	11522.96	12227.66	11843.84	6360.30	3463.47
20	11526.87	11462.91	12697.37	12483.42	14928.19	15657.59	15668.66	16373.36	15989.54	869.94	4471.42
21	10641.42	10474.80	9424.81	9210.86	11655.63	12385.03	12396.10	13100.80	12716.98	4081.36	7482.22
22	13274.58	13107.95	9289.38	9075.43	8584.49	9261.33	9272.40	9541.70	9495.16	11062.47	11753.94

Average:	9507.815
Max:	19731.1
Min:	99.9

Appendix 1b: Total length between terminal vertices along the network
Lengths are in meters

	12	13	14	15	16	17	18	19	20	21	22
1	6976.36	19731.10	3704.83	8175.91	8308.92	8673.48	7845.76	7593.77	11526.87	10641.42	13274.58
2	6948.27	19564.47	3573.10	8009.29	8142.30	8506.85	7781.80	7529.80	11462.91	10474.80	13107.95
3	9012.57	15745.90	5357.04	4190.72	4323.72	4688.28	9606.46	8551.67	12697.37	9424.81	9289.38
4	8798.62	15531.95	5143.09	3976.77	4109.77	4474.33	9392.50	8337.72	12483.42	9210.86	9075.43
5	15489.89	15041.01	12632.27	6975.87	5850.74	5565.35	13701.78	10782.49	14928.19	11655.63	8584.49
6	16219.29	15717.85	13361.66	7705.26	6580.14	6294.75	14431.17	11511.89	15657.59	12385.03	9261.33
7	16230.36	15728.92	13372.73	7716.33	6591.21	6305.82	14442.24	11522.96	15668.66	12396.10	9272.40
8	16935.06	15998.22	14077.43	8421.03	7295.91	7010.52	15146.94	12227.66	16373.36	13100.80	9541.70
9	16551.24	15951.68	13693.61	8037.21	6912.09	6626.70	14763.12	11843.84	15989.54	12716.98	9495.16
10	7960.80	12297.49	8061.53	9350.91	9868.31	10383.99	3745.54	6360.30	869.94	4081.36	11062.47
11	4631.72	15773.43	4732.46	8110.61	8628.01	9143.69	790.31	3463.47	4471.42	7482.22	11753.94
12	0.00	19335.78	3859.51	9365.76	9883.16	10398.84	4352.66	4718.62	8033.77	8737.37	13009.09
13	19335.78	0.00	17036.22	12942.44	11817.31	11531.92	15120.53	14758.20	11750.64	11690.86	6585.00
14	3859.51	17036.22	0.00	6508.13	7025.53	7541.22	4453.40	4137.44	8134.51	7392.60	10579.70
15	9365.76	12942.44	6508.13	0.00	1369.13	1884.81	7577.64	4658.36	8804.06	5531.50	6485.92
16	9883.16	11817.31	7025.53	1369.13	0.00	759.69	8095.04	5175.76	9321.46	6048.90	5360.79
17	10398.84	11531.92	7541.22	1884.81	759.69	0.00	8610.72	5691.44	9837.14	6564.58	5075.40
18	4352.66	15120.53	4453.40	7577.64	8095.04	8610.72	0.00	2930.51	3818.52	6904.40	11220.97
19	4718.62	14758.20	4137.44	4658.36	5175.76	5691.44	2930.51	0.00	6433.27	4029.97	8301.68
20	8033.77	11750.64	8134.51	8804.06	9321.46	9837.14	3818.52	6433.27	0.00	3534.51	10515.62
21	8737.37	11690.86	7392.60	5531.50	6048.90	6564.58	6904.40	4029.97	3534.51	0.00	9137.96
22	13009.09	6585.00	10579.70	6485.92	5360.79	5075.40	11220.97	8301.68	10515.62	9137.96	0.00

Average:	9507.815
Max:	19731.1
Min:	99.9

Appendix 2a: Total network cost between terminal vertices along the network
Values are unitless

	1	2	3	4	5	6	7	8	9	10	11
1	0.00	939.69	14721.78	14249.98	26782.28	24024.96	24047.11	25265.95	21891.51	13486.05	7765.94
2	939.69	0.00	13856.34	13384.54	26207.99	23450.67	23472.81	24691.66	21317.22	12916.55	7196.44
3	14721.78	13856.34	0.00	754.69	18473.43	15716.12	15738.26	16957.10	13582.66	16845.73	13726.46
4	14249.98	13384.54	754.69	0.00	18001.63	15244.32	15266.46	16485.30	13110.86	16373.93	13254.66
5	26782.28	26207.99	18473.43	18001.63	0.00	7270.44	7292.58	12961.02	8832.08	26776.03	23656.76
6	24024.96	23450.67	15716.12	15244.32	7270.44	0.00	199.86	10203.70	6074.76	24018.71	20899.44
7	24047.11	23472.81	15738.26	15266.46	7292.58	199.86	0.00	10225.84	6096.90	24040.85	20921.58
8	25265.95	24691.66	16957.10	16485.30	12961.02	10203.70	10225.84	0.00	4266.79	25259.70	22140.43
9	21891.51	21317.22	13582.66	13110.86	8832.08	6074.76	6096.90	4266.79	0.00	21885.26	18765.99
10	13486.05	12916.55	16845.73	16373.93	26776.03	24018.71	24040.85	25259.70	21885.26	0.00	6116.21
11	7765.94	7196.44	13726.46	13254.66	23656.76	20899.44	20921.58	22140.43	18765.99	6116.21	0.00
12	8554.99	7985.49	16564.16	16092.36	27531.84	24774.52	24796.66	26015.51	22641.07	12333.95	6613.84
13	36297.98	35728.47	30599.67	30127.87	32799.57	30042.25	30064.39	31283.24	27908.80	25927.90	28928.14
14	4306.24	3736.74	11825.47	11353.67	22793.14	20035.82	20057.96	21276.81	17902.37	9986.86	4266.75
15	12580.42	12006.13	4271.57	3799.77	14201.86	11444.54	11466.68	12685.53	9311.09	12574.16	9454.89
16	13672.99	13098.69	5364.14	4892.34	13539.90	10782.58	10804.72	12023.57	8649.13	13666.73	10547.46
17	15121.07	14546.78	6812.22	6340.42	13000.16	10242.84	10264.98	11483.82	8109.39	15114.81	11995.54
18	7830.69	7261.18	13265.62	12793.82	23195.91	20438.59	20460.73	21679.58	18305.14	5655.37	460.85
19	12229.41	11655.11	9450.04	8978.24	19380.33	16623.01	16645.15	17864.00	14489.56	8640.71	5521.44
20	12103.63	11534.12	15463.31	14991.51	25393.60	22636.28	22658.42	23877.27	20502.83	1396.64	4733.79
21	14080.87	13506.58	9855.63	9383.83	19785.92	17028.60	17050.74	18269.59	14895.15	7794.07	10187.27
22	23551.82	22977.53	17686.63	17214.83	19886.53	17129.21	17151.35	18370.20	14995.76	23330.18	20210.91

