RESOURCE APPLICATIONS OF GEOGRAPHIC INFORMATION SYSTEMS: THE DEVELOPMENT OF THE ROADS LAYER FOR THE SIUSLAW NATIONAL FOREST

by

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Resource Agency Applications of Geographic Information Systems: The Development of the Roads Layer for the Siuslaw National Forest

ABSTRACT: The U.S. Forest Service has been actively using new information technologies since the formation of the agency. Currently forests are using Geographic Information Systems (GIS) for mapping, data storage, modeling, and spatial analysis. The Siuslaw National Forest has an active GIS with many data layers. A project to correct the errors in the roads layer began in 1996 and involved linking the Transportation Management System Oracle database to the ArcInfo GIS roads layer using a dynamic segmentation process. The updated roads layer is more accurate and has more variables for mapping and analysis. As the Siuslaw has changed from a timber management forest to an ecosystem management forest following the implementation of the President's Northwest Forest Plan, the roads layer has been used for watershed analysis, restoration projects, and for other management purposes. The impacts of roads on forest ecosystems has been widely studied, and restoration activities on the Siuslaw are proving to be successful. The results of these activities and other forest characteristics are stored in the GIS.

INTRODUCTION

The disruptive impacts of roads on forest environments are well documented. For example, roads are known to accelerate erosion and sediment loading, alter channel morphology, and change runoff characteristics (Furniss et al. 1996). Road construction can trigger mass movements for decades following road completion (Sessions et al. 1987). Mass soil movements in the western Cascade Range in Oregon are at least 30 times more frequent in developed areas (Sessions et al. 1987). Chemicals and other

road treatments can contaminate land and waterways and are often transported in streams for long distances (Furniss et al. 1991). Stream crossings are especially sensitive areas on road networks, due to the high water diversion potential. When crossings fail, they tend to do so catastrophically, causing scouring, erosion, and undermining the crossing structure and fill (Furniss et al. 1996). Fragmentation caused by roads and related timber harvest negatively impacts endangered species, including the pileated woodpecker and northern spotted owl (Reed et al. 1996). Road density can affect human access to sensitive habitat sites and fire patterns (Forman et al. 1996).

Management of roads on public and private lands can be enhanced with the use of Geographic Information Systems (GIS). With GIS technology researchers are able to analyze the effects of individual roads and the cumulative effects of entire road networks (Reed et al. 1996). The U.S. Forest Service has been involved in the development and use of GIS technology. On the Siuslaw National Forest (hereafter Siuslaw) in western Oregon, there are ongoing efforts to improve the information about roads in the GIS database, which will help staff members make more rational management decisions. Management is coordinated with the Access and Travel Management Guide for the Siuslaw, the Northwest Forest Plan, and ongoing watershed analysis efforts. The route information in the GIS is being used for a variety of applications and models.

Objective

The objective of this paper is to describe the history, functionality, and importance of an up-to-date, accurate GIS for the Siuslaw, focusing on the benefits of a roads layer. Specific objectives are:

- to provide an overview of geospatial technology in the Forest Service;

- to describe the current GIS in place on the Siuslaw;

- to detail the current state of the roads layer and the recent roads update;

- to explain the benefits for Forest Service personnel of the roads layer;

- to portray how the roads layer relates to the Northwest Forest Plan, Access and Travel Management Guidelines for the Siuslaw, and watershed analysis guidelines; and

- to illustrate other GIS applications used in forest road studies.

Geospatial Technology Development in the U.S. Forest Service

The Forest Service manages over 191 million acres of land in 44 states, Puerto Rico, and the Virgin Islands. Surveying and mapping efforts quickly followed the creation of the Forest Service to help inventory the vast land holdings. The Forest Service management style and methodology has changed and adapted with advancements in geospatial technology (USDA Forest Service 1996). Figure 1 shows the history of geospatial technology in the Forest Service.

Today, each National Forest manages land survey activities and mapping efforts in conjunction with the geometronics community, which includes the Office of Geometronics in Washington, D.C., the Geometronics Service Center in Utah, and the regional geometronics staff. Operational support and implementation of GIS come from many areas including: field units; regional offices; research and experiment stations; The Geographic Information Systems Center of Excellence; The Geometronics Service Center; the Remote Sensing Applications Center; and the Washington Office Information Systems and Technology, Geometronics, and Remote Sensing staffs (USDA Forest Service 1996).

Origins and History of Geospatial Activities in the Forest Service

Technology	Origin/Purpose
Surveys	Surveys originally established forest boundaries and geodetic control for further surveying and mapping efforts. Surveys continue and many original monuments have been replaced.
Mapping	Mapping documented the physical and cultural landscape often for the first time. Mapping efforts established a geographic information inventory for resource management that continues to be updated.
Aerial Photography	Aerial photography was first used following World War 2, providing a cost effective, efficient means to inventory resources, monitor change, and update maps.
Multispectral Satellite Imagery	In the 1970s, multispectral satellite imagery in both digital and analog form became available to support resource inventories, forest health assessments, and related mapping applications.
1960s Computer Technology	Computer technology was initially used sparingly to assist in data processing and analysis. As costs fell and technology improved, geoprocessing tools became more popular
1980s Computer Technology	By the early 1980s, state-of-the-art systems were used throughout the Forest Service. In the late 1980s, planning for a service-wide Geographic Information System began.
1995 Computer Technology	The IBM/615 contract was awarded, allowing for the establishment of sophisticated GIS labs throughout the Forest Service.

Source: USDA Forest Service Geometronics Service Center. November 1996. Summary of USDA Forest Service Geospatial Activities. Salt Lake City, Utah.

