THESIS

MEASURING CHANGES IN AREAL EXTENT OF HISTORIC WETLANDS AT GREAT SAND DUNES NATIONAL MONUMENT, COLORADO 1936 - 1995

Submitted by

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In partial fulfillment of the requirements

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WE HERBY RECOMMEND THAT THE THESIS PREPARED UNDER OUR SUPERVISION BY DAVID J. HAMMOND ENTITLED MEASURING CHANGES IN AERIAL EXTENT OF HISTORIC WETLANDS AT GREAT SAND DUNES NATIONAL MONUMENT, COLORADO 1936 – 1995 BE ACCEPTED AS FULFILLING IN PART THE REQUIREMENTS FOR THE DEGREE OF MASTER OF SCIENCE

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ABSTRACT

Measuring Changes in Areal Extent of Historic Wetlands at Great Sand Dunes National Monument, Colorado 1936 - 1995

Great Sand Dunes National Monument (GRSA) is a unit of the National Park system in south central Colorado. With funding from the Colorado Historical Society, a series of studies were undertaken for an environmental history of the GRSA area and the San Luis Valley. Park managers were concerned over the disappearance of small wetlands in northwestern GRSA. The objective of this study is to document and analyze the changes to the wetlands through the study of digital, georeferenced images and to relate these changes to climatic and hydrologic factors.

Ten sets of aerial photographs were obtained, from 1936 to 1995, with at least one set from each decade except for the 1940s. All photos were scanned into a digital format. A system was devised to mosaic the images prior to rectification due to the lack of ground control in the area. Land cover was digitized from the mosaics including the wetlands and sand type. Size and spatial distribution of the wetlands were analyzed.

Analysis shows that the greatest total number of wetlands and acreage totals were present in the 1936 and 1937 photo sets. In 1937, 114 wetlands were found, 47% have water at the surface. By 1953 the total number of wetlands dropped to 38 and by 1975 only 22 remained, with only 1 having water at the surface. The total number of wetlands has increased in recent years primarily due to subirrigated meadows. A large increase in the vegetation cover has occurred since 1936 to the present, increasing from 20% of the area in 1936 to 47% by 1995.

Climatic data were collected to analyze possible causes of the changes to the wetlands but the study was limited by the lack of long term data. Weather data is consistently available since 1948. Well data is of short term and sporadic nature. Two sources of long term data were available. The discharge of the Rio Grande has been monitored in Del Norte, CO since 1906. A dendrochronology study was done in the area of GRSA in 1980. The precipitation data, discharge and dendrochronology data were summed, averaged or offset for monthly or annual intervals prior to the dates of the aerial photo sets. These values were correlated with the acreage of the wetlands for each of the photo years by means of linear regression. Very poor correlation resulted between the precipitation indices and wetland acreage.

A surprising result came from correlation of the wetland acreage with the dendrochronology and discharge data. Over 58% of the wetlands variation can be explained by the 15 to 19 year offsets of dendrochronology data, 55% can be explained by the 20 year offset of Rio Grande discharge. These results are interpreted that the offset indices are related to the slow change in total area of the wetlands rather than fluctuations in the water table.

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3 Acknowledgements

A great many people provided considerable assistance, support, advice and encouragement during the long course that this project took. All of the staff at Great Sand Dunes National Monument always were very supportive and generous in their encouragement. Thanks to former superintendent Bill Wellman, Andrew Valdez, Barb Irwin and especially Fred Bunch for his great sense of humor and place to stay.

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Dr. Ralph Root of the USGS Biological Resources Division was instrumental in providing guidance early on with how to deal with photographs of nothing but sand. The NPS lost a great mind and a person with great enthusiasm for the National Parks when the former GIS Division became the National Biological Service.

My Graduate Committee was always there for me even though I was frequently far away. Dr. Freeman Smith, Dr. Roger Hoffer and Dr. William Sanford always made time to answer my (frequent) questions when I was on campus.

Finally and most importantly, I wish to thank my wife Dale for her support during this process. I am very grateful for her love and support and am looking forward to spending nights at home with her again.

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1 Introduction

1.1 Background for Study

In 1995, with funding from the Colorado Historical Society, park managers at Great Sand Dunes National Monument undertook a series of projects as part of an interdisciplinary historical ecosystem study. Three projects encompassing short-term to long-term climatic trends form the core of this study. Long term trends will be analyzed through the study of tree ring cores and vegetation. Historical records and photographs were analyzed to give clues to changes that have taken place in the region since European settlement (Geary, 1997). Short-term changes are studied through differences in the Pinyon-Juniper woodland regeneration due to the effects of historical wood harvesting (Rowlands, 1997). Another aspect of short-term change is presented in this paper in which changes in the spatial and temporal distribution of small interdunal ponds are documented through digital analysis of aerial photographs.

Great Sand Dunes National Monument (GRSA), a unit of the National Park system, is located in south central Colorado (see Figures 1 & 2). GRSA was established on March 17, 1932 by Presidential Proclamation number 1994 when signed by President Herbert Hoover. The Monument occupies 38,662 acres (15,646 hectares) in the San Luis Valley of southern Colorado, covering parts of Saguache and Alamosa counties

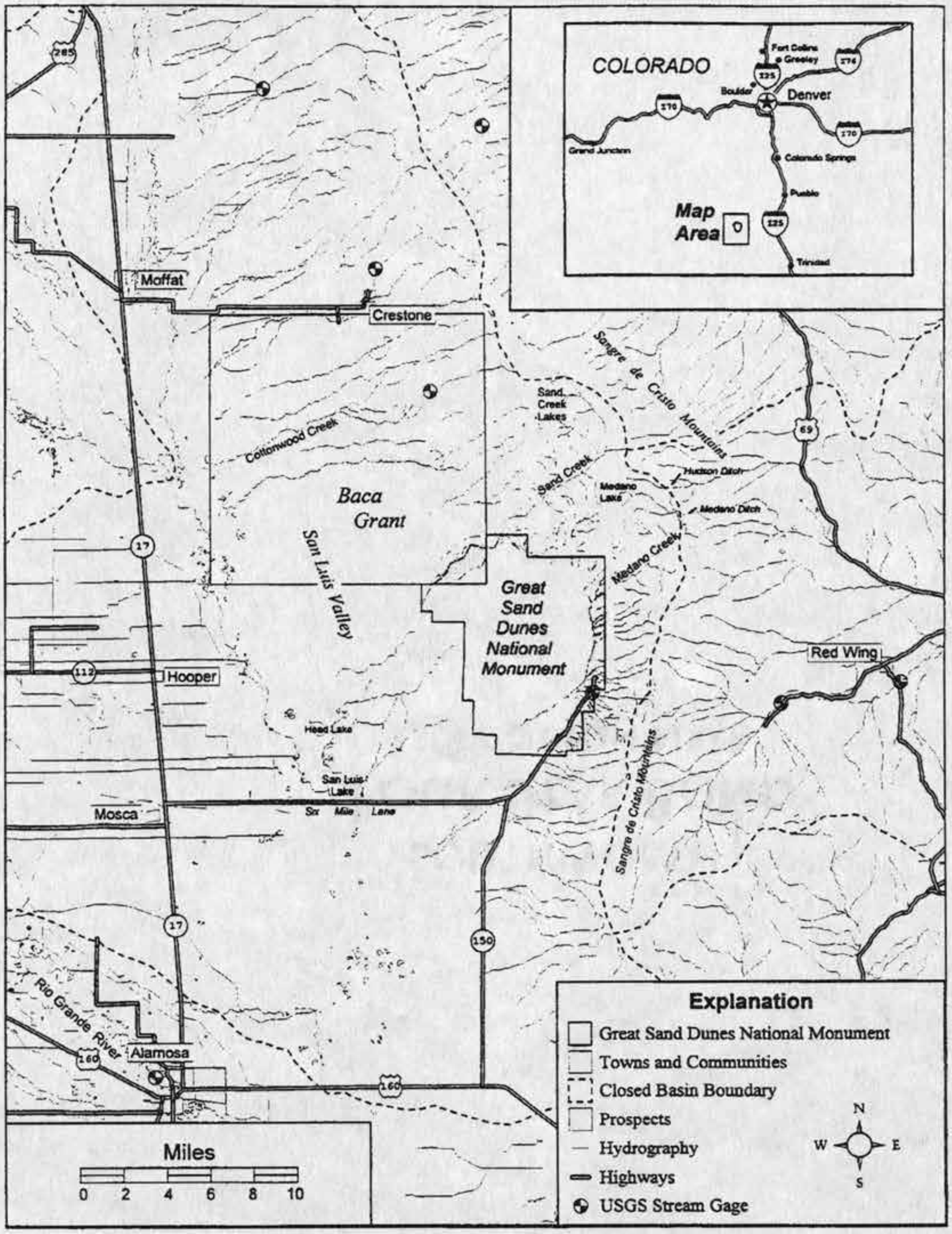

Figure 1-1 Location map of Great Sand Dunes National Monument, Colorado (Courtesy National Park Service)

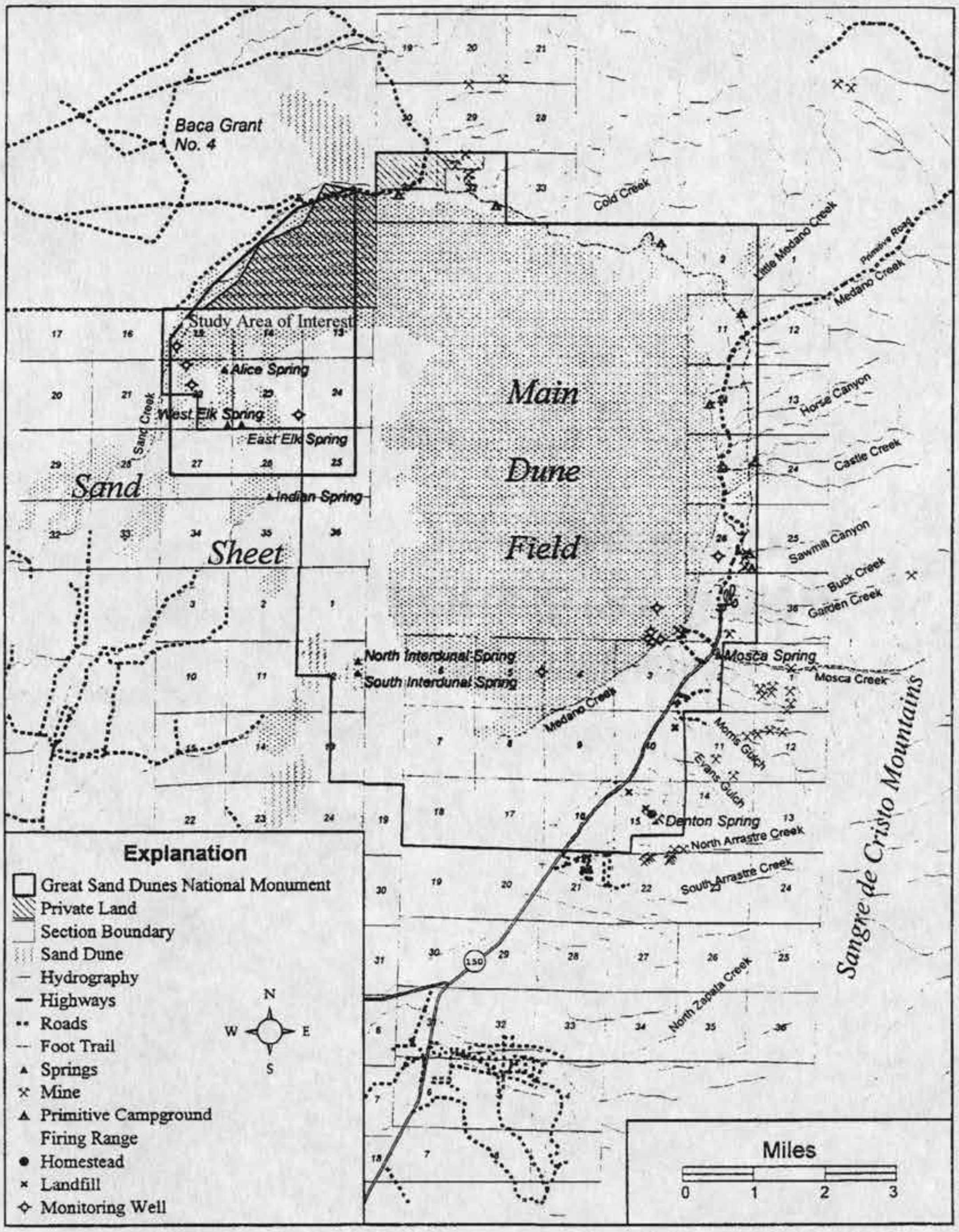

Figure 1-2 Great Sand Dunes National Monument, showing hydrography, land status, the dune field and other features related to water resources (Courtesy National Park Service)

(Chatman et al., 1997). The Monument was created in order to preserve the nations tallest sand dunes, which reach a height of 700 feet (>200 m) above the valley floor. In 1976, the Act of October 20th (90 Stat. 2692) designated 33,450 acres (13,357 ha) of the Monument as wilderness and another 670 acres (271 ha) as "potential wilderness".

Park managers are particularly concerned about the disappearance of small, interdunal ponds (a variety of wetlands) in the northwest quadrant of the park. In the early part of the twentieth century there were numerous small ponds in this area. These early ponds were not documented in the scientific literature, only through early newspaper articles and anecdotal stories (Geary, 1997, Bunch, personal communication, 1996). Thus, the only way to study the existence of and changes to these ponds was to acquire aerial photographs of the region.

1.2 National Park Service Management Objectives

1.2.1 National Park Service and Resource Management

Congress created the National Park Service (NPS) in 1916 with the intent to:

> "conserve the scenery and the natural and historic objects and the wild life therein and to provide for the enjoyment in the same in such manner and by such means as will leave them unimpaired for the enjoyment of future generations." (NPS Organic act, 16 USC 1)

The NPS since that time has pursued these mandates in areas that are deemed to have national significance for their natural or cultural resources. To this end, various Management Guidelines have been created to assist park personnel manage the resources for which they were created to preserve.

1.2.2 Water in the National Parks

Natural and cultural resources in National Parks are managed by guidelines set out in the NPS Management Policies (1988). This document addresses all aspects of resource and park management but specifically addresses water issues when it states:

> The National Park Service will seek to perpetuate surface and ground waters as integral components of park aquatic and terrestrial ecosystems. (Chapter 4, p.15)
>
> The NPS will seek to restore, maintain or enhance the quality of all surface and ground waters within the parks consistent with the Clean Water Act and other applicable federal, state and local laws and regulations (Chapter 4, p. 16).

The document continues by addressing various aspects of water quality, water quantity, cooperation with other federal, state and local agencies and water rights.

Water Resources Management Plans (WRMP) are prepared in units of the National Park Service where water resource issues are particularly important, complex or controversial (Chatman et al., 1997). A WRMP provides greater detail on issues related to water resources for a park unit than other types of park management plans (i.e., General Management Plans, Natural Resources and Cultural Resources Management Plans).

1.2.3 GRSA Water Management Goals

A Water Resources Management Plan was completed for GRSA in 1997. Water resources at the park are important to the stability of the dunes in many ways. In addition, due to the geology and hydrology of the area combined with water rights issues in the vicinity of the Monument, water issues are complex and controversial. WRMP's describe the water resources of the park and provide recommendations and proposed actions for planning and management of water resources in accordance with National Park Service and other Federal guidelines.

The following objectives outlined in the WRMP relate specifically to this study:

> Improve understanding of the hydrology, history and trends for the interdunal ponds and document the physical, biological and chemical resources of the remaining ponds.
>
> Establish and maintain long-term hydrologic monitoring program to document the condition, and provide an understanding of the surface and ground-water systems and their interactions.
>
> Acquire appropriate information to adequately understand and manage water-related resources.
>
> Enhance the understanding of the geohydrology and interactions between ground and surface water systems.

The historical ecosystem studies that this study is a part of were formulated in an attempt to document past environmental changes in the valley and determine how Monument resources have been affected. Protection of wetlands is an important NPS goal under Executive Order 11990 (Protection of Wetlands, May 24, 1977). If changes to the ponds are shown to be caused by climatic change or other "natural" causes, then no management action would be taken to stop or influence the change. If changes are determined to be caused by recent anthropogenic change, e.g. ground water pumping, then park management would want to take actions to mitigate environmental changes.

1.3 Study Objectives

Park staff are particularly interested in documenting the changes that have occurred to the interdunal ponds and to have this data available to them in a digital format. To this end, this studies objectives are:

1) Create digital, georeferenced mosaics of GRSA from aerial photos and land cover layers for a geographic information system (GIS) from the mosaics. Report on the reliability of the feature locations created from the mosaics.

2) Determine the extent of change to the ponds/wetlands. Specifically, the change in number, size and spatial distribution of the wetlands.

3) Statistically analyze the change to the wetlands in regard to climatic and hydrologic factors.

4) Recommend further courses of action for studying and understanding the relationship of the ponds to groundwater and how this relates to environmental change in the local area and the San Luis Valley.

2 Literature Review

This chapter presents a literature review of two geologic and hydrologic fields of study that are pertinent to this study. These are 1) the interaction of groundwater and surface water and 2) a review of the hydrologic model studies conducted in the San Luis Valley. Spatial accuracy is reviewed in a later chapter.

2.1 Groundwater/Precipitation Interaction

The hydrology of the immediate area of the wetlands in this study is not well known. The Sandhills of western Nebraska is an area that is similar in geology to the GRSA area. The Sandhills have been studied extensively in regard to the interaction of precipitation and groundwater levels. Ginsberg (1985) gives descriptions of the Sandhills' lakes and their relationship to the hydrogeology of the regions. The Sandhills area is similar to the GRSA area as a region containing "lakes, marshes and wet meadows occurring in broad, flat interdune valleys ... of a vegetation stabilized dune field."

Winter (1986) studied water level fluctuations in wells and in lakes in a wildlife refuge in the Sandhills area. He studied the relationship of groundwater recharge or discharge to the nature of the overlying topography of the dunes. His findings were that the water table is highly variable in dune topography. The water table is not necessarily a subdued replica of the land surface and there is not necessarily a steady gradient from high lakes to lower lakes. Also, the same lake can at times serve as a source of recharge to groundwater and at other times be a source of discharge.

Rundquist et al (1987) statistically analyzed the relationship between lake area and precipitation using Landsat MSS satellite data. This work studied two wildlife refuge areas in the Sandhills, one is the same area studied by Winter. Rundquist determined the surface area of the lakes in each study area from the Landsat data. They had 32 Landsat scenes over one of the study areas and 26 over the other. These measurements were correlated with precipitation indices. The indices represent the sum of precipitation prior to the dates of the imagery. Good (>50%) correlation between the surface area of lakes in one of the study areas with the 45 day precipitation index. No relationship could be found between any of the indices with the surface area of lakes in the second study area. They attributed this to other geologic or climatic factors not addressed in their study.

2.2 Computer Hydrologic Models and GIS

While applying a computer hydrologic model was not a goal of this study, I feel that it should be mentioned here since there has been extensive work in this area applied to the aquifers of the San Luis Valley. This work has centered on applications regarding the then proposed Closed Basin Division (CBD) project of the Bureau of Reclamation.

Emery (1970) was one of the early researchers to apply an electric analog model to the valley for the prediction of "salvageable" water and water table decline based on the depth of the water table below the surface. This work continued with Emery et al. (1975) with the development of a three-layer model simulating the unconfined aquifer and two layers of the confined aquifer to a depth of 3,120 feet. This model showed the effects that groundwater withdrawal would have on the flow of the two major streams of the valley, the Rio Grande and the Conejos River.

Hearne and Dewey (1988) developed a three-dimensional digital model to represent the aquifer system in five different flow regimes for the Rio Grande Basin north of Embudo, New Mexico. This model was also used to estimate effects of groundwater withdrawal in the CBD.

Qazi (1983) developed a quasi three-dimensional model to simulate the effects of groundwater withdrawals on surface stream flow. He proposes that this model be used as a management tool for the evaluation of junior groundwater right on senior surface water rights. The results of pre and post calibration model runs are presented in this study.

Williams (1992) linked a GIS with the USGS model MODFLOW for the study of the unconfined and confined aquifers. Data for entry into MODFLOW was developed from data input into the GIS. These data included geology, soils and land use/land cover digitized from maps and topography from digital elevation models. She found that the export of the data from the GIS to MODFLOW increased the speed and accuracy of the data to the modeling program.

Finally, Watts (1995) used regression modeling to predict monthly water level changes to an observation network of wells in and near the CBD. He used data such as streamflow depletion of the Rio Grande, precipitation, stream runoff and mean air temperature. Harmonic cosine and sine functions were used to predict residual values that were input to the regression equations for the prediction of water levels.

3 Physical Setting of Study Area

3.1 Geographic Setting of the Study Area

Great Sand Dunes National Monument is in south central Colorado, on the eastern side of the San Luis Valley (SLV). The SLV is a broad, flat, intermountain valley that is over 100 miles (>160 km) long in Colorado in a north-south direction and over 50 miles (>80 KM) wide from east to west. The SLV extends southward into New Mexico but this section is significantly different physiographically and geologically from the Colorado section. The southern end of the valley terminates south of Taos, New Mexico

Upson (1939) subdivided the valley into five physiographic provinces. The northern portion of the valley, north of Alamosa, Colorado is called the Alamosa Basin. The valley floor of the Alamosa Basin is an almost featureless, flat expanse that stretches northward to Poncha Pass, the northern entrance to the SLV. Mountains bound the valley on both sides, the Sangre de Cristo Range to the east and the San Juan Mountains to the west.

In contrast to the flat, featureless terrain of the SLV is the Sangre de Cristo Mountains, a long, linear range of mountains with nine summits over 14,000 feet (4,267 m). The tallest of these peaks is Blanca Peak at 14,345 ft (4,267 m), just 10 miles (16.1 km) SSE of GRSA. The steep western face of the Sangre de Cristos is due to the Neogene-aged, block-faulted nature of their formation (McAlpin, 1982). The only major break in this wall north of Blanca Peak are the low mountain passes to the east of GRSA, Mosca, Medano and Music Passes from south to north.

Geologically the Sangre de Cristos are primarily Upper Paleozoic age sedimentary rocks with lesser amounts of older Paleozoic and Precambrian crystalline rocks (McAlpin, 1982). As is typical of fault block mountains in arid climates, the northern Sangre de Cristos are flanked by a continuous belt of alluvial fans, which are deposited out into the SLV. These alluvial fans cover and obscure the Sangre de Cristo Fault Zone (SCFZ) at the base of the mountain front.

The Rio Grande River drains the SLV. The headwaters of the Rio Grande are in the San Juan Mountains to the west of Del Norte, Colorado. The river flows southeastward to Alamosa, then turns toward the south. A low topographic divide just north of Alamosa separates the Rio Grande drainage from an internally drained area that is the northern half of the SLV, an area known as the "Closed Basin". The lowest portion of the closed basin, locally known as the "sump", is near San Luis Lake, which is just 10 miles (16 km) to the west of GRSA headquarters. This area is characterized by a water table that is very near the surface, water here is discharged primarily through evapotranspiration (Powell, 1958).

Many potential causes for the changes that have occurred to the wetlands in this study have been proposed (Chatman, 1995a). The majority of these hypotheses are in part related to geologic factors, hydrologic factors or climatic factors. The following sections provide a discussion of the geology, hydrology and climate of the San Luis Valley and of the study area.

3.2 Geology of San Luis Valley

The San Luis Valley is part of a series of en echelon grabens that comprise the Rio Grande Rift, a large extensional feature extending from El Paso, Texas on the south to north of Leadville, Colorado (Burroughs, 1981). The SLV is asymmetrical, hinged on the west and tilting eastward, the downthrown block terminating on the east at the SCFZ, the western margin of the upthrown Sangre de Cristo Mountains.

As noted by Upson (1939), the Alamosa Basin is a physiographically and geologically distinct segment of the San Luis Valley. The Alamosa Basin is comprised of three major basement features. From west to east these are 1) the Monte Vista Graben, 2) the Alamosa horst in the central part of the valley and 3) the Baca graben. These are basement features that have affected the deposition of the Neogene Alamosa Formation but do not offset the surface (McAlpin, 1982). GRSA is located on the Baca graben. An oil test well, the Mapco-Amoco No. 1-32 State, in section 32, T 40 N, R 12 E, New Mexico Meridian bottomed at 9,480 ft (2,889 m) depth in Paleocene(?) rocks (Burroughs, 1981). This well is approximately 10 miles (16 km) WSW of GRSA headquarters and 8.5 miles (13.7 km) SSW of the study area. Basement rocks in the Baca graben are estimated to be at 12,000 ft (3,660 m) depth at the Mapco well. Ten miles to the north, in the vicinity of the study area, basement is estimated to be at 19,000 ft (5,800 m) depth. A gravity study by Gaca and Karig (1966) found a gravity low, 55 miles (>88 km) long, parallel to the Sangre de Cristo Range about 6 miles (10 km) to the west of the range. This would indicate a significant thickness of sediments extending to the northwest along the front of the range.

The first 180 ft (55 m) of the Mapco-Amoco well penetrated loose, unconsolidated sand (Burroughs, 1981). A test well at GRSA near Medano Creek (sec 4, T 27 S, R 73 W, 6th Principal Meridian) encountered 120 ft (37 m) of unconsolidated sand (Bunch, 1997, personal communication). Below 180 ft in the Mapco well, blue clays of the Alamosa Formation were present. The Alamosa formation comprised the first 2,500 ft (760 m) drilled in this well.

3.3 Geology of Great Sand Dunes National Monument

Great Sand Dunes National Monument is a concentrated eolian deposit that occurs in an amphitheater-like reentrant of the Sangre de Cristo Mountains (Andrews, 1981). Prevailing southwesterly winds have deflated sand and smaller grains from the valley floor and redeposited these grains in the east-central portion of the valley. The dunes that form are a result of three main localizing factors; 1) The inability of the wind to transport sand grains over the mountain front; 2) Periodic strong winds out of the northeast and 3) Erosion of the sand by streams that flow from the Sangre de Cristo Range, transporting sand grains back to the west side of the main dune field (Valdez, personal communication, 1997).

Wiegand (1977), Fryberger et al. (1979) and Andrews (1981) describe the sedimentology of the Great Sand Dunes in detail. Wiegand performed field studies on dune morphology, migration, bedding and grain size and found that transverse dunes dominate the main dune field. McKee (1966) describes transverse dunes as "an almost straight sand ridge oriented at approximately right angles to the dominant effective wind direction". The form of these dunes is very apparent on the aerial photos. It is the transverse dunes that build to a height of over 700 ft (>200 m) above the surrounding valley floor.

Accretion of the dunes is helped by strong winds out of the northeast, which occur predominantly in the spring. These winds form when "upslope" weather conditions occur to the east along the Front Range of the Rocky Mountains (Wellman, personal communication, 1996). Low-pressure zones pass to the south of the SLV ("Albuquerque lows") and bring counterclockwise rotation to bear against the mountain front of the eastern plains of Colorado. Winds funnel through the low mountain passes east of GRSA, reversing the common direction of eolian transport. These winds redeposit the sand forming reversing dunes. These dunes have the same features of the larger transverse dunes but are 180° out of phase from the primary dunes (Wiegand, 1977). These features are popularly called "Chinese Walls" and are apparent on the 1936 set of aerial photos for this study.

To the west and south of the main, active dune field, parabolic dunes are the dominant form. Parabolic dunes are controlled by vegetation. This dune type originates as a blowout (McKee, 1966) where vegetation has been removed. Under the influence of persistent winds, the middle dune mass moves downwind while the trailing arms are anchored by vegetation (Wiegand, 1977).

The works of Fryberger et al. (1979) and Andrews (1981) describe the morphology and sedimentation mechanisms of the "Sand Sheet" area to the west of the main dune field. Andrews divided the eolian sediments of the area into three provinces trending downwind (Figure 3-1). Province I is closest to the Rio Grande, the major source area for

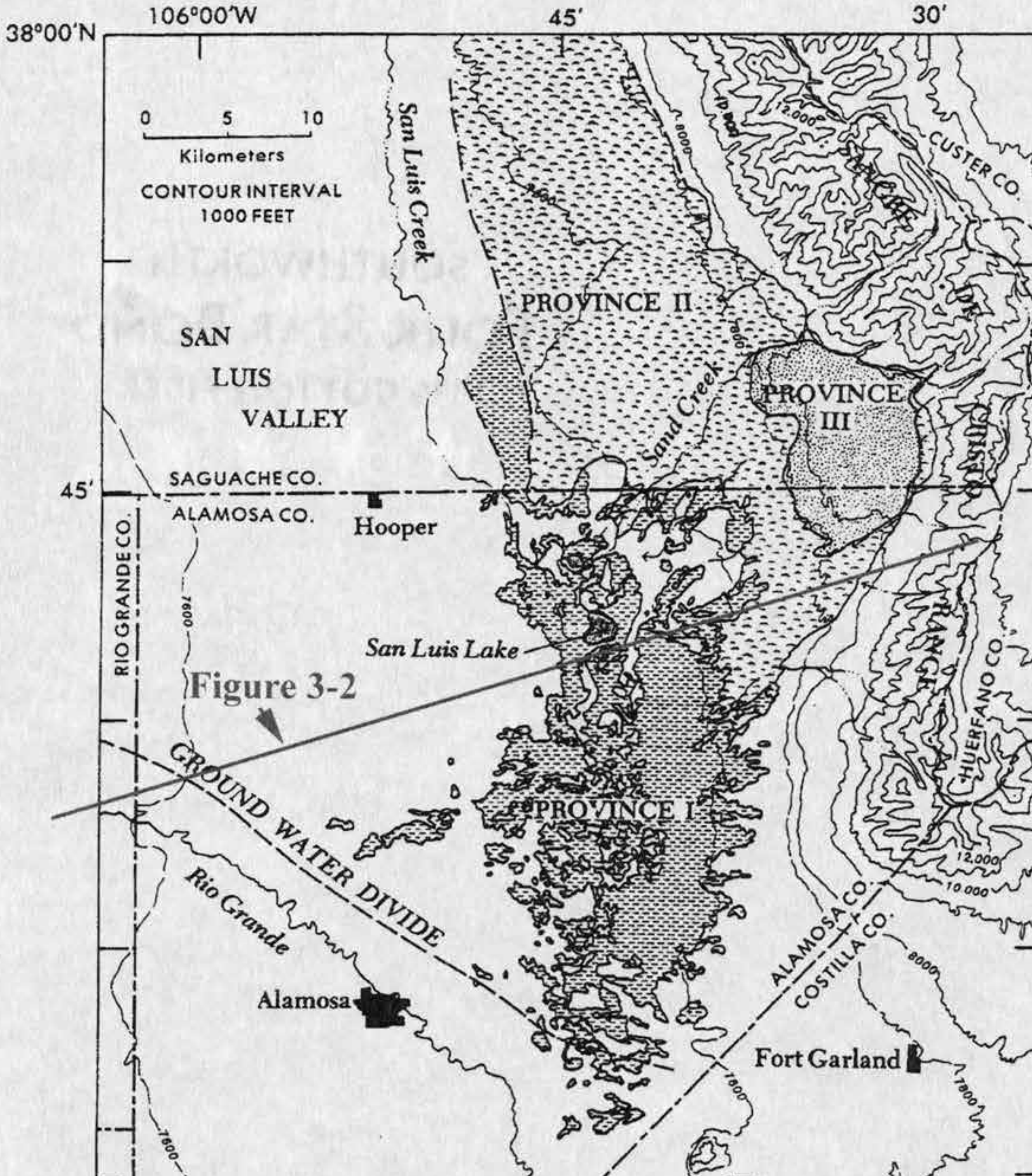

Figure 3-1 Eolian provinces of San Luis Valley, CO (from Andrews, 1981) showing location of cross section in Figure 3-2

the sand which forms the eolian deposits. A high water table characterizes this area, along with sand deposits forming low (10-30 ft high, 3.1-9.3 m) berm-like ridges surrounding alkaline lakes. Evaporation of surface runoff and ground water forms alkaline crusts in this area.

Province II is the sand sheet area, further downwind from Province I. Dunes here are low and rolling (about 30 ft high, 9.3 m). The dunes are controlled by vegetation. Where vegetation is present, wind speed is slowed and therefore dune migration is slowed. Low angle strata characterize dunes in this province. Andrews notes the presence of a springline along the southwest margin of Province II. Big Spring Creek and Little Spring Creek emerge from the sand just west of the GRSA boundary. The study area of wetlands for this paper covers a portion of Province II to the north of Big Spring Creek.

Province III is the main dune field. This has been discussed in Wiegand's study. This Province is the smallest in areal extent of the three, covering approximately 39 mi^2 (101 km^2). This area is the primary feature of Great Sand Dunes National Monument.

The San Juan Mountains has long been suspected to be the source of material that forms the sand of the dunes. As early as 1874, Endlich proposed this to be the source of the sand (Burford, 1961). Detailed petrographic studies of dune sand, soil samples, stream sands and rock samples from the surrounding region by Burford & Hutchison (1967) confirmed the San Juans as provenance for the eolian sands. Wiegand (1977) concurred with these findings that the San Juans were most likely the original source for the dune sand material.

3.4 Hydrology of the San Luis Valley

3.4.1 The Aquifer System and Artesian Flow

Despite being an arid climate, the SLV is a prolific agricultural area due to the presence of abundant groundwater. There is an extensive system of aquifers that consist of three identifiable units (Hanna & Harmon, 1989) (see Figure 3-2). These units are (in descending order) an upper unconfined unit, an intermediate ("active") confined unit, and a lower ("passive") confined unit. These units can be in hydrologic connection in various parts of the valley but not all units are present in every part of the valley.

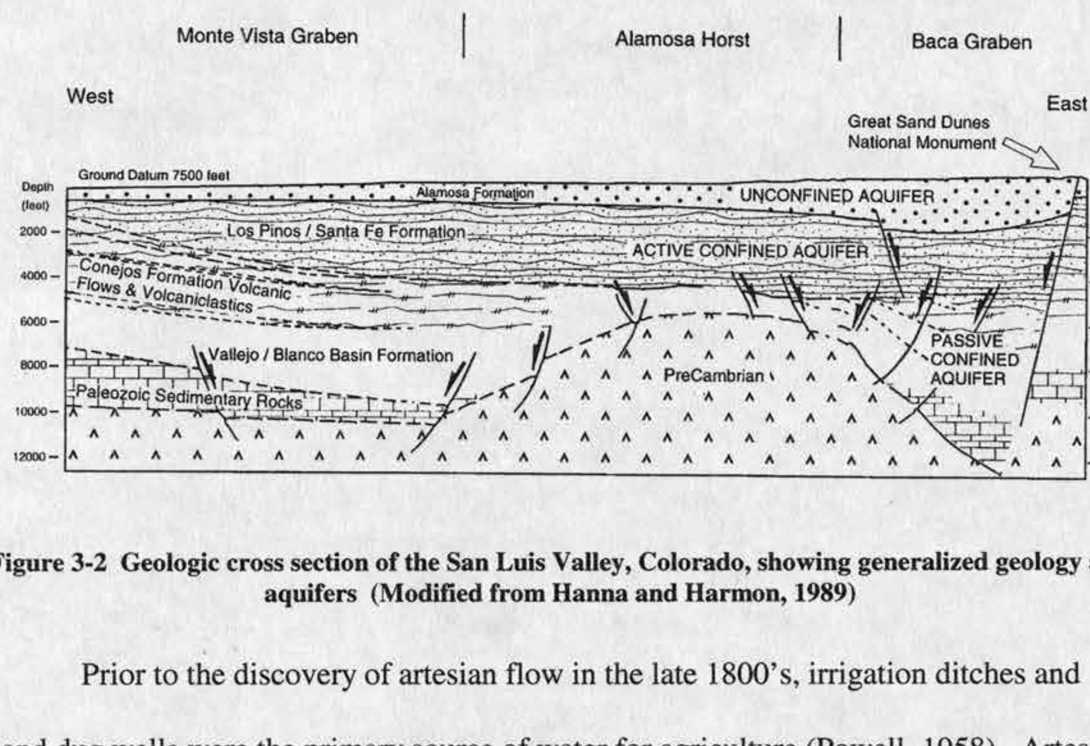

Figure 3-2 Geologic cross section of the San Luis Valley, Colorado, showing generalized geology and aquifers (Modified from Hanna and Harmon, 1989)

Prior to the discovery of artesian flow in the late 1800's, irrigation ditches and hand dug wells were the primary source of water for agriculture (Powell, 1958). Artesian flow was discovered in the valley in 1887 and development of this resource proliferated rapidly throughout the valley. Siebenthal (1910) mapped the limits of artesian flow in his classic work. In the vicinity of GRSA the limit is mapped as a northwest trending line, west of what is now GRSA, intersecting Big and Little Springs. (Big Springs is now shown as Indian Springs on the USGS topographic maps of the area.) Throughout most of the valley, the limit of artesian flow is defined by the presence of lacustrine "blue clays" in the upper Alamosa Fm (Hanna & Harmon, 1989).