Average:	14979.3
Maximum:	36297.98
Minimum:	199.86

Appendix 2b: Total network cost between terminal vertices along the network
Values are unitless

	12	13	14	15	16	17	18	19	20	21	22
1	8554.99	36297.98	4306.24	12580.42	13672.99	15121.07	7830.69	12229.41	12103.63	14080.87	23551.82
2	7985.49	35728.47	3736.74	12006.13	13098.69	14546.78	7261.18	11655.11	11534.12	13506.58	22977.53
3	16564.16	30599.67	11825.47	4271.57	5364.14	6812.22	13265.62	9450.04	15463.31	9855.63	17686.63
4	16092.36	30127.87	11353.67	3799.77	4892.34	6340.42	12793.82	8978.24	14991.51	9383.83	17214.83
5	27531.84	32799.57	22793.14	14201.86	13539.90	13000.16	23195.91	19380.33	25393.60	19785.92	19886.53
6	24774.52	30042.25	20035.82	11444.54	10782.58	10242.84	20438.59	16623.01	22636.28	17028.60	17129.21
7	24796.66	30064.39	20057.96	11466.68	10804.72	10264.98	20460.73	16645.15	22658.42	17050.74	17151.35
8	26015.51	31283.24	21276.81	12685.53	12023.57	11483.82	21679.58	17864.00	23877.27	18269.59	18370.20
9	22641.07	27908.80	17902.37	9311.09	8649.13	8109.39	18305.14	14489.56	20502.83	14895.15	14995.76
10	12333.95	25927.90	9986.86	12574.16	13666.73	15114.81	5655.37	8640.71	1396.64	7794.07	23330.18
11	6613.84	28928.14	4266.75	9454.89	10547.46	11995.54	460.85	5521.44	4733.79	10187.27	20210.91
12	0.00	35145.87	5055.80	13329.98	14422.54	15870.62	6678.58	11739.18	10951.52	14830.43	24301.37
13	35145.87	0.00	32475.72	26328.10	25666.14	25126.39	28467.29	28847.52	24531.27	24580.75	13170.00
14	5055.80	32475.72	0.00	8591.28	9683.84	11131.93	4331.49	8240.26	8604.43	10091.73	19562.68
15	13329.98	26328.10	8591.28	0.00	1092.56	2540.65	8994.05	5178.46	11191.74	5584.06	13415.06
16	14422.54	25666.14	9683.84	1092.56	0.00	1878.69	10086.61	6271.03	12284.30	6676.62	12753.10
17	15870.62	25126.39	11131.93	2540.65	1878.69	0.00	11534.69	7719.11	13732.38	8124.70	12213.35
18	6678.58	28467.29	4331.49	8994.05	10086.61	11534.69	0.00	5060.59	4272.94	9726.42	19750.06
19	11739.18	28847.52	8240.26	5178.46	6271.03	7719.11	5060.59	0.00	7258.28	5910.84	15934.48
20	10951.52	24531.27	8604.43	11191.74	12284.30	13732.38	4272.94	7258.28	0.00	6397.44	21947.75
21	14830.43	24580.75	10091.73	5584.06	6676.62	8124.70	9726.42	5910.84	6397.44	0.00	16340.07
22	24301.37	13170.00	19562.68	13415.06	12753.10	12213.35	19750.06	15934.48	21947.75	16340.07	0.00

Average:	14979.3
Maximum:	36297.98
Minimum:	199.86

Appendix 3: Average width class along each trail accounting for traversing low-cost areas along the network
Values are unitless

	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22
1	0.00	1.59	2.51	2.52	1.95	1.66	1.66	1.66	1.48	1.18	0.96	1.23	1.84	1.16	1.54	1.65	1.74	1.00	1.61	1.05	1.32	1.77
2	1.59	0.00	2.43	2.44	1.93	1.64	1.64	1.64	1.45	1.13	0.89	1.15	1.83	1.05	1.50	1.61	1.71	0.93	1.55	1.01	1.29	1.75
3	2.51	2.43	0.00	1.89	1.89	1.50	1.50	1.51	1.25	1.27	1.39	1.84	1.94	2.21	1.02	1.24	1.45	1.38	1.11	1.22	1.05	1.90
4	2.52	2.44	1.89	0.00	1.88	1.48	1.48	1.50	1.23	1.26	1.37	1.83	1.94	2.21	0.96	1.19	1.42	1.36	1.08	1.20	1.02	1.90
5	1.95	1.93	1.89	1.88	0.00	2.26	2.26	1.88	1.83	1.73	1.66	1.78	2.18	1.80	2.04	2.31	2.34	1.69	1.80	1.70	1.70	2.32
6	1.66	1.64	1.50	1.48	2.26	0.00	2.00	1.99	1.98	1.48	1.40	1.53	1.91	1.50	1.49	1.64	1.63	1.42	1.44	1.45	1.37	1.85
7	1.66	1.64	1.50	1.48	2.26	2.00	0.00	1.99	1.98	1.48	1.40	1.53	1.91	1.50	1.49	1.64	1.63	1.42	1.44	1.45	1.38	1.85
8	1.66	1.64	1.51	1.50	1.88	1.99	1.99	0.00	2.00	1.49	1.41	1.54	1.96	1.51	1.51	1.65	1.64	1.43	1.46	1.46	1.39	1.93
9	1.48	1.45	1.25	1.23	1.83	1.98	1.98	2.00	0.00	1.32	1.23	1.37	1.75	1.31	1.16	1.25	1.22	1.24	1.22	1.28	1.17	1.58
10	1.18	1.13	1.27	1.26	1.73	1.48	1.48	1.49	1.32	0.00	1.39	1.55	2.11	1.24	1.34	1.38	1.46	1.51	1.36	1.61	1.91	2.11
11	0.96	0.89	1.39	1.37	1.66	1.40	1.40	1.41	1.23	1.39	0.00	1.43	1.83	0.90	1.17	1.22	1.31	0.58	1.59	1.06	1.36	1.72
12	1.23	1.15	1.84	1.83	1.78	1.53	1.53	1.54	1.37	1.55	1.43	0.00	1.82	1.31	1.42	1.46	1.53	1.53	2.49	1.36	1.70	1.87
13	1.84	1.83	1.94	1.94	2.18	1.91	1.91	1.96	1.75	2.11	1.83	1.82	0.00	1.91	2.03	2.17	2.18	1.88	1.95	2.09	2.10	2.00
14	1.16	1.05	2.21	2.21	1.80	1.50	1.50	1.51	1.31	1.24	0.90	1.31	1.91	0.00	1.32	1.38	1.48	0.97	1.99	1.06	1.37	1.85
15	1.54	1.50	1.02	0.96	2.04	1.49	1.49	1.51	1.16	1.34	1.17	1.42	2.03	1.32	0.00	0.80	1.35	1.19	1.11	1.27	1.01	2.07
16	1.65	1.61	1.24	1.19	2.31	1.64	1.64	1.65	1.25	1.38	1.22	1.46	2.17	1.38	0.80	0.00	2.47	1.25	1.21	1.32	1.10	2.38
17	1.74	1.71	1.45	1.42	2.34	1.63	1.63	1.64	1.22	1.46	1.31	1.53	2.18	1.48	1.35	2.47	0.00	1.34	1.36	1.40	1.24	2.41
18	1.00	0.93	1.38	1.36	1.69	1.42	1.42	1.43	1.24	1.51	0.58	1.53	1.88	0.97	1.19	1.25	1.34	0.00	1.73	1.12	1.41	1.76
19	1.61	1.55	1.11	1.08	1.80	1.44	1.44	1.46	1.22	1.36	1.59	2.49	1.95	1.99	1.11	1.21	1.36	1.73	0.00	1.13	1.47	1.92
20	1.05	1.01	1.22	1.20	1.70	1.45	1.45	1.46	1.28	1.61	1.06	1.36	2.09	1.06	1.27	1.32	1.40	1.12	1.13	0.00	1.81	2.09
21	1.32	1.29	1.05	1.02	1.70	1.37	1.38	1.39	1.17	1.91	1.36	1.70	2.10	1.37	1.01	1.10	1.24	1.41	1.47	1.81	0.00	1.79
22	1.77	1.75	1.90	1.90	2.32	1.85	1.85	1.93	1.58	2.11	1.72	1.87	2.00	1.85	2.07	2.38	2.41	1.76	1.92	2.09	1.79	0.00