Figure 1

Geographic information technology is a common management tool used by the Forest Service, and can be defined as, "...a system for capturing, storing, checking, manipulating, analyzing, and displaying data that are spatially referenced to the Earth" (USDA Forest Service 1995, Glossary 4). Information is normally stored as themes or layers that can be combined to form additional layers. Attribute data can be linked to spatial data. For example, a road can be selected and relevant information about route number, length, or additional features previously inputted will be displayed on the computer monitor (USDA Forest Service 1995).
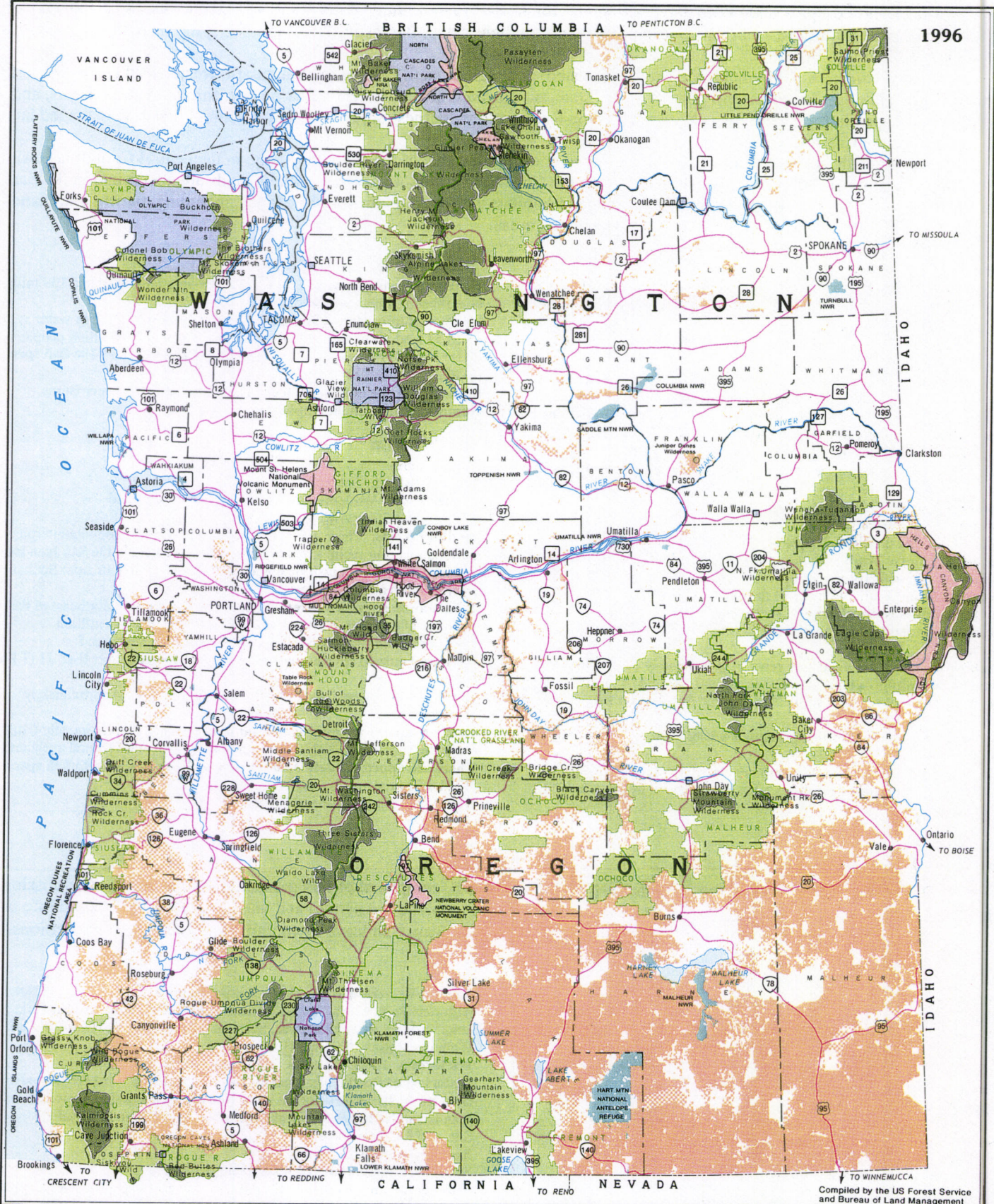
Planning for a Forest Service wide GIS began in the late 1980s, and the first systems were put into place in 1991. The planned benefits for the GIS included the ability to increase effectiveness by using accurate, consistent, and timely resource information that could be controlled within a computerized system (Valentine 1990). GIS also allows for site-specific analyses, repeatable, flexible, and defensible analyses, and ecosystem management support (USDA Forest Service 1995). Initial data used in the GIS came from Primary Base map planimetric digital data, U.S. Geological Survey Digital Elevation Model data, and Primary Base Series Maps and resource overlays (Valentine 1990). The Primary Base Series maps are 1:24,000-scale Forest Service maps, with information on trails, waterways, roads, and boundaries for all Forest Service land (USDA Forest Service 1995).

Global positioning system (GPS) satellites and aerial photography are both used to help control accuracy and to maintain a high level of data quality, and they are considered much better sources of control than traditional methods. Photos can be used to digitize roads, streams, and other features (Valentine 1990).

GIS Development on the Siuslaw National Forest

The Siuslaw has been greatly affected by recent changes in forest policy following implementation of the President's Northwest Forest Plan (Siuslaw National Forest 1994a). The Siuslaw is located in Region 6 of the National Forest System and was established on March 2, 1907 by Theodore Roosevelt (Siuslaw National Forest 1996a). The Regional Office is in Portland, Oregon, and administers 19 forests in Oregon and Washington (figure 2). The Supervisor's Office for the Siuslaw is located in Corvallis, Oregon. Figure 3 is a map of the Siuslaw. There are five District Ranger Stations in the Siuslaw: Hebo, Waldport, Alsea, Mapleton, and the Oregon Dunes National Recreation Area. The Siuslaw has 630,000 acres of forest and 22,500 acres of wilderness. The forest is 135 miles long by 27 miles wide, stretching from Coos to Tillamook counties. There are 1,200 miles of anadromous fish streams in the forest and 2,375 miles of roads. In 1996 there were 224 permanent employees in the forest and total expenditures were $19,484,400 (Shamber 1996).

Forest Service personnel work to provide accurate, up-to-date information about many areas of interest on the forest. Ongoing studies are monitoring road conditions, fish habitat, water quality, recreational use, potential construction sites, and other subjects essential for wise forest management. The GIS for the Siuslaw is an essential tool for data management and has many cartographic and informational uses; the GIS is especially useful for watershed analyses (McConnell 1997). Five full-time and two part-time GIS employees work at the Siuslaw. The two coordinators work at the Supervisor's Office in Corvallis, and the five district staff work on the districts (two in Mapleton, one in Hebo, one in Waldport and one in Alsea). Currently there are 14 computer terminals specifically for GIS work at the Siuslaw. The department is currently

1996

BRITISH COLUMBIA

TO VANCOUVER B.C.   TO PENTICTON B.C.

VANCOUVER ISLAND

WASHINGTON

OREGON

PACIFIC OCEAN

STRAIT OF JUAN DE FUCA

IDAHO

CALIFORNIA   NEVADA

TO CRESCENT CITY   TO REDDING   TO RENO   TO WINNEMUCCA

TO MISSOULA

TO BOISE

Compiled by the US Forest Service
and Bureau of Land Management

| 0 | 20 | 40 | 60 | 80 | 100 Miles |
| 0 | 20 | 40 | 60 | 80 | 100 Kilometers |

Legend

- NATIONAL FOREST
- NATIONAL FOREST WILDERNESS
- NATIONAL RECREATION AREA, SCENIC AREA OR VOLCANIC MONUMENT
- BUREAU OF LAND MANAGEMENT ADMINISTERED LANDS
- US FISH AND WILDLIFE SERVICE
- NATIONAL PARK