The unconfined aquifer is present throughout the valley and ranges from 50 to 200 feet (15 to 60 m) thick. It consists of valley fill deposits above the uppermost blue clay layer of the Alamosa Formation (Leonard & Watts, 1989). The clay layer is not continuous over the whole central portion of the valley, pinching out a few miles from the periphery of the central Valley area (Hanna & Harmon, 1989). Where present, the clay layer is discontinuous and can be cut by low energy, channel fill sands. Along the edges of the valley, the unconfined aquifer is in direct, lateral contact with the confined aquifer. Here, recharge of the confined aquifer can occur.

The intermediate ("active") confined aquifer is below the blue clay layer at the base of the unconfined aquifer. The intermediate confined aquifer ranges in thickness from 500 ft (152 m) on the west to over 5,000 ft (1524 m) in the Baca Graben (Hanna & Harmon, 1989). It is the major source of artesian water in the valley. Hydraulic conductivities of the aquifer decrease from west (235 feet per day, 71.6 meters per day) to east (35 feet per day, 10.7 meters per day) across the valley.

The lower ("passiive") confined aquifer is the deepest unit of the aquifers of the SLV. It can extend to over 10,000 ft (3,048 m) in thickness but relatively few wells tap this unit. It is characterized by low hydraulic conductivities, poor water quality and an elevated geothermal gradient.

3.4.2 GRSA Vicinity Hydrology

The configuration of the water table in the vicinity of GRSA and the study area are incompletely defined. Maps of the piezometric surface by Powell (1958) and Crouch (1985) do not extend eastward into the GRSA area. Well data is limited in the area, the closest well being about 4 miles (6.4 km) west of the western boundary of GRSA. The level of the water table can be inferred at Indian Spring, less than 1 mile from the western GRSA boundary. This flowing spring, at 7,680 ft (2,341 m) elevation, is visible on all sets of the aerial photos. Observations made by Colorado Division of Water Resources engineers in 1991 found that Big Spring Creek below Indian Springs is a gaining system. Discharge increased from 0.11 cfs (0.003 $m^3 \cdot s^{-1}$) at 525 feet (160 m) below the spring to 5.42 cfs (0.15 $m^3 \cdot s^{-1}$) at a point 2.8 miles (4,505 m) below the spring (Whitehead, unpublished memo, 1991).

Electrical resistivity soundings in Sand Creek by Harmon & Hajicek (1992) indicate a continuity of saturation between Sand Creek and the underlying aquifer system. Hadlock (1995) studied a network of wells in Medano Creek and found a discontinuous layer of low permeability about 20 ft (6.1 m) from the surface in some wells but not in others only 300 ft (91 m) apart. This well network is near the terminus of flow for Medano Creek. The sections of Sand Creek studied by Harmon & Hajicek apparently do not have this unsaturated layer.

3.4.3 The Closed Basin Project

The Closed Basin Division (CBD) was authorized by Public Law 92-514, October 20, 1972 (Watts, 1995). It is a multi-purpose water resource project that is designed to deliver water to the Rio Grande that would otherwise be lost to evapotranspiration. It will do this by the pumping of wells in the unconfined aquifer in order to lower the water table, thereby decreasing the amount of water that could be lost through evaporation or transpiration. The pumped water is supplemented to the Rio Grande so that the State of Colorado can meet its obligations to downstream users. Other uses for this water include maintenance of wildlife habitat, recreational use and other beneficial uses.

The project was first envisioned during negotiations of the Rio Grande Compact in the 1930's (Ogburn, 1996). As presently defined, the CBD covers over 130,000 acres (>52,600 ha) of the topographic low of the closed basin (the "sump" area) (Watts, 1995). When completed, it will include about 170 salvage wells that will withdraw up to 100,000 acre-feet per year ($1.23 \times 10^{8} \cdot m^{3}\ yr^{-1}$) from the unconfined aquifer. This water will be conveyed to the Rio Grande through a lined conveyance channel. As authorized, water level drawdown in excess of 2 feet (0.6 m) beyond the projects boundaries is prohibited so as not to harm previously existing wells in the unconfined or confined aquifers.

In places, the CBD boundary is less than 3 miles (4.8 km) to the southwest corner of GRSA. The wetlands of this study are located about 7 miles (11 km) northeast of the closest boundary of the CBD. Crouch (1985) shows a potentiometric surface of 7,520 feet (2,292 m) elevation in the vicinity of San Luis Lake (within the CBD). This level is over 150 ft (45 m) lower than what would be expected in the study area. There are other concerns regarding the CBD that could affect other aspects of GRSA but these are outside the scope of this study. Presumably, due to the design of the CBD project, water level change should not be one of these concerns.

3.4.4 Climatic and Weather Conditions of Study Area

The San Luis Valley has an arid climate (Doesken & McKee, 1989). The central portion of northern SLV typically receives only 8 inches (203 mm) of precipitation on average per year. This is in areas where the elevation is approximately 7,600 feet (2,316 m) above sea level. The weather station at GRSA, operated since 1951, is at 8,120 feet (2,475 m) elevation. Located on the flanks of the Sangre de Cristos, it collects a bit more moisture and averages 10.6 inches (269 mm) annually. The surrounding mountains can receive four to five times the amount of precipitation that occurs over the valley, although this is largely in the form of snow. See Figure 3-3 for the monthly precipitation averages.

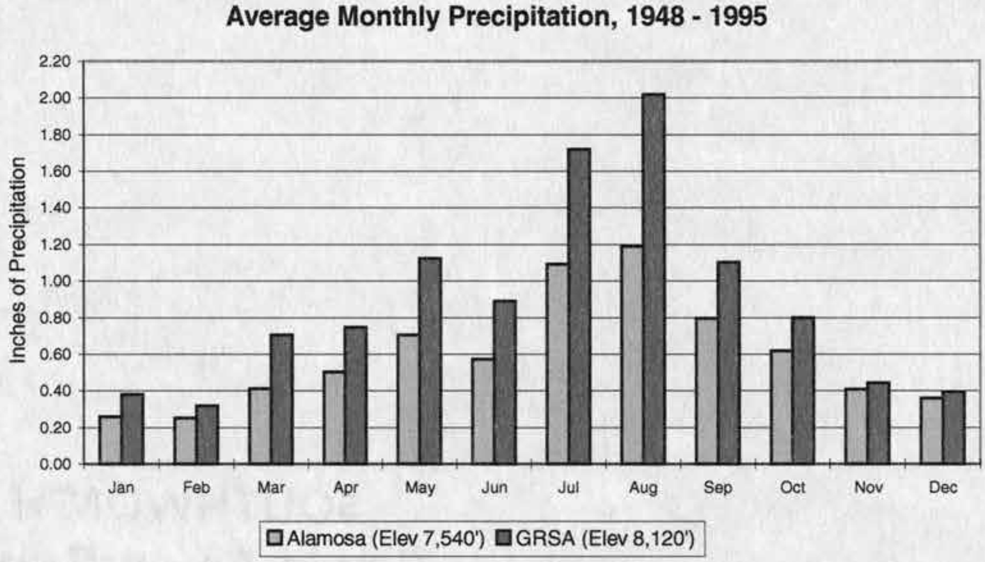

Figure 3-3. Average monthly precipitation for Alamosa (Station 0130) and Great Sand Dunes National Monument (Station 3541), Colorado

The dryness of the valley is almost entirely due to orographic effects (Doesken & McKee, 1989). The valley is shielded on all sides by mountains. Air currents typically warm and dry as they descend into the valley. Along the base of the Sangre de Cristo Mountains, slightly higher than the valley floor, July and August are the peak months for precipitation. This is caused by convectional rising of air by summer heating, forming thunderstorms that are blocked by the mountain front. The air cools as it rises, giving more moisture to the higher regions surrounding the valley.

The weather conditions in the San Luis Valley can be quite different than the rest of the state (Doesken, personal communication, 1997). This is due to the geographic effects already discussed. Climatic trends have been created for the state and for the SLV in a publication "Historic Dry and Wet Periods in Colorado" (McKee & Doesken, in review). Regional weather station observations for the SLV were prepared into a general summary of conditions overall for the Valley. These conditions reflect regional trends. The weather conditions of the valley are so highly variable and localized that individual weather station recordings could be quite different than that of the region for a particular year.

With that in mind, preliminary results indicate that the period from 1905 to the mid-1920's is a relatively wet cycle, regionally. Conditions begin to dry in the mid-1920s so that through the 1930's, conditions were dry ("Dust Bowl" times of the eastern Plains of Colorado). The middle decades of the century were highly variable. Wet periods and dry periods of 3 to 5 years in length followed one another. Since the 1970's, precipitation trends have slowly been increasing. This has been reflected in the precipitation data collected at GRSA (Figure 3-4). 1997 was the record year for precipitation at the Dunes with almost 20 inches (510 mm) of precipitation recorded. (See Appendix 1 for precipitation annual totals used in this study).

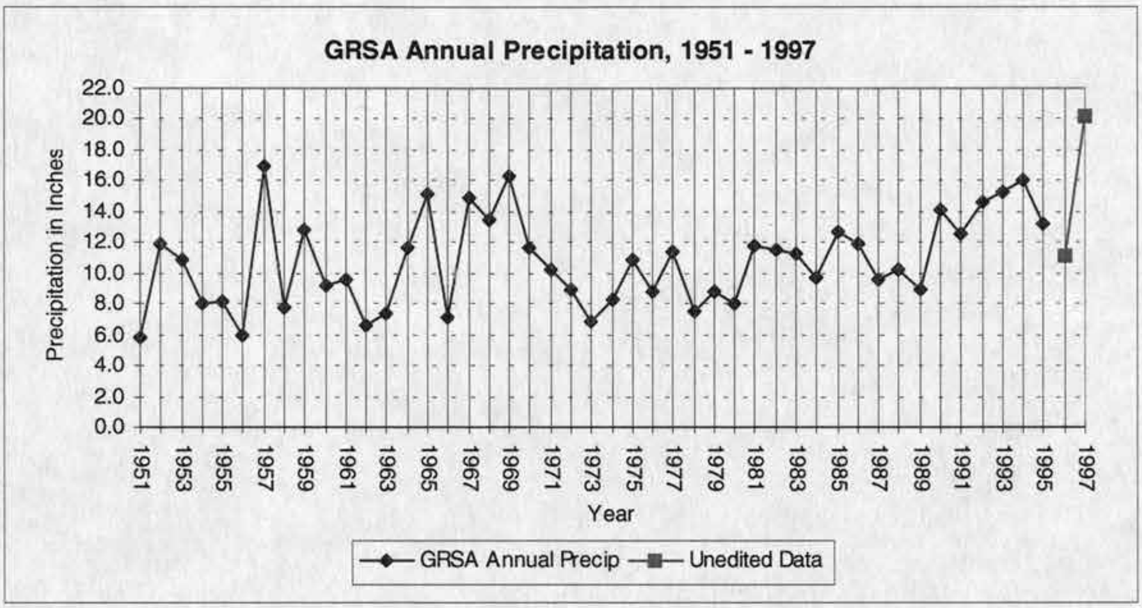

Figure 3-4. Annual precipitation for Great Sand Dunes National Monument, Colorado

3.4.5 Dendrochronology Studies

Weather data has been recorded intermittently in the SLV since 1851. The earliest instrumental readings were taken at Fort Massachusetts (Bradley, 1976). Fort Massachusetts was located near the present day Fort Garland, about 16 miles (26 km) SSE of GRSA, south of Blanca Peak. It has only been in the past five decades that regular recordings have been taken in the Valley. Long term climatic fluctuations have been inferred across the western United States through the use of dendroclimatic reconstructions (Bradley, 1976).

Mangimeli (1981) performed dendrochronological fieldwork and analysis as part of a Masters thesis at the University of Nebraska. Sites were chosen on the west flank of the Sierra Blanca and cores of Pinyon Pine were taken at the lower elevational limits of growth and of Bristlecone Pine at the upper limits of growth. One of the sample sites for Pinyon Pine was in the southeast corner of GRSA, near Denton Springs (Appendix 2).

Mangimeli states that by taking samples at the lower limits of a species growth limit, precipitation should be the limiting factor in regard to tree growth. For samples at the upper limits of a species growth, temperature should be the limiting factor. He found the Bristlecone chronology was not usable for temperature reconstruction. The Pinyon Pine chronology, however, did exhibit expected relationships between growth rate and precipitation. From this relationship he inferred periods of cool-moist conditions or warm-dry conditions. For the past 100 years he interpreted an extended period of cool-moist conditions from 1880 to 1925. The period from mid 1940's through mid 1960's was interpreted as warmer and drier than the long-term average but it was not the longest or greatest drought period of his study (from 1650 to 1975). These findings correspond well with those mentioned earlier from Doesken, which are derived from instrumental readings.

3.5 Local Factors

3.5.1 Soils

Soil survey maps have been produced for the two counties that cover the study area by the U. S. Department of Agriculture Soil Conservation Service (now the Natural Resources Conservation Service)(Pannel et al., 1973, Yenter, 1984). Soils were mapped at 1:24,000 scale. Two major soil types occur in the study area, Dune Lands and Cotopaxi Series Soils. Both have similar properties of high permeability and low surface runoff. The available water capacity is low to very low and potential for soil blowing is high. The difference between these two soil types is that the Dune Lands are mostly barren of vegetation while the Cotopaxi soils support light to moderate vegetation cover, such as Indian ricegrass (Oryzopsis hymenoides), needleandthread (Stipa comata) and blowoutgrass (Redfieldia flexuosa). The Dune Lands generally have greater relief with steep slipfaces, Cotopaxi Series soils are gently rolling, stabilized dunes (Yenter, 1984).

Medano fine sandy loam and Space City loamy sand occur in two limited areas, south of the study area, close to Indian Springs. The Medano soil occurs along Big Spring Creek. The Space City series occurs in small areas of heavier vegetation surrounding Indian Springs.

3.5.2 Wetlands

The U.S. Fish and Wildlife Service produce the National Wetlands Inventory (NWI) maps. The six quads over GRSA have been mapped from the 1983 National High Altitude Photography (NHAP) program color infrared (CIR) photography and from 1987 National Aerial Photography Program (NAPP) CIR photography. Wetlands are mapped from the photography and plotted on 1:24,000 scale topographic maps. Wetlands are classified by a hierarchical system that identifies system, subsystem, class and subclass (Cowardin et al., 1979). A code based on this system identifies the wetlands on the NWI maps.

Over the study area, 35 wetlands are mapped in the NWI, exclusive of Sand Creek. All the wetlands are classified as Palustrine system, which are small wetlands of less than 20 acres (8 ha) and less than 7 feet (2.1 m) deep. All of the wetlands are classified as "EM", emergent class, for erect, rooted, herbaceous hydrophytes. The class of the wetlands is modified as "A" for temporarily flooded or "C" for seasonally flooded.

Sand Creek forms the northern end of the study area and it is classified as Riverine system, Lower Perennial or Intermittent subsystem and Unconsolidated Bottom class. Paper copy maps and their digital counterparts were obtained for this study as a reference point and an indicator of the conditions of the wetlands at the time of NWI map production.

3.5.3 Vegetation

Curdts et al. (1992) used a Landsat Thematic Mapper (TM) image to produce a land cover classification of GRSA. Using an unsupervised classification algorithm, 13 cover type classes were derived, with an overall accuracy of 84.7%. Seven cover types are reported for this study area including; sand, sand with grass & forbs, grass & forbs with sand, grass & forbs with shrubs, shrubs, riparian/cottonwood/aspen and water.

McArthur and Sanderson of the USDA, Shrub Sciences Lab in Provo, UT, did a vegetation study for the park in 1991. Vegetation samples were obtained from 118 0.01-hectare plots across GRSA. Sixteen of these plots were in the study area. The sampling sites were primarily located at section corners or unique areas that were not on the grid.

Of the 16 sites in the study area, 9 were classified as "Stabilized Dunes". These plots were characterized by graminoids such as Indian ricegrass, needleandthread and blowoutgrass. Rubber rabbitbrush is a common shrub. Forbs such as the prairie sunflower and scurfpea were common. Overall, these 9 plots had 19 different species of forbs, 5 different species of graminoids and 2 species of shrubs. Bare soil ranged from 25 to 70% of the plot area.

Two sites fell in the "Active Sand" category in the study area. These had 70 to 75% bare soil and a limited plant community. Three species of forbs occurred, 1 species of graminoids (blowoutgrass), 1 species of shrub (sandbar willow) and 1 species of tree (narrowleaf cottonwood).

Of most interest to this study are the five sites categorized as "Marshes". These sites have the largest variety of plants with 31 species of forbs, 18 species of graminoids and 1 species of shrubs. Graminoids such as saltgrass, wiregrass, Douglas' sedge and Nevada bulrush are unique to these marshes. Most graminoids, forbs and shrubs already noted for the other categories are present around the marshes. One species not noted in the McArthur and Sanderson report but I have seen are cattails. These are present in Elk Springs, which is one of the plot sites in the McArthur and Sanderson report. Presumably the cattails did not occur within the 100 $meter^2$ circle of the plot. The marshes are much darker and richer in color than the other vegetation categories. Bare soil makes up only 1 to 2% of the plot areas in the marshes.

4 Mosaic Process and Creation of GIS Layers

4.1 Data Collection

4.1.1 Aerial Photographs

Twelve sets of aerial photographs were collected over GRSA. These were available from various sources including directly from the Monument staff. Other sets had to be researched from data repositories. These included the Earth Science Information Center (ESIC) at the USGS in Lakewood, CO., the US Forest Service offices in Lakewood, CO and in Salt Lake City, UT and the National Archives and Records Administration in Washington, D.C. The sets ordered were chosen based on the scale of the photos, completeness of coverage over the study area and the year of acquisition. Ideally, park managers wanted to have at least one set from each decade that photography was available. Unfortunately, there was no set from the 1940s that completely covered the study area or GRSA. A photo index was obtained for a set from November 1941 for Alamosa County. Since this was so close in time to the two sets from the 1930s and the set didn't cover the northern extent of the study area in Saguache County, it was rejected. For most of the other decades, two sets of photos at acceptable scales were available except for the 1960s, for which only one set fit the criteria. Also, two photo sets obtained from the park had to be rejected due to incomplete coverage over the study area or poor quality of the photo project. Table 4-1 shows the results of the photo search.

Table 4-1 Aerial photo projects over GRSA obtained for this study

AGENCY	PROJECT CODE	SCALE	PROJ DATE	2nd YR	FILM TYPE	INDEX MAP	CAMERA REPORT	NUMBER OF PHOTOS
SCS	DX	1:31,680	1936, Aug		B&W	No	No	31
USFS	CL	1:20,000	1937, Sept	1938	B&W	Photo Mosaic	No	40
Army	ABA00133	1:53,000	1953, Oct		B&W	No	No	13
USGS	CWQ	1:20,000	1955		B&W	No	No	16
USFS	ECB	1:20,000	1956, Sept	1957	B&W	Photo Mosaic	No	25
USGS	VBMA	1:20,157	1966, Aug		B&W	Photo Mosaic	Yes	28
USGS	VDSD	1:80,000	1975, Sept		B&W	Photo Mosaic	Yes	9
USGS	VEQQ	1:78,000	1979, Sept		B&W	Photo Mosaic	Yes	7
USGS	NHAP	1:58,000	1983, Sept	1985, Aug	CIR	Base Map	Yes	5
USGS	NAPP	1:40,000	1988, July	1988, Sept	CIR	Base Map	Yes	8
NPS		1:12,000	1990		B&W, Color	No	No	110
USFS/ NPS		1:24,000	1995, July	N/A	Color	No	No	38

Due to the detailed nature of the analysis and the small size of the features, a minimum scale of 1:80,000 was needed. Also, stereo coverage was obtained for all photo sets to minimize displacement of features. Older photo sets were black and white but the three most recent sets were Color Infrared (NHAP, 1985 & NAPP, 1988) and natural color (1995).

4.1.2 Scanning Process

After the photos were obtained, they were then scanned on an Anatech Eagle 4080 Black & White Scanner interfaced with a Sun IPX workstation. These were scanned at the USGS Mapping Division GIS Lab in Lakewood, CO. All photos were scanned at 800 dots per inch (dpi). (See Table 4-2)

Table 4-2 Pixel resolution of scanned aerial photos

	Pixel Size	
	Inches	**Centimeters**
@ 800 dpi	0.00125	0.003175
	Pixel Resolution	
Photo Scale	**in Feet (ft^2)**	**in Meters (M^2)**
1:12,000	1.25 (1.56)	0.38 (0.14)
1:20,000	2.08 (4.33)	0.64 (0.40)
1:20,157	2.10 (4.41)	0.64 (0.41)
1:24,000	2.50 (6.25)	0.76 (0.58)
1:31,680	3.30 (10.89)	1.01 (1.02)
1:40,000	4.17 (17.39)	1.27 (1.61)
1:53,000	5.52 (30.47)	1.68 (2.82)
1:58,000	6.04 (36.48)	1.84 (3.39)
1:78,000	8.13 (66.10)	2.48 (6.15)
1:80,000	8.33 (69.39)	2.54 (6.45)

The scanning process creates a TIFF (tag image file format) file that, even though it is a single band in black & white, is considerable in size. Image sizes varied with photograph formats, the 10 inch x10 inch photos from 1936 resulted in files that were 64.5 megabytes in size. Therefore, sufficient disk space is needed when mosaicking multiple images of considerable size. The scanned photos were then transferred by 8mm tape to a Unix workstation for mosaicking in ERDAS Imagine version 8.2. Unix compression routines reduced the size of the TIFF files by only 10% so files were tarred directly from the scanner workstation disk drive to the 8mm tape to save the time of compression. The rest of the digital processing and analysis took place at the National Park Service Intermountain Region GIS Office in Lakewood, CO.

The Unix workstation used for running the ERDAS software is a Sun Sparc 5 with three 1 Gigabyte disk partitions and 128 Mb of random access memory. After the images were untarred to the Sparc 5, they were imported into Imagine and converted to the ERDAS image (.img) format. "Pyramid layers" were created at this point during the import process. Pyramiding is an ERDAS technique of resampling large images for faster display (ERDAS Field Guide, 1994). Creating pyramid layers increased the size of the image by about 20% but the saving in display time was worth the effort.

4.1.3 Mosaicking Process

4.1.3.1 Difficulty of Analyzing Study Area

The study area is a very remote location, far removed from any permanent human development. Due to the nature of the dunes, e.g. the mobility of the surface material and the rapid drainage, there are very few features that are permanent and stable enough for use as ground control. Due to these factors, the images were first mosaicked before rectifying the majority of the aerial photo sets. This in effect created a digital version of a controlled mosaic. Only one print of each set of photos was available so this method conserved the original prints. The coordinates for the mosaics would be based on the 1988 NAPP photo set for which a digital orthophoto was created.

4.1.3.2 Description of Orthophotos

An orthophoto is a "reconstructed airphoto that shows natural and cultural features in their true planimetric positions. Geometric distortions and radial displacements have been removed.."(Avery & Berlin, 1992). Therefore, an orthophoto is similar to a map, features are shown in their true position at a true scale but with the ease of interpretation of a photograph. Lillesand and Kiefer (1987) state that "Because features can be photo-interpreted in their true, planimetric positions, orthophotos make excellent base maps for resource surveys".

4.1.3.3 Orthophoto Generation

There are numerous software products available for producing digital orthophotographs on computers. The items needed for the production of digital orthophotos include; 1) scanned aerial photography that includes the fiducial marks; 2) a camera calibration report for the flight from which the photograph was taken; 3) a digital elevation model; 4) a source for control points, such as a) a paper topographic map and a digitizer or b) points collected by Global Positioning System; 5) the software to handle the computations (Brown et al., 1993).

For the generation of the orthophoto, ten scanned NAPP photos were used. The camera report for the flight was obtained from the USGS Mapping Applications Center in Reston, VA. Thirty meter Digital Elevation Models (DEMs) of the six 7.5 minute quadrangles of the area were used. Ground control points were obtained from scanned versions of the paper, 7.5 minute topographic maps that were rectified to Universal Transverse Mercator (UTM) projection. GRSA falls in Zone 13 of the UTM grid and map coordinates are then reported in meters.

In 1988, the year of the NAPP photography, roads and fencelines are visible around the perimeter of the monument so that sufficient ground control can be located. At the scale of 1:40,000, the NAPP photos are small enough that some features from around the perimeter of the dunes can be seen on each photograph. The layout of the flight line is such that all photos had some identifiable features. The digital orthophoto was produced in ERDAS OrthoMax software.

4.1.3.4 "Normal" Mosaicking Process

Creation of image mosaics under normal circumstances requires that each of the separate images be rectified individually before mosaicking. This way each pixel has a x,y location associated with it that can be matched to corresponding pixels in the other images. By rectifying first to ground coordinates, any rotation of the image inherent in the photo mission or that was incurred through the scanning process is removed before mosaicking by the rectification.

4.1.3.5 Mosaicking Unrectified Photos

Due to lack of consistent and stable ground control points in this area, especially in the vicinity of the wetlands, it was decided to mosaic the photographs before rectifying. Also, due to the variety of scales of the photography, some photos from sets of larger scale photography (1:20,000) contain nothing but barren, dune sand. The smaller scale sets (1:80,000) contain all of GRSA in one image. By mosaicking the images first, sufficient ground control points could be realized around the perimeter of the dune field for rectification of mosaicked sets.

The ERDAS Field Guide states that "All of the images to be mosaicked must be georeferenced to the same coordinate system." In order to mosaic unreferenced images, a system was devised to merge photos based on the pixel coordinate values of the file. Pixel values of the images that will make up the mosaic need to be adjusted so that values are continuous across all images, increasing from minimum x,y values in the southwest corner to maximum values in the northeast. Once this has been done, then images can be combined based on these pixel values. Appendix 3 provides a detailed account of this process using the ERDAS Imagine software. Figure 4-1 is a flowchart outlining the major steps in the mosaicking process as discussed in the appendix.

After the photo sets were mosaicked, they were rectified using the 1988 NAPP orthophoto as source of coordinates. By selecting features that are relatively permanent, such as large trees that occur in groves along Sand Creek, a reasonable rectification could be achieved. By having a full image of the GRSA area to rectify, features could be identified around the perimeter of the dune field, allowing for more potential ground control points (GCP). No GCPs were picked in the interior of the dune field but this region was not critical to the analysis of the wetlands.

All mosaics were rectified using a nearest neighbor resampling method. Nearest neighbor calculates the output pixel value by assigning the brightness value from the closest pixel prior to transformation. This method transfers original values and does not average an array of pixels which is an important consideration. Jensen (1986) states "It (nearest neighbor) is especially liked by earth scientists because it does not alter pixel brightness values during resampling. It is often very subtle changes in brightness value that make all the difference when discriminating between one type of vegetation versus another...".

1) Import scanned images into ERDAS Imagine .img format.

2) Open two viewer windows, first with the "destination" image, second with the "source" image.

3) Subset original images for minimum overlap with surrounding images. (Leave about 10% overlap)

4) Place crosshairs on distinctive feature in both images in the middle of overlap area.

5) Adjust x & y value of pixel from the crosshair location of the source image to match the value of the same point in the destination image.

6) Move to left side of the destination image along the crosshair.

7) Find a point in the source image that is along the crosshair in the destination image and read the source x,y value. (Lx, Ly)

8) Move to the right side of both images and read pixel value from source image that is along the crosshair of the destination image. (Rx, Ry)

9) Rotate source image by the arc tan of (Ry-Ly)/(Rx-Lx).

10) Readjust x,y values of source image after rotation to match destination image.

11) Repeat process with newly adjusted image as destination and next image along flight line as the source.

Figure 4-1 Flowchart of mosaicking process for unregistered images

For the final transformation of the mosaics, all pixels were output equal to two meters. This was for the sake of consistency with the orthophoto and also to limit the file size of the final product. This did cause some loss of detail in the final product compared to the original scanning. Table 4-3 displays the results of the mosaicking/rectification process. All mosaics are presented in Appendix 4.

Table 4-3 RMS values for photo mosaics over Great Sand Dunes National Monument, CO

Project	Photo Date	Scale	Full Park?	Number of Photos	Number of GCPs	Trans-form Order	X RMS (meters)	Y RMS (meters)	Total RMS (meters)
DX	12-Aug-36	31,680	Yes	20	8	2	5.541	4.338	7.036
CL	26-Sept-37	20,000	No	11	7	2	1.435	1.250	1.903
ABA00133	9-Oct-53	53,000	Yes	3	9	2	3.283	5.040	6.010
ECB	25-Sept-57	20,000	No	12	6	1	2.987	4.994	5.820
VBMA	25-Aug-66	20,157	Yes	1	13	2	2.363	3.894	4.555
VDSD	26-June-75	80,000	No	6	8	1	8.778	4.661	9.939
VEQQ	5-Sept-79	78,000	Yes	1	14	1	10.949	8.739	14.012
NHAP	13-Aug-85	53,000	No	1	8	1	4.077	3.070	5.104
NAPP	12-July-88	40,000	Yes	11	0	Ortho			
USFS/NPS	26-July-95	24,000	Yes	13	12	3	2.727	2.198	3.504

4.1.3.6 Problems Introduced by this Method

The method described above works to create an unrectified mosaic based solely on pixel values. I found it to work best by starting with an initial image over the main portion of the study area and working outward from there. Work progressed along that flight line to adjust the pixel values for these photos. Then images from the next flight line were matched to the appropriate image from the first flight. Once the pixel values for all individual photos have been adjusted in this manner and increase continuously from southwest to northeast, then all photos are merged at once. Better results for the final mosaic were achieved by this method rather than mosaicking individual flight lines and then mosaicking these mosaics..

The problem with adjusting all photos individually is that the further away an image is from the original destination image, the more rotation is needed to match the images. This is due to all of the distortion factors that are present in aerial photos; radial displacement, crabbing in the original photos and misalignment from scanning. The factor that introduced the most error to the mosaics was the terrain. From the study area east to the lower portions of the Sangre de Cristo Mountains, there is an elevation range of up to 1400 feet (427 m). Having stereo coverage of all photo sets helped to minimize the amount of rotational adjustment needed to match the photos but the majority needed some correction.

4.2 Data Layers & GIS Design

4.2.1 Purpose of Digital Analysis

Natural Resource managers at GRSA have been building a GIS database since the early 1990's. They were interested in continuing the development of this database by having all the components of this study available digitally. This includes the raw, scanned aerial photos, the mosaicked and rectified photo sets and the polygons created from the analysis of the photo mosaics. The mosaicked images and the digital GIS layer will be delivered to the park on CD-ROM. The raw, scanned images are too numerous and sizable to place on CD so these data will stay on 8mm tape.

4.2.2 Digitizing Wetlands & Other Features

After the mosaics were created, land cover was digitized into a GIS. Two coverages were created in Arc/Info version 7.1.1, one for sand type and one for the wetlands for each year of photo coverage. "Heads up" digitizing was used to create these coverages. This process entails having a mosaic on the screen as backdrop and using a mouse to digitize from that mosaic. Stereo pairs of photos were set up next to the workstation and viewed with a simple pocket stereoscope to check features being viewed on the screen.

The primary features to be analyzed from the mosaics are the wetlands. The wetlands occur to the east of Sand Creek and the perimeters of the wetlands were digitized. Brightness (or darkness) and texture were the main recognition factors used to identify the wetlands. The wetlands that have water at the surface show up as black on the black & white aerial photos and also on the CIR sets. The vegetation surrounding the wetlands is also much darker than the surrounding sand or sparsely vegetated sand. Since vegetation of the wetlands is much denser in cover, the texture is noticeably different than that of the sand dunes.

Wetlands were distinguished as "wet" or "dry" for further analysis. Wetlands, such as "Elk Springs" along the park boundary through the study area (see Figure 1-3 for location), has open water in most photo sets and the distinction between vegetation and open water could be digitized. For those wetlands that contain obvious open water, the whole polygon is classified as wet. Other wetlands, such as two in the southwest corner of GRSA, are filled with willows and open water is not visible in these. These wetlands and others that do not have visible open water are classified as dry wetlands.

The 1936 set was photographed early in the morning. Shadows from the sand dunes are a feature that could be confused as water or wetlands (Figure 4-2). However, difference is easily distinguished under closer inspection with stereo viewing. Shadows, although very dark, are much smoother along the perimeter. The wetlands generally have a much more irregular perimeter.