Average: 1.57
Maximum: 2.52
Minimum: 0.58

Appendix 4a: Total length between terminal vertices along the spanning tree
Lengths are in meters

	1	2	3	4	5	6	7	8	9	10	11
1	0.00	589.38	26010.22	25796.26	30554.05	29307.40	29318.47	30285.46	30238.93	13015.94	9218.93
2	589.38	0.00	25723.34	25509.38	30267.17	29020.52	29031.59	29998.58	29952.05	12729.06	8932.05
3	26010.22	25723.34	0.00	399.29	13190.51	11943.86	11954.93	12921.92	12875.39	14160.33	17920.01
4	25796.26	25509.38	399.29	0.00	12976.55	11729.91	11740.98	12707.97	12661.44	13946.38	17706.05
5	30554.05	30267.17	13190.51	12976.55	0.00	3217.85	3228.92	6984.60	4920.13	18704.16	22463.84
6	29307.40	29020.52	11943.86	11729.91	3217.85	0.00	99.93	5737.96	3673.48	17457.51	21217.19
7	29318.47	29031.59	11954.93	11740.98	3228.92	99.93	0.00	5749.03	3684.55	17468.58	21228.26
8	30285.46	29998.58	12921.92	12707.97	6984.60	5737.96	5749.03	0.00	2133.40	18435.57	22195.25
9	30238.93	29952.05	12875.39	12661.44	4920.13	3673.48	3684.55	2133.40	0.00	18389.04	22148.72
10	13015.94	12729.06	14160.33	13946.38	18704.16	17457.51	17468.58	18435.57	18389.04	0.00	4925.73
11	9218.93	8932.05	17920.01	17706.05	22463.84	21217.19	21228.26	22195.25	22148.72	4925.73	0.00
12	7791.22	7504.34	21846.44	21632.49	26390.27	25143.63	25154.70	26121.69	26075.15	8852.17	5055.16
13	35039.02	34752.14	17675.48	17461.52	17106.01	15859.36	15870.43	16837.43	16790.89	23189.13	26948.81
14	5739.39	5452.51	22334.02	22120.07	26877.85	25631.20	25642.28	26609.27	26562.73	9339.75	5542.73
15	21913.13	21626.25	4198.24	3984.29	9093.42	7846.77	7857.84	8824.84	8778.30	10063.24	13822.92
16	22829.76	22542.88	5466.22	5252.27	7968.29	6721.65	6732.72	7699.71	7653.18	10979.87	14739.55
17	23345.44	23058.56	5981.90	5767.95	7682.91	6436.26	6447.33	7414.32	7367.79	11495.55	15255.23
18	8880.51	8593.64	17267.11	17053.15	21810.94	20564.29	20575.36	21542.35	21495.82	4272.83	790.31
19	19833.61	19546.73	8825.07	8611.12	13368.90	12122.26	12133.33	13100.32	13053.79	7983.72	11743.40
20	12719.82	12432.95	13633.63	13419.68	18177.46	16930.81	16941.88	17908.87	17862.34	869.94	4629.62
21	15972.43	15685.55	10299.74	10085.79	14843.57	13596.93	13608.00	14574.99	14528.46	4122.54	7882.22
22	28637.50	28350.62	11273.96	11060.01	10704.49	9457.85	9468.92	10435.91	10389.38	16787.61	20547.29

Average: 14291.56
Max: 35039.0
Min: 99.9

Appendix 4b: Total length between terminal vertices along the spanning tree
Lengths are in meters