PUBLIC LANDS IN

OREGON AND WASHINGTON

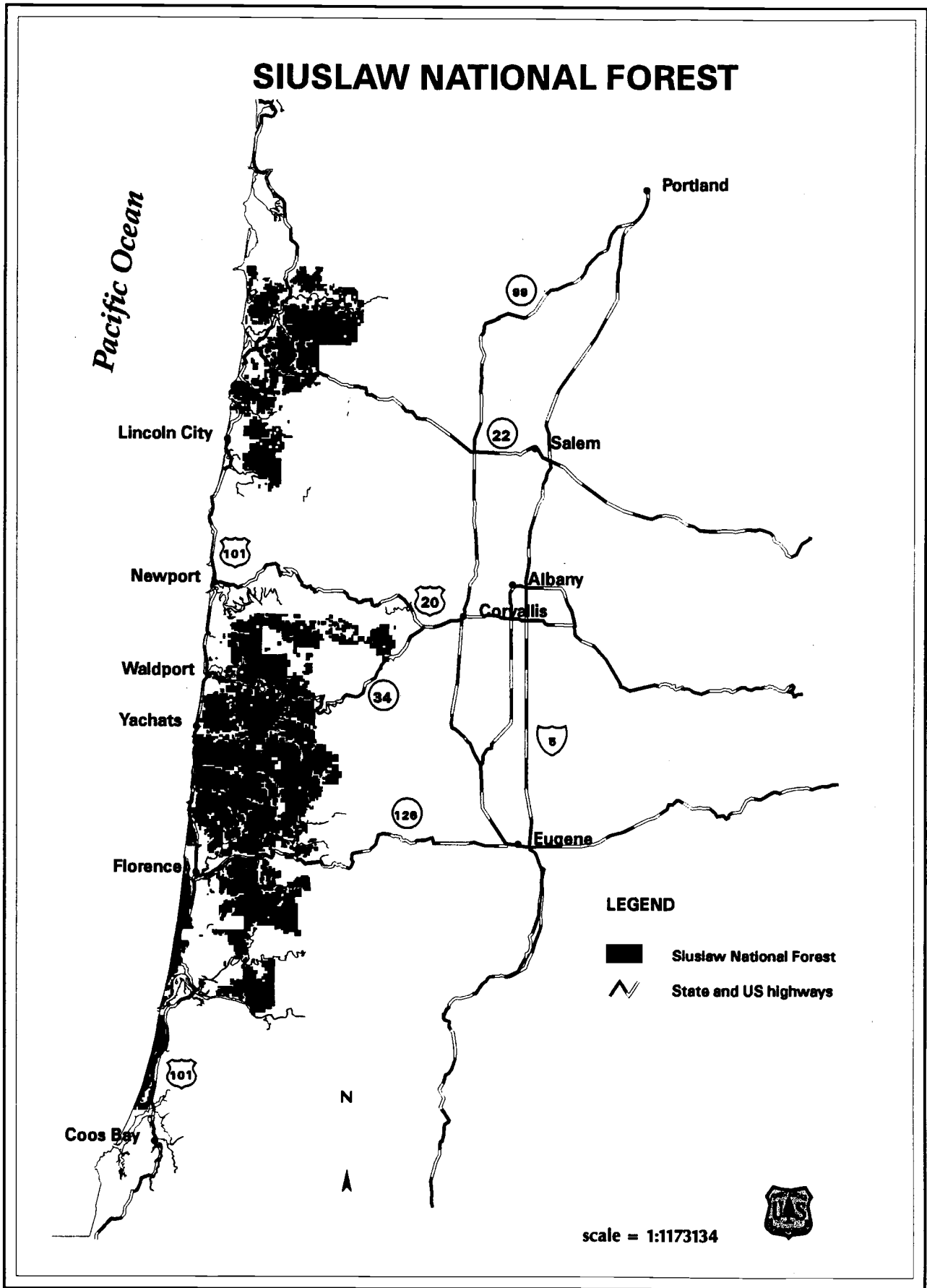# SIUSLAW NATIONAL FOREST

Figure 3

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running version 7.4 of ArcInfo and version 3 of ArcView. The current plotter is a HP650 Design Jet (Eldred 1996).

There are a wide variety of layers in the GIS on the Siuslaw including streams, roads, property lines, trails, habitats, soils, and vegetation. In the GIS lab at the Supervisor's Office there is a large three-ring binder with metadata (background on the data sources) on all of the layers. Although the information varies depending on the layer, the typical information is a display of the layer, a listing of the path name or library where the layer can be located, and any details about the creation of the layer. There is also information on who did the preparation and how the attributes were derived for the different layers (Siuslaw National Forest 1994b). Standardized records have not been kept.

ArcInfo is the current GIS program used by Forest Service personnel, and it is best used for watershed planning, mapping, and mid-level to forest-level use. Currently on the districts, the GIS staff assist on watershed planning teams, but timber production work is almost nonexistent due to severely limited harvesting (Murdock 1996). At the Supervisor's Office, the GIS staff supports the districts, does forest-wide and smaller scale analysis, and creates maps by individual department requests (Murdock 1996). There is daily map creation and extensive watershed modeling (Eldred 1996).

METHODOLOGY FOR THE ROADS UPDATE

General Project Information

The Siuslaw has an extensive roads network throughout the forest. The map in figure 4 is a display of the roads network in the GIS. Even wilderness areas have old roads that have now been converted to trails. Although there has been an on-going effort to maintain current route information, including route numbers and locations, the roads layer in the GIS became out-of-date and