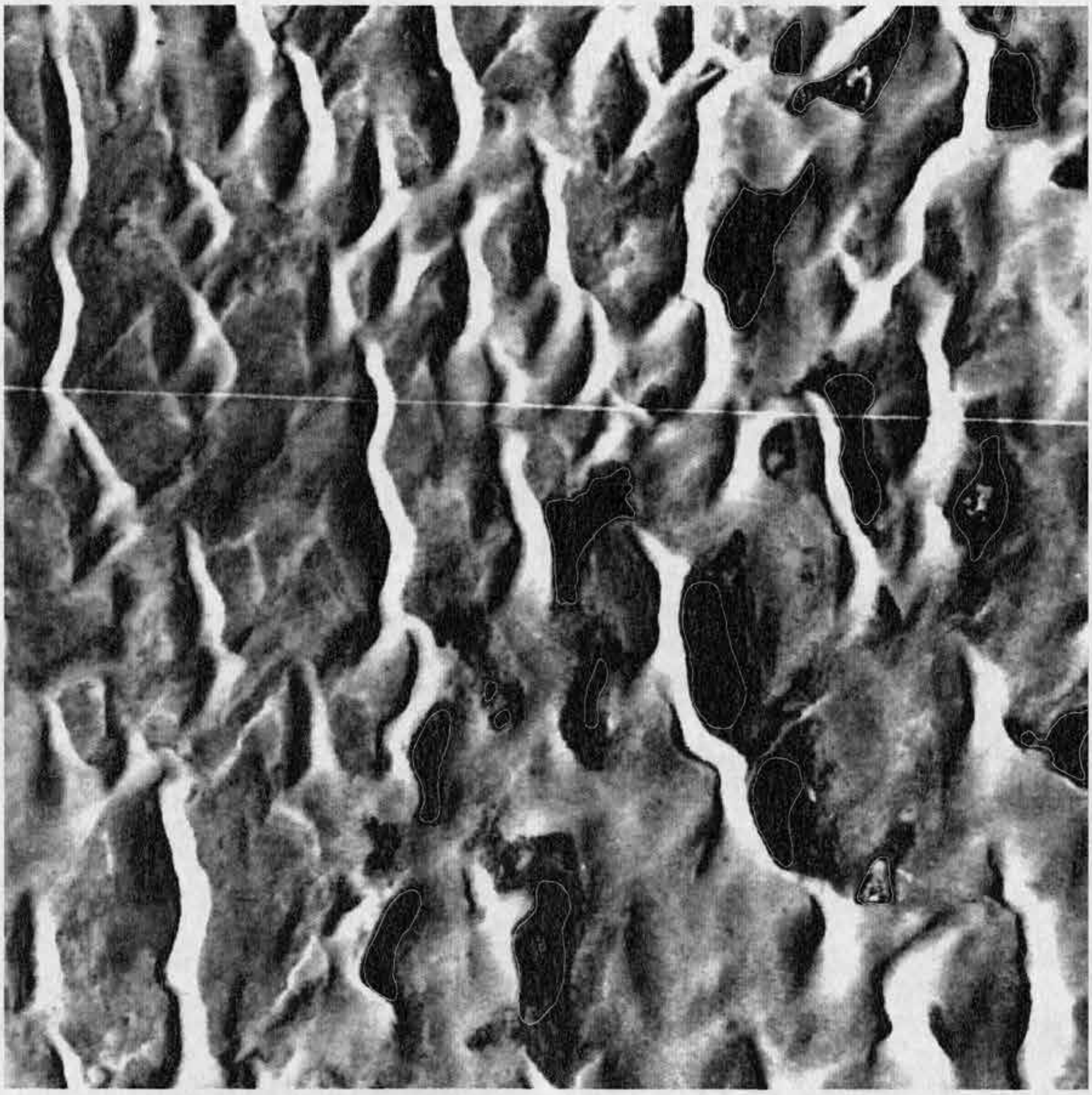

Figure 4-2 Portion of 1936 mosaic of GRSA study area showing wetlands (outlined), brightly lit dune slipfaces and dark shadows on western side of dunes

Another feature that could sometimes be confusing but distinguishable under stereo is black sands (Figure 4-3). These appear very dark and, on an individual photo, could appear similar to a wetland. The main distinguishing characteristic of these deposits is visible under stereoscopy, black sands occur at or near the top of the sand dunes.

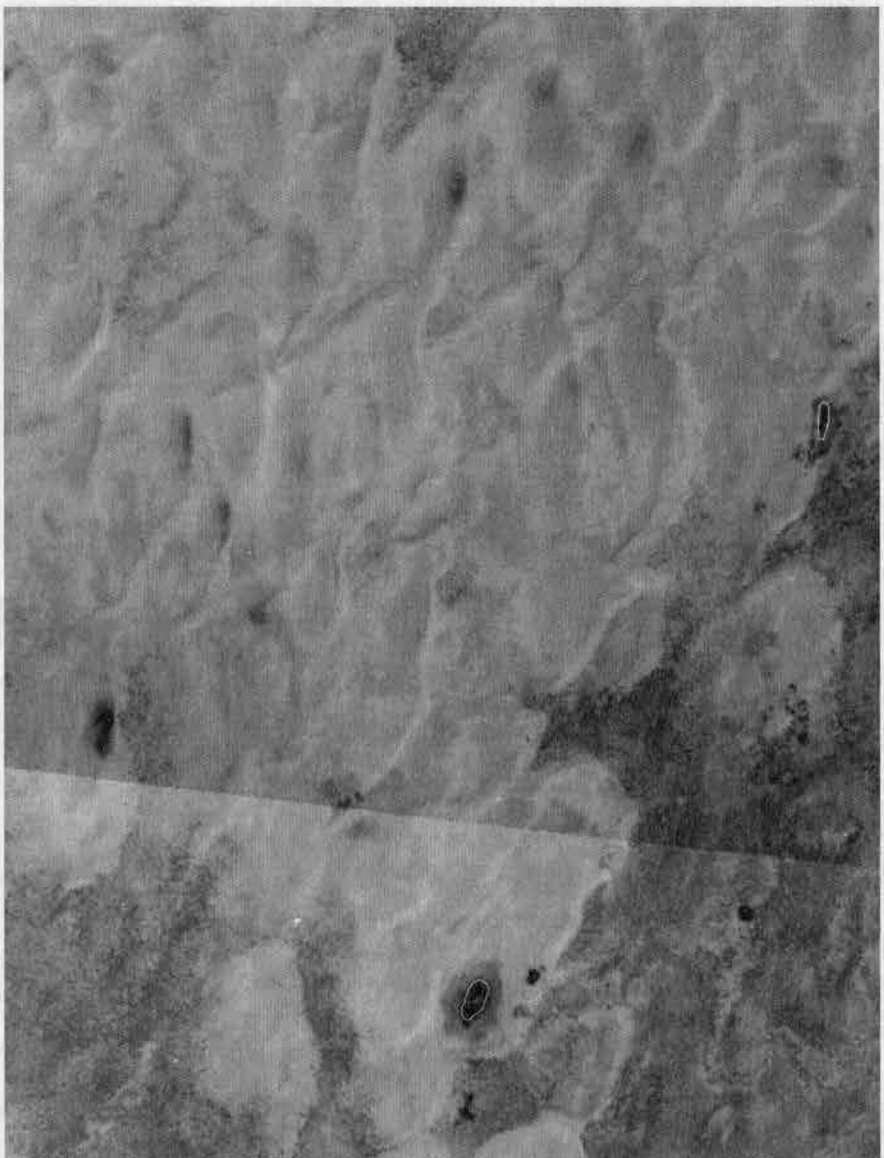

Figure 4-3 Portion of 1995 mosaic of GRSA showing wetlands features (outlined) and black sand deposits at top of sand dunes to north and west

Besides the wetlands, the rest of the land cover of GRSA could be distinguished under stereo and digitized. Seven distinct land cover types were digitized from the digital aerial photo mosaics. The land cover characteristics are based in part on the physiographic regions that were identified by Andrews (1981). The study area covers portions of Province II and III. The main dune field (Province III) is easily distinguished on the aerial photographs. The sand sheet (Province II) contains areas of barren sand that are easily distinguished from the surrounding areas that are lightly vegetated. This distinction is important because the vegetation, sparse as it is, exerts a stabilizing force on the dunes.

Areas of barren sand in other parts of GRSA were digitized. There are some small packets of sand to the south of the dune field, near the south boundary of the park. These are small parabolic dunes and can be seen on all of the aerial photo sets covering that area. Another sand type is an area called the "escape dunes". These occur to the east of Medano Creek and are on the alluvial deposits of the mountain front.

The final sand type that was distinguished is the area of the two stream channels, Sand and Medano Creeks. These areas were further broken down to show the extent of flowing water and/or water saturated sand or dry sand in the stream channel. The saturated sand or active streamflow appears darker in color than the dry streambed. The streambed of these channels, when not constricted by riparian vegetation, is broad and flat and slightly downcut into the surrounding terrain.

4.2.3 Summary of Digital Layers

For those mosaics covering the entire Monument, all of these features were digitized. Digitizing of the wetlands was done separately from the digitizing of sand type. Wetland coverages were named "apxxpond". Ap for aerial photo, xx for year of the photo set (i.e. 36, 37, 53, etc.). (Arc/Info does not allow coverage names to begin with a number so the "ap" characters were used instead.) The same naming convention was used for the sand coverages, called apxxsand. These two coverages were merged after the pond polygons were subtracted from the sand polygons. An area that is southeast of Sand Creek, north of Indian Spring and west of the main dune field was subset for all years for analysis of the areas of the land cover types.

In order to analyze the extent of pond change, one other layer was created. In Arc/Info, each polygon has a label point. These label points can be used for posting attribute data for the polygons when creating a map. The label points were moved to the centroid position of each of the wetland polygons with the "Centroidlabel" command using the [inside] option so that the label stayed inside the polygon. These points were extracted to a point coverage called "plabxxxx", pond, label, xxxx = year. Using the "Addxy" command, the x,y coordinates were added as an attribute of the coverage. The elevation of the point was extracted from the DEM with the "Latticespot" command and added as an attribute. Elevation is stored in the DEM as meters, this was converted to feet for posting on the topographic map of the area. The other attributes of the wetlands polygons were retained when the label point was extracted and kept in the point coverage. These attributes include surface water present (wet or dry) and acreage of the wetland.

All of these attributes were later used for analysis of their spatial distribution in Splus version 4.0 or Microsoft Excel version 5.0.

4.3 Results of the Mosaicking Process and Wetlands Digitizing

4.3.1 Reliability of Mosaics and Polygons

Before further analysis of the wetlands could proceed, the reliability of the digitized wetland polygons needed to be established. Since the majority of the mosaics were not orthorectified, we need to know how reliable the wetland features are in terms of their location from year to year. Assuming that the features did not migrate on the ground, other than changes in size or shape, a consistent offset to the polygon or label point would be caused by errors in the mosaic.

The reliability of the mosaics was checked by analyzing the positions of the features that were digitized from them. Plates 1 to 11 present the results of this digitizing. The features depicted on these will be discussed in a later section.

4.3.2 Previous Studies

A study by Bolstad (1992) found that positional location errors of points varied positively with the increasing tilt of the camera and increasing relief of the study area. Location errors varied inversely with the scale of the photograph (the smaller the scale, the greater potential for error). Area estimation for polygons varied positively with tilt and terrain range and was not related to scale or polygon size. The scale of photography investigated varied from 1:10,000 to 1:40,000. The smallest polygon size was 40 hectares. This is almost 20x the largest wetland observed in this study.

Table 4-4 Average and (standard deviation) of positional error (in meters) or polygon area (in hectares) by terrain range, photo scale and photo tilt (After Bolstad, 1992)

Terrain Relief Range = 0 m					
	Photo Scale (1: x 1000)				Polygon area
Tilt (°)	10	20	30	40	40 – 55
0	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)
<1.4	4 (1.7)	7 (3.2)	10 (3.8)	16 (4.0)	1.3 (3.1)
1.4 to 2.8	11 (1.5)	23 (3.4)	32 (4.1)	44 (6.1)	3.8 (9.9)
2.8 to 4.2	19 (1.9)	35 (4.4)	56 (6.8)	72 (7.0)	6.4 (16.9)
Terrain Relief Range = 250 m					
	Photo Scale (1: x 1000)				Polygon area
Tilt (°)	10	20	30	40	40 - 55
0	10 (2.8)	12 (3.6)	19 (3.0)	20 (4.1)	1.1 (3.6)
<1.4	10 (3.3)	17 (5.4)	24 (4.4)	28 (6.5)	3.0 (7.6)
1.4 to 2.8	15 (2.0)	28 (4.5)	38 (3.9)	53 (11.1)	5.0 (12.5)
2.8 to 4.2	20 (3.6)	41 (3.2)	59 (3.9)	82 (9.6)	7.3 (19.5)

From Table 4-4 it can be seen that the tilt of the camera has a dramatic effect on both positional estimation and area estimations. Scale of the photograph had little effect on position in the absence of tilt. The elevation range of the GRSA study area is 7,680 ft (2,340 m) in the southwest corner to 7,760 ft (2,365 m) in the northeast by the main dune field, a range of 80 ft (25 m). Elevations along the flanks of the Sangre de Cristos in southeast GRSA are about 8,000 ft (2,438 m). In the northeast corner of GRSA, elevations along the Sangre de Cristos are 9000 ft (2,743 m). This is an elevation range of 1,320 ft (403 m), more than the 250 m increment analyzed by Bolstad. The Bolstad study was on a single aerial photograph. By mosaicking images first before rectifying, errors can be compounded. Given the minimal relief of the study area and small size of the wetlands, I felt that area estimations should be good for all photo sets. Positional estimation of the wetlands could be off by as much as 80 m in the small scale photos (1975, 1979) if there was camera tilt.

4.3.3 Reliability Checks for This Study

The continuity and reliability of the wetland polygons were checked in three ways. A qualitative check was performed by displaying the features created from two successive sets of photography on one map display. A more specific check of individual features was performed by analyzing the ponds by size and location of the centroid point versus their continuity across the photo sets. Also, "ground truthing" was performed by hiking over the area north of Elk Springs with a global positioning system (GPS) unit and walking the perimeter of the wetlands encountered.

The first reliability check was to create plots of the wetland polygons from two successive sets of photography on one plot along with the wetlands from the 1988 orthophoto (Appendix 5). This method is a check of how the locations resulting from rectification of the mosaics compare to one another. By including the wetlands from the 1988 set, reliability of the features can be compared to the polygons digitized from the mosaic used as the coordinate source of the other mosaics. Also included on the plots is a 200 meter grid based on UTM coordinates.

From inspection of the plots, it can be seen that there is some positional displacement in all of the polygons digitized from the uncontrolled mosaics. Polygons are offset from one photo set to the next and from the 1988 orthophoto. The three most recent sets, 1995, 1988 and 1985 match very well to each other. Polygons from the 1979 set are offset to the north from the 1988 set. This offset can range from 20 meters in the vicinity of 443,200E, 4,182,200N to 40 meters for the Elk Springs features. Overall, the 1979 and the 1953 polygons have the most offset from the 1988 features, both are offset to the north from 1988. 1936 is offset to the west about 30 meters from 1988 so that when 1936 and 1937 are displayed together, polygons are offset from each other for successive years.

This offset would be critical if I were trying to precisely locate the wetlands, particularly those wetlands smaller than 1 acre (4047 m^2) in size. The mosaicking method used is sufficient for determining a qualitative understanding of the changes to the wetlands. One cannot tell from this method whether the offset is due to movement of the feature or results from the mosaic process. The area represented by these features is more important to this report and this has already been discussed.

After the wetlands had been digitized, a site visit occurred in June 1997. The purpose of the visit was to observe some of the wetlands away from the access road and to check locations of the wetlands found with a Global Positioning System (GPS) unit. A Trimble Pathfinder Pro GPS unit was used to collect the locations. Fred Bunch, the Chief of Natural Resources at GRSA and I hiked around the area, at first collecting the wetland locations as points. On the return to the vehicle, a line was collected by the GPS as I hiked. When a wetland area was encountered, the perimeter was walked. The line and point data were overlain on the mosaics after differential correction of the data. The line overlays very well on the digitized wetlands (see Figure 4-4). In fact, some very small wetlands (approximately 0.01 acres, 40.5 m^2) that had been overlooked during digitizing were found while collecting the GPS data. These features could be seen on the mosaic but were very small and didn't have water at the surface so were not added to the coverage.

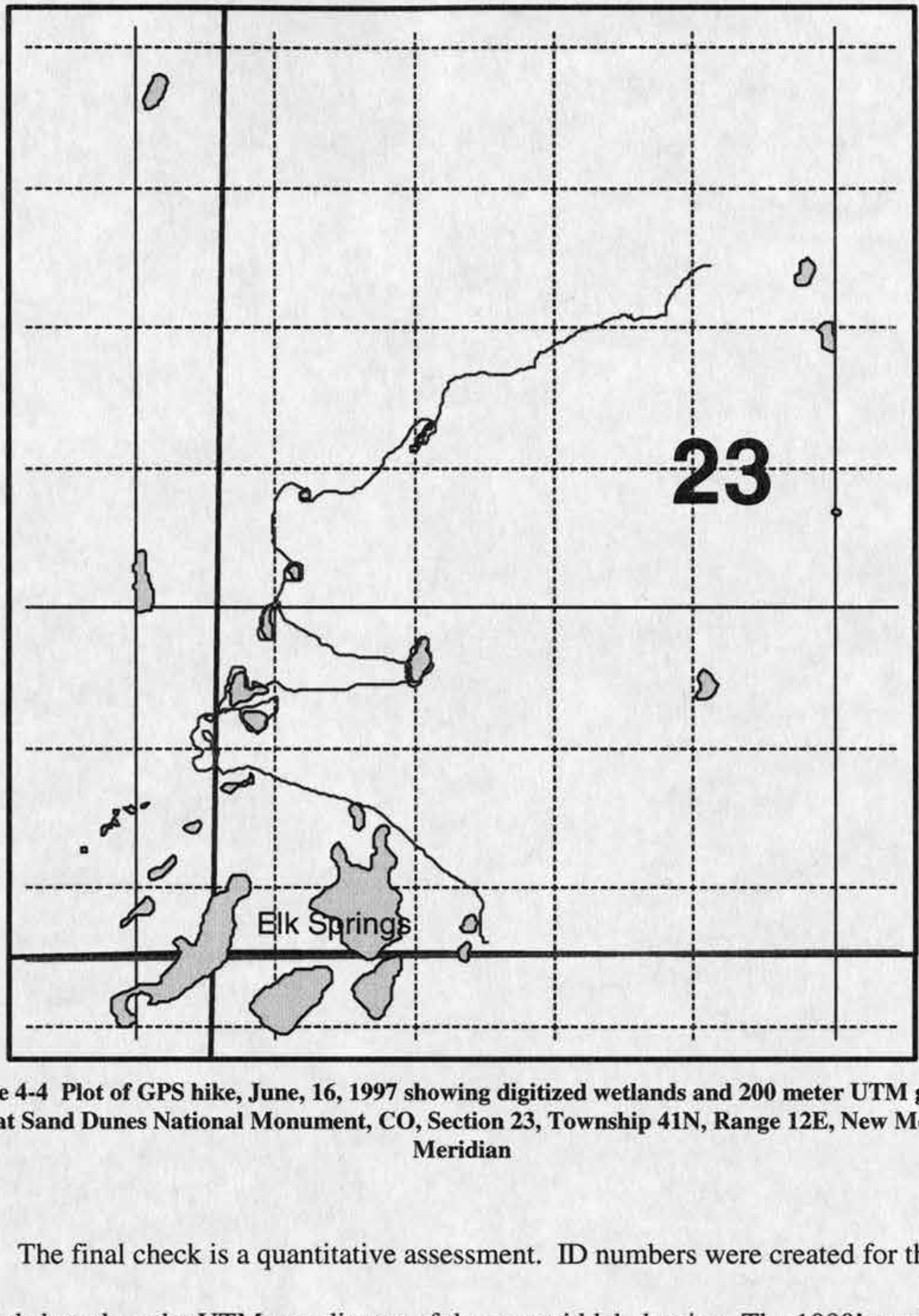

Figure 4-4 Plot of GPS hike, June, 16, 1997 showing digitized wetlands and 200 meter UTM grid at Great Sand Dunes National Monument, CO, Section 23, Township 41N, Range 12E, New Mexico Meridian

The final check is a quantitative assessment. ID numbers were created for the wetlands based on the UTM coordinates of the centroid label point. The 1000's and 100's value from the Northing and Easting coordinates were extracted to create a four-digit code (yyxx) for each wetland. From the raw ID number (uncorrected for any error introduced by the result of mosaicking), 207 wetlands resulted for the 9 years of data analyzed (see Appendix 6). Two of these were selected for comparison of the full x,y values over the years. "Bones" wetland (ID# 1944) is about 200 meters north of East Elk Springs and is present on every photo set. Another small wetland, ID# 3153 was analyzed in this manner. It is one of the few wetlands present in the northern portion of the study area that occurs over a number of years.

The coordinates for Bones range over 45 meters in the X direction and over 58 meters in the Y direction (Table 4-5, Figure 4-5). The ranges for 3153 are just slightly less than those for Bones (Table 4-6, Figure 4-6). By comparing the offset from 1988 graphically, 3 years stand out for Bones, 1936, 1953 and 1979 all have over 20 meters variation in the +Y direction (north from 1988 location) and 1936 is offset 36 meters to the west (-X direction) from 1988. 3153 exhibits a slightly different pattern but it also is offset over 50 meters north on the 1979 mosaic from the 1988 location. The 1957 mosaic is included here but 3153 is present on the western limits of that mosaic and is offset 40 meters west of the 1988 location. This is due to distortion from the unrectified aerial photo. Bones is west of the western edge of the 1957 mosaic so can't be compared for that photo year.

Table 4-5 X,Y Coordinates for "Bones" wetland for all photo years

Photo Year	UTM X Coordinate Meters	Change from Previous Yr	Offset from 1988	UTM Y Coordinate Meters	Change from Previous Yr	Offset from 1988	Elevation Feet	Acres	Water?
1936	444368.50		-36.09	4181958.75		25.75	7704.03	0.43	Yes
1937	444405.53	37.03	0.94	4181941.00	-17.75	8.00	7700.62	0.67	Yes
1953	444410.50	4.97	5.91	4181956.25	15.25	23.25	7702.28	0.30	Yes
1966	444414.16	3.66	9.56	4181939.50	-16.75	6.50	7700.51	0.11	No
1975	444406.91	-7.25	2.31	4181939.00	-0.50	6.00	7700.51	0.51	No
1979	444409.72	2.81	5.13	4181988.00	49.00	55.00	7705.76	0.44	No
1985	444399.28	-10.44	-5.31	4181929.25	-58.75	-3.75	7700.51	0.21	Yes
1988	444404.59	5.31	0.00	4181933.00	3.75	0.00	7700.51	0.21	Yes
1995	444407.16	2.56	2.56	4181923.50	-9.50	-9.50	7700.51	0.29	Yes
Max =	444414.16			4181988.00			7705.76	0.67	
Min =	444368.50			4181929.25			7700.51	0.11	
Range =	45.66			58.75			5.25	0.57	
Average =	444402.40			4181948.09			7701.84	0.36	
Median =	444406.22			4181940.25			7700.56	0.36	
StDev =	14.40			19.13			2.03	0.19	

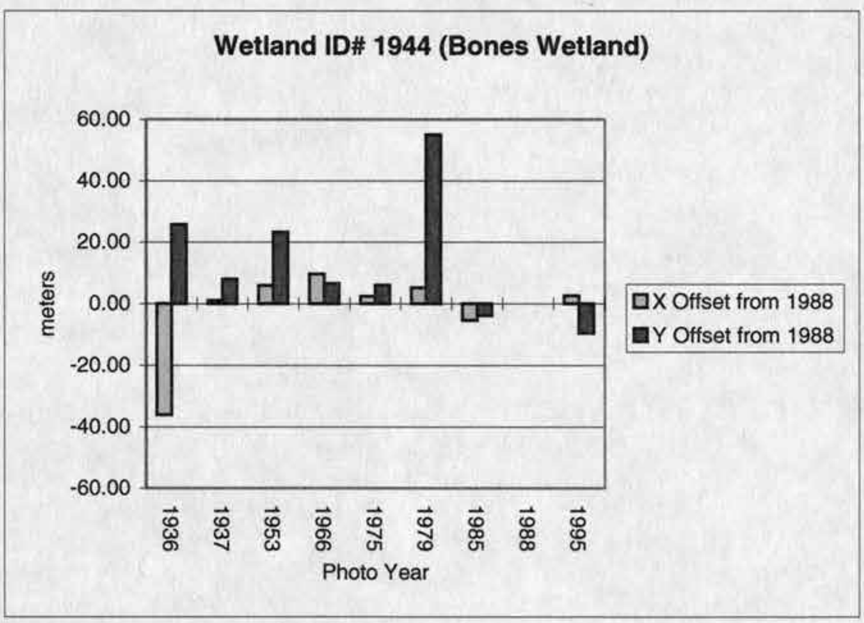

Figure 4-5 X,Y coordinate variation of centroid label point for aerial photo years versus 1988 location for "Bones" Wetland (Id #1944), Great Sand Dunes National Monument, CO

Table 4-6 X,Y coordinates for wetland ID #3153, 1936 - 1995

Photo Year	UTM X Coordinate Meters	Change from Previous Yr	Offset from 1988	UTM Y Coordinate Meters	Change from Previous Yr	Offset from 1988	Elevation Feet	Acres	Water?
1936	Not Present								
1937	Not Present								
1953	Not Present								
1957	445329.69		-45.22	4183139.00		-1.50	7730.15	0.16	No
1966	445353.84	24.16	-21.06	4183148.50	9.50	8.00	7729.53	0.02	No
1975	445354.94	1.09	-19.97	4183136.75	-11.75	-3.75	7730.93	0.10	No
1979	445361.16	6.22	-13.75	4183193.00	56.25	52.50	7730.49	0.10	No
1985	445369.19	8.03	-5.72	4183141.00	-52.00	0.50	7732.03	0.11	No
1988	445374.91	5.72	0.00	4183140.50	-0.50	0.00	7732.71	0.11	No
1995	Not present			Not present					
Max =	445369.19			4183193			7732.025	0.161	
Min =	445329.69			4183136.75			7729.526	0.022	
Range =	39.5			56.25			2.499	0.139	
Average =	445353.76			4183151.65			7730.624	0.098	
Median =	445354.94			4183141			7730.49	0.098	
StDev =	14.778195			23.5329722			0.936629	0.05	

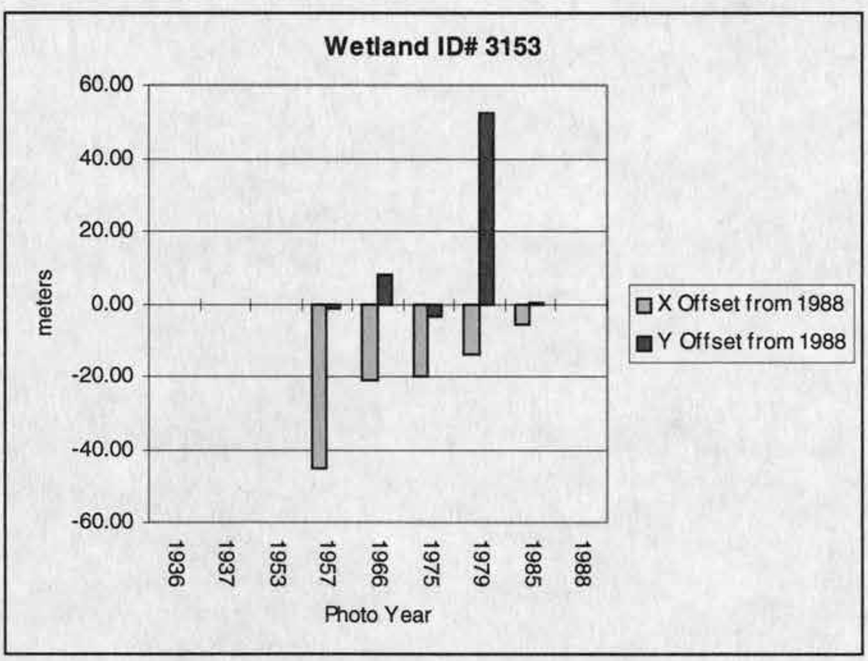

Figure 4-6 X,Y coordinate variation of centroid label point for aerial photo years versus 1988 location, for Wetland ID #3153, Great Sand Dunes National Monument, CO

4.3.4 Wetland Continuity

Table 4-7 summarizes the extent of wetlands that are less than 0.1 acres (40.5 m^2) in size. Table 4-8 summarizes the number of pixels that these small polygons represent. From the tabulation of all wetlands I noticed that wetlands smaller than this size had less continuity across the years than those larger. This is primarily due to the scale and quality of the imagery. Since the total percentage of acreage of these wetlands generally amounts to 1-2% of the total wetland acreage, these small wetlands were not excluded from subsequent analysis.

Table 4-7 Summary of Wetlands Less Than 0.1 Acres at GRSA

	All Wetlands		Wetlands Less Than 0.1 Acres			
Year	Total # Wetlands	Total Acres	Total #	# Unique to Photo Set	Total Acres (ha)	% of Total Acreage
1936	80	50.33 (20.36)	14	8	0.81 (0.33)	1.61%
1937	114	70.29 (28.45)	19	10	1.09 (0.44)	1.55%
1953	38	20.83 (8.43)	4	0	0.24 (0.10)	1.15%
1966	31	17.81 (7.21)	4	1	0.21 (0.08)	1.18%
1975	26	21.69 (8.78)	4	0	0.27 (0.11)	1.24%
1979	22	12.68 (5.13)	3	1	0.21 (0.08)	1.66%
1985	30	15.09 (6.11)	9	1	0.40 (0.16)	2.65%
1988	32	14.00 (5.67)	6	0	0.34 (0.14)	2.43%
1995	51	16.63 (6.73)	18	9	0.73 (0.30)	4.39%
1957 (partial)	16	11.22 (4.54)	2	2	0.14 (0.06)	1.25%

Table 4-8: Wetland acreage vs. total pixels

Wetland Acres	Ft^2	M^2	# Pixels @ 2Mx2M
1.00	43560.0	4047.00	1011.75
0.50	21780.0	2023.50	505.87
0.20	8712.0	809.40	202.35
0.10	4356.0	404.70	101.17
0.08	3484.8	323.76	80.94
0.06	2613.6	242.82	60.70
0.04	1742.4	161.88	40.47
0.02	871.2	80.94	20.23
0.01	435.6	40.47	10.12

5 Spatial Distribution of the Wetlands

5.1 Display of the Coverage Attributes

After the wetlands and sand types were digitized and attributed, plots could be made in the GIS. Plates 1 through 11 present the results of digitizing the wetlands and sand types. Plate 1 is the USGS topographic map of the study area. Included on this and all plots is the boundary of the National Monument and a 200 meter grid based on UTM coordinates. All plates have been plotted at 1:24,000 scale. The contour interval of the map is 40 feet (12.2 m).

Plates 2 through 11 show the results of digitizing the two coverages, wetlands and sand type. The wetlands are distinguished by the presence ("wet") or absence ("dry) of surface water. Sand type is also shown, whether barren ("Unvegetated") or vegetated, the Sand Creek streambed or the main dune field. Included on these plots are the aerial photo date, photo scale and RMS error from the rectification process. Also, a simple table of statistics for the wetlands for that year is included. The table shows the number of wetlands ("count"), the total acreage these represent and the range of sizes present.

Plots are produced in the Arcplot module of Arc/Info by creating a series of commands that are stored as a macro. An AML (Arc Macro Language) is used in order to more easily duplicate and automate the process of map production and to facilitate ease of updating and changing the features selected and displayed.

5.2 Area Analysis of the Coverages

The first step in analyzing the changes that have taken place over the study area through the years was to clip (subset) the coverages to a consistent area. The clip cover used for this encompassed an area north of Indian Springs, west of the main dune field and southeast of Sand Creek. 4,180,500 N (UTM coordinates in meters, Zone 13) is the southern boundary of the clip cover, 446,000 E is the eastern boundary of the clipped area. This is a total area of 4,127 acres (1670 ha).

Table 5-1 presents the breakdown of land cover analysis extracted from the coverages. The results presented are the after subsetting to the area of interest. Wetlands are presented as "wet" (water present at the surface) acres and "dry" (no water present) acres. The sand sheet is broken down as Unvegetated or Vegetated sand. The main dune field is just a small segment of the northeast corner of the study area. Finally, the portion of the Sand Creek streambed that overlapped the clipped cover is presented as total streambed.

Figure 5-1 is a graphical display of the Wetlands vs. Sand Sheet covers. This graph shows the large amount of wetlands area present during the 1930's. Also note the dramatic increase in wet wetlands from 1936 to 1937. The wetlands for the most part "disappear" during the 16 year period between 1937 and 1953. It is unknown whether this is a gradual decline or a sharp decrease but a photo index from a 1941 set of aerial photography that partially covers the study area still appears to have a large number of

Table 5-1 Acreage (hectares) of land cover types for study area, Great Sand Dunes National Monument, CO

Photo Year	Wet Wetland	Dry Wetland	Total Wetland	Unveg Sand	Veg Sand	Total Sand	% Veg Sand of Total Sand	Main Dune Field	Total Streambed
1936	27.89 (11.29)	22.44 (9.08)	50.33 (20.37)	3067.55 (1241.44)	813.55 (329.24)	3881.10 (1570.68)	21.0%	41.23 (16.69)	154.48 (62.52)
1937	58.86 (23.82)	11.43 (4.63)	70.29 (28.45)	2682.47 (1085.60)	1168.78 (473.01)	3851.25 (1558.60)	30.3%	41.23 (16.69)	164.35 (66.51)
1953	12.20 (4.94)	8.63 (3.49)	20.83 (8.43)	3039.45 (1230.07)	947.67 (383.52)	3987.12 (1613.59)	23.8%	14.87 (6.02)	104.26 (42.19)
1966	5.38 (2.18)	12.43 (5.03)	17.81 (7.21)	2340.02 (947.01)	1673.62 (677.31)	4013.64 (1624.32)	41.7%	1.67 (0.68)	94.01 (38.05)
1975	5.78 (2.34)	15.91 (6.44)	21.69 (8.78)	2682.11 (1085.45)	1353.51 (547.77)	4035.62 (1633.22)	33.5%	17.13 (6.93)	52.68 (21.32)
1979	8.01 (3.24)	4.67 (1.89)	12.68 (5.13)	2705.63 (1094.97)	1340.43 (542.47)	4046.05 (1637.44)	33.1%	17.13 (6.93)	51.14 (20.70)
1985	7.71 (3.12)	7.38 (2.99)	15.09 (6.11)	2290.39 (926.92)	1756.54 (710.87)	4046.93 (1637.79)	43.4%	0.02 (0.01)	65.07 (26.33)
1988	9.40 (3.80)	4.60 (1.86)	14.00 (5.67)	2253.52 (912.00)	1790.76 (724.72)	4044.28 (1636.72)	44.3%	0.02 (0.01)	68.82 (27.85)
1995	8.81 (3.57)	7.81 (3.16)	16.63 (6.73)	2131.51 (862.62)	1924.52 (778.85)	4056.03 (1641.48)	47.4%	0.02 (0.01)	54.47 (22.04)

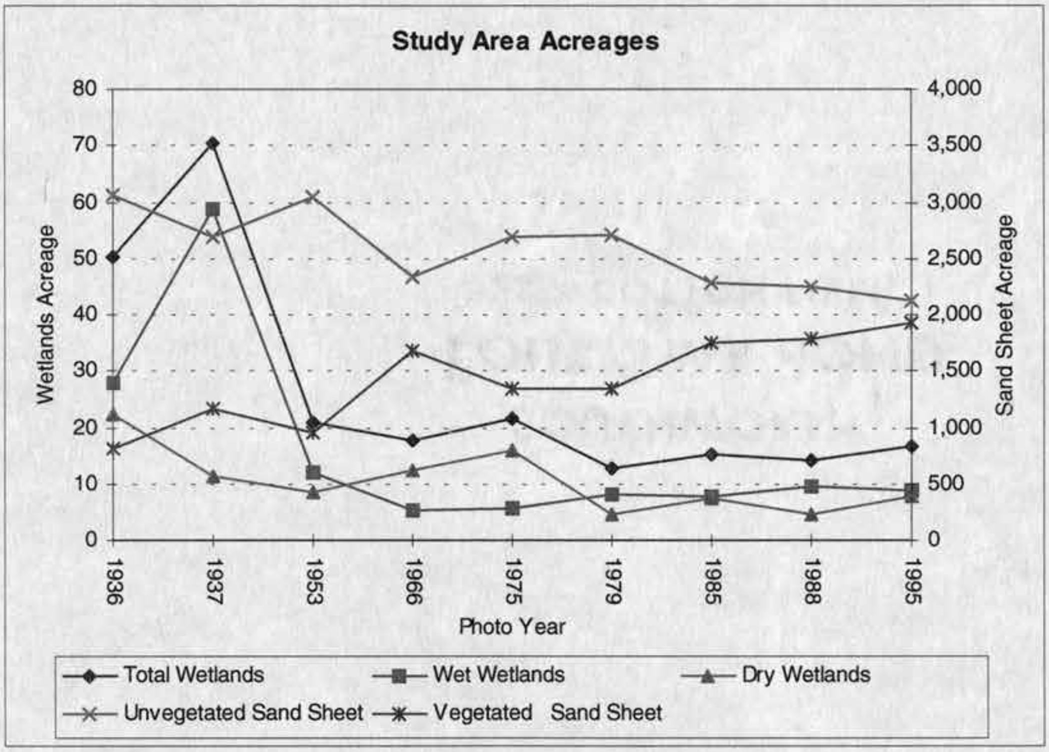

Figure 5-1 Wetland and sand sheet acreage

wetlands visible. After this decrease, the total area of the wetlands has remained between 10 to 20 acres (4.05 – 8.09 ha). The area of the wet wetlands slightly increases since their minimum in 1966.