	12	13	14	15	16	17	18	19	20	21	22
1	7791.22	35039.02	5739.39	21913.13	22829.76	23345.44	8880.51	19833.61	12719.82	15972.43	28637.50
2	7504.34	34752.14	5452.51	21626.25	22542.88	23058.56	8593.64	19546.73	12432.95	15685.55	28350.62
3	21846.44	17675.48	22334.02	4198.24	5466.22	5981.90	17267.11	8825.07	13633.63	10299.74	11273.96
4	21632.49	17461.52	22120.07	3984.29	5252.27	5767.95	17053.15	8611.12	13419.68	10085.79	11060.01
5	26390.27	17106.01	26877.85	9093.42	7968.29	7682.91	21810.94	13368.90	18177.46	14843.57	10704.49
6	25143.63	15859.36	25631.20	7846.77	6721.65	6436.26	20564.29	12122.26	16930.81	13596.93	9457.85
7	25154.70	15870.43	25642.28	7857.84	6732.72	6447.33	20575.36	12133.33	16941.88	13608.00	9468.92
8	26121.69	16837.43	26609.27	8824.84	7699.71	7414.32	21542.35	13100.32	17908.87	14574.99	10435.91
9	26075.15	16790.89	26562.73	8778.30	7653.18	7367.79	21495.82	13053.79	17862.34	14528.46	10389.38
10	8852.17	23189.13	9339.75	10063.24	10979.87	11495.55	4272.83	7983.72	869.94	4122.54	16787.61
11	5055.16	26948.81	5542.73	13822.92	14739.55	15255.23	790.31	11743.40	4629.62	7882.22	20547.29
12	0.00	30875.24	4115.02	17749.36	18665.98	19181.67	4716.74	15669.84	8556.05	11808.65	24473.73
13	30875.24	0.00	31362.82	13578.39	12453.26	12167.88	26295.91	17853.87	22662.43	19328.54	6585.00
14	4115.02	31362.82	0.00	18236.93	19153.56	19669.25	5204.32	16157.41	9043.63	12296.23	24961.30
15	17749.36	13578.39	18236.93	0.00	1369.13	1884.81	13170.02	4727.99	9536.54	6202.66	7176.87
16	18665.98	12453.26	19153.56	1369.13	0.00	759.69	14086.65	5644.62	10453.17	7119.29	6051.75
17	19181.67	12167.88	19669.25	1884.81	759.69	0.00	14602.33	6160.30	10968.85	7634.97	5766.36
18	4716.74	26295.91	5204.32	13170.02	14086.65	14602.33	0.00	11090.50	3976.72	7229.32	19894.39
19	15669.84	17853.87	16157.41	4727.99	5644.62	6160.30	11090.50	0.00	7457.02	4123.14	11452.36
20	8556.05	22662.43	9043.63	9536.54	10453.17	10968.85	3976.72	7457.02	0.00	3595.84	16260.91
21	11808.65	19328.54	12296.23	6202.66	7119.29	7634.97	7229.32	4123.14	3595.84	0.00	12927.03
22	24473.73	6585.00	24961.30	7176.87	6051.75	5766.36	19894.39	11452.36	16260.91	12927.03	0.00

Average: 14291.56
Max: 35039.0
Min: 99.9

Appendix 5a: Total network cost between terminal vertices along the spanning tree
Values are unitless

	1	2	3	4	5	6	7	8	9	10	11
1	0.00	939.69	31278.54	30806.74	41208.83	38451.51	38473.65	39692.50	39599.43	13880.91	8057.42
2	939.69	0.00	30641.36	30169.56	40571.65	37814.33	37836.47	39055.32	38962.25	13243.73	7420.24
3	31278.54	30641.36	0.00	754.69	18473.43	15716.12	15738.26	16957.10	16864.04	19729.73	23513.84
4	30806.74	30169.56	754.69	0.00	18001.63	15244.32	15266.46	16485.30	16392.24	19257.93	23042.04
5	41208.83	40571.65	18473.43	18001.63	0.00	7270.44	7292.58	12961.02	8832.08	29660.02	33444.13
6	38451.51	37814.33	15716.12	15244.32	7270.44	0.00	199.86	10203.70	6074.76	26902.70	30686.81
7	38473.65	37836.47	15738.26	15266.46	7292.58	199.86	0.00	10225.84	6096.90	26924.84	30708.95
8	39692.50	39055.32	16957.10	16485.30	12961.02	10203.70	10225.84	0.00	4266.79	28143.69	31927.80
9	39599.43	38962.25	16864.04	16392.24	8832.08	6074.76	6096.90	4266.79	0.00	28050.63	31834.73
10	13880.91	13243.73	19729.73	19257.93	29660.02	26902.70	26924.84	28143.69	28050.63	0.00	6116.21
11	8057.42	7420.24	23513.84	23042.04	33444.13	30686.81	30708.95	31927.80	31834.73	6116.21	0.00
12	8698.47	8061.29	29834.95	29363.15	39765.24	37007.92	37030.06	38248.91	38155.85	12437.33	6613.84
13	53748.97	53111.79	31013.58	30541.78	32799.57	30042.25	30064.39	31283.24	31190.18	42200.17	45984.27
14	4373.92	3736.74	27635.87	27164.07	37566.16	34808.84	34830.98	36049.83	35956.76	10238.24	4414.75
15	27006.97	26369.78	4271.57	3799.77	14201.86	11444.54	11466.68	12685.53	12592.47	15458.16	19242.27
16	28099.53	27462.35	5364.14	4892.34	13539.90	10782.58	10804.72	12023.57	11930.51	16550.72	20334.83
17	29547.61	28910.43	6812.22	6340.42	13000.16	10242.84	10264.98	11483.82	11390.76	17998.81	21782.91
18	8225.55	7588.36	23052.99	22581.19	32983.28	30225.96	30248.10	31466.95	31373.89	5655.37	460.85
19	25253.72	24616.53	9450.04	8978.24	19380.33	16623.01	16645.15	17864.00	17770.93	13704.91	17489.02
20	12945.44	12308.26	18333.10	17861.30	28263.39	25506.07	25528.21	26747.06	26653.99	1396.64	5180.74
21	19342.88	18705.70	11935.66	11463.86	21865.95	19108.63	19130.77	20349.62	20256.56	7794.07	11578.18
22	40945.94	40308.76	18210.55	17738.75	19996.54	17239.22	17261.36	18480.21	18387.15	29397.14	33181.24

Average: 20537.47
Maximum: 53748.97
Minimum: 199.86

Appendix 5b: Total network cost between terminal vertices along the spanning tree
Values are unitless