Siuslaw National Forest Road Network

LEGEND

N State and US highways

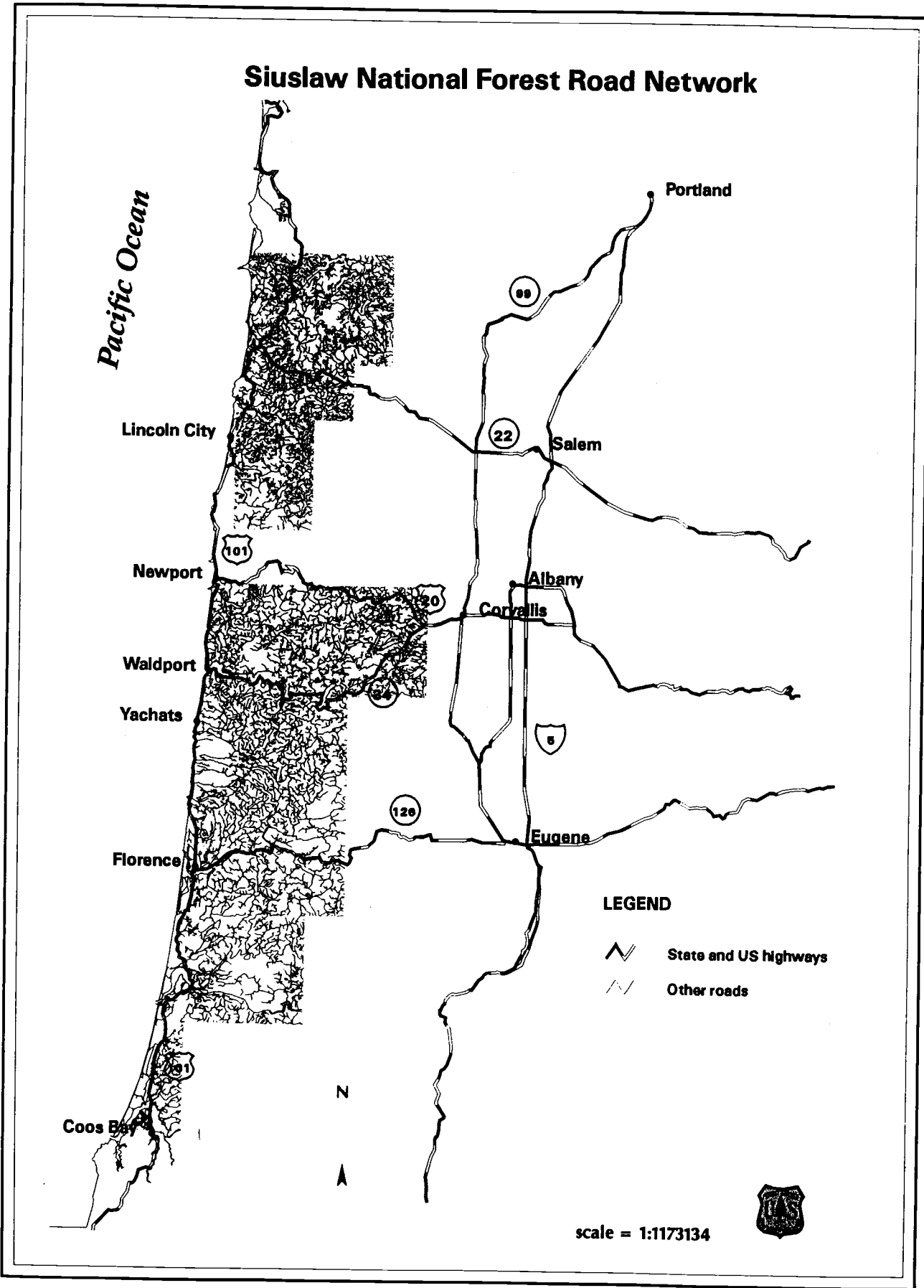N Other roads

scale = 1:1173134

Figure 4

a considerable number of roads were misplaced on the roads layer. After a lawsuit against the Okanagan National Forest on inadequate record keeping and insufficient road data collection (Flatten 1996), the senior staff on the Siuslaw began to recognize the importance and benefits of an updated roads layer for political as well as administrative reasons. They initiated a roads update to clean the GIS roads layer, make any needed corrections, and assist in using dynamic segmentation to link the roads layer to an Oracle database called the Transportation Management System or TMS. The overall objective was to increase accuracy of the roads layer in the GIS in order to provide more accurate and accessible attributed spatial data to ecosystem managers.

The Roads Layer

The original data for the roads layer came from Cartographic Features Files (CFF) from the Geometronics Service Center (GSC). Road features were digitized off of the Primary Base Quadrangles that were coded based on the type of road feature (Siuslaw National Forest 1994b). Roads were updated in 1990-1991 based on information supplied by the District Road Managers; this update occurred in conjunction with Forest Primary Base Map updates. The updating procedure is described in the Siuslaw Data Dictionary (Siuslaw National Forest 1994b) as follows:

> The new roads were digitized from the "hard copy" which in turn was photogrammetically corrected by GSC and then a new CFF was supplied to the road managers. They did a review of all the road segments for those Quads on their District and added the Route Number, Classification, Maintenance Level, and Map Number for system roads. The Supervisor's Office then made "final review" of all the quads noting conflicts and discussing these with each District where necessary.

Future updates were the responsibility of the districts with assistance from the Supervisor's Office.

The Transportation Management System

Other road data are stored in the Transportation Management System (TMS) on the Data General terminals. TMS is an Oracle database traditionally updated by the road managers on the districts. The main purpose of the 1996 roads update was to link the TMS data with the ArcInfo data through a dynamic segmentation process. In order for this link to be accurate, the data in both systems needed to match and be as current as possible. The main reason to link the two systems was to take advantage of the data stored in each one without having to do duplicate data entry. Having the TMS data in the GIS also allows for spatial analysis of the data, an application that is not possible within TMS. With the update, the information in TMS can be mapped and viewed on the computer monitor by attribute. The ability to map the data in TMS, which includes surface types, road conditions, and route status greatly benefits engineers, ecologists and other staff members analyzing cause and effect relationships. The attributes in TMS are also important for District Map creation.

Procedure

The roads update involved many steps, though most of the procedures used fairly simple ArcInfo commands. The first step in the project involved editing the existing routes in the roads layer. After some experimenting, the most effective method for route correction was to have the land survey information with section numbers as one back-cover, and to have the quad index and quad names as the other back-cover. A back-cover is another GIS layer or image that can be displayed with the active layer. Digital orthophotos

served as a final background, and they could be selected on a quad by quad basis. The route numbers were displayed as part of the roads coverage, called ROADSNEW.

Corrections began in the northwest corner of the forest in Hebo, and over the course of two months all of the system roads were edited to within thirty meters of accuracy. Non-system roads were usually not corrected unless the position blocked the placement of a system road. Each section usually required at least two changes. Digital orthophotos served as a guide for road placement, but overgrown roads were sometimes difficult to see for proper placement and were cross checked with other hard copy maps.

The second stage of the correction process involved updating the accuracy of the database to assist in the dynamic segmentation process. Route entries in TMS had to be up-to-date and coded properly in order to match the routes in GIS. District road managers worked to update the TMS records, and made lists of obliterated roads so they could be attributed as obliterated on the GIS and be taken off the system. Different frequencies (computer tests to check if routes in both systems matched) were run in ArcInfo to check how well the system roads in the GIS matched with the routes in TMS.

Initial numbers of mismatches were large; roughly 300 routes were in the GIS that were not in the TMS, and about 260 routes were in TMS and not in GIS. Maps of the routes in the GIS facilitated the correction process in the TMS because seeing the suggested route location on the map usually sparked district managers' memories about the specific road. Some routes on the GIS were very old, overgrown operator spurs that were unofficially taken off the system years before. These were marked obliterated in the GIS and were taken off the system. Other incorrect routes were the results of typos or had been missed in updates where parts of the seven digit route number were changed.

These changes were made in the GIS. Other routes needed to be added to TMS or to the GIS. District road managers received lists of routes that required attention and circled the correction areas and wrote in route numbers on district maps to assist in location identification on the GIS.

Errors

The roads layer had a considerable number of problems from a variety of causes. Many of the route numbers were incorrectly documented, or had not been updated after a change in status such as obliteration or waterbarring. Until digital orthophotos were routine, the errors in route placement were difficult to observe. With the photos, even routes a few meters off were obvious and people began to doubt the quality of the data. Many of the errors at small scales were consistent with map standards. Other errors were larger; many were the result of poorly supervised digitizing contracts in three watersheds. The roads were digitized off of district maps, not orthophotos, and tended to match up poorly with the rest of the system (Eldred 1996).

In the last five years, the Forest Service has been operating on tighter budgets with less staff (Siuslaw National Forest 1994a). This reduced condition creates an environment where only the most important, crucial tasks are performed. Ground-truthing road locations on obscure routes was not a high priority. Road Managers were also asked to take on larger workloads, and got behind on routine route corrections and additions. Many of the road managers have hard copy file systems with road data that they rely on, and do not tend to use computerized information as a resource for decision making (Grilley 1996).

Project Future

The roads update is an ongoing process that depends on cooperation between engineers, district staff, and GIS personnel. The dynamic segmentation process is complete, and significant problems with route matching and directionality have been addressed. Requests for data and maps from the updated layer have been filled, and applications previously impossible without dynamic segmentation are in progress. GIS personnel are scheduling training sessions for district staff to help explain how to program and manipulate data within the GIS (Eldred 1997).

DISCUSSION

There have been many changes in the Siuslaw in the past five years related to the Northwest Forest Plan and a move toward watershed analysis and ecosystem management. In this section, these changes and their effect on the Siuslaw are explained in detail. The GIS has become an important tool for watershed analysis, restoration, modeling, and mapping at small scales. Roads have had considerable impact on the forest ecosystem and are a major part of ongoing studies and restoration efforts. The roads layer in the GIS is widely used by forest personnel; many of these applications are explained in this section.