The sand sheet has changed steadily since the 1930s. The area covered with vegetation has steadily increased over these years from 813 acres (329 ha) in 1936 to over 1,900 acres (769 ha) in 1995. This has been at the expense of the barren dune of the sand sheet (as distinguished from the main dune field). Table 5-1 shows that the vegetated sand increases from 21% of the total sand area to almost 50% today. A large increase in vegetation in 1966 can't be explained since that was also a time when the wet wetlands were at minimum. During the 1950's, a fence was erected around the western boundary of the National Monument. It is possible that the exclusion of cattle since that time has enabled the vegetation to increase over the area. Due to the mobile nature of the sand, numerous breaches occur in the fence line and cattle and bison, grazing on leased State Lands west of GRSA, are able to get into this area. This presents a management problem for GRSA management regarding the protection of the wetlands.

5.3 Areal Distribution of the Wetlands

5.3.1 Wetland Extent Versus X,Y Coordinates and Elevation

The X,Y points created from the label coverage were used for analysis of the distribution and extent of the wetlands. These points were analyzed for the extent of the values and for their relationship to the elevation value derived from the DEM.

The change in the extent was analyzed in order to determine if change was more significant in one direction versus the other. Distributions are summarized in Tables 5-2 (X values) and 5-3 (Y values) and displayed graphically in Figure 5-2. From the graphs it can be seen that the total East-West extent doesn't vary considerably over the years. Most of the loss has occurred from the east, those wetlands east of 445,000 E. The range from the 10th to the 90th percentile has narrowed though the years becoming more focused around 444,000 E, which is in the area of Elk Springs.

Table 5-2 All wetlands centroid point distribution, X (Easting) values (meters), Great Sand Dunes National Monument, CO

Photo Year	Number	Min	Max	Median	Mean	St Dev	10th Percentile	90th Percentile
1936	80	442,802.3	445,750.1	444,767.6	444,584.1	764.4	443,173.2	445,399.4
1937	114	442,816.8	445,758.0	444,674.4	444,528.6	729.2	443,400.4	445,381.0
1953	38	442,808.8	445,495.3	444,192.3	444,169.3	797.4	443,056.2	445,183.2
1966	31	442,822.4	445,353.8	444,331.3	444,147.3	888.2	442,906.0	445,158.7
1975	26	442,809.4	445,354.9	444,057.8	443,988.4	721.7	442,989.4	444,932.0
1979	22	442,812.8	445,361.2	444,156.4	443,987.6	787.3	442,917.0	444,967.2
1985	31	442,822.2	445,599.6	444,153.3	444,076.4	833.9	443,115.2	445,591.9
1988	28	442,815.3	445,599.2	444,155.7	444,071.2	775.2	443,027.3	445,050.9
1995	51	442,729.4	445,573.9	444,081.4	444,010.2	657.1	443,107.8	444,816.8

Table 5-3 All wetland centroid point distribution, Y (Northing) values (meters), Great Sand Dunes National Monument, CO

Photo Year	Number	Min	Max	Median	Mean	St Dev	10th Percentile	90th Percentile
1936	80	4,180,862.8	4,185,558.3	4,182,977.9	4,183,073.8	1,264.7	4,181,587.8	4,184,883.2
1937	114	4,180,959.5	4,185,540.0	4,182,420.9	4,182,797.8	1,240.8	4,181,475.8	4,184,686.3
1953	38	4,181,108.8	4,184,859.5	4,182,169.1	4,182,454.3	966.6	4,181,482.8	4,183,976.6
1966	31	4,181,088.0	4,185,114.5	4,182,150.0	4,182,605.4	1,101.8	4,181,481.5	4,183,913.3
1975	26	4,181,086.3	4,183,952.0	4,181,808.0	4,182,066.1	768.6	4,181,455.5	4,183,153.1
1979	22	4,181,085.8	4,183,952.0	4,181,964.3	4,182,149.6	804.0	4,181,507.0	4,183,225.6
1985	31	4,180,719.5	4,184,315.8	4,181,747.8	4,181,986.8	809.7	4,182,052.2	4,183,830.9
1988	28	4,180,719.5	4,184,315.8	4,181,729.0	4,181,918.3	735.9	4,181,461.7	4,182,463.3
1995	51	4,180,950.8	4,184,313.3	4,181,717.0	4,181,905.5	620.0	4,181,351.5	4,182,388.3

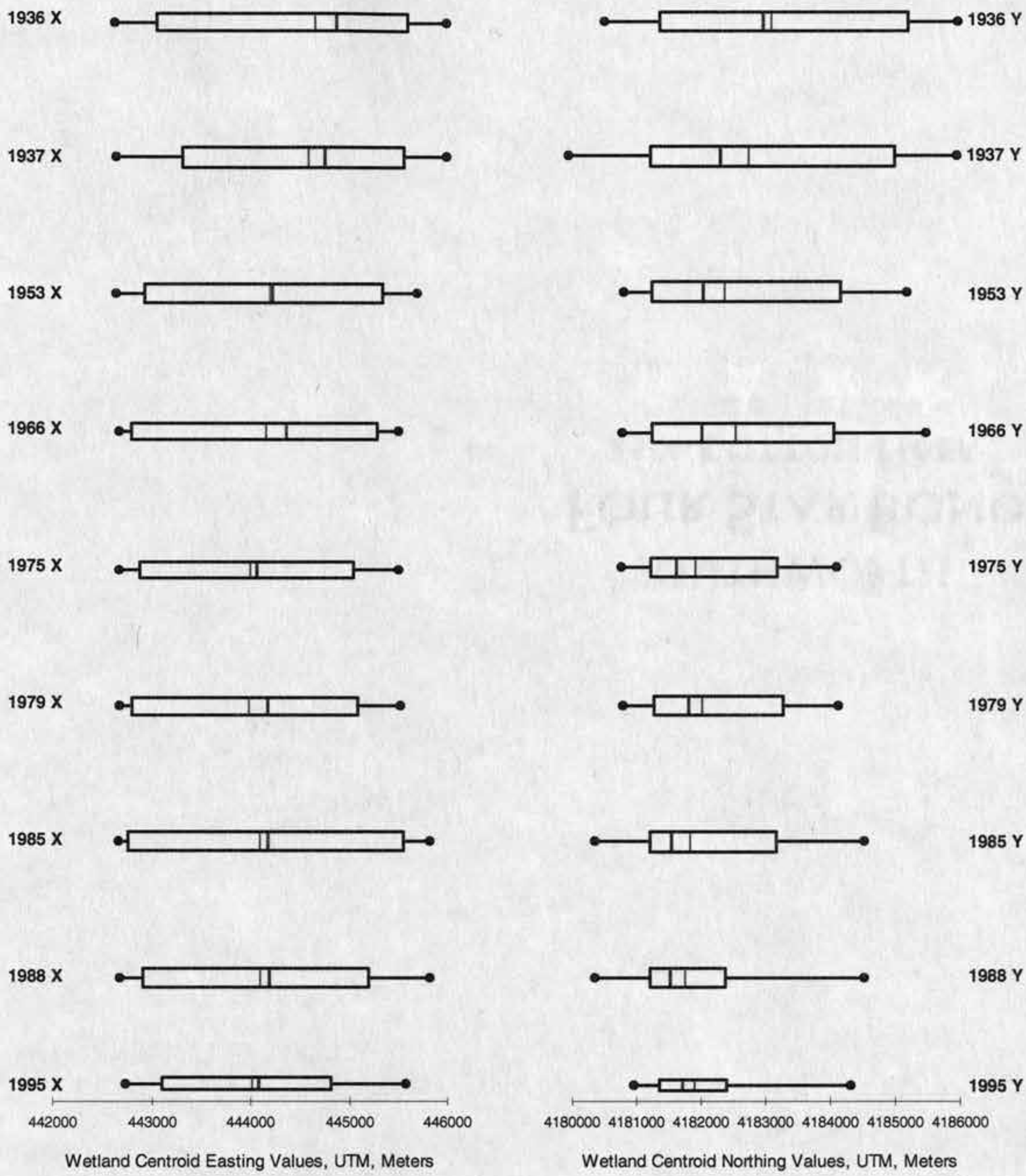

Figure 5-2 Centroid location distributions of all wetlands, Great Sand Dunes National Monument, CO

Thin, red vertical line indicates the mean, thick, blue vertical line indicates the median, the box indicates the range of the central 80th percentile and the horizontal lines extending to the dots indicate the total range.

The most dramatic change has occurred in the Northing values. The greatest loss in the wetland locations has occurred from the north. The furthest extent north of the wetlands occurs in 1936. By the 1970's, the wetlands have receded from the northern 1,600 meters of the study area. This may be an exaggeration due to the small scale of the some of the photo sets, some wetlands in the north may not be visible. Taking this into account, the northern extent in the most recent photos is still 1,200 meters south of the 1936 set.

Looking at the extent of the wetlands in just one dimension doesn't give a good understanding of what is happening to the wetlands. The next step is to understand if there is a relationship between the x,y location and elevation. If there is a relationship, this could be evidence for a relationship between the wetlands and the groundwater level. By running some of the a simple linear regression on the wetland locations for 1937 the result is:

$$\text{Elev. (ft.)} = -55592.0 + 0.0137\ (\text{Easting}) + 0.0137\ (\text{Northing})$$

This is significant with a r^2 of .84 (p value = 0) (see Figures 5-3 & 5-4). There is a strong relation between the elevation of the wetlands and their location for the early years. 1995 was tested in this manner and also exhibits a strong relationship (r^2 0.90, p value = 0) between these variables. Therefore, I interpret these relationships as showing that the wetlands have receded down slope, to the south.

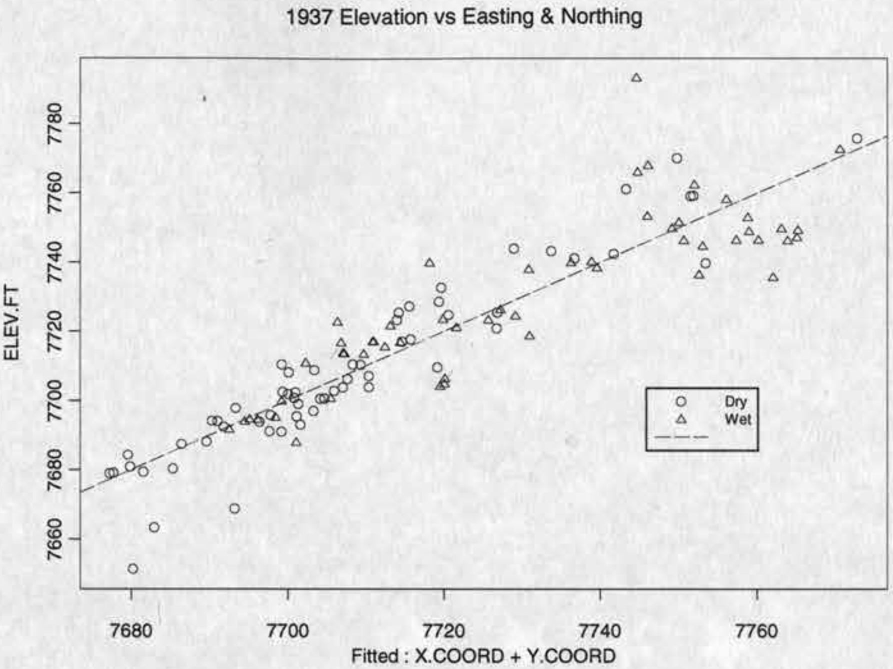

Figure 5-3 Results of regression of 1937 wetland elevations vs. Easting & Northing coordinate values

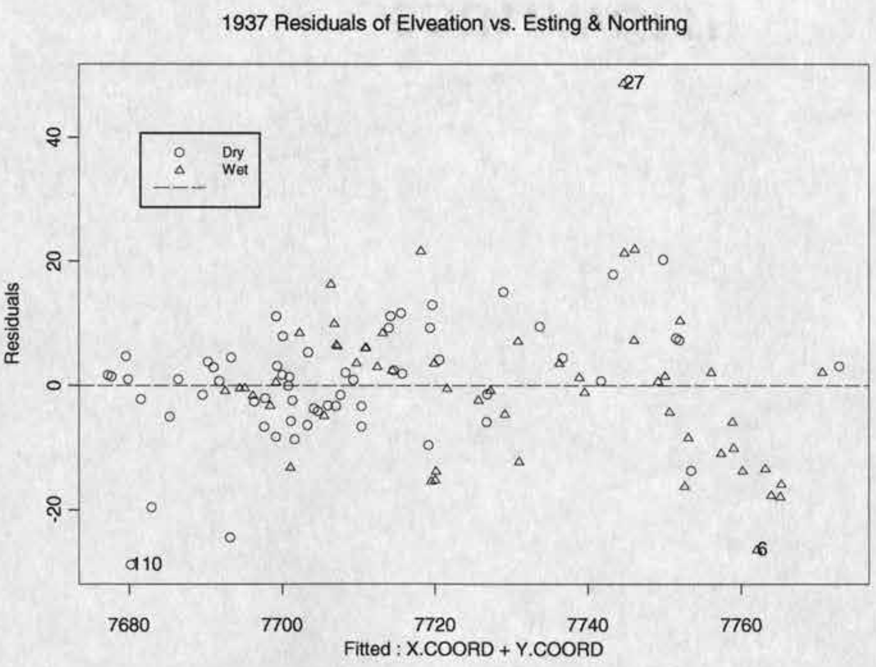

Figure 5-4 Residuals from regression of 1937 wetland elevations vs. Easting & Northing coordinate values

5.3.2 Wetlands versus Sand Type

From simple inspection of the aerial photos, one can derive these same conclusions, that the present extent of the wetlands is not as great as in the past. By analyzing the extent of the wetlands in a GIS, we can get a more accurate picture of how much change has taken place in the x,y & z axes. There are other attributes that can be analyzed along with the coordinates. The attribute of surface water present ("wet") or not ("dry") was interpreted from the photos. As previously mentioned, the area of the open water was not digitized but water at the surface was interpreted for the wetlands for all image sets.

Sand distribution can also analyzed. Soil maps are available for Saguache and Alamosa counties from the Natural Resources Conservation Service (formerly Soil Conservation Service). The soils maps were not digitized but comparison of the sand distribution with the soils maps revealed that what I had classified as "Unvegetated Sand" corresponds with the Dune Lands (Dun) soil type. "Vegetated Sand" corresponds well with the Cotopaxi Series (Cte) soils. In Arc/Info, the wetlands that occur surrounded by barren sand were extracted by overlapping the two coverages. The wetlands occurring in Cotopaxi soils were extracted in this manner also. The soil type was then added as an attribute of the wetlands coverage for each wetland.

As previously noted in the analysis of the land cover areas (Figure 5-1 & Table 5-1), the extent of vegetated sand has increased dramatically over the course of the study period. With the attributes that have been created, we can analyze how the wetlands have changed as the land cover has changed. The point coverage for the wetlands containing the x,y & z coordinates, surface water and soil type were exported from the GIS database for each photo year. These database files were then imported into Microsoft Access version 2.0 database software. This program is more robust and user friendly than the Info database of Arc/Info and greatly eased accomplishing the analysis and graphical output.

Table 5-4 is the resulting output of analysis of wetlands by surface water and soil type. Appendix 7 is a graphical display of the results. The results are presented as an analysis of the total numbers of wetlands broken down by wetlands attribute and by soil type and by total area of these attributes.

From the charts a very interesting relationship becomes apparent. For 1936 and 1937, the percentage of wetlands (by number) that occur in dune sand is 78% and 71% respectively. The acreage totals that these counts represent are even higher at 88% for each year. Not only do these wetlands represent a significant amount of the total number of wetlands but also the average area for wetlands occurring in Dune soil is greater than the wetlands occurring in Cotopaxi soils.

As the area of the vegetated sand increases through the years, the number of wetlands that occur in the Dune sands experiences a reduction in number so that by 1985, there are no wetlands with surface water occurring in Dune sands. The two "dry" wetlands that do occur in the Dunes represent only 6.5% of the total number and 2% of the total acreage for that year.

Table 5-4 Wetland distribution by surface water and soil type, Great Sand Dunes National Monument, CO

	Overall Wetland Occurrence								
				By Soil Type					
				Cte (Cotopaxi)			Dun (Dune Lands)		
Photo Year	Total Wetland Number	Wet Wetland Number	Dry Wetland Number	Total Wetland Number	Wet Wetland Number	Dry Wetland Number	Total Wetland Number	Wet Wetland Number	Dry Wetland Number
1936	80	30	50	17	4	13	63	26	37
1937	114	54	60	40	9	31	74	45	29
1953	38	14	24	22	5	17	16	9	7
1966	31	2	29	22	2	20	9	0	9
1975	26	1	25	24	1	23	2	0	2
1979	22	4	18	19	4	15	3	0	3
1985	31	5	26	29	5	24	2	0	2
1988	28	6	22	25	5	20	3	1	2
1995	51	6	45	48	5	43	3	1	2

	Overall Wetlands Acreage (ha)								
				By Soil Type					
				Cte (Cotopaxi)			Dun (Dune Lands)		
Photo Year	Total Acres	Wet Wetland Acres	Dry Wetland Acres	Total Acres	Wet Wetland Acres	Dry Wetland Acres	Total Acres	Wet Wetland Acres	Dry Wetland Acres
1936	49.95 (20.24)	27.88 (11.29)	22.07 (8.94)	6.11 (2.47)	3.51 (1.42)	2.61 (1.05)	43.84 (17.73)	24.37 (9.87)	19.47 (7.89)
1937	70.29 (28.45)	58.86 (23.84)	11.43 (4.61)	17.36 (7.04)	11.37 (4.61)	5.99 (2.43)	52.93 (21.41)	47.49 (19.22)	5.44 (2.19)
1953	20.83 (8.42)	12.20 (4.94)	8.63 (3.48)	14.75 (5.99)	8.86 (3.60)	5.89 (2.39)	6.08 (2.47)	3.34 (1.34)	2.74 (1.09)
1966	17.82 (7.20)	5.38 (2.19)	12.44 (5.02)	14.93 (6.03)	5.38 (2.19)	9.55 (3.89)	2.89 (1.17)	0.00 (0.00)	2.89 (1.17)
1975	21.69 (8.78)	5.78 (2.35)	15.91 (6.43)	21.39 (8.66)	5.78 (2.35)	15.61 (6.31)	0.30 (0.12)	0.00 (0.00)	0.30 (0.12)
1979	12.69 (5.14)	8.01 (3.24)	4.68 (1.90)	12.02 (4.86)	8.01 (3.24)	4.01 (1.62)	0.67 (0.28)	0.00 (0.00)	0.67 (0.28)
1985	14.58 (5.91)	7.37 (2.99)	7.21 (2.91)	14.26 (5.79)	7.37 (2.99)	6.89 (2.79)	0.32 (0.12)	0.00 (0.00)	0.32 (0.12)
1988	14.01 (5.67)	9.40 (3.80)	4.61 (1.86)	13.67 (5.54)	9.20 (3.72)	4.47 (1.82)	0.34 (0.12)	0.20 (0.08)	0.14 (0.04)
1995	16.75 (6.80)	8.84 (3.56)	7.91 (3.20)	16.10 (6.52)	8.58 (3.48)	7.52 (3.04)	0.65 (0.28)	0.26 (0.12)	0.39 (0.16)

The wetlands occurring in vegetated sand (Cotopaxi series soils) increase in percentage in relation to the unvegetated wetlands but these are mostly represented by the Elk Springs complex. After the disappearance of the northern Dune Land wetlands from the 1930's, the Elk Springs wetlands represent the largest wetlands in size of the whole of the study area. Even though these amount to four wetlands in number, this area represents a significant amount of the wetland acreage for the vegetated dunes wetlands. Given the permanence of these features, they are most likely a spring, a groundwater discharge area that doesn't discharge enough to form a stream such as Indian Springs to the south.

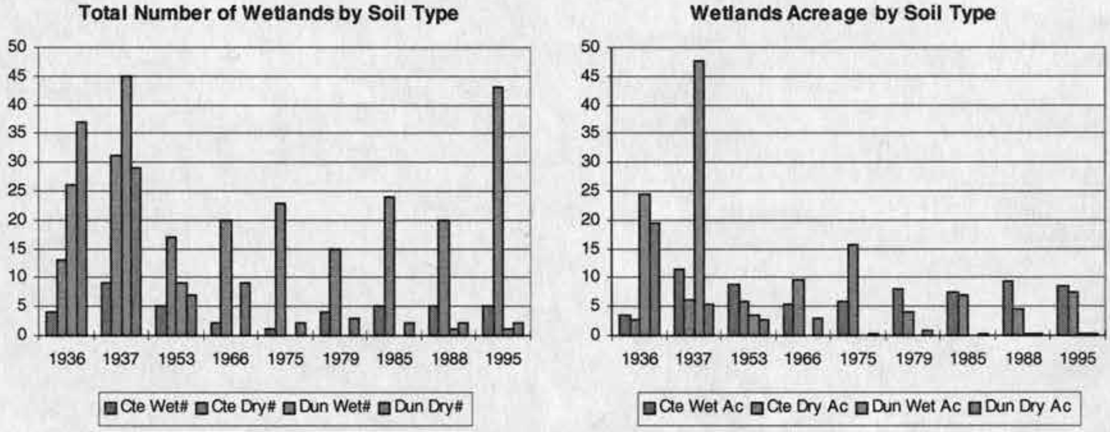

Figure 5-5 Wetlands summary by surface water and soil type

The distribution of the wetlands is also displayed by bar charts (Figure 5-5). The total number of wetlands remains relatively the same after the 1950's, about 22 - 25. The high number in 1995 is in part a result of the resolution of the aerial photography.

In summary, from the GIS analysis, it can be seen that the both the number and extent of wetlands over the study period have experience a significant reduction. While the areal extent of the wetlands has decreased, the area of the sand sheet covered with vegetation has increased dramatically. The majority of the former wetlands occurred in the unvegetated dune sands in the northern part of the study area. These are the features that have suffered the most significant decline that occurred between 1937 and 1953.

Since the 1950's, the majority of the wetlands have been localized around the Elk Springs area and have remained relatively stable in number and size since that time until the most recent decade. An increasing trend in precipitation in the past 10 years has contributed to an increase in the number of small, subirrigated meadows that do not have water at the surface.

Two sets of wetlands occur on all photo sets. Elk Springs is made up of four wetland meadows, at least two of which usually have water at the surface. The other permanent feature is the wetlands around 443,200 E, 4,182,100 N. The two large subirrigated meadows do not usually have water at the surface but on three sets of photos (1937, 1979 and 1988) the eastern wetland of this group does appear to have had water at the surface.

6 Hydrologic & Climatic Data Analysis

6.1 Methodology

The following section presents a discussion on the types of data available to this study, hypotheses of how this data was expected to relate to the study area and problems encountered in the analysis. Groundwater data in the form of water level data was collected from the EarthInfo Inc. CD-ROM. This data is equivalent to the WATSTORE database of the USGS. Streamflow data for the six county area in the SLV was also available from this CD-ROM. Data was also made available from the USGS Water Resources Division in Pueblo, CO. This data constituted water level data from wells in the vicinity of the Closed Basin Division.

Precipitation data was available from the EarthInfo Inc. CD-ROM of National Climatic Data Center (NCDC) Daily Climate data. These data were downloaded initially for the six counties that cover the San Luis Valley. Discussions with Nolan Doesken, the Colorado Assistant State Climatologist, supplemented missing data. Finally, dendrochronology data was available in the form of a tree ring study on the western flanks of the Sierra Blanca. Mangimeli (1981) collected cores from the lower tree line of Pinyon Pine and from the upper tree line Bristlecone.

All ancillary data proved to be a problem for this study as very few were of long enough duration to cover the entire set of aerial photographic data. Continuous, digitally available precipitation data for the SLV extended back to 1948. Digital well data from the EarthInfo Inc. CD-ROM was of short duration and irregular collection intervals. Figure 6-1 depicts the time intervals available for various forms of data used in this part of the study.

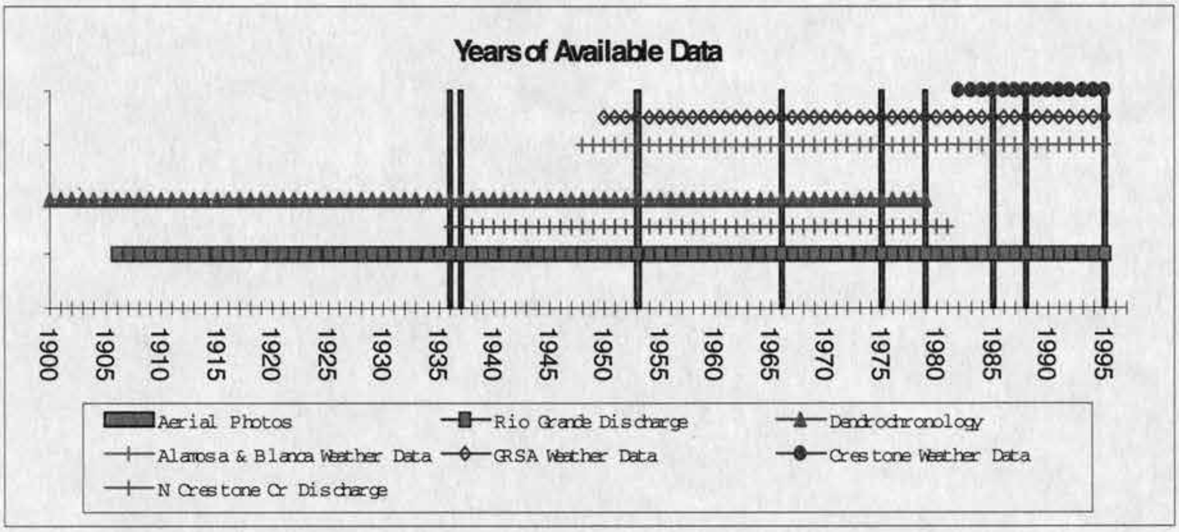

Figure 6-1 Distribution of ancillary data years available for San Luis Valley

6.2 Index Creation for Ancillary Data

6.2.1 Indices

For the periods of these data that did overlap the aerial photo sets, indices were created which represented the sums of preceding months or years data, average values for months or years or values lagged from x number of years prior to the date of the photo set. This method, based on the work of Rundquist et al (1987), was used to detect lake surface area variations versus precipitation. That study was of limited duration using LANDSAT data. Precipitation records were continuous across the dates of all the satellite data so indices could be created from the day of data acquisition. Watts (1995) used lagging of data to analyze water levels in wells for the Closed Basin Division. The assumption is that the events of the previous month contributed to the water level change in a well.

For this study, the smallest period of time used for an index value was a month. Most photo sets were obtained late in the month of acquisition. For these sets, the calendar month value for data was used for statistical comparison if monthly values were available. If a photo set was acquired before the 15th of the month, then the previous calendar month was used for comparison. For data only available annually (dendrochronology), the calendar year value of the photo set was used for the creation of indices.

After the index values for a particular data set were created, the index values for the years corresponding with years of aerial photography were extracted. These values were regressed against the wetland acreage values (both wet wetlands and total wetland acreage) for those particular years

6.2.2 Groundwater

Groundwater, surface water and lake data were retrieved for three counties, Alamosa, Costilla and Saguache from the EarthInfo CD-ROM. The longest well record available had 11 years of data from 1978 to 1989. Due to the short extent of the data and the irregular collection interval, these data were rejected.

Other well data were obtained from the Water Resources Division of the U.S. Geological Survey in Pueblo, Colorado. These were mostly monitoring sites in and around the CBD in Alamosa and Saguache Counties. All are in the unconfined aquifer.

Most of these were also of short duration but some of these wells were monitored starting in the late 1940s. Initially these wells were monitored on a monthly basis but as time progressed the monitoring intervals on some became very irregular.

Appendix 2 includes a map of the location of these wells as well as plots of the water levels of those wells with the most monitored dates. The data is presented in feet below the ground surface. Most wells show a variation of 1-3 feet (0.30 - 0.90 m) in the water level but there is no consistent trend through time. In some wells, the trend is rising, in others the level is falling.

6.2.3 Precipitation

Weather records were collected from the EarthInfo, Inc. CD-ROM of NCDC data. These records have been digitized back to 1948. There are 21 stations in the six counties of the Rio Grande watershed available on this CD (see Appendix 1 for index map of weather stations). Nine of these have over 40 years worth of records, including the station at GRSA. All stations generally include precipitation, snowfall and minimum and maximum temperatures on a daily basis. The station at Alamosa (Station 0130) is the only station in the valley that includes evaporation data.

There are three stations on the eastern side of the SLV in the vicinity of the study area. GRSA (Station 3541), is located at the park headquarters in the southeast corner of the park. Records for the station at Blanca, CO (Station 0776), approximately 20 miles (32 km) south of GRSA, go back to 1948. The station at Crestone, CO (Station 1964) is approximately 15 miles (24 km) northwest of the study area but its records only extend back to 1981.

An unsuccessful attempt was made to extend back the GRSA precipitation annual value using the dendrochronology index. Mangimeli (1981) cites previous studies that show that the growth of arid site conifers respond less to summer precipitation than to cool season precipitation. As to be expected, resulting correlation of the pinyon pine index with GRSA annual precipitation resulted in an r^2 of 0.07 with a p-value of 0.14.

Appendix 1 shows the annual totals used for creation of precipitation indices from selected SLV weather stations. The appendix also indicates the number of missing days of data for that year. Estimates were made for those months that were completely missing from the GRSA records in discussion with Nolan Doesken. The State Climate office produces monthly isohyetal maps from the reporting weather stations throughout the state. Due to the high daily variability between stations in the SLV, missing monthly values were estimated from these isohyetal maps for the GRSA station. Also included in the appendix is a Table of the monthly values for GRSA, which includes the estimated monthly values.

Initially, indices were created by summing annual data (reported in inches) for years prior to the date of the photography. Since the precipitation data begins in August, 1950, the 1930s photography can't be included in this analysis. Some of the longer indices can't be created for the early photography for this time period (i.e. 5, 10 and 20 years of data are not available prior to the 1953 photo set). Presented in Table 6-1 are the indices used along with the acreage totals for wet wetlands and for the total wetland acreage.

Table 6-1 GRSA wetland acreage and annual precipitation indices (in inches)

Photo Year	Wet Wetland Acreage	Total Wetland Acreage	1 Year Precip Total	2 Year Precip Total	3 Year Precip Total	5 Year Precip Total	10 Year Precip Total	20 Year Precip Total
1953	12.20	20.83	10.89	22.78	28.63			
1966	5.38	17.81	7.08	22.20	33.84	47.72	103.96	
1975	5.78	21.69	10.81	17.66	24.48	43.63	107.00	209.82
1979	8.01	12.68	8.13	15.69	27.10	46.71	91.15	202.25
1985	7.71	15.09	12.64	22.40	33.68	57.00	100.86	207.86
1988	9.40	14.00	9.52	17.20	29.14	51.54	102.23	201.54
1995	8.81	16.63	13.22	29.29	44.59	71.79	123.96	224.82

Monthly precipitation indices were also created from the GRSA data. Since the data could be created in this time frame, I expected that a better fit to acreage totals could be achieved than by using the more general annual data. Precipitation indices created from monthly values reflect the actual precipitation totals received prior to the actual dates of photography. If there is a relationship between precipitation and the surface area of the wetlands, the monthly indices could more accurately show this relationship. These indices are presented in the Table 6-2.

Table 6-2 GRSA monthly precipitation indices (in inches)

Photo Year	1 Month	2 Month	3 Month	6 Month	12 Month	24 Month	36 Month	60 Month	120 Month	240 Month
1953	0.00	1.30	4.02	7.46	9.00	21.81	26.95			
1966	2.26	4.58	5.56	6.12	12.00	25.05	34.63	50.52	104.5	
1975	0.80	0.82	1.45	3.00	8.83	15.32	24.95	45.79	110.1	207.8
1979	1.37	1.66	2.35	5.41	10.21	18.22	27.65	48.68	95.6	206.4
1985	2.66	2.82	4.34	6.10	13.16	21.36	33.82	52.43	101.5	211.1
1988	1.12	2.94	3.51	3.71	6.57	18.86	31.09	52.45	103.0	205.5
1995	1.33	3.74	5.80	9.47	17.76	34.05	46.84	75.03	128.7	230.1

6.2.4 Dendrochronology

Pinyon Pine chronology data from Mangimeli's 1981 thesis were used in this study in a slightly different manner than the precipitation data. Mangimeli found that a relatively low percentage of the Pinyon Pine growth could be explained by climate. Results were encouraging enough that he was able to use the chronology to reconstruct the climate of the vicinity of the Pinyon Pine site. He interpreted periods of below normal growth as periods of warm and dry conditions, above normal growth as cool and wet. To determine general trends of growth, he used a nine year centered mean of the pinyon pine index (see Figure 6-2). For consistency with the precipitation data, I used a mean value of the nine years prior to and including the photography year. Rather than sum the data for periods of years, I lagged the data.

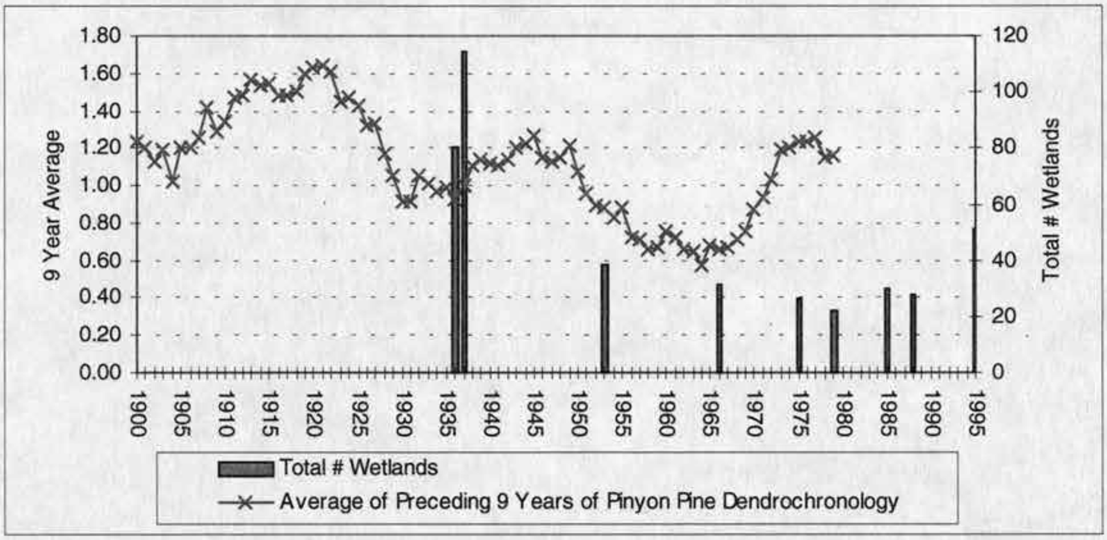

Figure 6-2 Nine year mean of Pinyon Pine chronology for eastern San Luis Valley with total number of wetlands for Great Sand Dunes National Monument study area

The graph of the nine year mean shows above average Pinyon growth for the period from 1900 through the mid-1920s. The complete data in Mangimeli's report extends this period back to 1885. The value for the nine year mean is at maximum for this period in 1917. This is 20 years previous to the maximum number of wetlands from the 1937 aerial photos. To test the assumption that the climatic conditions affecting the pinyon pine chronology could affect the extent of the wetlands, the nine year mean was lagged by various numbers of years. The chronology was offset by 5, 10, 15, 16, 17, 18, 19, 20 and 21 years for this test. This method also had the advantage of fully overlapping the aerial photo years. Since the dendrochronology study was completed in 1980, using the raw data does not cover the final three years of aerial photo data. By lagging the data for 16 or more years, all sets of aerial photos can be analyzed. The Pinyon Pine indices are presented in Table 6-3.