	12	13	14	15	16	17	18	19	20	21	22
1	8698.47	53748.97	4373.92	27006.97	28099.53	29547.61	8225.55	25253.72	12945.44	19342.88	40945.94
2	8061.29	53111.79	3736.74	26369.78	27462.35	28910.43	7588.36	24616.53	12308.26	18705.70	40308.76
3	29834.95	31013.58	27635.87	4271.57	5364.14	6812.22	23052.99	9450.04	18333.10	11935.66	18210.55
4	29363.15	30541.78	27164.07	3799.77	4892.34	6340.42	22581.19	8978.24	17861.30	11463.86	17738.75
5	39765.24	32799.57	37566.16	14201.86	13539.90	13000.16	32983.28	19380.33	28263.39	21865.95	19996.54
6	37007.92	30042.25	34808.84	11444.54	10782.58	10242.84	30225.96	16623.01	25506.07	19108.63	17239.22
7	37030.06	30064.39	34830.98	11466.68	10804.72	10264.98	30248.10	16645.15	25528.21	19130.77	17261.36
8	38248.91	31283.24	36049.83	12685.53	12023.57	11483.82	31466.95	17864.00	26747.06	20349.62	18480.21
9	38155.85	31190.18	35956.76	12592.47	11930.51	11390.76	31373.89	17770.93	26653.99	20256.56	18387.15
10	12437.33	42200.17	10238.24	15458.16	16550.72	17998.81	5655.37	13704.91	1396.64	7794.07	29397.14
11	6613.84	45984.27	4414.75	19242.27	20334.83	21782.91	460.85	17489.02	5180.74	11578.18	33181.24
12	0.00	52305.39	5055.80	25563.38	26655.94	28104.03	6781.96	23810.13	11501.86	17899.29	39502.35
13	52305.39	0.00	50106.30	26742.01	26080.05	25540.30	45523.43	31920.47	40803.53	34406.09	13170.00
14	5055.80	50106.30	0.00	23364.29	24456.86	25904.94	4582.87	21611.05	9302.77	15700.21	37303.27
15	25563.38	26742.01	23364.29	0.00	1092.56	2540.65	18781.42	5178.46	14061.52	7664.09	13938.98
16	26655.94	26080.05	24456.86	1092.56	0.00	1878.69	19873.98	6271.03	15154.09	8756.65	13277.01
17	28104.03	25540.30	25904.94	2540.65	1878.69	0.00	21322.07	7719.11	16602.17	10204.73	12737.27
18	6781.96	45523.43	4582.87	18781.42	19873.98	21322.07	0.00	17028.17	4719.90	11117.33	32720.40
19	23810.13	31920.47	21611.05	5178.46	6271.03	7719.11	17028.17	0.00	12308.27	5910.84	19117.44
20	11501.86	40803.53	9302.77	14061.52	15154.09	16602.17	4719.90	12308.27	0.00	6397.44	28000.50
21	17899.29	34406.09	15700.21	7664.09	8756.65	10204.73	11117.33	5910.84	6397.44	0.00	21603.06
22	39502.35	13170.00	37303.27	13938.98	13277.01	12737.27	32720.40	19117.44	28000.50	21603.06	0.00

Average: 20537.47
Maximum: 53748.97
Minimum: 199.86

Appendix 6: Average width class along each trail accounting for traversing low-cost areas along the spanning tree
Values are unitless

	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22
1	0.00	1.59	1.20	1.19	1.35	1.31	1.31	1.31	1.31	1.07	0.87	1.12	1.53	0.76	1.23	1.23	1.27	0.93	1.27	1.02	1.21	1.43
2	1.59	0.00	1.19	1.18	1.34	1.30	1.30	1.30	1.30	1.04	0.83	1.07	1.53	0.69	1.22	1.22	1.25	0.88	1.26	0.99	1.19	1.42
3	1.20	1.19	0.00	1.89	1.40	1.32	1.32	1.31	1.31	1.39	1.31	1.37	1.75	1.24	1.02	0.98	1.14	1.34	1.07	1.34	1.16	1.62
4	1.19	1.18	1.89	0.00	1.39	1.30	1.30	1.30	1.29	1.38	1.30	1.36	1.75	1.23	0.95	0.93	1.10	1.32	1.04	1.33	1.14	1.60
5	1.35	1.34	1.40	1.39	0.00	2.26	2.26	1.86	1.80	1.59	1.49	1.51	1.92	1.40	1.56	1.70	1.69	1.51	1.45	1.55	1.47	1.87
6	1.31	1.30	1.32	1.30	2.26	0.00	2.00	1.78	1.65	1.54	1.45	1.47	1.89	1.36	1.46	1.60	1.59	1.47	1.37	1.51	1.41	1.82
7	1.31	1.30	1.32	1.30	2.26	2.00	0.00	1.78	1.65	1.54	1.45	1.47	1.89	1.36	1.46	1.60	1.59	1.47	1.37	1.51	1.41	1.82
8	1.31	1.30	1.31	1.30	1.86	1.78	1.78	0.00	2.00	1.53	1.44	1.46	1.86	1.35	1.44	1.56	1.55	1.46	1.36	1.49	1.40	1.77
9	1.31	1.30	1.31	1.29	1.80	1.65	1.65	2.00	0.00	1.53	1.44	1.46	1.86	1.35	1.43	1.56	1.55	1.46	1.36	1.49	1.39	1.77
10	1.07	1.04	1.39	1.38	1.59	1.54	1.54	1.53	1.53	0.00	1.24	1.41	1.82	1.10	1.54	1.51	1.57	1.32	1.72	1.61	1.89	1.75
11	0.87	0.83	1.31	1.30	1.49	1.45	1.45	1.44	1.44	1.24	0.00	1.31	1.71	0.80	1.39	1.38	1.43	0.58	1.49	1.12	1.47	1.61
12	1.12	1.07	1.37	1.36	1.51	1.47	1.47	1.46	1.46	1.41	1.31	0.00	1.69	1.23	1.44	1.43	1.47	1.44	1.52	1.34	1.52	1.61
13	1.53	1.53	1.75	1.75	1.92	1.89	1.89	1.86	1.86	1.82	1.71	1.69	0.00	1.60	1.97	2.09	2.10	1.73	1.79	1.80	1.78	2.00
14	0.76	0.69	1.24	1.23	1.40	1.36	1.36	1.35	1.35	1.10	0.80	1.23	1.60	0.00	1.28	1.28	1.32	0.88	1.34	1.03	1.28	1.49
15	1.23	1.22	1.02	0.95	1.56	1.46	1.46	1.44	1.43	1.54	1.39	1.44	1.97	1.28	0.00	0.80	1.35	1.43	1.10	1.47	1.24	1.94
16	1.23	1.22	0.98	0.93	1.70	1.60	1.60	1.56	1.56	1.51	1.38	1.43	2.09	1.28	0.80	0.00	2.47	1.41	1.11	1.45	1.23	2.19
17	1.27	1.25	1.14	1.10	1.69	1.59	1.59	1.55	1.55	1.57	1.43	1.47	2.10	1.32	1.35	2.47	0.00	1.46	1.25	1.51	1.34	2.21
18	0.93	0.88	1.34	1.32	1.51	1.47	1.47	1.46	1.46	1.32	0.58	1.44	1.73	0.88	1.43	1.41	1.46	0.00	1.54	1.19	1.54	1.64
19	1.27	1.26	1.07	1.04	1.45	1.37	1.37	1.36	1.36	1.72	1.49	1.52	1.79	1.34	1.10	1.11	1.25	1.54	0.00	1.65	1.43	1.67
20	1.02	0.99	1.34	1.33	1.55	1.51	1.51	1.49	1.49	1.61	1.12	1.34	1.80	1.03	1.47	1.45	1.51	1.19	1.65	0.00	1.78	1.72
21	1.21	1.19	1.16	1.14	1.47	1.41	1.41	1.40	1.39	1.89	1.47	1.52	1.78	1.28	1.24	1.23	1.34	1.54	1.43	1.78	0.00	1.67
22	1.43	1.42	1.62	1.60	1.87	1.82	1.82	1.77	1.77	1.75	1.61	1.61	2.00	1.49	1.94	2.19	2.21	1.64	1.67	1.72	1.67	0.00