The Northwest Forest Plan

In the late 1980's and early 1990's, a debate erupted over the protection of the northern spotted owl and management of federal lands by the Forest Service and Bureau of Land Management. Environmental groups sued the agencies in three lawsuits, and the federal district judges decided in favor of the environmentalists. Court injunctions on timber sales followed the trials

(Anderson 1994). The situation continued to escalate, and the issue became more controversial and complex. Research showing the depletion of anadromous fish stocks in the Pacific Northwest added to the controversy, along with the proposed listing of the marbled murrelet under the Endangered Species Act (Anderson 1994). President Clinton, in an attempt to resolve the growing controversy, held a Forest Conference in Portland, Oregon on April 2, 1993. The President's Forest Plan was presented on July 1, 1993 (USDA Forest Service et al. 1994).

The Forest Plan amends Forest Service and Bureau of Land Management management plans and provides standards and guidelines to govern actions in different management areas. These guidelines include: requiring agencies to complete a watershed analysis before building roads in riparian reserves; prohibiting road construction in key watersheds (fish and wildlife habitat refuges and sources of high quality water); and dividing all federal lands within spotted owl range into land management categories (USDA Forest Service et al. 1994). Agency decisions for management should be based on the results of the watershed analyses.

Following the implementation of the Northwest Forest Plan, the Siuslaw changed from an emphasis on timber management to an emphasis on ecosystem management. Historically, timber sales paid for road construction and maintenance, and an extensive network of roads existed to facilitate timber harvest (Siuslaw National Forest 1994a). The change in budget reduced the amount of funds available to support the road network. Personnel began to complete watershed analyses throughout the Siuslaw, and restoration projects were initiated. Restoration work has focused on roads as a major causal agent of environmental degradation (Bush 1997).

Changes in Road Management

Properly managing existing roads is a priority throughout the Forest Service. In the past, there were many practices that have been proven to be detrimental to a healthy forest ecosystem. These practices include eradicating vegetation, soil disturbance, and slope steepening during road construction (Moll 1996); causing sedimentation and interference with natural drainage patterns. The Forest Service is now concentrating on minimizing the impacts of roads on the environment by considering effects on entire watersheds. Efforts focus on restoring hydrology, reducing erosion and sedimentation, increasing stability, revegetating, and closing or obliterating roads when appropriate (Moll 1996). Monitoring efforts are crucial to understanding successes and failures and are currently a high priority at the Siuslaw (Bush 1997).

The Siuslaw began to change road management strategies in the late 1970's, when concerns about long-term degradation of aquatic habitats surfaced. Steep slope harvesting was restricted, roads were located on ridgelines away from sideslopes, and excavated material was not sidecast in place (Bush et al. 1997). There was little decrease in timber harvest until 1991, when the Siuslaw was enjoined from selling mature conifer due to the spotted owl habitat requirements and implementation of the Northwest Forest Plan. Over $5 million has been spent since 1994 on watershed restoration projects (Bush et al. 1997). Efforts related to roads have been focused on sidecast pullback, subsoiling, waterbarring, seeding, culvert removals, road surface scarification, and road maintenance (Siuslaw National Forest 1995). These techniques are described in detail in the Forest Service publication, *A Guide for Road Closure and Obliteration in the Forest Service*, publication number 4E41L03. The current road network and suggested changes are outlined in the

Siuslaw Access and Travel Management Guide (Siuslaw National Forest
1994a).

Access and Travel Management

The engineering staff are responsible for the implementation of the
Siuslaw's Access and Travel Management (ATM) Guide. The guidelines
establish use requirements for existing roads, and close or obliterate routes that
are not essential to the use of the system. The purpose of the ATM Guide is to
(Siuslaw National Forest 1994a, 4): "...provide clear and consistent direction
throughout the Forest for road and trail management decisions. It promotes
both safe access for travelers and protection for natural resources". The ability
to use GIS to spatially display the information previously stored in the TMS
database has been very beneficial in making ATM decisions. Following the
ATM guidelines, some roads will be removed from the system, some will be
closed, and others will be kept at a reduced maintenance level (Siuslaw
National Forest 1994a). These changes are beneficial financially and
ecologically.

Closing or obliterating roads to minimize the effects of motorized vehicle
access has been found to be an effective solution to the ecological impacts of
roads (Forman et al. 1996). As part of the Northwest Forest Plan, any new road
construction in key watersheds must be offset by closing or obliterating an equal
amount of forest roads (Anderson 1994). Road obliteration is defined by Moll
(1996, 1) as:

> "To unbuild, decomission, deactivate, or dismantle a road; the denial of
> use, elimination of travelway functionality, and removal of the road from
> the forest system; return of the road corridor to resource production by
> natural or designed means".

Upgrading or stabilization leaves the road open, and involves management practices to decrease landslide risk and to improve stream crossings that impact riparian areas (Siuslaw National Forest 1995).

At the Siuslaw, roughly 800 miles of roads have been stabilized or obliterated since 1992 (Bush et al. 1997). Decisions are based on land inventories, and should be consistent with forest land management plans (Moll 1996). ATM routes are maintained for long-term access (Siuslaw National Forest 1996b). Obliterated routes are in a separate GIS layer, and can be merged with the roads layer.

The updated roads layer facilitates concise monitoring of the ATM system. Printing maps of the ATM information helps managers analyze route location information for accuracy. The GIS can also be used to calculate miles of ATM roads by district, and it can display the routes by management type. There are three management types on the ATM system, defined as follows (Siuslaw National Forest 1996b):

Primary Forest Road, for any highway vehicle travel, mapped in red,

Secondary Forest Road-Low Clearance, acceptable for passenger car travel, mapped in blue,

Secondary Forest Road-High Clearance, passenger car travel discouraged, rough roads, mapped in green.

Information on road miles calculated in the GIS for Hebo are displayed below:
Total ATM Miles: 210.74
Total Non-ATM Miles: 590.33
Primary Low Clearance Miles: 54
Secondary Low Clearance Miles: 39.14
Secondary High Clearance Miles: 117.6

Information on road miles is possible to analyze for any length of road, and can be selected using the route number or by highlighting the road on the monitor with the mouse. It is also possible to query for distances between roads and other features.

Watershed Analysis and GIS

Since the implementation of the Northwest Forest Plan, Siuslaw personnel have been working to complete watershed analyses for the entire forest. GIS has been an essential tool for watershed level work and allows for spatial analysis and data storage previously unavailable (Bush 1997). With the completion of the Indian/Deadwood Watershed Analysis, 65% of the Siuslaw River Basin has been analyzed (Siuslaw National Forest 1996a). The results of the analyses are stored in the GIS and in written reports. A description of the Indian/Deadwood Analysis (henceforth, the Analysis) and how GIS was used in the Analysis follows.

The Analysis was completed in June of 1996, and provides an example of GIS applications used for all of the Siuslaw watershed analyses. Figure 5 is the Indian/Deadwood watershed analysis area. The Analysis is intended to, "...provide guidance on how best to implement direction of the Northwest Forest Plan at the watershed scale, and in particular, within the Indian/Deadwood watershed" (Siuslaw National Forest 1996a, 1). The Analysis is especially for use by federal forest use managers, and was completed by an interdisciplinary team of six people from the Siuslaw and other agencies.