Table 6-3 Indices from 9 year mean of Pinyon Pine dendrochronology

Photo Year	9 Year Mean	5 Year Lag	10 Year Lag	15 Year Lag	16 Year Lag	17 Year Lag	18 Year Lag	19 Year Lag	20 Year Lag	21 Year Lag
1936	0.93	0.91	1.32	1.64	1.63	1.60	1.51	1.48	1.48	1.54
1937	1.00	1.05	1.33	1.61	1.64	1.63	1.60	1.51	1.48	1.48
1953	0.89	1.15	1.20	1.11	1.00	0.93	0.99	0.97	1.01	1.05
1966	0.66	0.73	0.72	0.96	1.08	1.21	1.15	1.13	1.15	1.27
1975	1.24	0.87	0.68	0.75	0.67	0.66	0.71	0.72	0.88	0.83
1979	1.16	1.20	0.76	0.58	0.65	0.66	0.73	0.75	0.67	0.66
1985			1.24	0.87	0.76	0.71	0.67	0.66	0.68	0.58
1988			1.16	1.20	1.03	0.94	0.87	0.76	0.71	0.67
1995					1.16	1.16	1.25	1.24	1.24	1.20

6.2.5 Streamflow

Snowfall data was only available for the SLV and none was available for the Sangre de Cristo Mountains. The runoff for streams of the area is dominated by snowmelt. In lieu of not having any snowfall data, streamflow gives evidence of the available snowfall.

Two streams from the SLV were used for creation of indices. While there is an extensive network of monitoring sites throughout the valley, again the number that fully cover the aerial photo years are very small. Data from two sites were selected for differing reasons.

Streamflow has been monitored on the Rio Grande at Del Norte (ID# 0822000) since 1906. This data was downloaded from the USGS hydrologic data World Wide Web site. The watershed of the Rio Grande above Del Norte is in the San Juan Mountains which receives the most precipitation in the state, much more than the Sangre de Cristos. Nevertheless, this data was used because of its completeness over the photo years, the only source of data for which this was true. The data is reported in cubic feet per second from the USGS. This was converted to acre-feet and summed on an annual basis (differences were minor when compared with summing by water-year). In order to avoid excessively large numbers the data were averaged for the creation of indices. These data are reported in Table 6-4.

Table 6-4 Indices for Rio Grande at Del Norte, CO (ID# 08220000) annual discharge (acre-feet)

Photo Year	Annual Ac-Ft	Ac-Ft 3 Year Mean	Ac-Ft 5 Year Mean	Ac-Ft 10 Year Mean	Ac-Ft 20 Year Mean
1936	471,525	492,122	572,864	631,350	722,902
1937	576,719	577,488	511,438	592,557	707,049
1953	400,831	511,484	584,364	628,118	618,066
1966	578,562	625,889	592,704	599,608	577,235
1975	806,642	658,390	587,156	589,257	582,171
1979	952,861	524,489	594,167	575,459	577,157
1985	1,008,699	814,281	709,625	646,204	617,730
1988	434,095	826,933	850,067	773,151	659,539
1995	829,955	674,507	623,240	661,525	653,864

Streamflow was monitored on North Crestone Creek, about 16 miles (25.7 km) north of the study area between 1936 and 1981. This is the closest gaging site to the study area that extends this far back and it covers the initial years of the study. For this dataset, acre-feet were summed by months prior to the photography (Table 6-5). The final table (table 9) represents the indices for annual precipitation for the Blanca, CO (Station 0776) weather station.

Table 6-5: Indices for N Crestone Creek CO (ID# 08227500) in acre-feet

Photo Year	1 month Discharge	2 month Discharge	3 month Discharge	6 month Discharge	9 month Discharge	12 month Discharge
Jul-36	1457.87	2378.18	3791.90	4458.50	4998.26	
Sep-37	451.24	821.90	1410.95	7192.55	7574.89	8871.70
Sep-53	168.50	619.34	1720.22	6785.06	7179.68	7765.96
Aug-66	1102.46	2011.28	3537.86	5873.87	6693.98	8766.65
Jun-75	3864.96	5798.43	6062.17	6461.53	7169.18	8430.05
Aug-79	711.61	2691.61	7516.87	11021.47	11383.42	11811.69

Table 6-6: Indices for Blanca, CO (Station 0776) annual precipitation in inches

Photo Year	Blanca (0776) Annual Precip
1953	9.93
1966	6.56
1975	4.84
1979	8.76
1985	9.89
1988	9.76
1995	10.08

6.3 Analysis

Linear regression was performed on 40 indices versus the total acreage for all wetlands and against wet wetland acreage (Appendix 8). Indices for the GRSA precipitation totals all had a very poor correlation with either acreage total. All had very low correlation coefficients with very high p values. This is true for indices created from the annual total and for those from months prior to the photo dates. Indices for N Crestone Creek also had very poor results along with all indices representing short periods of time, close to the date of the photography.

The indices that had the highest correlation with the acreage totals (Tables 6-7 & 6-8) are the Pinyon Pine dendrochronology index, 9 year mean, lagged by 15 to 20 years and the Rio Grande discharge lagged by 20 years. The 1930s was a period of drought in the SLV as was the first half of the 1950s. The early photo sets are the ones with the largest numbers of wetlands present. Since the indices for periods close to the date of photography (previous month to previous year) have such poor correlation with the wetlands, I interpret this as the wetlands responding poorly to precipitation. Better correlation with the indices lagged for 15 to 20 years could suggest that the wetlands are sourced by groundwater rather than surface water input.

Table 6-7 Regression results for indices with highest correlation to wet wetlands acreage

	Linear Regression Results					
	Wet Wetland Acres vs. Index					
Index	Slope	Intercept	r^2	rse	df	p
Pinyon - 9 Yr Mn offset by 18 Years	43.841	-19.666	0.678	12.110	7	0.006
Pinyon - 9 Yr Mn offset by 19 Years	46.811	-22.736	0.660	12.440	7	0.008
Pinyon - 9 Yr Mn offset by 16 Years	37.687	-24.268	0.633	11.320	7	0.010
Pinyon - 9 Yr Mn offset by 15 Years	37.845	-24.359	0.613	12.390	6	0.022
Pinyon - 9 Yr Mn offset by 17 Years	35.664	-21.617	0.586	12.010	7	0.016
Blanca (0776) Annual Precipitation	0.857	0.864	0.586	1.621	7	0.045
Rio Grande 20 Yr Mn Annual Ac-Ft	0.000	-134.193	0.548	12.550	7	0.022
Pinyon - 1 Yr Total offset by 20 Yrs	29.890	-14.244	0.538	12.690	7	0.024
Pinyon - 9 Yr Mn offset by 20 Years	37.466	-22.653	0.479	13.490	7	0.039

Table 6-8 Regression results for indices with highest correlation to total wetland acreage

	Linear Regression Results					
	Total Wetland Acres vs. Index					
Index	Slope	Intercept	r^2	rse	df	p
Pinyon - 9 Yr Mn offset by 16 Years	45.556	-22.106	0.708	11.540	7	0.005
Pinyon - 9 Yr Mn offset by 15 Years	45.608	-21.900	0.689	12.630	6	0.011
Pinyon - 9 Yr Mn offset by 17 Years	43.842	-19.666	0.678	12.110	7	0.006
Pinyon - 9 Yr Mn offset by 20 Years	49.073	-24.053	0.628	13.020	7	0.011
Pinyon - 9 Yr Mn offset by 18 Years	38.578	-24.639	0.586	12.010	7	0.016
Rio Grande 20 Yr Mn Annual Ac-Ft	0.000	-148.591	0.571	13.990	7	0.019
Pinyon - 9 Yr Mn offset by 21 Years	41.134	-15.860	0.560	14.170	7	0.020
Pinyon - 9 Yr Mn offset by 19 Years	39.147	-24.039	0.539	12.680	7	0.024
Pinyon - 1 Yr Total offset by 20 Yrs	33.854	-7.679	0.528	14.660	7	0.027

7 Summary and Conclusions

7.1 Project Process and Results

The purpose of this study was to map the extent of wetlands visible on aerial photographs for a remote area at Great Sand Dunes National Monument, Colorado. Since the area is so remote with few permanent features, scanned images of the aerial photographs could not be rectified before mosaicking due to the lack of distinctive ground control points on the photographs. The mosaics were thus created in advance of rectification in order to encompass a large enough area for the selection of ground control points.

A technique was developed in ERDAS Imagine version 8.2 that allowed for unrectified images to be mosaicked prior to rectification. After all images were mosaicked and rectified to a 1988 digital orthophotograph, wetlands and other land covers were digitized "heads up" from the digital mosaics. The mosaicking process used does not correct for radial distortion present in the aerial photographs. One study has shown that distortion should be minimal if the area is flat and there is no camera tilt. This study area is very flat regionally with low, rolling sand dunes covering the majority of the area. Checks for the consistency of digitized wetland polygons were performed by comparing the x,y value of the centroid point of the polygon for all occurrences of the polygon over all of the photo sets. Results of this check found that for most of the mosaics, the feature occurred within a 10 meter radius. Two of the mosaics in particular did have errors greater than this and ranged up to ± 50 meters from the location digitized from the orthophotograph.

Mosaics were created for 10 sets of photography, 6 of these covered the entire National Monument. The photos sets from 1936, 1953, 1966, 1979, 1988 and 1995 cover the whole National Monument. This is an area of over 40 mi^2 (103.60 km^2). The years of 1937, 1957 (partially covering the study area), 1975 and 1985 were then mosaicked in the immediate vicinity of the study area. The number of photos per mosaic ranged from 1 to 20 due to the scale of the photography. It took a number of hours to create each mosaic over the entire area, not a timely process for most projects.

Analysis of the digitized photos indicates that the number and area of the wetlands is greatest in the 1930's. By 1953, the number of wetlands has dropped to almost 1/3 of the 1937 total number, from 114 to 38. The total area that these represent dropped from over 70 acres (28.3 ha) to about 21 acres (8.5 ha) for the same time period. Since that time the total area of all the wetlands has ranged from 15 to 20 acres (6.1 to 8.1 ha), the total number of wetlands dropped to 22 by 1979 and then has increased to 51 in the 1995 photography. The increase in number are in part caused by the resolution of the photography. The two sets from the 1970s are both a very small scale relative to the rest of the photos obtained and the 1995 set has the highest resolution. Despite an increase in number by over 2x between 1975 and 1995, the total acreage between these same years increased by just over 30%.

The total acreage of all wetlands and the area of the wet wetlands were also analyzed against indices created from ancillary data from the SLV. Climatic and groundwater data is sparse throughout this part of the SLV. Weather data is available digitally back to 1948. Previous to that time, the few stations that operated have large gaps of no data. The weather station at GRSA has operated since August of 1950. Seven months of missing data for these records were estimated from monthly isohyetal maps of the state. Groundwater data that was located was found to be too short of duration and too irregular for statistical use. A Pinyon Pine dendrochronology for the SLV had been created in part from a site on GRSA in 1980. These data extended back over the early years of photography for this study. Another source of long term data for the valley is the discharge of the Rio Grande at Del Norte, CO. This gaging site is 50 miles (80.5 km) west of GRSA but has operated since the turn of the century.

Index values were created from the ancillary data for statistical analysis against the total area of the wetlands. Data was summed, averaged or lagged for various monthly or annual intervals and compared to the wetland acreage by simple linear regression. The lack of data for all sets across the entire time period of aerial photography limits the conclusions that can be drawn by comparing one data set to another.

The data that was summed for months or years closest in time to the photography dates (i.e. 1 month prior to photography to 12 months or 1 year prior) show almost no correlation with the acreage totals. Correlation coefficients ranged from .01 to .3 for these data. When the discharge data or the dendrochronology data were lagged by 15 to

20 years, correlation coefficients of .5 to .7 resulted with p values of .01 to .05. These results are significant to the extent of the wetlands acreage.

The results are interpreted as showing that the wetlands respond poorly to precipitation or surficial input. The response of the wetlands to the lagged data from two different sources suggests that the driving force of the wetlands could be related to groundwater discharge which exhibits a slower rate of change than to short term climatic variations.

7.2 Further Research

This study has shown that significant change has taken place to the wetlands over the course of the years of available aerial photography. The consistency, availability and extent of ancillary data limited the study, especially in regard to groundwater well data.

The next step in the understanding of the hydrology of these wetlands is for more localized water table data. This study is already beginning as shallow wells are being installed around the Elk Springs area. A network of wells are needed to study the configuration of the water table in the vicinity of the wetlands and also the effects of plant transpiration on the water table around the wetlands.

1997 and early 1998 have seen many months of record precipitation in the area. The total annual precipitation recorded for 1997 at GRSA is over 3 inches (76 mm) greater than the previous record. A site visit in late March, 1998 revealed much more water at the surface than the previous visit in June, 1997, which was prior to the record precipitation events. More frequent monitoring of the wetlands in regard to the recent changes in precipitation is needed to better understand how the wetlands respond to these events. A flume has been installed along Sand Creek near the mouth of its watershed from the Sangre de Cristo Mountains. The flume is about 3 miles (4.8 km) to the north of the study area. Longer term records from this source will help to better understand the response of the wetlands to spring runoff.

Finally, a more detailed topographic survey of the area is needed. The current topographic map of the western portion of the National Monument is published with a 40 foot contour interval. Much of the subtle topography of the area cannot be seen at this scale. Presently, the interdunal areas where these wetlands occur are broad and of low topographic relief. A small difference in the water table elevation can make a large difference in the amount of water present at the surface of the wetlands. Therefore, a more detailed survey of the area is needed. This could most likely be accomplished with a network of high resolution control points and creation of a more detailed digital elevation model from the 1995 aerial photography than is currently available.

The study of this area has demonstrated that through the use of aerial photography, a better understanding of the wetlands of this area can be achieved. It has also shown that the hydrology of the area is highly complex and responds to climatic input in unexpected ways. Understanding the area will be improved with the installation of groundwater wells in the area to measure the response of the wetlands to changes in the water table.

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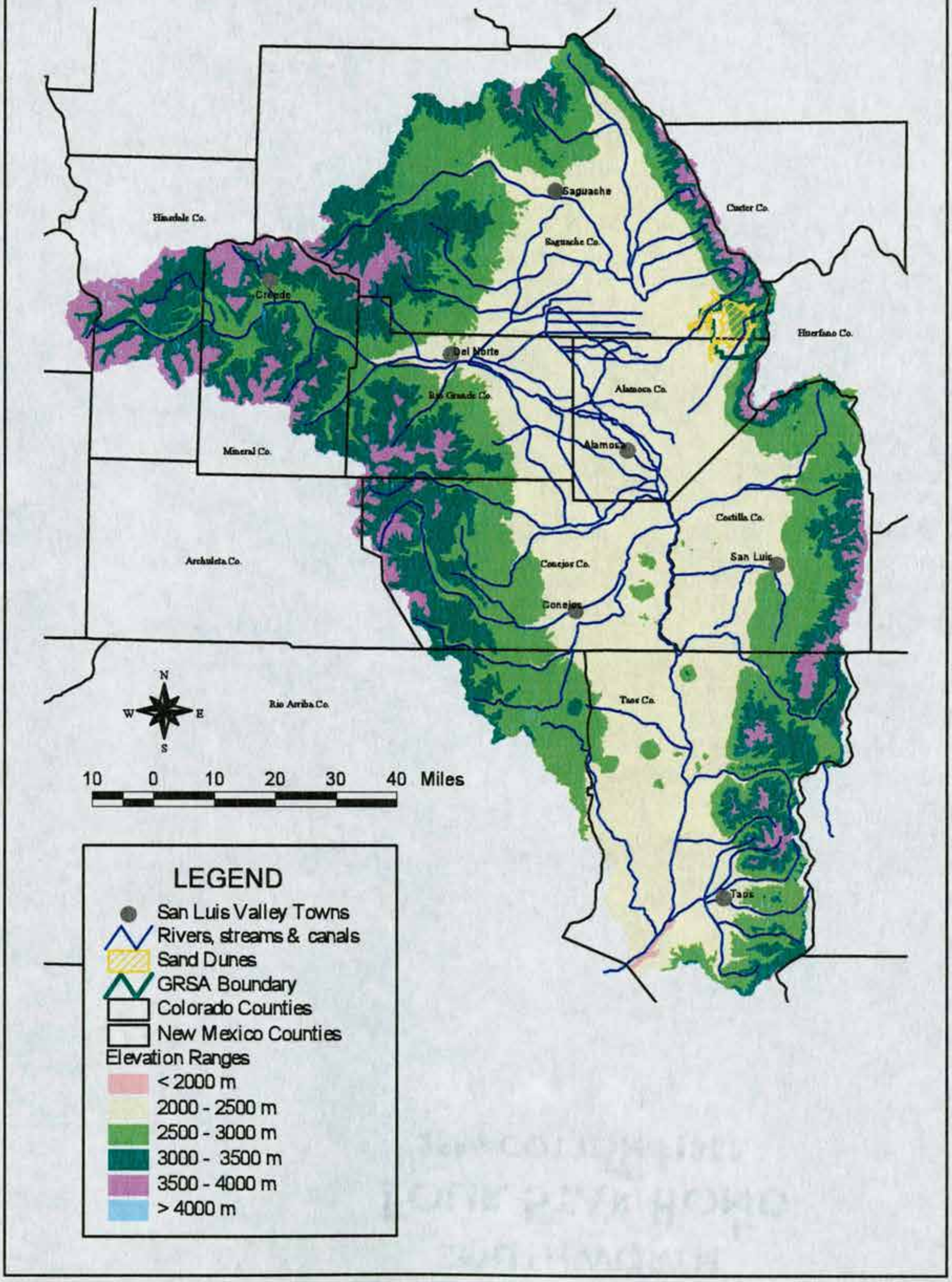
Appendix 1

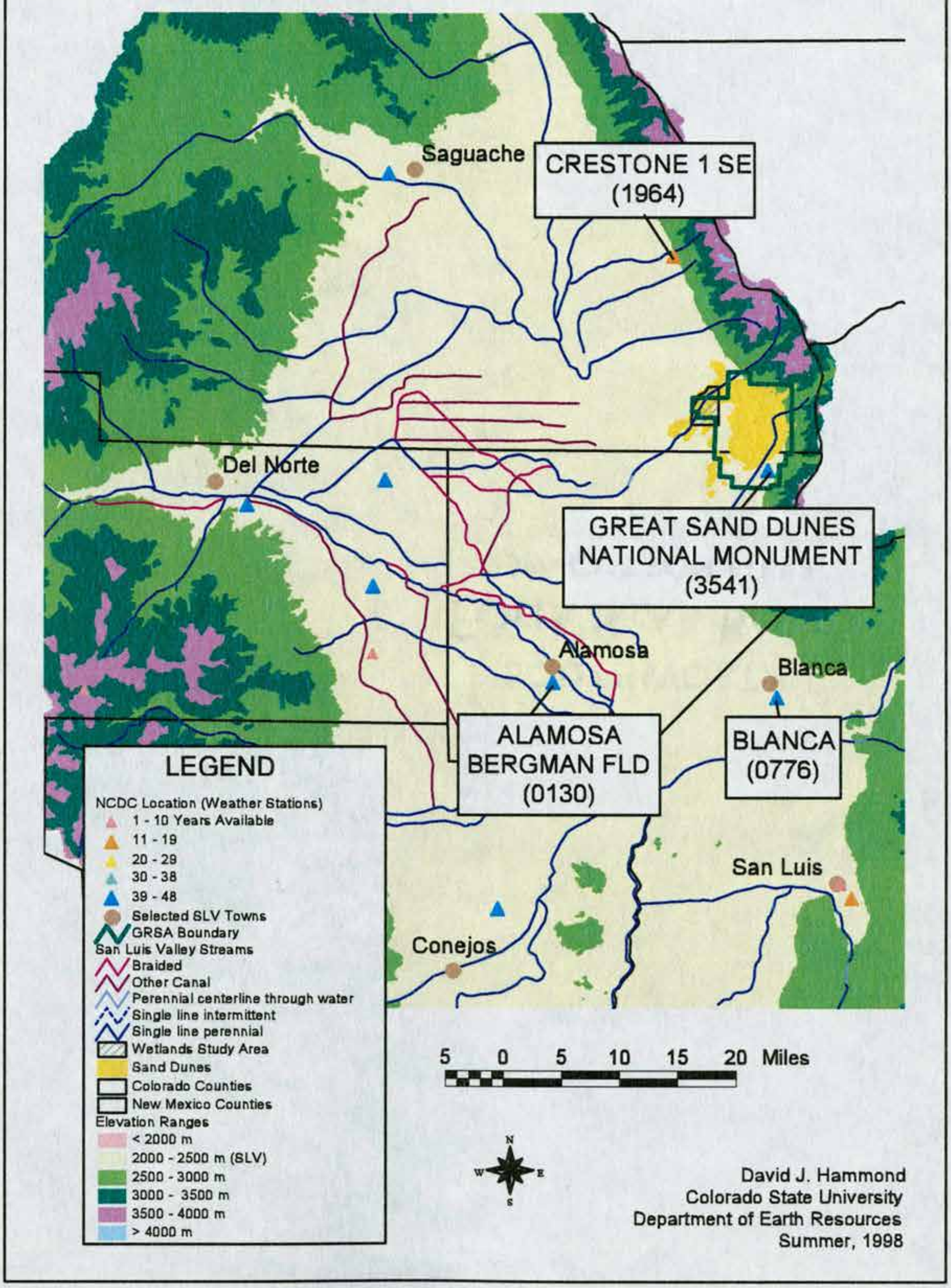
Data Locations:

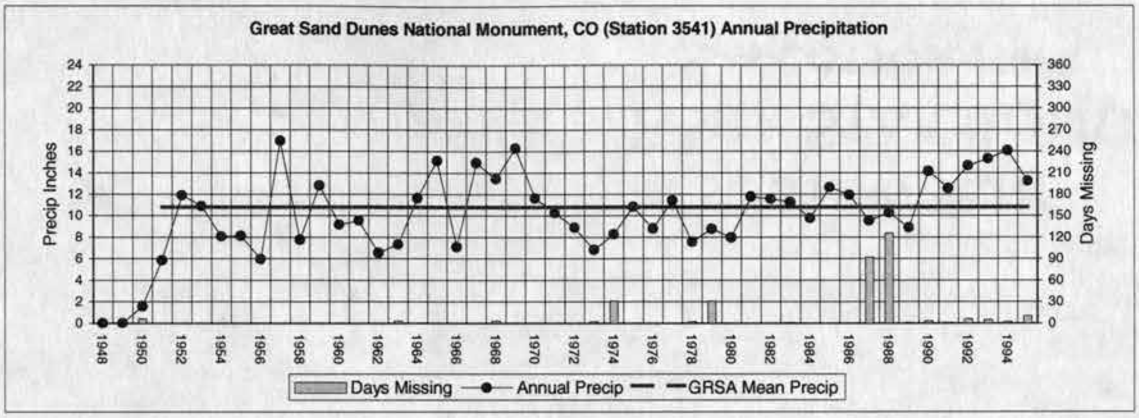
Precipitation Data for Select San Luis Valley Locations

Watershed of the Rio Grande including the San Luis Valley



Selected NCDC Climate Data Locations in the San Luis Valley





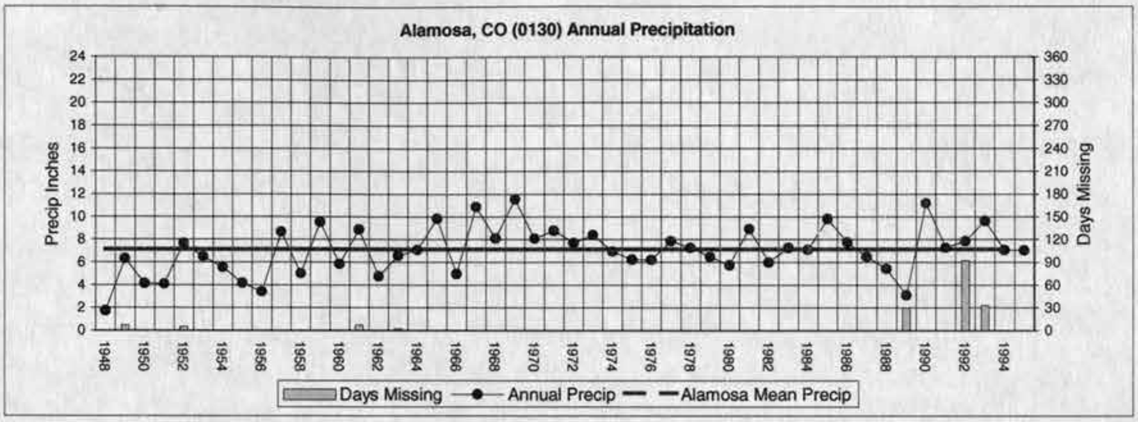
ID	3541	
STANAME	GREAT SAND DUNES NATIONAL MONUMENT	
ELEVATION	8,120	
YEAR	PRECIP (in.)	DAYS MISSING
1948	0.00	0
1949	0.00	0
1950	1.56	6
1951	5.85	0
1952	11.89	0
1953	10.89	0
1954	8.06	0
1955	8.13	0
1956	5.94	0
1957	16.96	0
1958	7.75	0
1959	12.82	0
1960	9.17	0
1961	9.54	0
1962	6.55	0
1963	7.33	3
1964	11.64	0
1965	15.12	0
1966	7.08	0
1967	14.94	0
1968	13.44	3
1969	16.29	0
1970	11.62	0
1971	10.25	0
1972	8.90	0
1973	6.82	2
1974	8.27	31
1975	10.81	0
1976	8.80	0
1977	11.41	0
1978	7.56	2
1979	8.77	31
1980	7.96	0
1981	11.76	0
1982	11.56	0
1983	11.28	1
1984	9.76	0
1985	12.64	0
1986	11.94	0
1987	9.55	92
1988	10.29	126
1989	8.89	1
1990	14.14	3
1991	12.55	1
1992	14.65	6
1993	15.30	5
1994	16.07	2
1995	13.22	10

Mean Precip = 10.76

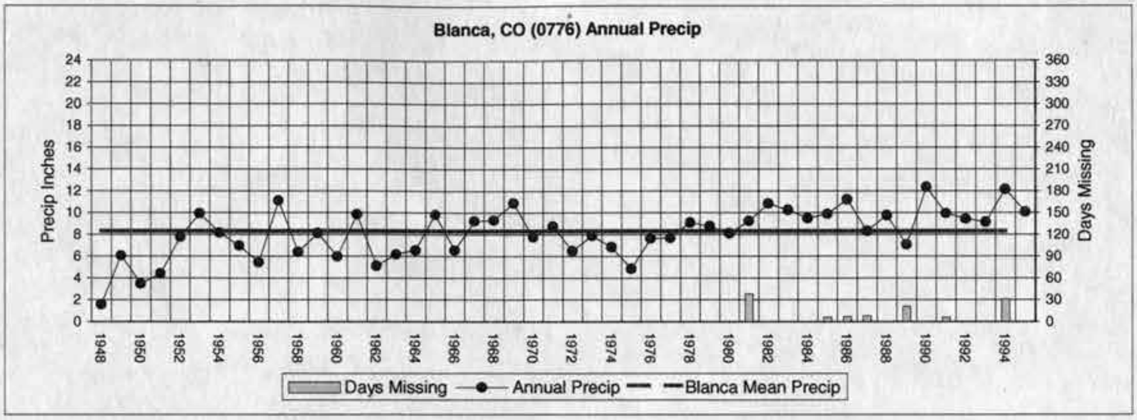
The following pages present the monthly precipitation totals for the GRSA weather station used for the creation of the index values. Included are the values estimated for missing months.

MONTH	PRECIP	DAYS MISSING	MONTH	PRECIP	DAYS MISSING	MONTH	PRECIP	DAYS MISSING	MONTH	PRECIP	DAYS MISSING
Jan-48			Jan-54	0.25		Jan-60	0.42		Jan-66	0.43	
Feb-48			Feb-54	0.05		Feb-60	1.08		Feb-66	0.12	
Mar-48			Mar-54	0.24		Mar-60	0.22		Mar-66	0.05	
Apr-48			Apr-54	0.18		Apr-60	0.70		Apr-66	0.19	
May-48			May-54	1.28		May-60	0.42		May-66	0.32	
Jun-48			Jun-54	0.05		Jun-60	1.47		Jun-66	0.98	
Jul-48			Jul-54	1.34		Jul-60	2.13		Jul-66	2.32	
Aug-48			Aug-54	2.84		Aug-60	0.26		Aug-66	2.26	
Sep-48			Sep-54	1.18		Sep-60	0.44		Sep-66	0.11	
Oct-48			Oct-54	0.22		Oct-60	1.48		Oct-66	0.07	
Nov-48			Nov-54	0.32		Nov-60	0.10		Nov-66	0.06	
Dec-48			Dec-54	0.11		Dec-60	0.45		Dec-66	0.17	
Jan-49			Jan-55	0.45		Jan-61	0.21		Jan-67	0.13	
Feb-49			Feb-55	0.09		Feb-61	0.47		Feb-67	0.61	
Mar-49			Mar-55	0.06		Mar-61	0.52		Mar-67	0.24	
Apr-49			Apr-55	0.47		Apr-61	0.46		Apr-67	0.96	
May-49			May-55	2.65		May-61	0.46		May-67	2.08	
Jun-49			Jun-55	0.04		Jun-61	0.29		Jun-67	1.29	
Jul-49			Jul-55	1.23		Jul-61	1.51		Jul-67	2.80	
Aug-49			Aug-55	2.51		Aug-61	2.41		Aug-67	4.22	
Sep-49			Sep-55	0.18		Sep-61	1.47		Sep-67	1.10	
Oct-49			Oct-55	0.03		Oct-61	0.82		Oct-67	0.60	
Nov-49			Nov-55	0.20		Nov-61	0.39		Nov-67	0.00	
Dec-49			Dec-55	0.22		Dec-61	0.53		Dec-67	0.91	
Jan-50			Jan-56	0.66		Jan-62	0.08		Jan-68	0.08	
Feb-50			Feb-56	0.13		Feb-62	0.30		Feb-68	0.57	
Mar-50			Mar-56	0.20		Mar-62	0.57		Mar-68	0.51	
Apr-50			Apr-56	1.08		Apr-62	0.36		Apr-68	0.22	3
May-50			May-56	1.19		May-62	0.15		May-68	1.39	
Jun-50			Jun-56	0.15		Jun-62	0.59		Jun-68	0.05	
Jul-50			Jul-56	0.51		Jul-62	1.38		Jul-68	5.01	
Aug-50			Aug-56	1.09		Aug-62	0.30		Aug-68	3.52	
Sep-50	0.85		Sep-56	0.04		Sep-62	1.46		Sep-68	1.11	
Oct-50	0.24		Oct-56	0.17		Oct-62	0.59		Oct-68	0.46	
Nov-50	0.00	6	Nov-56	0.53		Nov-62	0.62		Nov-68	0.45	
Dec-50	0.47		Dec-56	0.19		Dec-62	0.15		Dec-68	0.07	
Jan-51	0.32		Jan-57	0.37		Jan-63	0.77		Jan-69	0.04	
Feb-51	0.06		Feb-57	0.20		Feb-63	0.27		Feb-69	0.09	
Mar-51	0.12		Mar-57	0.53		Mar-63	0.24		Mar-69	0.64	
Apr-51	1.08		Apr-57	2.08		Apr-63	0.00		Apr-69	0.20	
May-51	0.35		May-57	3.83		May-63	0.35		May-69	2.20	
Jun-51	0.05		Jun-57	0.88		Jun-63	0.81		Jun-69	4.32	
Jul-51	0.08		Jul-57	4.62		Jul-63	1.66		Jul-69	2.18	
Aug-51	2.03		Aug-57	2.61		Aug-63	2.03	3	Aug-69	2.49	
Sep-51	0.34		Sep-57	0.00		Sep-63	0.58		Sep-69	1.15	
Oct-51	0.89		Oct-57	0.97		Oct-63	0.41		Oct-69	2.14	
Nov-51	0.15		Nov-57	0.84		Nov-63	0.07		Nov-69	0.11	
Dec-51	0.38		Dec-57	0.03		Dec-63	0.14		Dec-69	0.73	
Jan-52	0.99		Jan-58	0.76		Jan-64	0.05		Jan-70	0.02	
Feb-52	0.05		Feb-58	0.30		Feb-64	0.55		Feb-70	0.01	
Mar-52	0.29		Mar-58	1.00		Mar-64	0.70		Mar-70	1.01	
Apr-52	1.64		Apr-58	1.12		Apr-64	0.51		Apr-70	0.56	
May-52	1.07		May-58	0.61		May-64	0.90		May-70	0.18	
Jun-52	0.22		Jun-58	0.71		Jun-64	0.99		Jun-70	1.29	
Jul-52	0.82		Jul-58	0.47		Jul-64	2.43		Jul-70	1.83	
Aug-52	3.98		Aug-58	0.94		Aug-64	2.25		Aug-70	3.25	
Sep-52	2.33		Sep-58	0.44		Sep-64	1.81		Sep-70	2.51	
Oct-52	0.00		Oct-58	0.72		Oct-64	0.16		Oct-70	0.85	
Nov-52	0.40		Nov-58	0.47		Nov-64	0.82		Nov-70	0.11	
Dec-52	0.10		Dec-58	0.21		Dec-64	0.47		Dec-70	0.00	
Jan-53	0.03		Jan-59	0.44		Jan-65	0.19		Jan-71	0.01	
Feb-53	0.14		Feb-59	0.19		Feb-65	0.51		Feb-71	0.22	
Mar-53	0.87		Mar-59	0.79		Mar-65	1.04		Mar-71	0.12	
Apr-53	0.80		Apr-59	1.25		Apr-65	0.36		Apr-71	0.30	
May-53	1.39		May-59	1.63		May-65	0.90		May-71	0.48	
Jun-53	1.25		Jun-59	0.66		Jun-65	2.64		Jun-71	0.19	
Jul-53	2.72		Jul-59	1.98		Jul-65	2.68		Jul-71	3.74	
Aug-53	1.30		Aug-59	2.08		Aug-65	1.47		Aug-71	1.87	
Sep-53	0.00		Sep-59	1.26		Sep-65	3.87		Sep-71	1.37	
Oct-53	1.43		Oct-59	2.15		Oct-65	0.97		Oct-71	1.02	
Nov-53	0.72		Nov-59	0.12		Nov-65	0.11		Nov-71	0.48	
Dec-53	0.24		Dec-59	0.27		Dec-65	0.38		Dec-71	0.45	