Average:	1.44
Maximum:	2.47
Minimum:	0.58

Appendix 7a: Total length between terminal vertices along the proposed network
Lengths are in meters

	1	2	3	4	5	6	7	8	9	10	11
1	0.00	589.38	12803.31	12589.36	17550.91	16304.26	16315.33	17282.32	16494.70	12586.67	8841.34
2	589.38	0.00	12407.63	12193.68	17155.23	15908.58	15919.65	16886.64	16099.02	12558.57	8813.25
3	12803.31	12407.63	0.00	399.29	12986.74	11740.09	11751.16	12718.15	11930.53	13285.40	15895.06
4	12589.36	12193.68	399.29	0.00	12772.78	11526.14	11537.21	12504.20	11716.58	13071.45	15681.11
5	17550.91	17155.23	12986.74	12772.78	0.00	3217.85	3228.92	6984.60	4920.13	18033.00	20642.66
6	16304.26	15908.58	11740.09	11526.14	3217.85	0.00	99.93	5737.96	3673.48	16786.35	19396.01
7	16315.33	15919.65	11751.16	11537.21	3228.92	99.93	0.00	5749.03	3684.55	16797.42	19407.08
8	17282.32	16886.64	12718.15	12504.20	6984.60	5737.96	5749.03	0.00	2133.40	17764.41	20374.08
9	16494.70	16099.02	11930.53	11716.58	4920.13	3673.48	3684.55	2133.40	0.00	16976.79	19586.45
10	12586.67	12558.57	13285.40	13071.45	18033.00	16786.35	16797.42	17764.41	16976.79	0.00	4925.73
11	8841.34	8813.25	15895.06	15681.11	20642.66	19396.01	19407.08	20374.08	19586.45	4925.73	0.00
12	7413.63	7385.53	14467.35	14253.39	19214.95	17968.30	17979.37	18946.36	18158.74	8800.48	5055.16
13	19576.68	19180.99	17471.71	17257.75	17106.01	15859.36	15870.43	16837.43	16049.80	12339.84	15842.63
14	5361.80	5333.70	10598.26	10384.30	15345.86	14099.21	14110.28	15077.27	14289.65	9288.06	5542.73
15	8909.99	8514.31	4190.72	3976.77	9093.42	7846.77	7857.84	8824.84	8037.21	9392.08	12001.74
16	9826.62	9430.94	5262.45	5048.50	7968.29	6721.65	6732.72	7699.71	6912.09	10308.71	12918.37
17	10342.30	9946.62	5778.13	5564.18	7682.91	6436.26	6447.33	7414.32	6626.70	10824.39	13434.05
18	8451.24	8423.14	15504.96	15291.00	20252.56	19005.91	19016.98	19983.97	19196.35	4272.83	790.31
19	8501.68	8106.00	8621.30	8407.35	13368.90	12122.26	12133.33	13100.32	12312.70	7983.72	11486.51
20	12245.99	12217.90	12758.70	12544.75	17506.30	16259.65	16270.72	17237.71	16450.09	869.94	4585.06
21	9787.14	9391.46	9424.81	9210.86	14172.41	12925.77	12936.84	13903.83	13116.20	4122.54	7625.32
22	13175.16	12779.48	11070.19	10856.24	10704.49	9457.85	9468.92	10435.91	9648.29	13446.75	16266.91

Average:	10975.02
Max:	20642.7
Min:	99.9

Appendix 7b: Total length between terminal vertices along the proposed network
Lengths are in meters

	12	13	14	15	16	17	18	19	20	21	22
1	7413.63	19576.68	5361.80	8909.99	9826.62	10342.30	8451.24	8501.68	12245.99	9787.14	13175.16
2	7385.53	19180.99	5333.70	8514.31	9430.94	9946.62	8423.14	8106.00	12217.90	9391.46	12779.48
3	14467.35	17471.71	10598.26	4190.72	5262.45	5778.13	15504.96	8621.30	12758.70	9424.81	11070.19
4	14253.39	17257.75	10384.30	3976.77	5048.50	5564.18	15291.00	8407.35	12544.75	9210.86	10856.24
5	19214.95	17106.01	15345.86	9093.42	7968.29	7682.91	20252.56	13368.90	17506.30	14172.41	10704.49
6	17968.30	15859.36	14099.21	7846.77	6721.65	6436.26	19005.91	12122.26	16259.65	12925.77	9457.85
7	17979.37	15870.43	14110.28	7857.84	6732.72	6447.33	19016.98	12133.33	16270.72	12936.84	9468.92
8	18946.36	16837.43	15077.27	8824.84	7699.71	7414.32	19983.97	13100.32	17237.71	13903.83	10435.91
9	18158.74	16049.80	14289.65	8037.21	6912.09	6626.70	19196.35	12312.70	16450.09	13116.20	9648.29
10	8800.48	12339.84	9288.06	9392.08	10308.71	10824.39	4272.83	7983.72	869.94	4122.54	13446.75
11	5055.16	15842.63	5542.73	12001.74	12918.37	13434.05	790.31	11486.51	4585.06	7625.32	16266.91
12	0.00	19717.38	4115.02	10574.03	11490.66	12006.34	4665.05	10165.71	8459.81	11451.18	14839.20
13	19717.38	0.00	17371.62	13578.39	12453.26	12167.88	15189.73	15184.17	11813.14	14712.66	6585.00
14	4115.02	17371.62	0.00	6704.94	7621.57	8137.25	5152.63	6296.62	8947.38	7582.09	10970.11
15	10574.03	13578.39	6704.94	0.00	1369.13	1884.81	11611.64	4727.99	8865.38	5531.50	7176.87
16	11490.66	12453.26	7621.57	1369.13	0.00	759.69	12528.27	5644.62	9782.01	6448.13	6051.75
17	12006.34	12167.88	8137.25	1884.81	759.69	0.00	13043.95	6160.30	10297.69	6963.81	5766.36
18	4665.05	15189.73	5152.63	11611.64	12528.27	13043.95	0.00	10833.61	3932.16	6972.42	15876.81
19	10165.71	15184.17	6296.62	4727.99	5644.62	6160.30	10833.61	0.00	7457.02	4123.14	8782.66
20	8459.81	11813.14	8947.38	8865.38	9782.01	10297.69	3932.16	7457.02	0.00	3595.84	12920.05
21	11451.18	14712.66	7582.09	5531.50	6448.13	6963.81	6972.42	4123.14	3595.84	0.00	9586.17
22	14839.20	6585.00	10970.11	7176.87	6051.75	5766.36	15876.81	8782.66	12920.05	9586.17	0.00