The Analysis is an extensive document divided into the following topical sections: characterization of the Indian/Deadwood Watershed; issues and key questions; natural resources characteristics and processes; current conditions, landscape objectives and management recommendations; and monitoring and adaptive management (Siuslaw National Forest 1996a).

There is an extensive road network throughout the Indian/Deadwood watershed, built to accommodate a dispersed setting harvest pattern (a patchwork of clearcuts). This pattern resulted in a very fragmented forest with patches of habitat, and severe environmental impacts from road construction and logging practices. Logging and road building began in the late 1800s, following European settlement (Siuslaw National Forest 1996a). The high demand for lumber following World War II maintained high rates of road construction and harvest (Siuslaw National Forest 1957).

The road network was found to pose the greatest threat to the aquatic ecosystem. A variety of treatments were recommended by the researchers, including waterbarring, subsoiling, and obliteration. Methods that create self-draining roads, do not include structures, and require little maintenance are favored to limit expense (Siuslaw National Forest 1996a). These treatments are already in place in the high risk areas of the watershed (Bush 1997).

Appendix C describes the study methods for the Analysis. The GIS was used to characterize and map the gradation in landform features from east to west. The plant association group map was overlayed with the landscape map to describe potential vegetation. New information gathered in the field was added to the GIS to help establish vegetation distribution. The streams layer was updated during the analysis at the watershed scale, and included private and public lands. The streams update was very similar to the roads update and involved using aerial photography and orthoquad maps. Confinement and gradient information for the stream network was also digitized into the GIS.

There are 23 maps in the Analysis created in the GIS including maps of historic roads (figure 6) and the current road system (Siuslaw National Forest 1996a). Both system and nonsystem roads were included in the current road system map (Eldred 1996). There is a road inventory in Appendix I that lists all
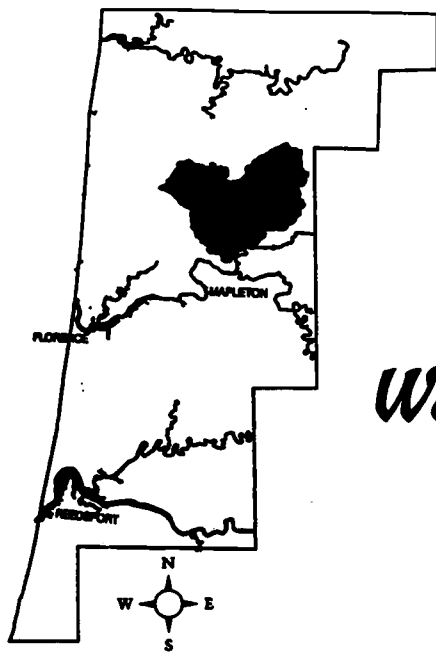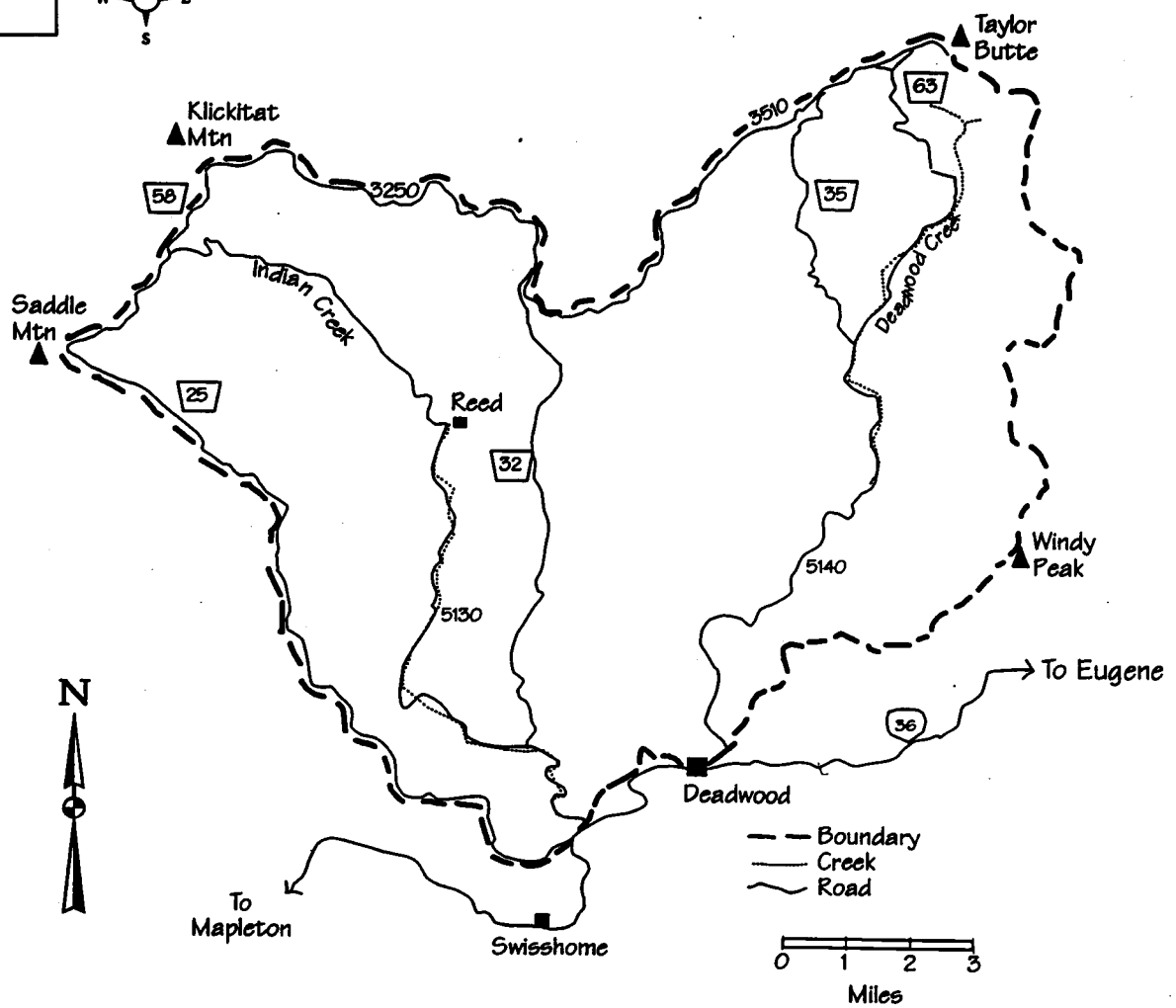
Indian Deadwood
Watershed Analysis Area

Figure 5: Indian/Deadwood Watershed Analysis Area (Siuslaw National Forest 1995).

of the Forest Service and county roads in the study area. The roads are rated for their potential to adversely impact aquatic resources on a scale from one to five (low to high). Part of the information for the inventory came from the roads layer in the GIS; this information includes miles, current maintenance, subwatershed, ATM status, year built, and landscape block (Siuslaw National Forest 1996a). This is used for management decisions to prioritize restoration projects (McConnell 1997).