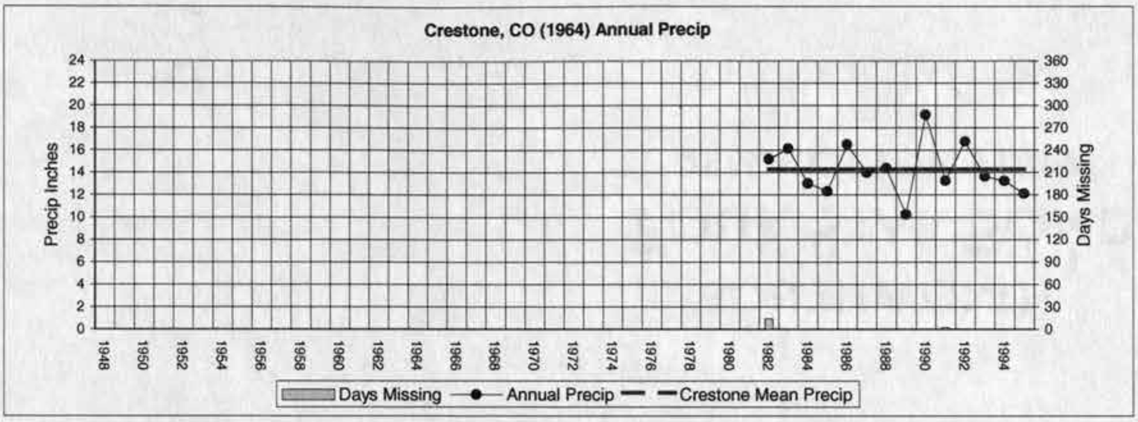
		DAYS			DAYS			DAYS			DAYS
MONTH	PRECIP	MISSING	MONTH	PRECIP	MISSING	MONTH	PRECIP	MISSING	MONTH	PRECIP	MISSING
Jan-72	0.10		Jan-78	0.46		Jan-84	0.20		Jan-90	0.46	
Feb-72	0.05		Feb-78	0.26		Feb-84	0.54		Feb-90	0.23	
Mar-72	0.23		Mar-78	0.17		Mar-84	0.48		Mar-90	2.17	
Apr-72	0.05		Apr-78	0.26		Apr-84	0.37		Apr-90	1.85	
May-72	0.38		May-78	0.85		May-84	0.80		May-90	0.60	
Jun-72	1.23		Jun-78	1.18		Jun-84	0.72		Jun-90	0.15	
Jul-72	0.99		Jul-78	0.56		Jul-84	0.50		Jul-90	1.88	
Aug-72	1.29		Aug-78	0.65		Aug-84	3.32		Aug-90	1.63	3
Sep-72	1.17		Sep-78	0.04		Sep-84	0.23		Sep-90	2.48	
Oct-72	1.55		Oct-78	1.28		Oct-84	2.26		Oct-90	1.67	
Nov-72	0.74		Nov-78	1.32		Nov-84	0.12		Nov-90	0.51	
Dec-72	1.12		Dec-78	0.53	2	Dec-84	0.22		Dec-90	0.51	
Jan-73	0.03		Jan-79	1.55		Jan-85	0.91		Jan-91	0.15	
Feb-73	0.17		Feb-79	0.08		Feb-85	0.18		Feb-91	0.17	
Mar-73	0.57		Mar-79	0.72		Mar-85	0.71		Mar-91	1.05	
Apr-73	1.12		Apr-79	0.96		Apr-85	0.87		Apr-91	1.00	
May-73	0.62		May-79	1.38		May-85	1.52		May-91	1.07	
Jun-73	0.26		Jun-79	0.69		Jun-85	0.16		Jun-91	1.14	
Jul-73	1.37		Jul-79	0.29		Jul-85	2.66		Jul-91	1.64	
Aug-73	0.96		Aug-79	1.37		Aug-85	0.25		Aug-91	3.10	
Sep-73	0.77		Sep-79	0.42		Sep-85	3.50		Sep-91	0.69	
Oct-73	0.27		Oct-79	0.64	31	Oct-85	1.02		Oct-91	0.70	
Nov-73	0.05	2	Nov-79	0.40		Nov-85	0.74		Nov-91	0.71	1
Dec-73	0.63		Dec-79	0.27		Dec-85	0.12		Dec-91	1.13	
Jan-74	0.86		Jan-80	0.26		Jan-86	0.02		Jan-92	0.75	1
Feb-74	0.19		Feb-80	0.39		Feb-86	0.35		Feb-92	0.47	
Mar-74	0.46		Mar-80	0.97		Mar-86	0.31		Mar-92	2.41	1
Apr-74	0.00		Apr-80	1.93		Apr-86	1.59		Apr-92	0.24	
May-74	0.10		May-80	2.43		May-86	1.02		May-92	1.69	1
Jun-74	0.83		Jun-80	0.05		Jun-86	1.37		Jun-92	0.80	
Jul-74	1.42	31	Jul-80	0.87		Jul-86	1.94		Jul-92	2.48	
Aug-74	1.35		Aug-80	0.36		Aug-86	1.83		Aug-92	3.06	
Sep-74	0.40		Sep-80	0.43		Sep-86	0.95		Sep-92	0.57	1
Oct-74	1.74		Oct-80	0.25		Oct-86	1.62		Oct-92	0.14	1
Nov-74	0.05		Nov-80	0.01		Nov-86	0.76		Nov-92	0.85	
Dec-74	0.87		Dec-80	0.01		Dec-86	0.18		Dec-92	1.19	1
Jan-75	0.58		Jan-81	0.01		Jan-87	0.74		Jan-93	0.60	
Feb-75	0.19		Feb-81	0.04		Feb-87	0.55		Feb-93	0.63	
Mar-75	0.78		Mar-81	2.14		Mar-87	1.08		Mar-93	1.39	2
Apr-75	0.63		Apr-81	0.02		Apr-87	0.39		Apr-93	0.95	
May-75	0.02		May-81	0.89		May-87	2.06		May-93	2.97	1
Jun-75	0.80		Jun-81	1.05		Jun-87	1.47		Jun-93	0.13	2
Jul-75	2.23		Jul-81	1.72		Jul-87	0.66		Jul-93	0.31	
Aug-75	1.01		Aug-81	3.09		Aug-87	0.25	31	Aug-93	5.14	
Sep-75	3.42		Sep-81	0.95		Sep-87	0.25	30	Sep-93	1.38	
Oct-75	0.37		Oct-81	0.51		Oct-87	0.20		Oct-93	0.84	
Nov-75	0.60		Nov-81	0.84		Nov-87	1.37	30	Nov-93	0.40	
Dec-75	0.18		Dec-81	0.50		Dec-87	0.53	1	Dec-93	0.56	
Jan-76	0.05		Jan-82	0.14		Jan-88	0.26	2	Jan-94	0.96	
Feb-76	0.35		Feb-82	0.54		Feb-88	0.08	28	Feb-94	0.52	
Mar-76	0.54		Mar-82	0.51		Mar-88	0.03	31	Mar-94	1.22	
Apr-76	1.38		Apr-82	0.34		Apr-88	0.09	30	Apr-94	1.43	
May-76	1.48		May-82	1.18		May-88	0.57	31	May-94	2.44	1
Jun-76	0.13		Jun-82	0.21		Jun-88	1.82		Jun-94	1.18	
Jul-76	1.29		Jul-82	2.87		Jul-88	1.12	3	Jul-94	0.22	
Aug-76	1.94		Aug-82	1.71		Aug-88	2.81	1	Aug-94	3.25	1
Sep-76	0.65		Sep-82	2.85		Sep-88	1.12		Sep-94	1.21	
Oct-76	0.62		Oct-82	0.39		Oct-88	0.70		Oct-94	2.21	
Nov-76	0.34		Nov-82	0.30		Nov-88	0.75		Nov-94	1.26	
Dec-76	0.03		Dec-82	0.52		Dec-88	0.94		Dec-94	0.17	
Jan-77	0.32		Jan-83	0.11		Jan-89	0.74		Jan-95	0.19	2
Feb-77	0.47		Feb-83	0.45		Feb-89	1.41		Feb-95	0.03	
Mar-77	0.35		Mar-83	1.46		Mar-89	0.20		Mar-95	1.78	
Apr-77	0.92		Apr-83	0.81		Apr-89	0.01		Apr-95	1.86	
May-77	0.39		May-83	0.35		May-89	0.41		May-95	2.06	3
Jun-77	0.81		Jun-83	2.26		Jun-89	0.18		Jun-95	2.41	
Jul-77	2.40		Jul-83	1.25		Jul-89	3.28		Jul-95	1.33	
Aug-77	2.13		Aug-83	2.17		Aug-89	0.74		Aug-95	1.90	1
Sep-77	1.32		Sep-83	0.45		Sep-89	0.97		Sep-95	1.07	
Oct-77	0.68		Oct-83	0.33		Oct-89	0.87		Oct-95	0.09	
Nov-77	1.41		Nov-83	0.84		Nov-89	0.00		Nov-95	0.36	2
Dec-77	0.21		Dec-83	0.80	1	Dec-89	0.08	1	Dec-95	0.14	2



ID	130	
STANAME	ALAMOSA BERGMAN FLD	
ELEVATION	7,538	
YEAR	PRECIP (in.)	DAYS MISSING
1948	1.72	0
1949	6.32	7
1950	4.12	0
1951	4.09	0
1952	7.66	5
1953	6.49	0
1954	5.56	0
1955	4.16	0
1956	3.40	0
1957	8.66	0
1958	5.01	0
1959	9.55	0
1960	5.85	0
1961	8.88	7
1962	4.74	0
1963	6.55	2
1964	7.07	0
1965	9.84	0
1966	4.96	0
1967	10.86	0
1968	8.10	0
1969	11.55	0
1970	8.08	0
1971	8.77	0
1972	7.70	0
1973	8.39	0
1974	6.94	0
1975	6.22	0
1976	6.21	0
1977	7.86	0
1978	7.27	0
1979	6.47	0
1980	5.71	0
1981	8.92	0
1982	5.99	0
1983	7.25	0
1984	7.10	0
1985	9.80	0
1986	7.73	0
1987	6.49	0
1988	5.42	0
1989	3.09	30
1990	11.19	0
1991	7.27	0
1992	7.84	92
1993	9.64	33
1994	7.07	0
1995	7.05	0
Mean Precip =	7.13	



ID	776	
STANAME	BLANCA	
ELEVATION	7,750	
YEAR	PRECIP (in.)	DAYS MISSING
1948	1.57	0
1949	6.06	0
1950	3.49	0
1951	4.41	0
1952	7.77	0
1953	9.93	0
1954	8.16	0
1955	6.97	0
1956	5.45	0
1957	11.12	0
1958	6.38	0
1959	8.11	0
1960	5.96	0
1961	9.84	0
1962	5.11	0
1963	6.18	0
1964	6.55	0
1965	9.82	0
1966	6.56	0
1967	9.24	0
1968	9.33	0
1969	10.90	0
1970	7.74	0
1971	8.78	0
1972	6.48	0
1973	7.88	0
1974	6.82	0
1975	4.84	0
1976	7.63	0
1977	7.67	0
1978	9.08	0
1979	8.76	0
1980	8.09	0
1981	9.23	38
1982	10.85	0
1983	10.25	0
1984	9.48	0
1985	9.89	6
1986	11.20	7
1987	8.31	8
1988	9.76	0
1989	7.07	21
1990	12.36	0
1991	9.94	6
1992	9.44	0
1993	9.15	0
1994	12.17	31
1995	10.08	0
Mean Precip =	8.30	

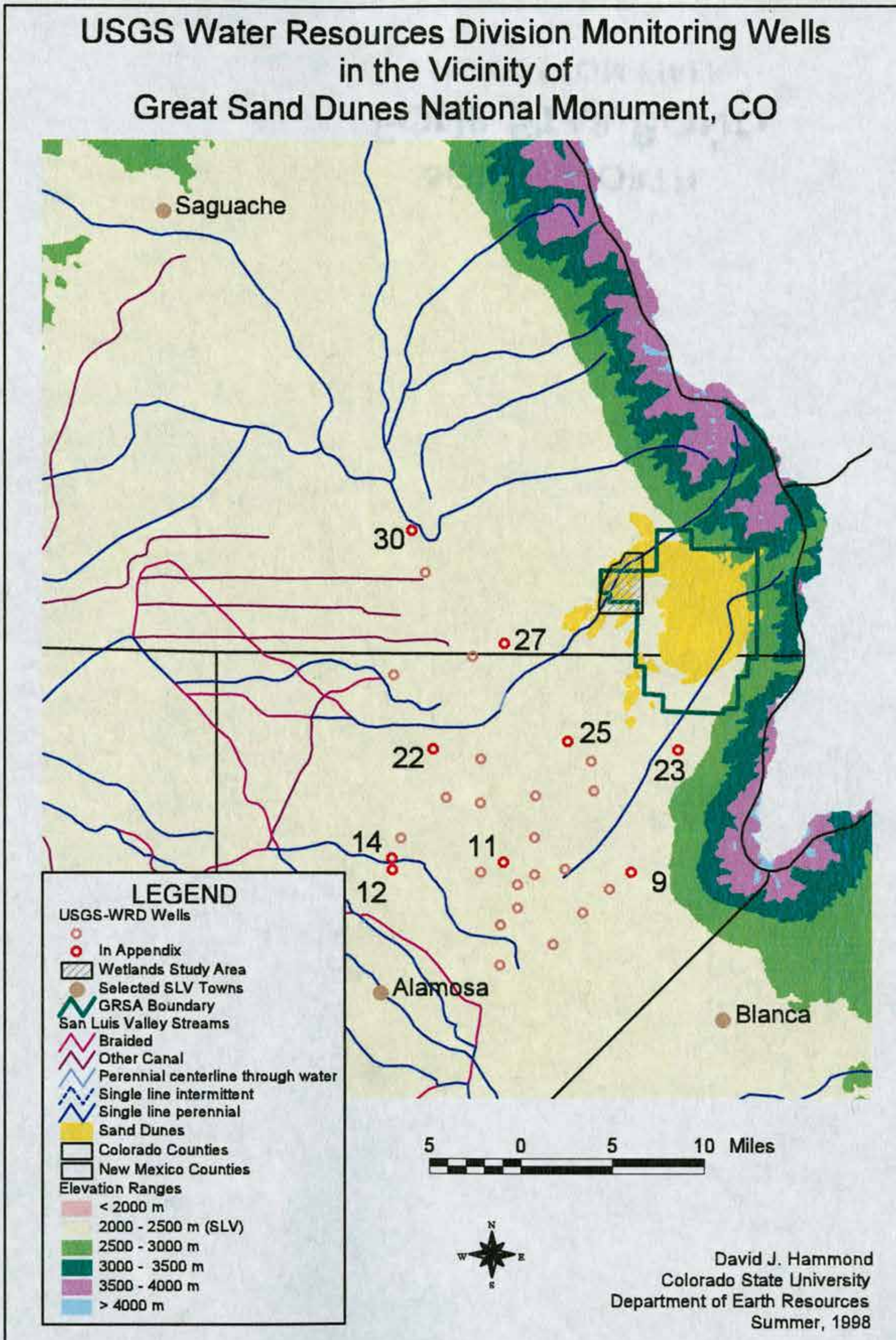


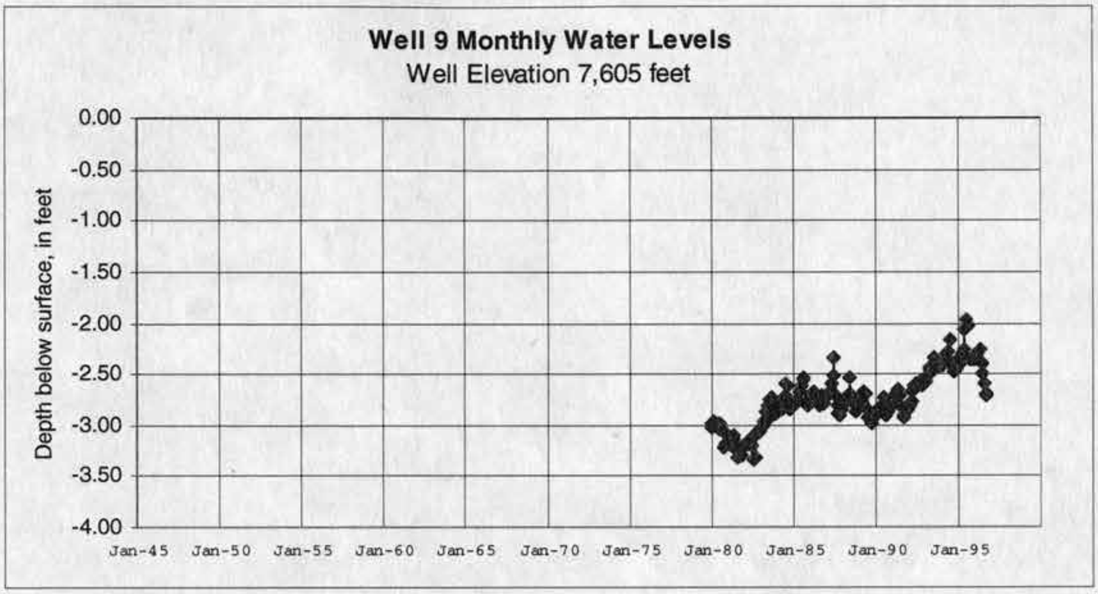
ID	1964	
STANAME	CRESTONE 1 SE	
ELEVATION	8,116	
YEAR	PRECIP (in.)	DAYS MISSING
1948		
1949		
1950		
1951		
1952		
1953		
1954		
1955		
1956		
1957		
1958		
1959		
1960		
1961		
1962		
1963		
1964		
1965		
1966		
1967		
1968		
1969		
1970		
1971		
1972		
1973		
1974		
1975		
1976		
1977		
1978		
1979		
1980		
1981		
1982	15.17	14
1983	16.13	
1984	13.01	
1985	12.32	
1986	16.51	
1987	13.97	
1988	14.39	
1989	10.26	
1990	19.15	
1991	13.25	2
1992	16.77	
1993	13.65	
1994	13.26	
1995	12.11	
Mean =	14.28	

Appendix 2

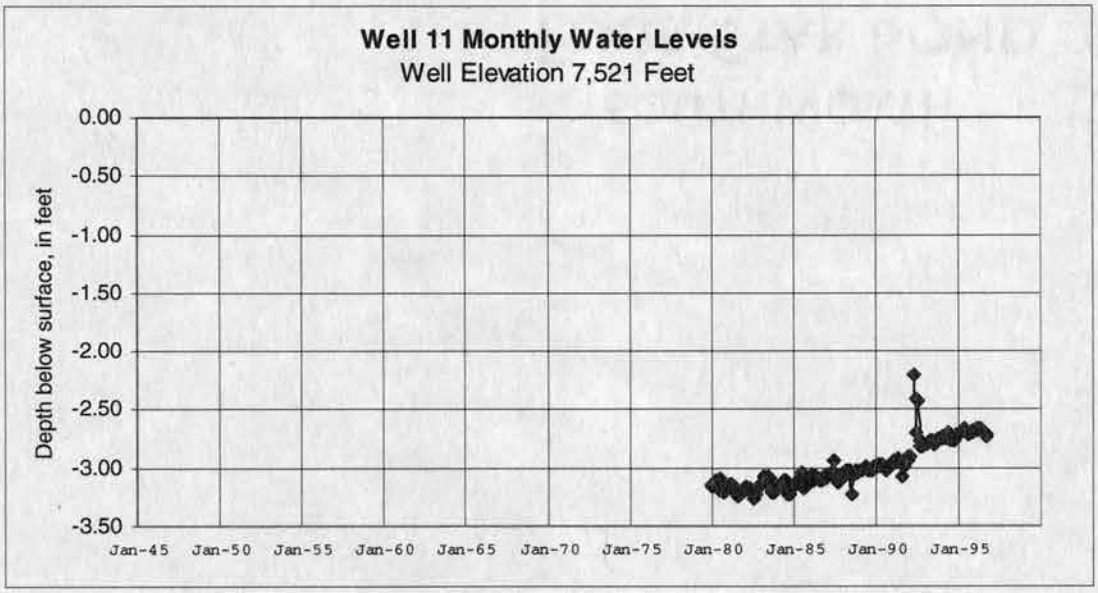
Data Locations:

Groundwater, Discharge & Dendrochronology Data

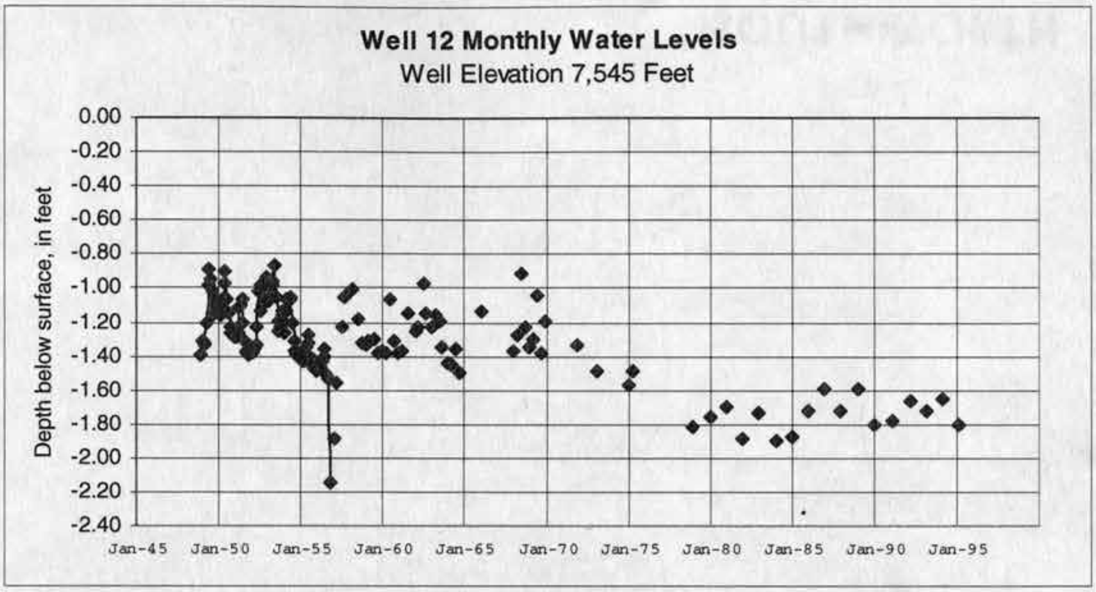

USGS Water Resources Division Monitoring Wells
in the Vicinity of
Great Sand Dunes National Monument, CO
Saguache
30
27
25
22
23
14
11
12
9
Alamosa
Blanca
LEGEND
USGS-WRD Wells
In Appendix
Wetlands Study Area
Selected SLV Towns
GRSA Boundary
San Luis Valley Streams
Braided
Other Canal
Perennial centerline through water
Single line intermittent
Single line perennial
Sand Dunes
Colorado Counties
New Mexico Counties
Elevation Ranges
< 2000 m
2000 - 2500 m (SLV)
2500 - 3000 m
3000 - 3500 m
3500 - 4000 m
> 4000 m
5 0 5 10 Miles
N
W
E
S
David J. Hammond
Colorado State University
Department of Earth Resources
Summer, 1998

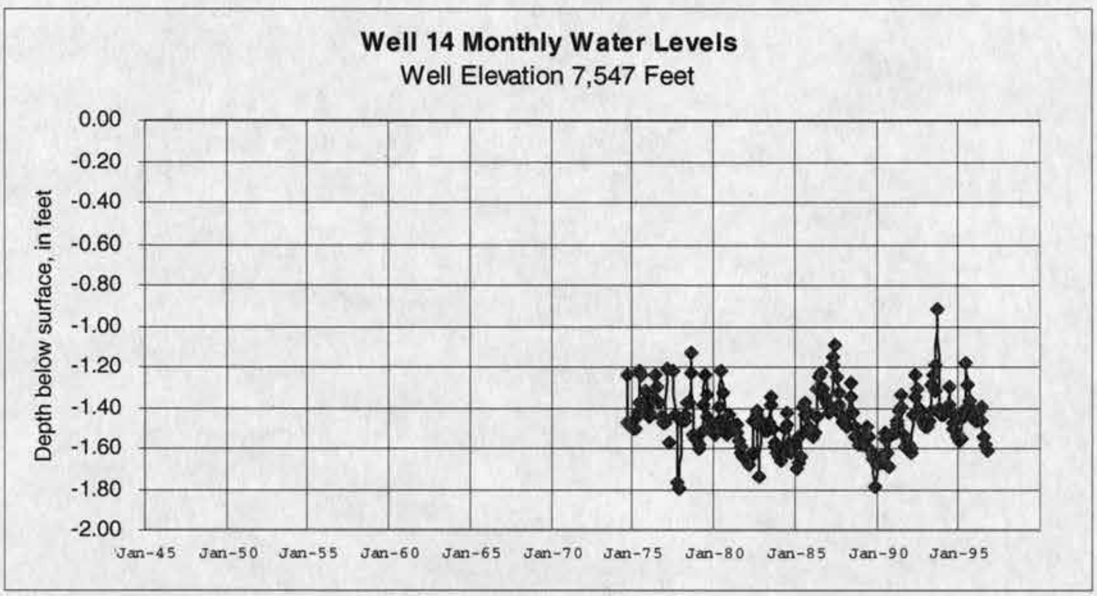


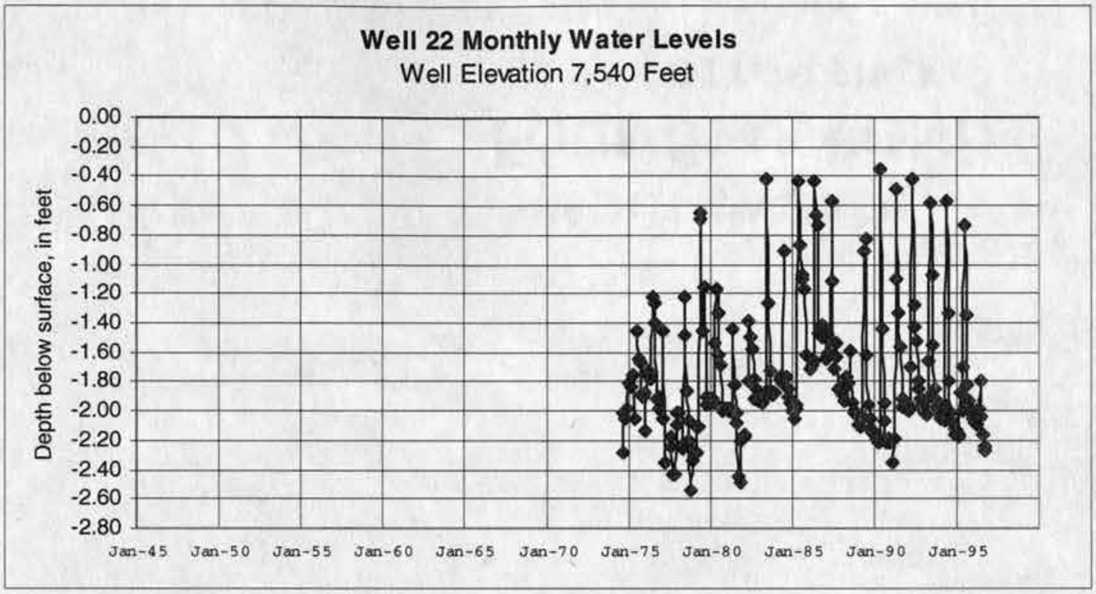
Well 9 Monthly Water Levels
Well Elevation 7,605 feet
Depth below surface, in feet
0.00
-0.50
-1.00
-1.50
-2.00
-2.50
-3.00
-3.50
-4.00
Jan-45
Jan-50
Jan-55
Jan-60
Jan-65
Jan-70
Jan-75
Jan-80
Jan-85
Jan-90
Jan-95

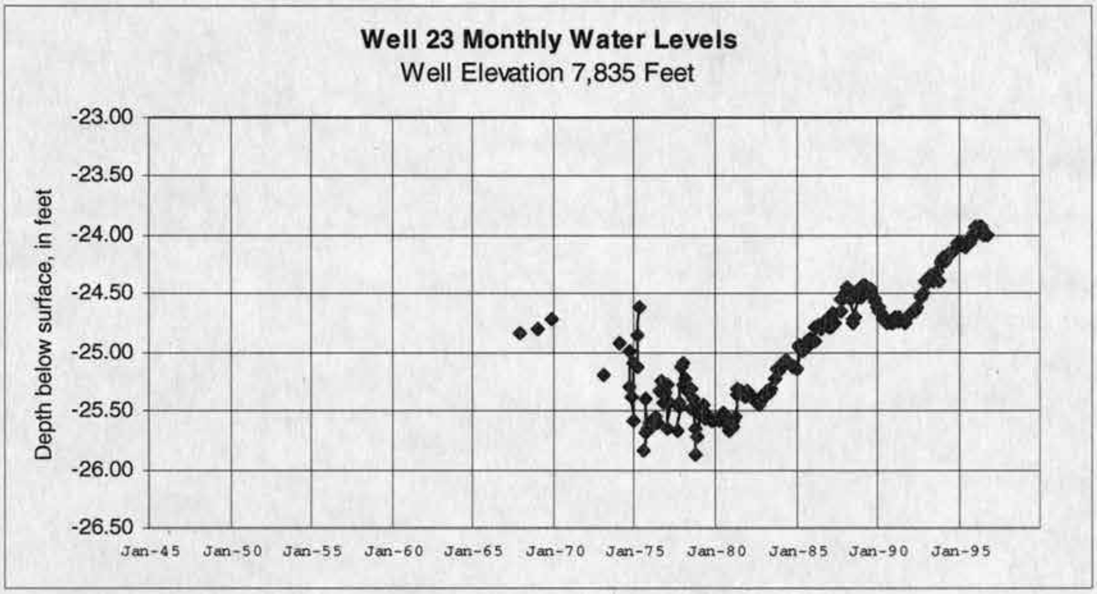


Well 11 Monthly Water Levels
Well Elevation 7,521 Feet
Depth below surface, in feet
0.00
-0.50
-1.00
-1.50
-2.00
-2.50
-3.00
-3.50
Jan-45
Jan-50
Jan-55
Jan-60
Jan-65
Jan-70
Jan-75
Jan-80
Jan-85
Jan-90
Jan-95


Well 12 Monthly Water Levels
Well Elevation 7,545 Feet
Depth below surface, in feet
0.00
-0.20
-0.40
-0.60
-0.80
-1.00
-1.20
-1.40
-1.60
-1.80
-2.00
-2.20
-2.40
Jan-45
Jan-50
Jan-55
Jan-60
Jan-65
Jan-70
Jan-75
Jan-80
Jan-85
Jan-90
Jan-95


Well 14 Monthly Water Levels
Well Elevation 7,547 Feet
Depth below surface, in feet
0.00
-0.20
-0.40
-0.60
-0.80
-1.00
-1.20
-1.40
-1.60
-1.80
-2.00
Jan-45
Jan-50
Jan-55
Jan-60
Jan-65
Jan-70
Jan-75
Jan-80
Jan-85
Jan-90
Jan-95


Well 22 Monthly Water Levels
Well Elevation 7,540 Feet
Depth below surface, in feet
0.00
-0.20
-0.40
-0.60
-0.80
-1.00
-1.20
-1.40
-1.60
-1.80
-2.00
-2.20
-2.40
-2.60
-2.80
Jan-45
Jan-50
Jan-55
Jan-60
Jan-65
Jan-70
Jan-75
Jan-80
Jan-85
Jan-90
Jan-95


Well 23 Monthly Water Levels
Well Elevation 7,835 Feet
Depth below surface, in feet
-23.00
-23.50
-24.00
-24.50
-25.00
-25.50
-26.00
-26.50
Jan-45
Jan-50
Jan-55
Jan-60
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Jan-70
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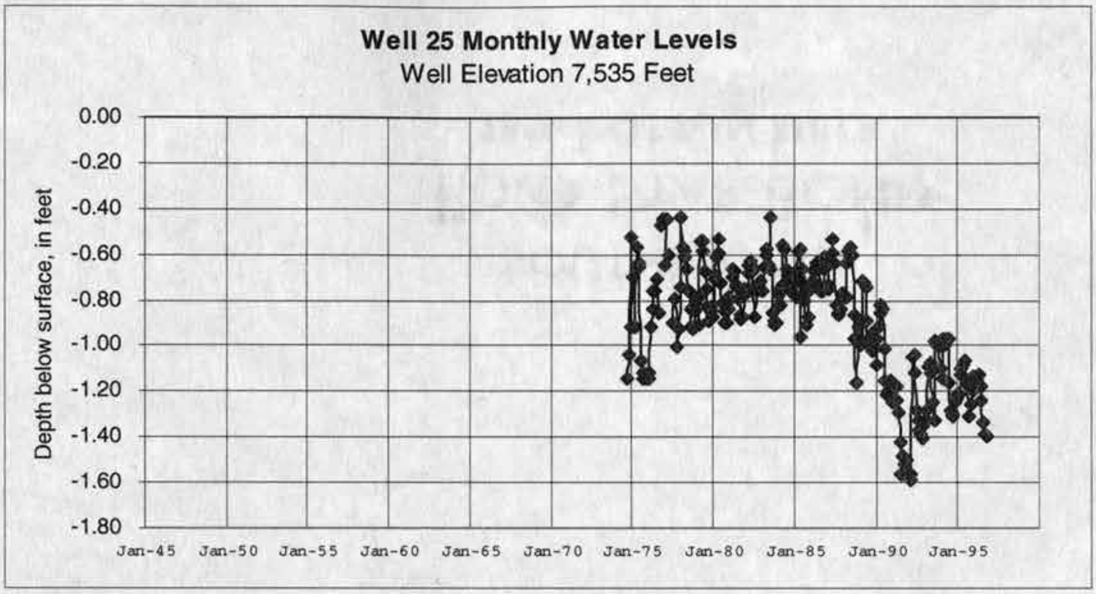
Jan-80
Jan-85
Jan-90
Jan-95