Average:	10975.02
Max:	20642.7
Min:	99.9

Appendix 8a: Total network cost between terminal vertices along the proposed network
Values are unitless

	1	2	3	4	5	6	7	8	9	10	11
1	0.00	939.69	14632.17	14160.37	24562.46	21805.14	21827.28	23046.13	19671.69	13798.09	7989.74
2	939.69	0.00	13766.73	13294.93	23697.03	20939.71	20961.85	22180.70	18806.26	13228.58	7420.24
3	14632.17	13766.73	0.00	754.69	18473.43	15716.12	15738.26	16957.10	13582.66	17649.70	19111.94
4	14160.37	13294.93	754.69	0.00	18001.63	15244.32	15266.46	16485.30	13110.86	17177.90	18640.15
5	24562.46	23697.03	18473.43	18001.63	0.00	7270.44	7292.58	12961.02	8832.08	27580.00	29042.24
6	21805.14	20939.71	15716.12	15244.32	7270.44	0.00	199.86	10203.70	6074.76	24822.68	26284.92
7	21827.28	20961.85	15738.26	15266.46	7292.58	199.86	0.00	10225.84	6096.90	24844.82	26307.06
8	23046.13	22180.70	16957.10	16485.30	12961.02	10203.70	10225.84	0.00	4266.79	26063.67	27525.91
9	19671.69	18806.26	13582.66	13110.86	8832.08	6074.76	6096.90	4266.79	0.00	22689.23	24151.47
10	13798.09	13228.58	17649.70	17177.90	27580.00	24822.68	24844.82	26063.67	22689.23	0.00	6116.21
11	7989.74	7420.24	19111.94	18640.15	29042.24	26284.92	26307.06	27525.91	24151.47	6116.21	0.00
12	8630.79	8061.29	19752.99	19281.19	29683.28	26925.96	26948.10	28166.95	24792.51	12422.18	6613.84
13	37102.61	36237.17	31013.58	30541.78	32799.57	30042.25	30064.39	31283.24	27908.80	33255.31	36534.08
14	4306.24	3736.74	15014.29	14542.49	24944.58	22187.26	22209.41	23428.25	20053.81	10223.10	4414.75
15	10360.60	9495.16	4271.57	3799.77	14201.86	11444.54	11466.68	12685.53	9311.09	13378.13	14840.37
16	11453.16	10587.73	5364.14	4892.34	13539.90	10782.58	10804.72	12023.57	8649.13	14470.70	15932.94
17	12901.25	12035.81	6812.22	6340.42	13000.16	10242.84	10264.98	11483.82	8109.39	15918.78	17381.02
18	8142.72	7573.22	19264.92	18793.12	29195.21	26437.89	26460.03	27678.88	24304.44	5655.37	460.85
19	10009.58	9144.15	9450.04	8978.24	19380.33	16623.01	16645.15	17864.00	14489.56	13704.91	14489.36
20	12694.19	12124.69	16253.07	15781.27	26183.36	23426.04	23448.18	24667.03	21292.59	1396.64	5012.32
21	11861.05	10995.61	9855.63	9383.83	19785.92	17028.60	17050.74	18269.59	14895.15	7794.07	11072.84
22	24299.58	23434.14	18210.55	17738.75	19996.54	17239.22	17261.36	18480.21	15105.77	27317.11	28779.35

Average: 16181.39
Maximum: 42223.42
Minimum: 199.86

Appendix 8b: Total network cost between terminal vertices along the proposed network
Values are unitless

	12	13	14	15	16	17	18	19	20	21	22
1	8630.79	37102.61	4306.24	10360.60	11453.16	12901.25	8142.72	10009.58	12694.19	11861.05	24299.58
2	8061.29	36237.17	3736.74	9495.16	10587.73	12035.81	7573.22	9144.15	12124.69	10995.61	23434.14
3	19752.99	31013.58	15014.29	4271.57	5364.14	6812.22	19264.92	9450.04	16253.07	9855.63	18210.55
4	19281.19	30541.78	14542.49	3799.77	4892.34	6340.42	18793.12	8978.24	15781.27	9383.83	17738.75
5	29683.28	32799.57	24944.58	14201.86	13539.90	13000.16	29195.21	19380.33	26183.36	19785.92	19996.54
6	26925.96	30042.25	22187.26	11444.54	10782.58	10242.84	26437.89	16623.01	23426.04	17028.60	17239.22
7	26948.10	30064.39	22209.41	11466.68	10804.72	10264.98	26460.03	16645.15	23448.18	17050.74	17261.36
8	28166.95	31283.24	23428.25	12685.53	12023.57	11483.82	27678.88	17864.00	24667.03	18269.59	18480.21
9	24792.51	27908.80	20053.81	9311.09	8649.13	8109.39	24304.44	14489.56	21292.59	14895.15	15105.77
10	12422.18	33255.31	10223.10	13378.13	14470.70	15918.78	5655.37	13704.91	1396.64	7794.07	27317.11
11	6613.84	36534.08	4414.75	14840.37	15932.94	17381.02	460.85	14489.36	5012.32	11072.84	28779.35
12	0.00	42223.42	5055.80	15481.42	16573.98	18022.06	6766.81	15130.40	11318.28	16981.87	29420.39
13	42223.42	0.00	37484.73	26742.01	26080.05	25540.30	36073.23	31920.47	31858.67	32326.06	13170.00
14	5055.80	37484.73	0.00	10742.72	11835.29	13283.37	4567.73	10391.71	9119.20	12243.17	24681.70
15	15481.42	26742.01	10742.72	0.00	1092.56	2540.65	14993.35	5178.46	11981.50	5584.06	13938.98
16	16573.98	26080.05	11835.29	1092.56	0.00	1878.69	16085.91	6271.03	13074.06	6676.62	13277.01
17	18022.06	25540.30	13283.37	2540.65	1878.69	0.00	17533.99	7719.11	14522.14	8124.70	12737.27
18	6766.81	36073.23	4567.73	14993.35	16085.91	17533.99	0.00	14642.33	4551.47	10611.99	28932.32
19	15130.40	31920.47	10391.71	5178.46	6271.03	7719.11	14642.33	0.00	12308.27	5910.84	19117.44
20	11318.28	31858.67	9119.20	11981.50	13074.06	14522.14	4551.47	12308.27	0.00	6397.44	25920.47
21	16981.87	32326.06	12243.17	5584.06	6676.62	8124.70	10611.99	5910.84	6397.44	0.00	19523.03
22	29420.39	13170.00	24681.70	13938.98	13277.01	12737.27	28932.32	19117.44	25920.47	19523.03	0.00