A culvert analysis was also done for the Analysis. Previous road assessments only dealt with a portion of the culverts in the study area, so additional data were needed. A 30-meter resolution digital elevation model was used to estimate areas representing culvert drainage areas (culvert sheds). The results were mapped in the GIS and were cross referenced with topographic maps (Siuslaw National Forest 1996a).

The Analysis provides an example of the data layers available in GIS, and the variety of possible applications of the layers. Mapping, one of the many uses of the GIS, was used extensively in the Analysis. Many of the maps include information from multiple layers, and some involve buffering and shading to demonstrate areas of interest or concern.

Anadromous Fish Population Management

Part of the management efforts in the Northwest Timber Plan focuses on limiting or removing negative impacts on anadromous fish populations (Siuslaw National Forest 1995). The negative effects of roads on anadromous fish populations are well documented. Accelerated erosion and sediment loading, alterations in channel morphology, and changes in runoff characteristics all affect fish (Furniss et al. 1991). Sedimentation and other effects are increased when roads cross waterways (Eaglin et al. 1993). Before modifications on
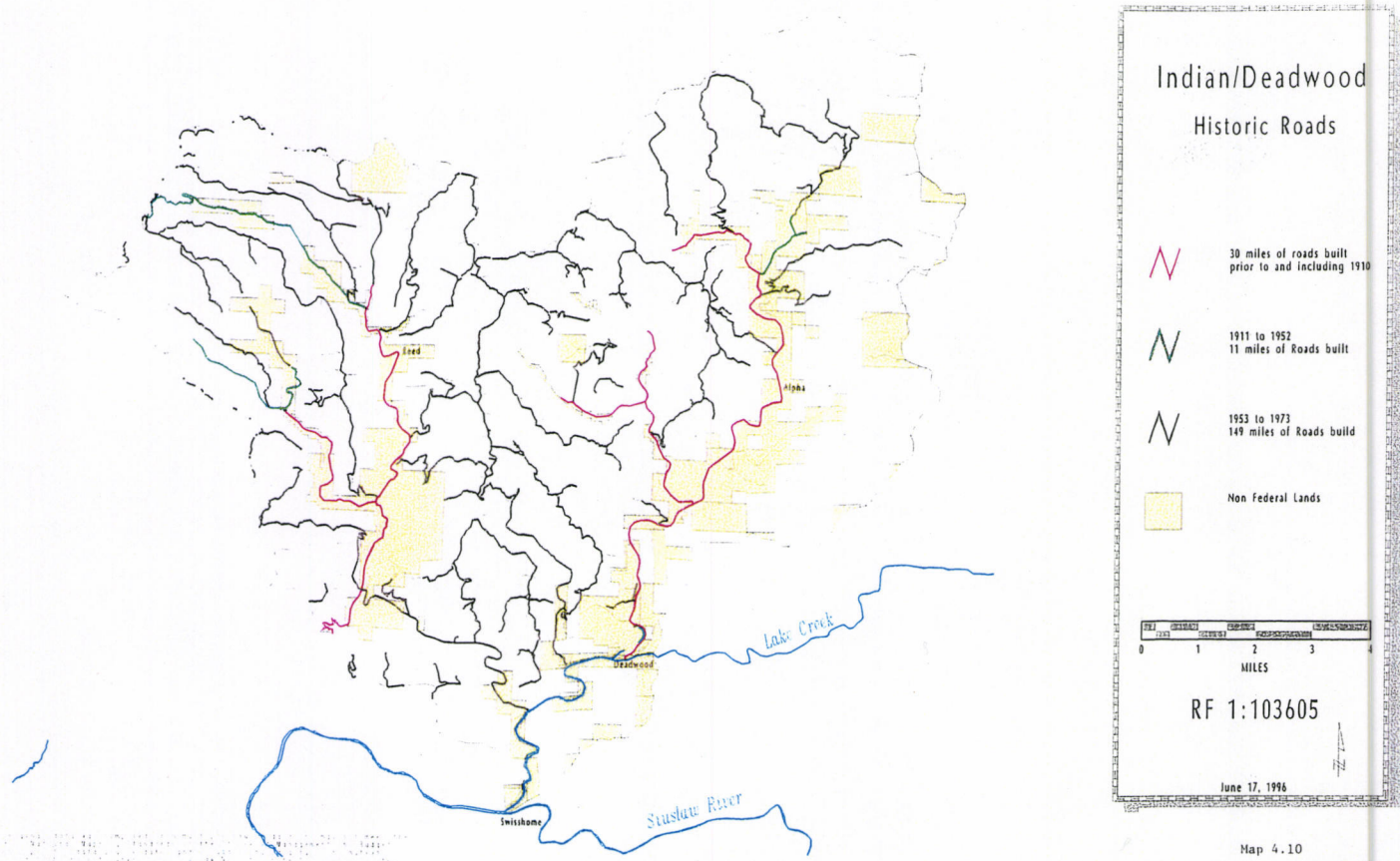
Figure 6: Indian/Deadwood Watershed Historic Roads Map (Siuslaw National Forest June 1996).

existing roads or trails and any new construction, the Siuslaw fish biologist reviews proposed construction design to ensure minimal or no impact on fish populations (Cloyd 1997). New construction cannot take place until a watershed analysis has been completed for the area (Siuslaw National Forest 1996a). There are GIS layers for streams and habitat areas that are used to assist in decision making.

1996 Storm, Testing Restoration Methods

Restoration and stabilization methods were tested in 1996 after an intense storm hit the Oregon Coast Range. Following the storm, Siuslaw personnel initiated studies to evaluate the effectiveness of the recent restoration efforts. One of these studies evaluated the effectiveness of road stabilization methods in reducing landslides and erosion associated with roads. The results of the study were positive, finding that the effects from the storm on untreated roads were much more severe than on treated roads (Bush et al. 1997).

The study sites were randomly selected, and were then mapped using the GIS. Data on the impacts of landslides were transferred to the GIS from aerial photographs. Researchers using the GIS were able to assess landslide frequency by watershed sub-basin and ownership (Siuslaw National Forest 1997). The research team used the GIS as a repository for known information and current conditions, and added new information with changes in restoration activities (Cloyd 1997).

This new information on storm-related activity and the roads layer in the GIS were used to map points of damage (usually landslides) by route number and milepost. This means the GIS roads data was able to be correlated with slide data by placing points on a map of hazard areas. Creation of a point map from the roads layer had not been possible before dynamic segmentation. The

information can be transferred to the watershed layers in the GIS to display areas of focus or concern for future events and can be used to guide restoration activity (Cloyd 1997).

Data Sharing and Cooperation

The Siuslaw borders state, Bureau of Land Management, and private lands. The changing role of the Forest Service from timber harvest managers to ecosystem managers has created a situation where sharing data is important (Siuslaw National Forest 1994a). As Belton explains, the "... shift to ecosystem management will also expand the area of interest to include adjacent federal, state, and private lands" (1995, 135). The Siuslaw staff work together with other agencies to gather and analyze as much information as possible through data sharing and cooperation (Eldred 1996).

The Forest Service is also working in coordination with private timber companies. Industries like Louisiana-Pacific, based in Portland, are working on resource management using ArcInfo and other GIS packages. They analyze different harvest and management possibilities through modeling, then display the mapped results in ArcView. Using the GIS has helped Louisiana Pacific prepare state mandated sustained yield plans, and has led to a more ecosystem minded approach to timber management (Thompson 1996).