Well 25 Monthly Water Levels
Well Elevation 7,535 Feet
Depth below surface, in feet
0.00
-0.20
-0.40
-0.60
-0.80
-1.00
-1.20
-1.40
-1.60
-1.80
Jan-45
Jan-50
Jan-55
Jan-60
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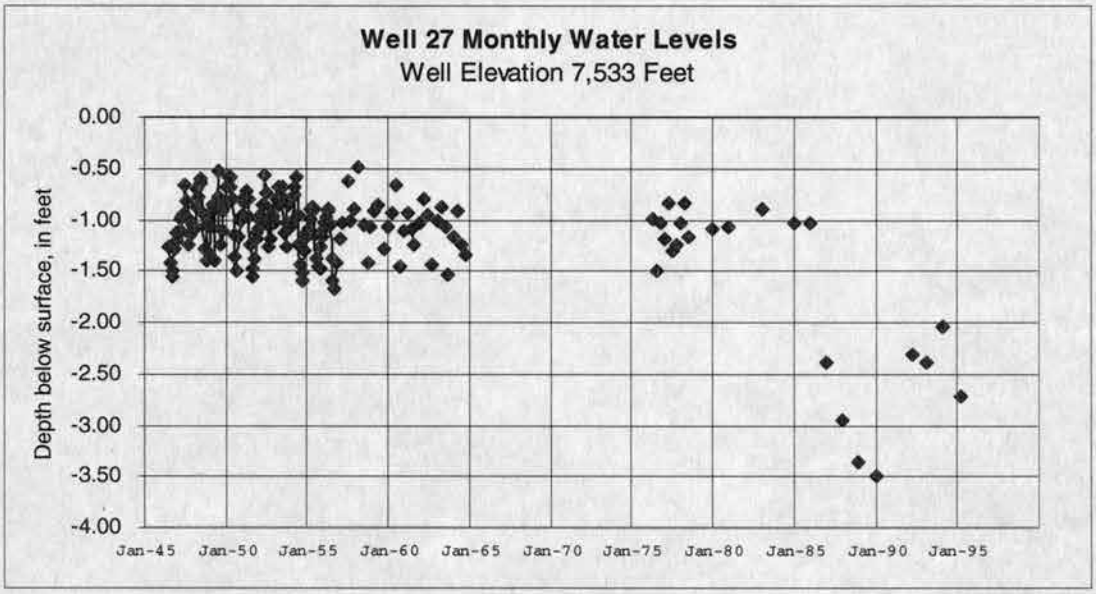
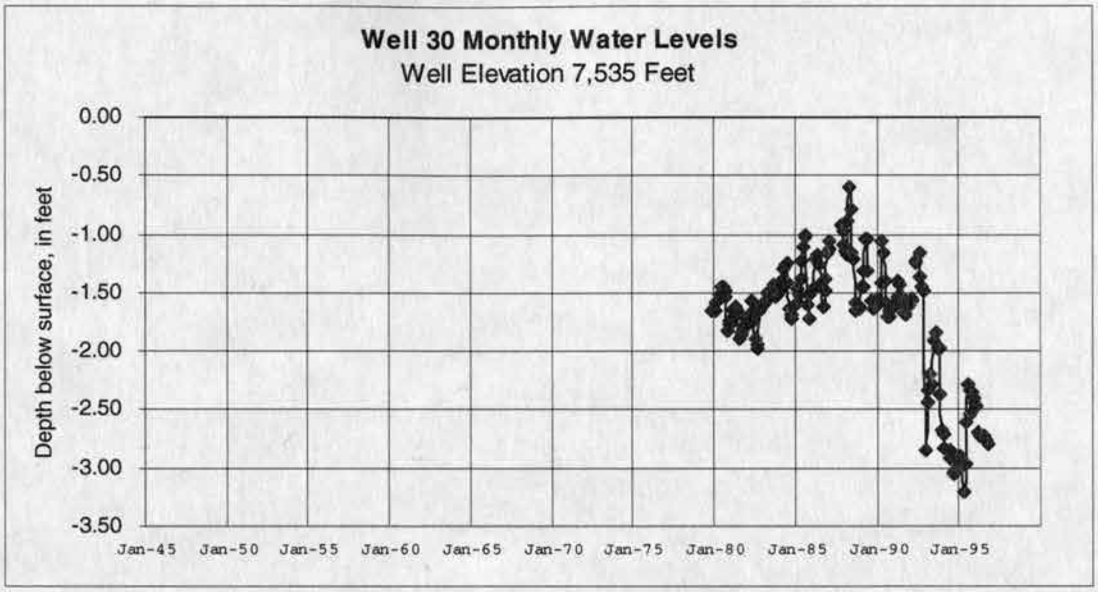
Jan-70
Jan-75
Jan-80
Jan-85
Jan-90
Jan-95


Well 27 Monthly Water Levels
Well Elevation 7,533 Feet
Depth below surface, in feet
0.00
-0.50
-1.00
-1.50
-2.00
-2.50
-3.00
-3.50
-4.00
Jan-45
Jan-50
Jan-55
Jan-60
Jan-65
Jan-70
Jan-75
Jan-80
Jan-85
Jan-90
Jan-95



Well 30 Monthly Water Levels
Well Elevation 7,535 Feet
Depth below surface, in feet
0.00
-0.50
-1.00
-1.50
-2.00
-2.50
-3.00
-3.50
Jan-45
Jan-50
Jan-55
Jan-60
Jan-65
Jan-70
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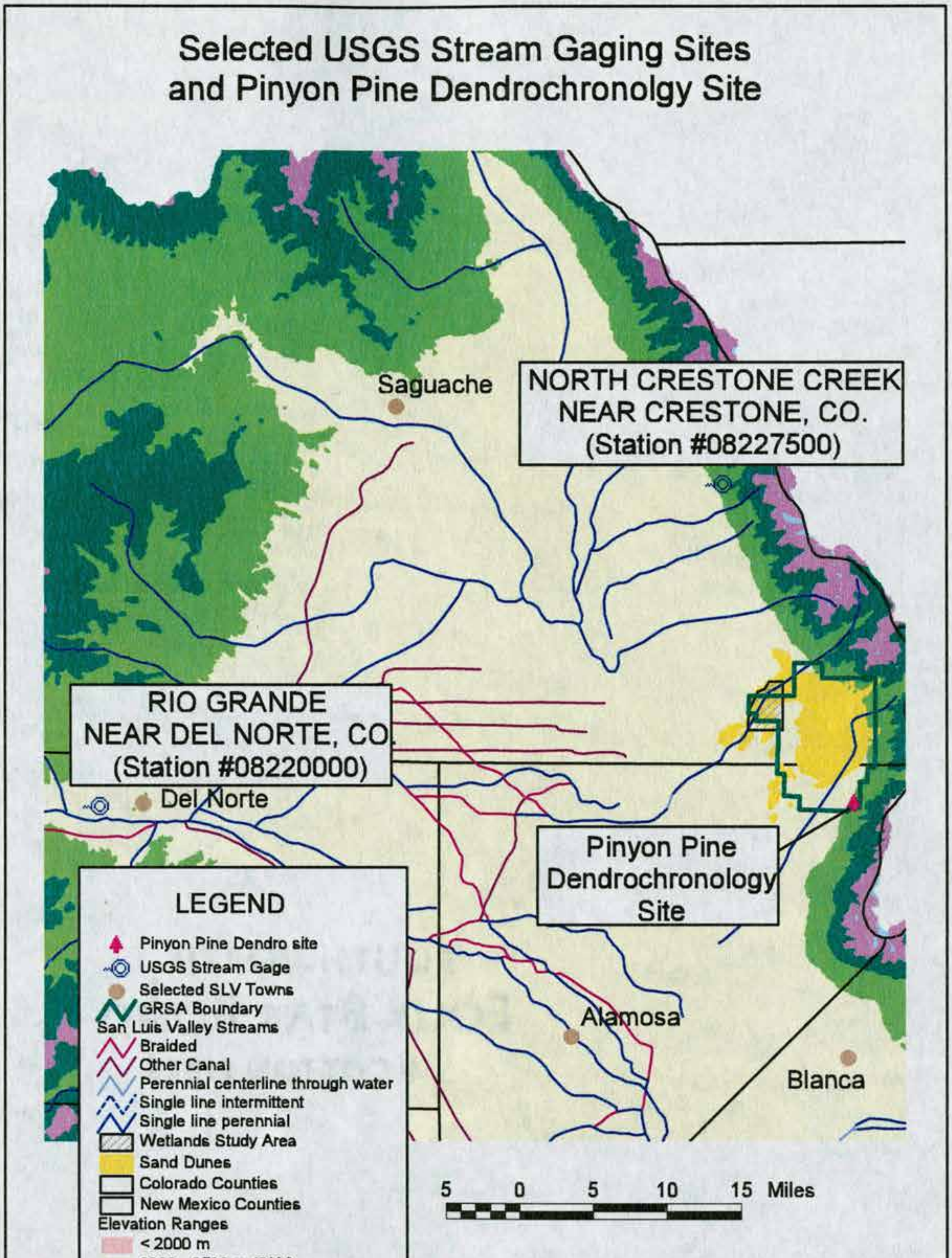
Jan-85
Jan-90
Jan-95


Selected USGS Stream Gaging Sites
and Pinyon Pine Dendrochronolgy Site
Saguache
NORTH CRESTONE CREEK
NEAR CRESTONE, CO.
(Station #08227500)
RIO GRANDE
NEAR DEL NORTE, CO.
(Station #08220000)
Del Norte
Pinyon Pine
Dendrochronology
Site
Alamosa
Blanca
LEGEND
Pinyon Pine Dendro site
USGS Stream Gage
Selected SLV Towns
GRSA Boundary
San Luis Valley Streams
Braided
Other Canal
Perennial centerline through water
Single line intermittent
Single line perennial
Wetlands Study Area
Sand Dunes
Colorado Counties
New Mexico Counties
Elevation Ranges
< 2000 m
2000 - 2500 m (SLV)
2500 - 3000 m
3000 - 3500 m
3500 - 4000 m
> 4000 m
5 0 5 10 15 Miles
N
W
E
S
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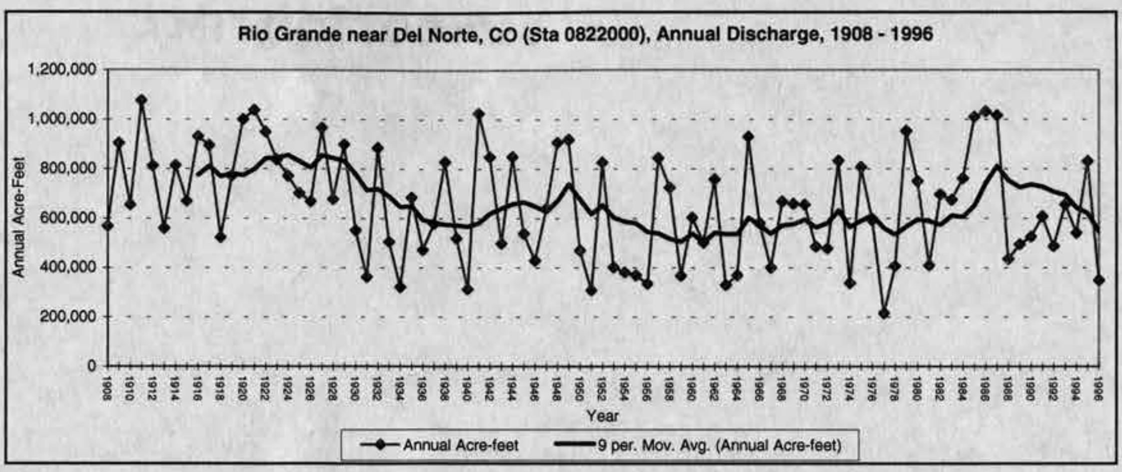
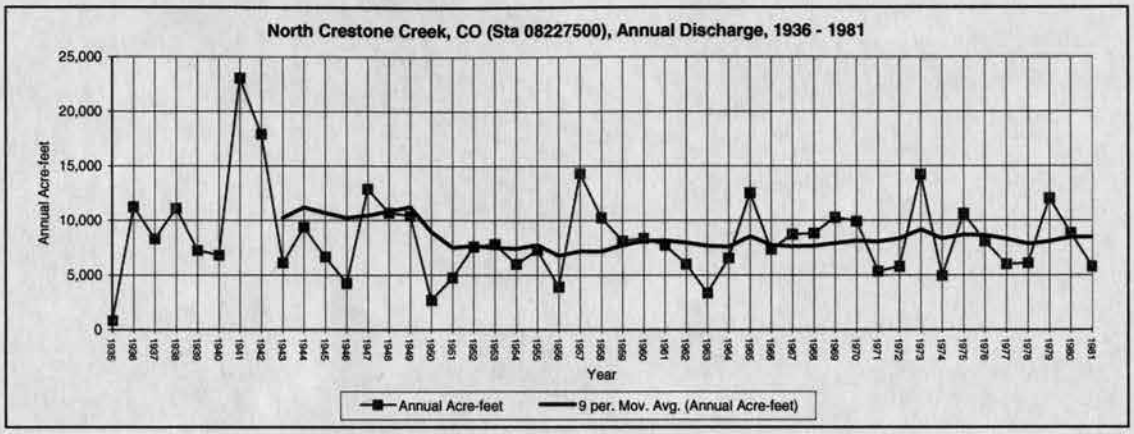


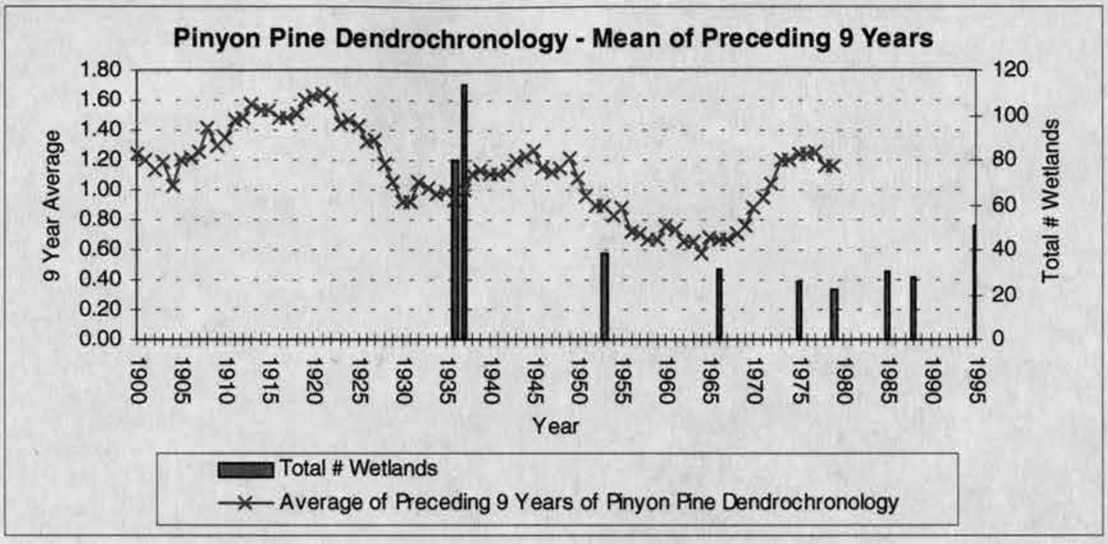
POCode CO
Sta_ID 08220000
Sta_Name RIO GRANDE NEAR DEL NORTE, CO.
Datum 7,980

1908	566,975	1950	469,496
1909	903,488	1951	308,656
1910	654,109	1952	824,963
1911	1,074,130	1953	400,831
1912	810,774	1954	380,639
1913	558,724	1955	367,896
1914	813,010	1956	333,331
1915	669,028	1957	841,906
1916	929,885	1958	722,833
1917	893,778	1959	366,395
1918	522,021	1960	601,164
1919	770,747	1961	500,265
1920	999,765	1962	756,903
1921	1,036,918	1963	328,953
1922	948,711	1964	369,484
1923	835,400	1965	929,620
1924	769,816	1966	578,562
1925	700,768	1967	398,717
1926	666,615	1968	667,341
1927	964,650	1969	657,552
1928	676,281	1970	654,616
1929	898,140	1971	483,851
1930	549,436	1972	476,760
1931	360,671	1973	831,598
1932	883,846	1974	336,929
1933	504,106	1975	806,642
1934	320,621	1976	590,725
1935	684,221	1977	214,729
1936	471,525	1978	405,876
1937	576,719	1979	952,861
1938	828,214	1980	749,719
1939	518,006	1981	408,815
1940	311,852	1982	696,469
1941	1,023,923	1983	673,307
1942	847,361	1984	760,837
1943	497,699	1985	1,008,699
1944	849,178	1986	1,031,135
1945	537,356	1987	1,015,570
1946	427,890	1988	434,095
1947	638,649	1989	493,222
1948	906,290	1990	525,027
1949	917,873	1991	606,387
		1992	486,290
		1993	654,455
		1994	539,112
		1995	829,955
		1996	348,397



POCode CO
Sta_ID 08227500
Sta_name NORTH CRESTONE CREEK NEAR CRESTONE, CO.
Datum 8,360'

1935	808.60		
1936	11,200.27		
1937	8,287.94		
1938	11,069.84		
1939	7,223.30		
1940	6,786.61	1960	8,348.08
1941	23,006.07	1961	7,713.88
1942	17,883.47	1962	5,973.66
1943	6,079.51	1963	3,329.57
1944	9,348.13	1964	6,514.20
1945	6,630.23	1965	12,488.65
1946	4,231.18	1966	7,306.79
1947	12,861.49	1967	8,703.29
1948	10,655.96	1968	8,790.61
1949	10,392.62	1969	10,261.35
1950	2,650.23	1970	9,884.56
1951	4,728.64	1971	5,308.58
1952	7,554.10	1972	5,748.93
1953	7,794.86	1973	14,194.03
1954	5,964.75	1974	4,911.19
1955	7,254.52	1975	10,590.23
1956	3,877.04	1976	8,047.51
1957	14,280.35	1977	5,960.00
1958	10,208.29	1978	6,068.50
1959	8,085.92	1979	11,984.35
		1980	8,822.88
		1981	5,758.83



Year	Pinyon Chron Index	Year	Pinyon Chron Index	Year	Pinyon Chron Index
1900	1.74	1930	0.75	1960	1.27
1901	0.92	1931	1.13	1961	0.36
1902	0.45	1932	1.60	1962	0.44
1903	1.74	1933	1.32	1963	0.33
1904	0.66	1934	0.64	1964	0.23
1905	2.11	1935	0.86	1965	0.95
1906	1.50	1936	0.50	1966	0.96
1907	1.88	1937	1.55	1967	1.07
1908	1.71	1938	1.66	1968	0.79
1909	0.62	1939	0.98	1969	1.67
1910	1.45	1940	0.91	1970	1.43
1911	1.52	1941	1.55	1971	1.04
1912	1.86	1942	1.57	1972	1.16
1913	1.47	1943	1.21	1973	1.70
1914	1.79	1944	1.11	1974	1.01
1915	1.56	1945	0.90	1975	1.29
1916	1.31	1946	0.43	1976	1.03
1917	1.70	1947	1.47	1977	0.96
1918	0.89	1948	1.23	1978	0.78
1919	2.31	1949	1.42	1979	1.47
1920	1.79	1950	0.34	1980	
1921	1.95	1951	0.54		
1922	1.16	1952	0.59		
1923	0.34	1953	1.08		
1924	1.74	1954	0.38		
1925	0.98	1955	0.88		
1926	0.71	1956	0.06		
1927	1.02	1957	1.09		
1928	0.90	1958	0.99		
1929	0.65	1959	0.44		

Appendix 3

Mosaicking of Unrectified Images

In order to mosaic unreferenced images, a system was devised to merge photos based on the pixel coordinate values of the file. File coordinates in ERDAS start with minimum x,y values in the upper left corner of the image and increase to the right and downwards. Map coordinates start with the minimum x,y in the lower left and increase to the right ("east") and upwards ("north"). Mosaics are created using the map coordinates so it is these values that are used.

The first step of the mosaic process for the unreferenced photos involved subsetting the full image to the effective area of the photo. Sufficient, but not excessive overlap or sidelap, should be available between successive images so that similar features can be picked from both images. By subsetting to the central portion, the area of maximum radial distortion along the edges of a photograph is removed. This is where having full stereo coverage is critical for better results of the mosaic. The only exception to this subsetting is the outer edges of photos along the exterior margins of the photo set were not removed. These margins were included in the final mosaics.

After the image has been subset, then map coordinates are created for the pixels. Map coordinates can be created for an unreferenced image with the Image Info pulldown menu. Map coordinate values can also be adjusted using this same menu by simply typing in a new number.

For analysis of the study area, the best results were obtained by starting with the photo over the wetlands and "building out" from there. The starting image is called the "destination image" and the image to be adjusted is the "source image". If photos to the south of the destination image are to be included, the coordinates of the destination image have to be increased in value. This allows for the pixel values at the southern extent of the images to be mosaicked to be greater than zero.

The adjustment of pixel values is a simple process. By starting crosshairs in the Viewer windows (View/Inquire Cursor) of both images, the pixel coordinate values can be read. A distinctive point is found on both images in approximately the middle of the overlap area and the pixel value for the source image is adjusted (in Image Info) to match the coordinate value of the destination image pixel. Points such as small bushes, distinctive shadow patterns due to dune topography or points of light were used. Since the photos along a flight line are taken only seconds apart, these types of points can be used by this method.

The images are then checked for rotation by following the crosshairs, from the common central point to both sides of the two images. A point is found on the left side of the source image that is on the crosshairs in the destination image and the values for this point (source image; lx,ly) are read. Move along the crosshairs to the right side of both images. Another point is found on the right side of the images that is on the crosshairs of the destination image. Read the x,y values for this point in the source image (source image; rx,ry). By subtracting the x values and the y values for the points in the source image you get the legs of a right triangle. Take the arc tangent of $\Delta y/\Delta x$ to get the degrees of rotation for the source image to better match the destination image. The rotation can be adjusted from the "Apply Linear Adjustment" pulldown menu in the Transform Editor. Most of the photos needed a slight amount (1^{o}- 2^{o}) of rotation to compensate for misalignment introduced in scanning or due to flight line crabbing.

After final rotation of the source image, the x,y values for the central point are rechecked since this had changed. Pixel values in the source image are then readjusted to match the destination image. Now the pixel values will be continuous across the two images. This process is then repeated to match the next photo along the flight line. What was the source image is now the destination image for the next match.

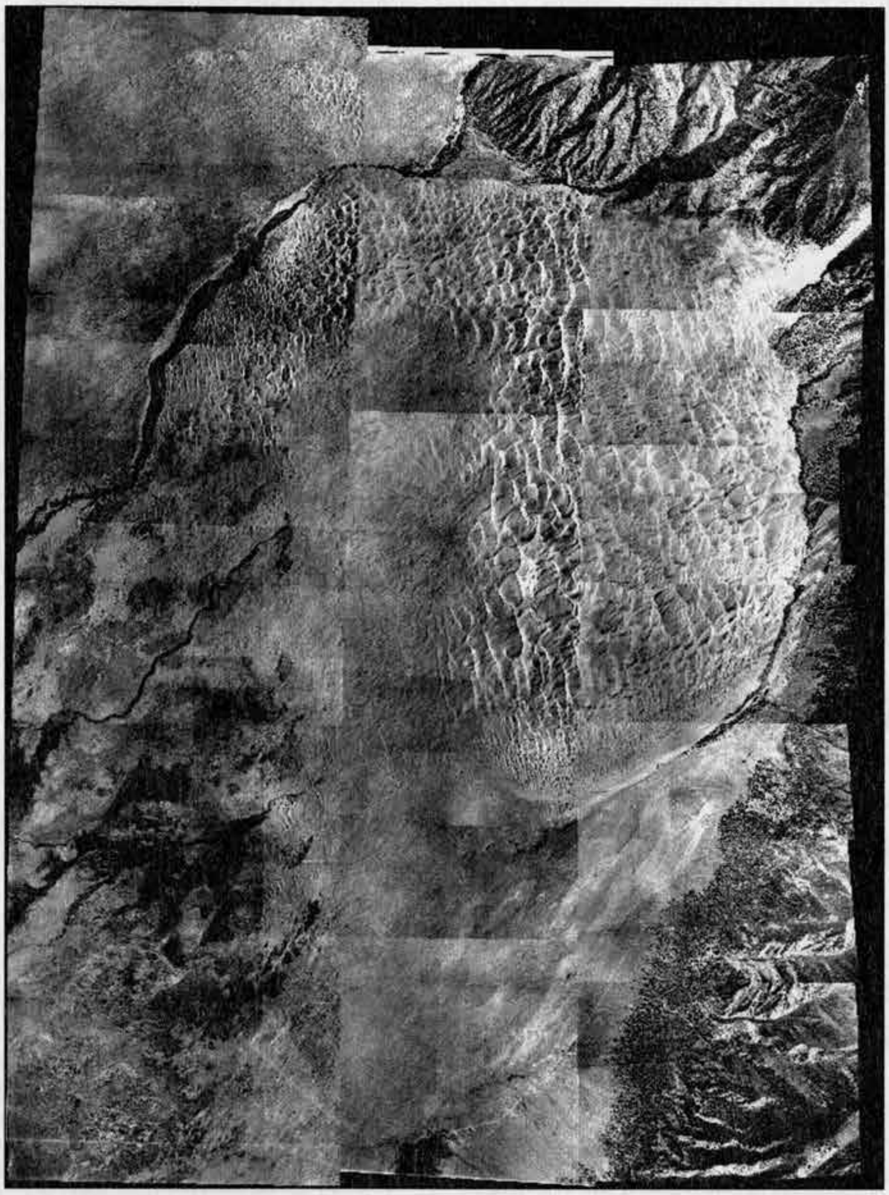
Once all photos for the mosaic have been adjusted in this manner then they can be mosaicked based on the pixel coordinates. The mosaic tool is found under Utility/Mosaic Images. As each file for the mosaic is added to the list in the Mosaic Tool CellArray, a graphic preview is also created in another window. Outlines of the extents of the images are displayed in the Preview window. If there is an error in the values of the map coordinates, the image will not appear in the proper place. The mosaic process must then be abandoned and the correct values input to the file in error.

The images for the mosaic are selected in reverse order from which they were adjusted. This allows for the image over the area of interest to lie on top by using the " " stitching option. Type in the name of the output image and the job is ready to run.

Appendix 4

Aerial Photo Mosaics

1936 Aerial Photo Mosaic
Great Sand Dunes National Monument, CO



3000 0 3000 6000 9000 Meters

Photo Scale: 1:31,680
Number of GCP: 8
Transformation Order: 2

X RMS: 5.541 meters
Y RMS: 4.338
Total RMS: 7.036

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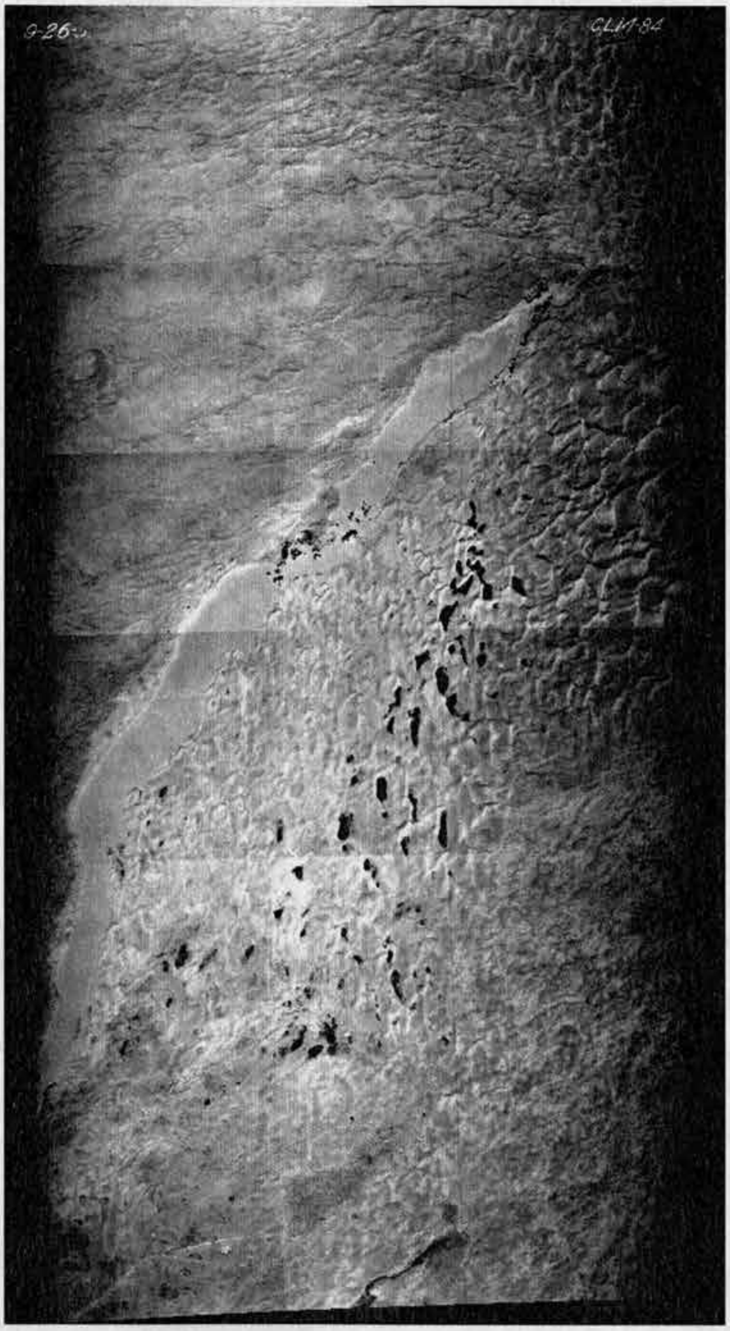
1937 Aerial Photo Mosaic

Great Sand Dunes National Monument, CO



500 0 500 1000 1500 2000 2500 3000 Meters

Photo Scale: 1:20,000
Number of GCP: 7
Transformation Order: 2

X RMS: 1.435 meters
Y RMS: 1.250
Total RMS: 1.903

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1953 Aerial Photo Mosaic
Great Sand Dunes National Monument, CO

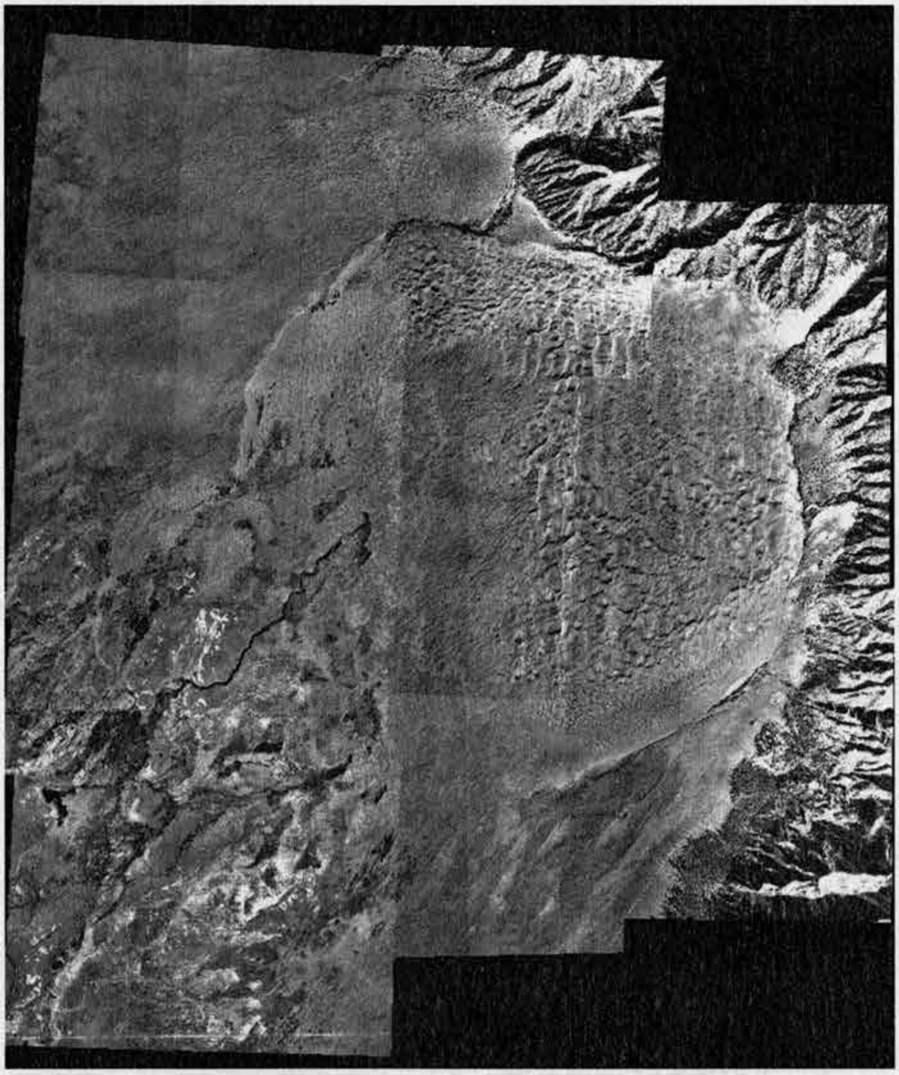

Photo Scale: 1:53,000
Number of GCP: 9
Transformation Order: 2

X RMS: 3.283 meters
Y RMS: 5.040
Total RMS: 6.014

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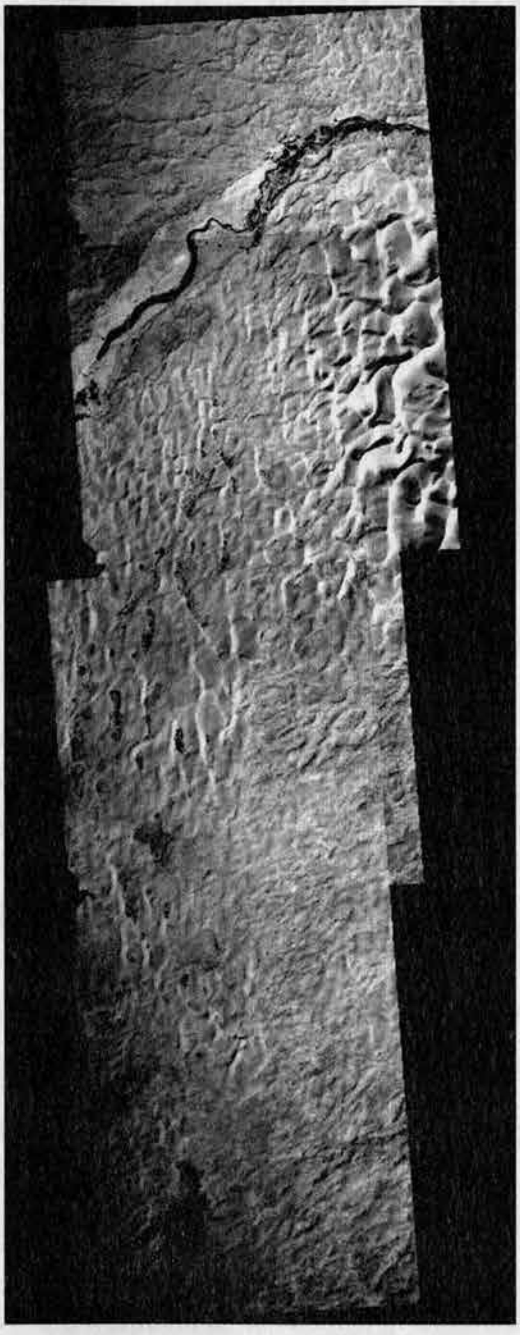
1957 Aerial Photo Mosaic
Great Sand Dunes National Monument, CO



600 0 600 1200 1800 Meters

Photo Scale: 1:20,000
Number of GCP: 6
Transformation Order: 1

X RMS: 2.987 meters
Y RMS: 4.994
Total RMS: 5.820

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1966 Aerial Photo Mosaic
Great Sand Dunes National Monument, CO

3000 0 3000 6000 9000 Meters

Photo Scale: 1:20,157
Number of GCP: 13
Transformation Order: 2

X RMS: 2.363 meters
Y RMS: 3.894
Total RMS: 4.555

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1975 Aerial Photo Mosaic
Great Sand Dunes National Monument, CO