Average: 16181.39
Maximum: 42223.42
Minimum: 199.86

Appendix 9: Average width class along each trail accounting for traversing low-cost areas along the proposed network
Values are unitless

	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22
1	0.00	1.59	1.14	1.12	1.40	1.34	1.34	1.33	1.19	1.10	0.90	1.16	1.90	0.80	1.16	1.17	1.25	0.96	1.18	1.04	1.21	1.84
2	1.59	0.00	1.11	1.09	1.38	1.32	1.32	1.31	1.17	1.05	0.84	1.09	1.89	0.70	1.12	1.12	1.21	0.90	1.13	0.99	1.17	1.83
3	1.14	1.11	0.00	1.89	1.42	1.34	1.34	1.33	1.14	1.33	1.20	1.37	1.78	1.42	1.02	1.02	1.18	1.24	1.10	1.27	1.05	1.65
4	1.12	1.09	1.89	0.00	1.41	1.32	1.32	1.32	1.12	1.31	1.19	1.35	1.77	1.40	0.96	0.97	1.14	1.23	1.07	1.26	1.02	1.63
5	1.40	1.38	1.42	1.41	0.00	2.26	2.26	1.86	1.80	1.53	1.41	1.54	1.92	1.63	1.56	1.70	1.69	1.44	1.45	1.50	1.40	1.87
6	1.34	1.32	1.34	1.32	2.26	0.00	2.00	1.78	1.65	1.48	1.36	1.50	1.89	1.57	1.46	1.60	1.59	1.39	1.37	1.44	1.32	1.82
7	1.34	1.32	1.34	1.32	2.26	2.00	0.00	1.78	1.65	1.48	1.36	1.50	1.89	1.57	1.46	1.60	1.59	1.39	1.37	1.44	1.32	1.82
8	1.33	1.31	1.33	1.32	1.86	1.78	1.78	0.00	2.00	1.47	1.35	1.49	1.86	1.55	1.44	1.56	1.55	1.39	1.36	1.43	1.31	1.77
9	1.19	1.17	1.14	1.12	1.80	1.65	1.65	2.00	0.00	1.34	1.23	1.37	1.74	1.40	1.16	1.25	1.22	1.27	1.18	1.29	1.14	1.57
10	1.10	1.05	1.33	1.31	1.53	1.48	1.48	1.47	1.34	0.00	1.24	1.41	2.69	1.10	1.42	1.40	1.47	1.32	1.72	1.61	1.89	2.03
11	0.90	0.84	1.20	1.19	1.41	1.36	1.36	1.35	1.23	1.24	0.00	1.31	2.31	0.80	1.24	1.23	1.29	0.58	1.26	1.09	1.45	1.77
12	1.16	1.09	1.37	1.35	1.54	1.50	1.50	1.49	1.37	1.41	1.31	0.00	2.14	1.23	1.46	1.44	1.50	1.45	1.49	1.34	1.48	1.98
13	1.90	1.89	1.78	1.77	1.92	1.89	1.89	1.86	1.74	2.69	2.31	2.14	0.00	2.16	1.97	2.09	2.10	2.37	2.10	2.70	2.20	2.00
14	0.80	0.70	1.42	1.40	1.63	1.57	1.57	1.55	1.40	1.10	0.80	1.23	2.16	0.00	1.60	1.55	1.63	0.89	1.65	1.02	1.61	2.25
15	1.16	1.12	1.02	0.96	1.56	1.46	1.46	1.44	1.16	1.42	1.24	1.46	1.97	1.60	0.00	0.80	1.35	1.29	1.10	1.35	1.01	1.94
16	1.17	1.12	1.02	0.97	1.70	1.60	1.60	1.56	1.25	1.40	1.23	1.44	2.09	1.55	0.80	0.00	2.47	1.28	1.11	1.34	1.04	2.19
17	1.25	1.21	1.18	1.14	1.69	1.59	1.59	1.55	1.22	1.47	1.29	1.50	2.10	1.63	1.35	2.47	0.00	1.34	1.25	1.41	1.17	2.21
18	0.96	0.90	1.24	1.23	1.44	1.39	1.39	1.39	1.27	1.32	0.58	1.45	2.37	0.89	1.29	1.28	1.34	0.00	1.35	1.16	1.52	1.82
19	1.18	1.13	1.10	1.07	1.45	1.37	1.37	1.36	1.18	1.72	1.26	1.49	2.10	1.65	1.10	1.11	1.25	1.35	0.00	1.65	1.43	2.18
20	1.04	0.99	1.27	1.26	1.50	1.44	1.44	1.43	1.29	1.61	1.09	1.34	2.70	1.02	1.35	1.34	1.41	1.16	1.65	0.00	1.78	2.01
21	1.21	1.17	1.05	1.02	1.40	1.32	1.32	1.31	1.14	1.89	1.45	1.48	2.20	1.61	1.01	1.04	1.17	1.52	1.43	1.78	0.00	2.04
22	1.84	1.83	1.65	1.63	1.87	1.82	1.82	1.77	1.57	2.03	1.77	1.98	2.00	2.25	1.94	2.19	2.21	1.82	2.18	2.01	2.04	0.00

Average: 1.46
Maximum: 2.70
Minimum: 0.58