Forest Road Research

There have been a wide variety of studies focusing on the effects of roads on Federal and Private forest lands. GIS is commonly used to facilitate information storage, analysis, and manipulation of data. Within the Forest Service, research is commonly done as needed and does not follow scientific process. The Forest Service funds outside researchers to complete studies to

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prove or disprove theories within the agency, which then are used as reference material to assist in management decisions (Bush 1997).

Research by Wemple (1994) examined how forest roads interacted with stream networks in two basins in the Oregon Cascades. The results of this study have been utilized by Siuslaw personnel for watershed management decisions (Cloyd 1997). Wemple used a GIS modeling program to spatially analyze data on the potential road effects on hydrology. She found that road networks have the potential to become integrated into stream networks, even when the roads were constructed on unchannelled hillslopes. After using the GIS to extrapolate field surveys, the results suggested roads could extend stream networks by as much 40% during storms when water created channels on or along roads (Wemple 1994). Wemple (1994) suggests that the road changes on hydrology are important to address for watershed management projects. She suggests increasing culvert density, outsloping road surfaces, and restoring vegetation to disperse water to subsurface pathways.

Freid (1994) studied the relationship between road density and slope position between areas with different patterns of ownership. He used a GIS to sample and analyze existing data for BLM, Forest Service, and industrial lands in the Oregon Coast Range. The Forest Service lands had higher road density on ridges. Using the GIS allowed Freid to work from existing data, and in doing so he was able to avoid the difficulties of working across many forest boundaries with sometimes uncooperative land owners. Multi-jurisdictional studies are important for watershed and habitat management. Roads can have a heavy impact on the forest, including alterations in watershed function, increased sedimentation, and interference in riparian zones. Road density and placement greatly affects these potential impacts (Freid 1994).

A landslide study by Sessions et al. (1987) analyzed landslide frequency and size at road locations in a 300,000 acre area of the Oregon Coast Range. Part of the study area included the Mapleton Ranger District. The researchers compared the landslide frequency between roads in two groups. Group one roads were constructed using improved techniques. Group two roads were typical 1960's construction, with sidecast road construction, little endhaul, and moderate road grades. Inventory of landslides occurred on the ground and by using aerial photographs. The researchers found that the improved construction methods were beneficial, and encountered fewer landslide events on group 1 roads (Sessions et al. 1987).

The effects of roads on habitat fragmentation have been studied in detail. Roads create edges, which fragment (divide) habitat. Although some species prefer edges (elk and deer), the effects negatively impact species that avoid edges like the northern spotted owl, Townsend's warbler, and the pileated woodpecker (Ripple et al. 1991). Other species that avoid edges include pine martens and brown creepers (Reed et al. 1996). Historically, Siuslaw timber management encouraged fragmentation management; managers believed the fragments were better for watershed health and provided habitat (Siuslaw National Forest 1996a).

Ripple et al. (1991) studied fragmentation in the Oregon Cascade Range, and used a GIS to gather and analyze data. The GIS provided an automated method to quantify forest fragmentation to aid forest managers in making wildlife decisions. Field and image data can be used together. The GIS is also beneficial because it is able to handle large amounts of data, which is often unmanageable without automation. The GIS was used to model the amounts of potential fragmentation using five groups of statistics: patch size, patch abundance, patch shape, patch spacing, and matrix characteristics (Ripple et al.

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1991). Managers could use the model to evaluate forest fragmentation based on different wildlife decisions. The pileated woodpecker and northern spotted owl are both active species at the Siuslaw.

Reed et al. (1996) researched how roads have contributed to fragmentation in a section of the Medicine Bow-Routt National Forest in Wyoming. Using a GIS, the researchers overlaid historical maps from the 1950s with the road networks to evaluate the effects of fragmentation. The earlier maps show roads, but were created before clearcut logging. Again using the GIS, the authors used several different indices to evaluate the effects of fragmentation. The final study results show that roads caused a greater degree of fragmentation than what is caused by clearcutting alone. The edge habitat created by the clearcuts and roads increases evaporation, temperature and incident solar radiation while decreasing available soil moisture. The effects of roads on fragmentation were found to be most severe, because they dissect large patches into smaller pieces and create more edges in interior habitat. Road edges tend to exist longer, and are disturbed more frequently. The authors recommended revegetating old roads, and obliterating newly constructed roads following timber harvest (Reed et al. 1996). The recommendations correspond with the current Forest Service management plan.

Stinton (1996) received funding from the Mt. Hood National Forest to study the effects of windthrow in the Bull Run Watershed. She mapped clearcuts and windthrow patterns in a GIS, and used a model to estimate future windthrow risk. Roads were not part of the study area (Stinton 1996). At the Siuslaw, the watershed analysis team has worked with a blowdown model, using aspect, species, and distance from the coast as indicators, and has found that most windthrow occurs near clearcuts and roads (McConnell 1997).

Parendes (1997) studied the introduction of exotic plant species into the H.J. Andrews Experimental Forest in the Oregon Cascades. The research focused on roads as a point of entry for exotic plants, and evaluated the different patterns of distribution along roads. A GIS was used in the study to create data layers for the eight target species found along the road network. These layers were used to spatially relate the survey data with other physical attributes, including aspect, elevation, road age, average annual precipitation, road use level, and solar radiation (Parendes 1997). The study is unique because it evaluates plant invasion at a landscape scale, and results can be used to analyze the vulnerability of the entire landscape to invasion (Parendes 1997). This type of study could provide pertinent data to the Siuslaw personnel about exotic plant invasion. Parendes (1997) used ArcInfo and ArcView layers for the study, which are also used on the Siuslaw. Her methodology could be duplicated.

CONCLUSION

The specific objectives of this paper were met by explaining the history of geospatial technology in the Forest Service, describing the current GIS in place on the Siuslaw; and detailing the current state and importance of the roads layer at the Siuslaw and the current roads update. The other objectives were met by expanding on how the roads layer relates to the Northwest Forest Plan, watershed analysis guidelines, and the Access and Travel Management Guide for the Siuslaw. Other GIS applications used in forest road studies were addressed in detail in the *Forest Road Research* section.

Geospatial technology has been used and developed throughout the USDA Forest Service; GIS are now common throughout the agency (USDA Forest Service 1996). The GIS has been a valuable management tool at the

Siuslaw as the focus of forest management plans has switched from timber production to ecosystem structure and function (Siuslaw National Forest 1994a). Management of road systems is important because of the severe impact roads can have on ecosystems (Furniss et al. 1991). Before it was updated in 1996, the roads layer in the GIS had some inaccuracies as well as some missing data.

A current, accurate roads layer in the Siuslaw GIS has been beneficial for a variety of research and management activities, including watershed analysis, modeling, restoration planning, mapping, and forest studies. In the Indian/Deadwood watershed analysis, for example, the effects of roads are well documented, and over 20 GIS-generated maps display watershed characteristics (Siuslaw National Forest 1996a).

Benefits to using GIS include the ability to store large amounts of data, analyzing data spatially, and using information to model possible outcomes of management decisions. GIS can be an effective, efficient tool for studying road systems, and has been widely used at the Siuslaw and by other researchers for management and research purposes.

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