Photo Scale: 1:80,000
Number of GCP: 8
Transformation Order: 1

X RMS: 8.778 meters
Y RMS: 4.661
Total RMS: 9.939

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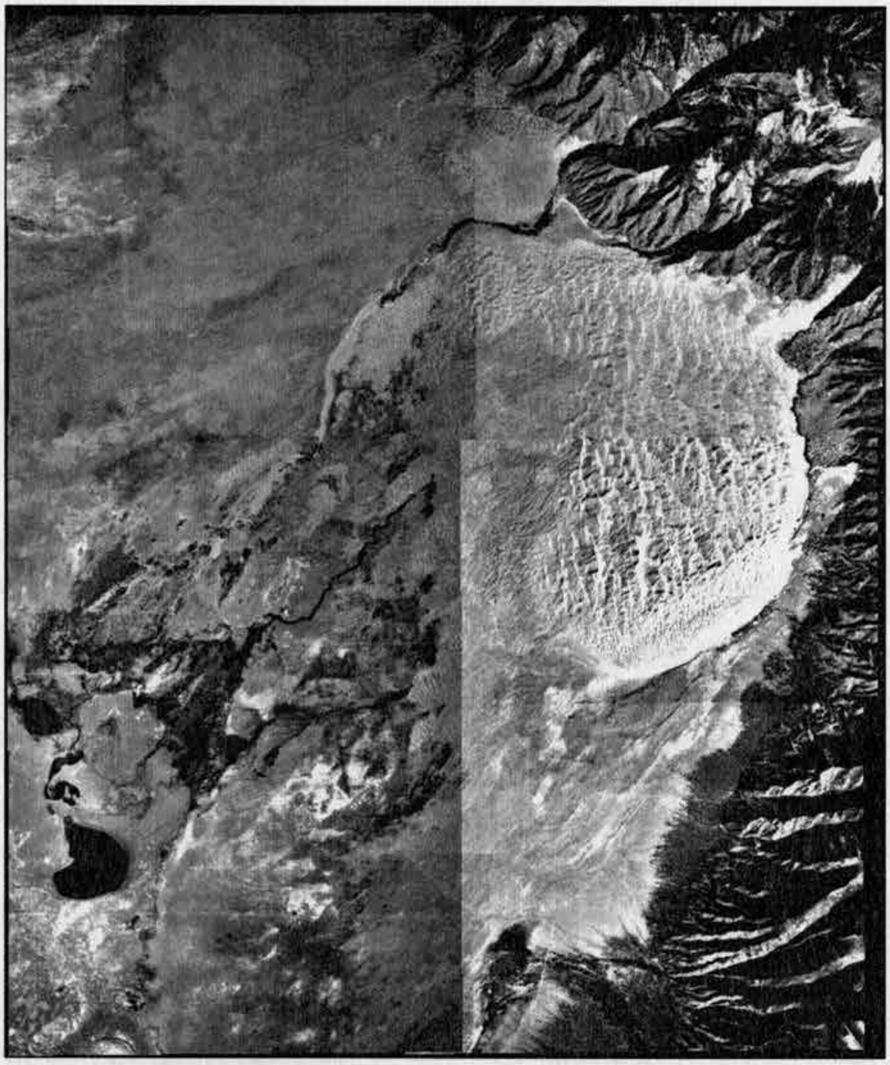
1979 Aerial Photo Mosaic
Great Sand Dunes National Monument, CO



3000 0 3000 6000 9000 12000 Meters

Photo Scale: 1:78,000
Number of GCP: 14
Transformation Order: 1

X RMS: 10.949 meters
Y RMS: 8.739
Total RMS: 14.012

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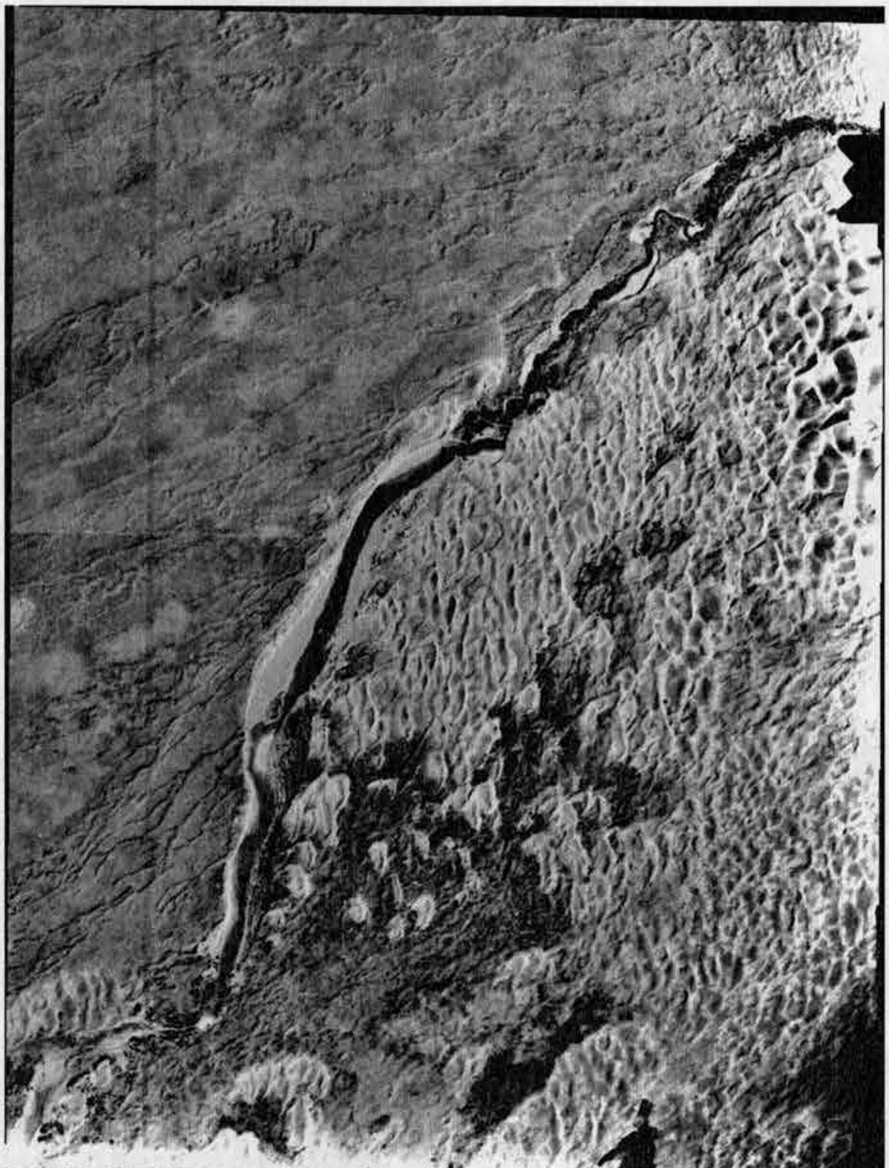
1985 Aerial Photo Mosaic
Great Sand Dunes National Monument, CO



1000 0 1000 2000 3000 Meters

Photo Scale: 1:58,000
Number of GCP: 8
Transformation Order: 1

X RMS: 4.077 meters
Y RMS: 3.069
Total RMS: 5.104

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1988 Aerial Photo OrthophotoMosaic
Great Sand Dunes National Monument, CO

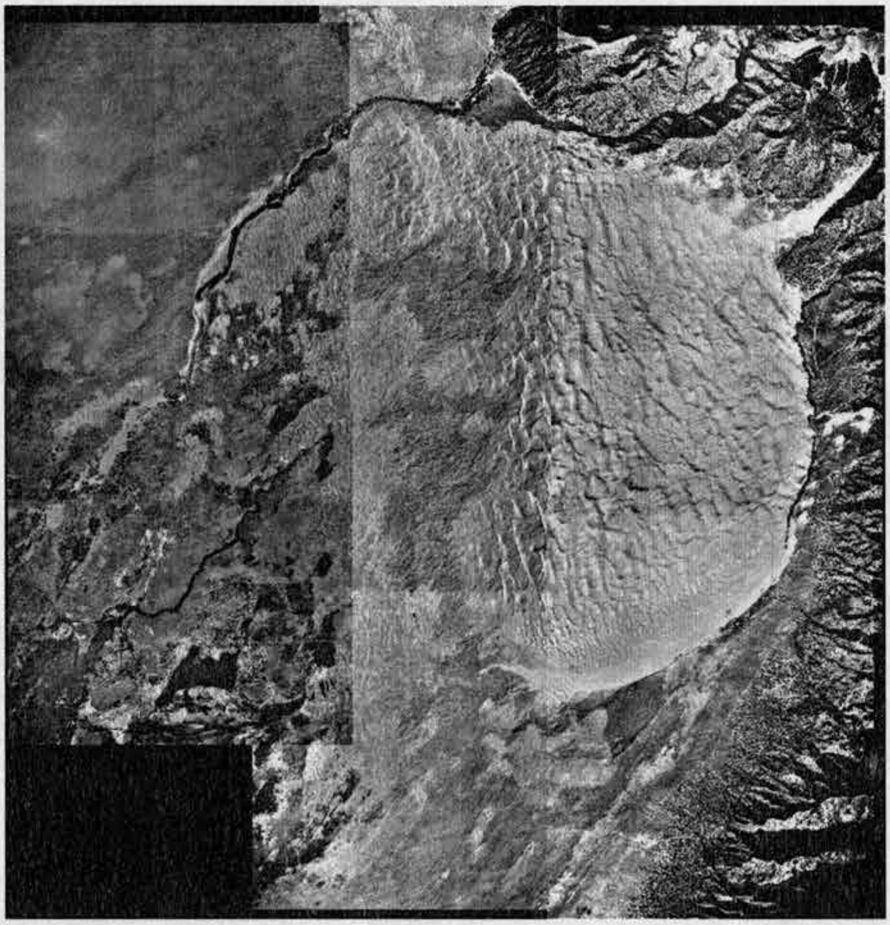

Photo Scale: 1:40,000
Number of GCP:
Transformation Order:

X RMS:
Y RMS:
Total RMS: Orthophoto

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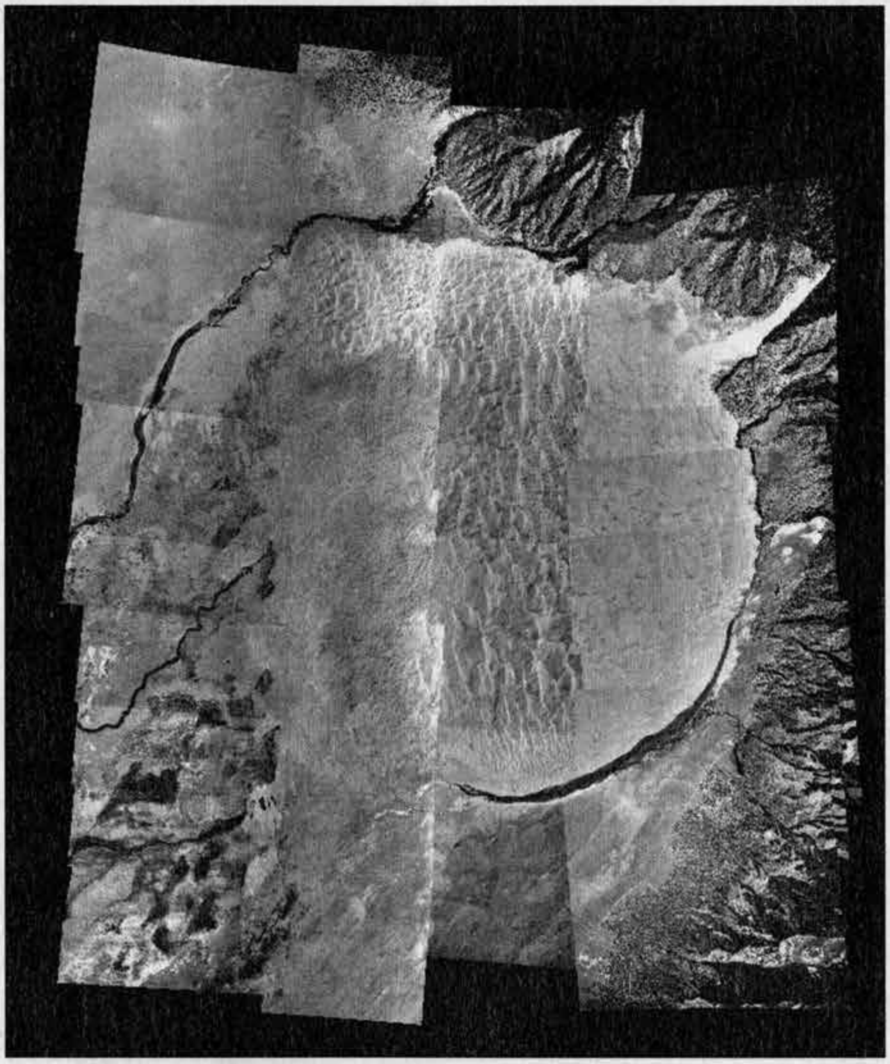
1995 Aerial Photo Mosaic
Great Sand Dunes National Monument, CO



3000 0 3000 6000 9000 Meters

Photo Scale: 1:24,000 X RMS: 2.727 meters
Number of GCP: 12 Y RMS: 2.198
Transformation Order: 3 Total RMS: 3.504

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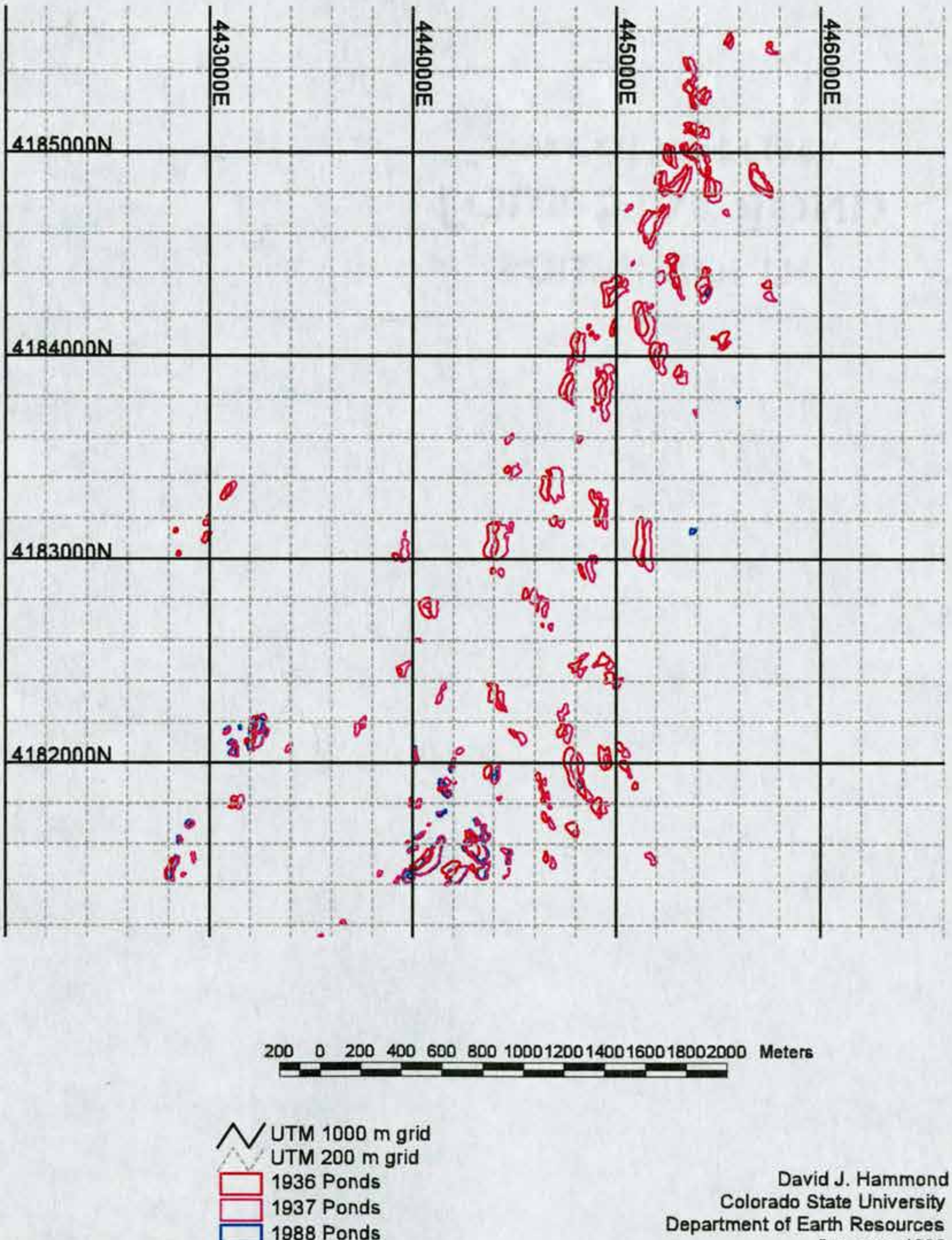
Appendix 5

Wetland Polygon Comparison Plots

Wetland Polygon Comparison View

Great Sand Dunes National Monument, CO

1936 vs. 1937



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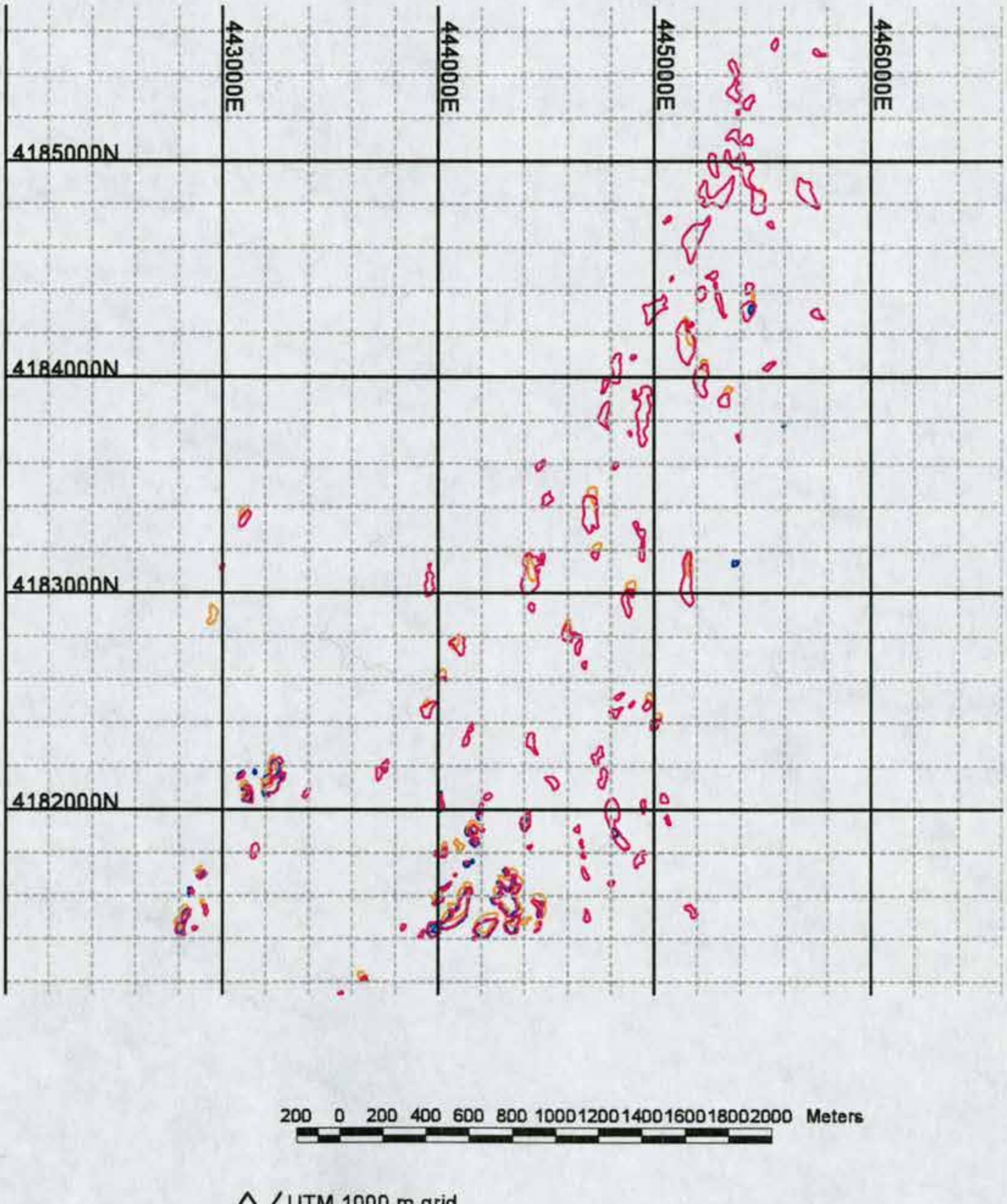
Wetland Polygon Comparison View

Great Sand Dunes National Monument, CO

1937 vs. 1953



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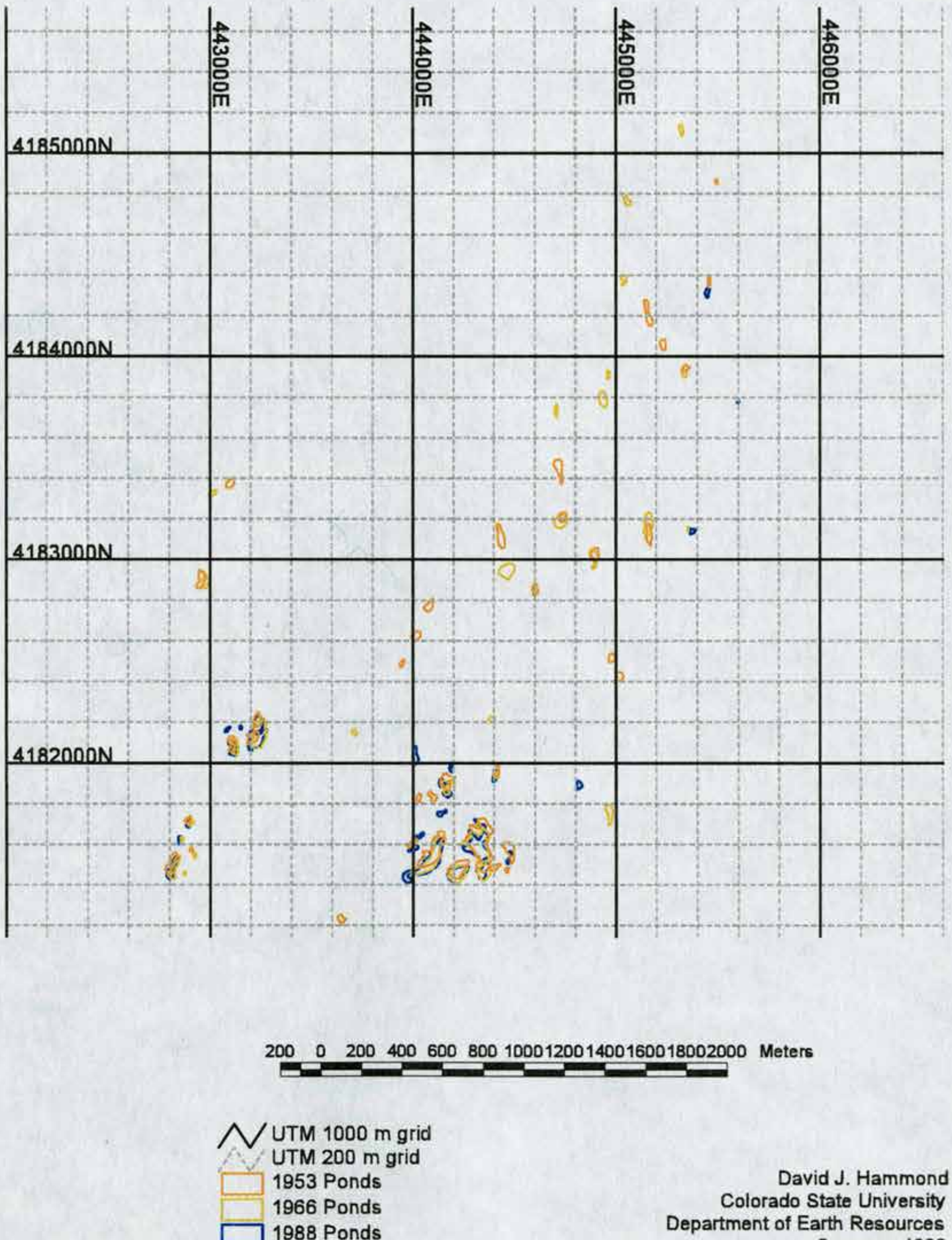
Wetland Polygon Comparison View

Great Sand Dunes National Monument, CO

1953 vs. 1966



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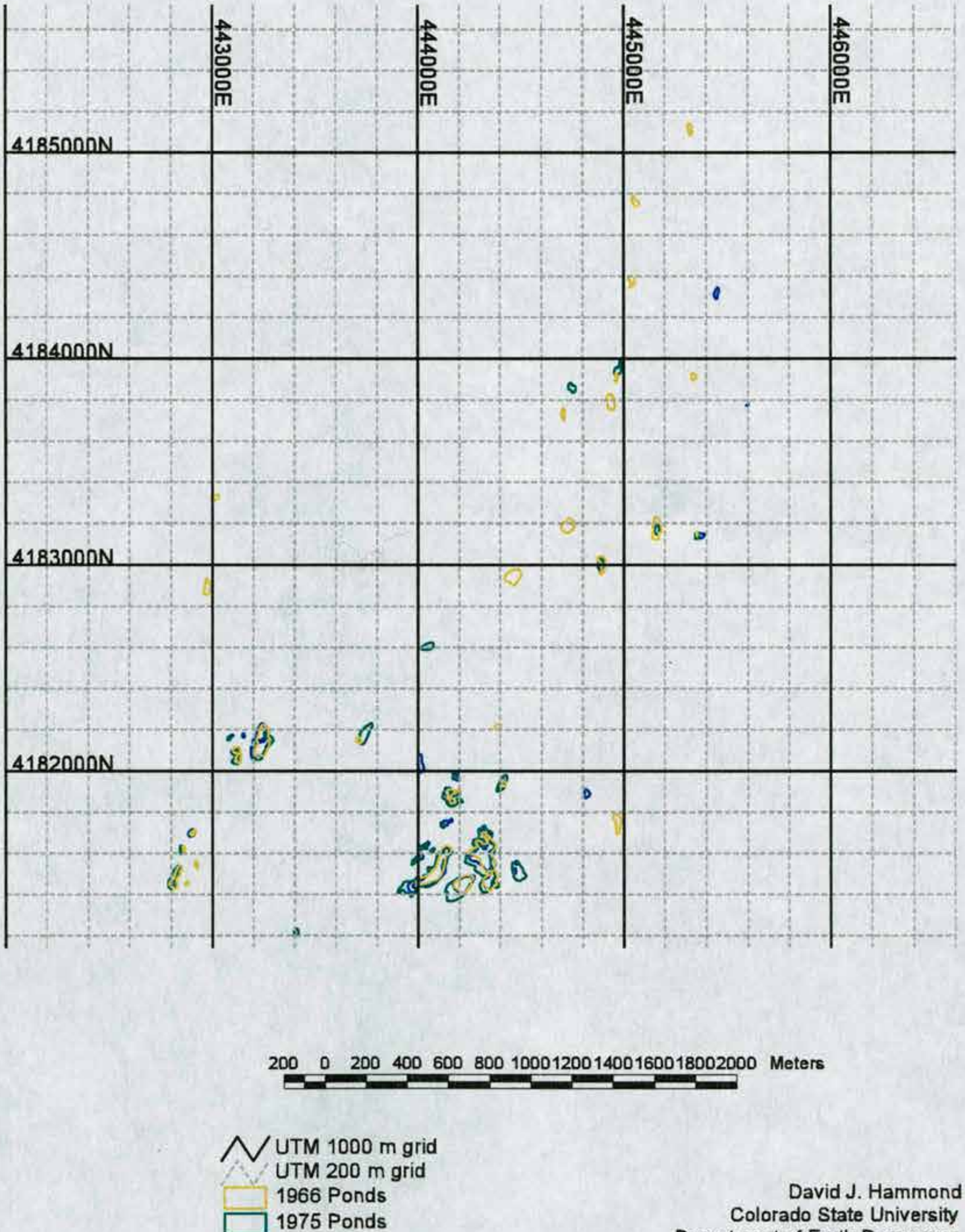
Wetland Polygon Comparison View

Great Sand Dunes National Monument, CO

1966 vs. 1975



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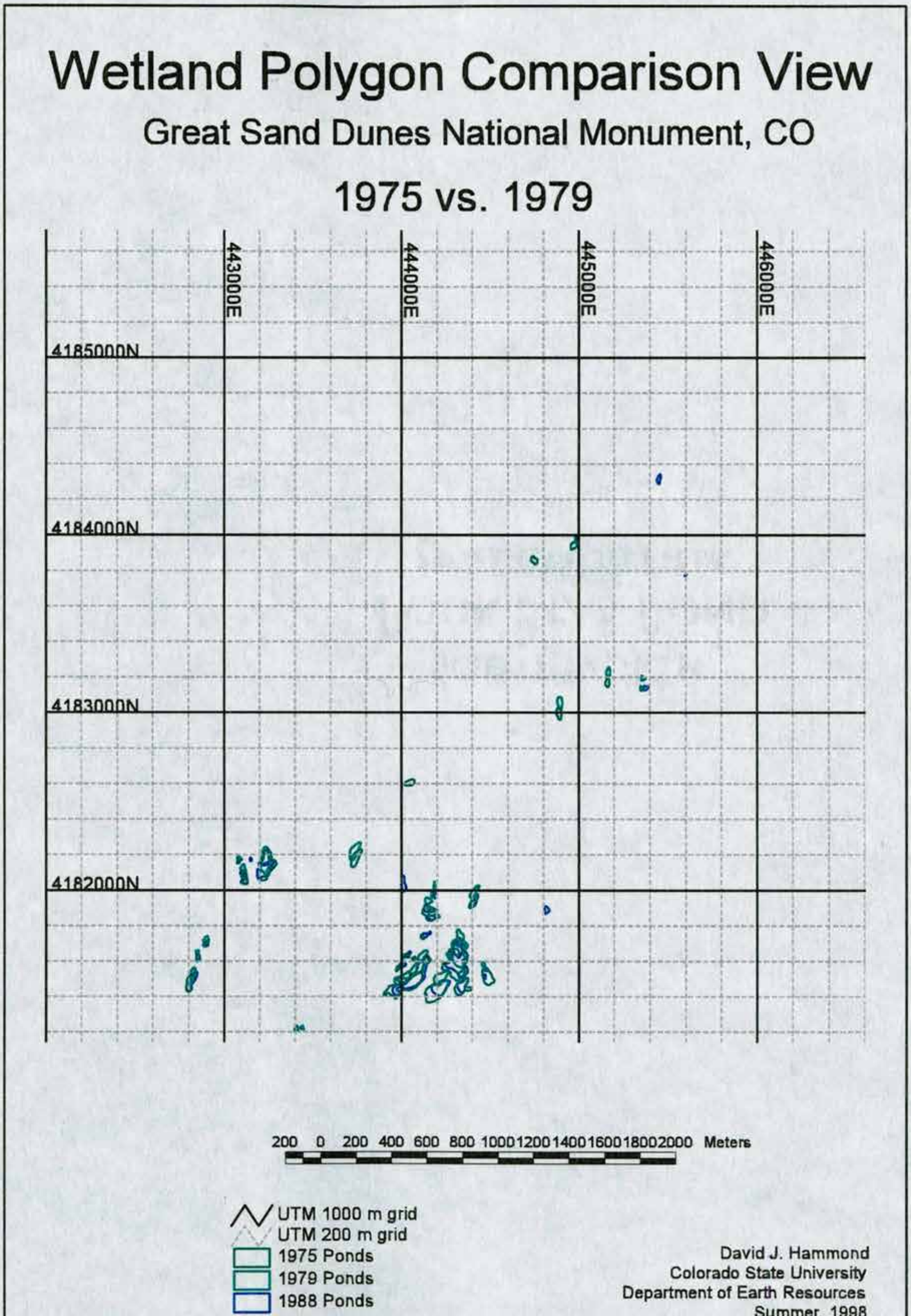
Wetland Polygon Comparison View
Great Sand Dunes National Monument, CO
1975 vs. 1979
443000E
444000E
445000E
446000E
4185000N
4184000N
4183000N
4182000N
200 0 200 400 600 800 1000 1200 1400 1600 1800 2000 Meters
UTM 1000 m grid
UTM 200 m grid
1975 Ponds
1979 Ponds
1988 Ponds
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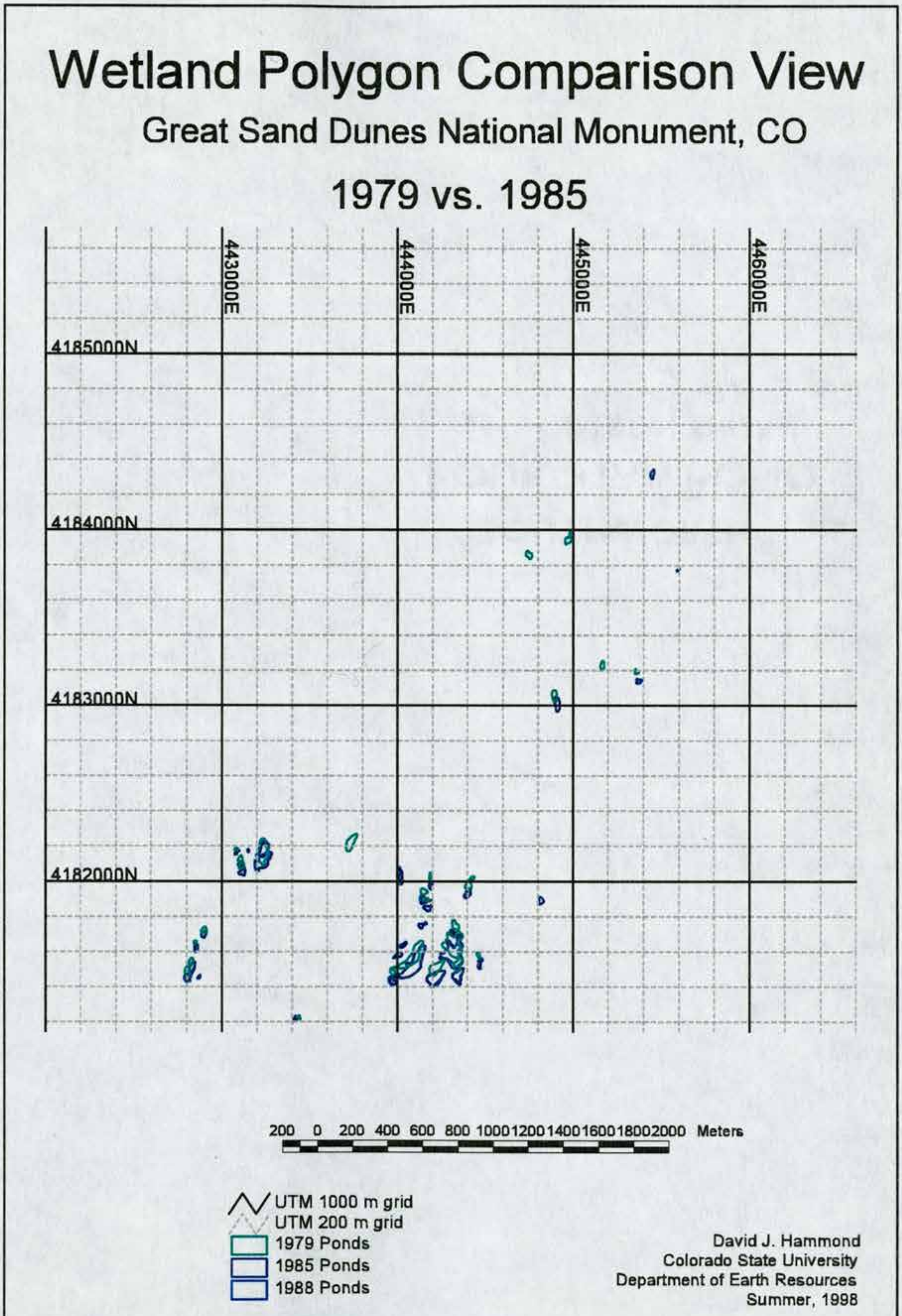
Wetland Polygon Comparison View
Great Sand Dunes National Monument, CO
1979 vs. 1985
443000E
444000E
445000E
446000E
4185000N
4184000N
4183000N
4182000N
200 0 200 400 600 800 1000 1200 1400 1600 1800 2000 Meters
UTM 1000 m grid
UTM 200 m grid
1979 Ponds
1985 Ponds
1988 Ponds
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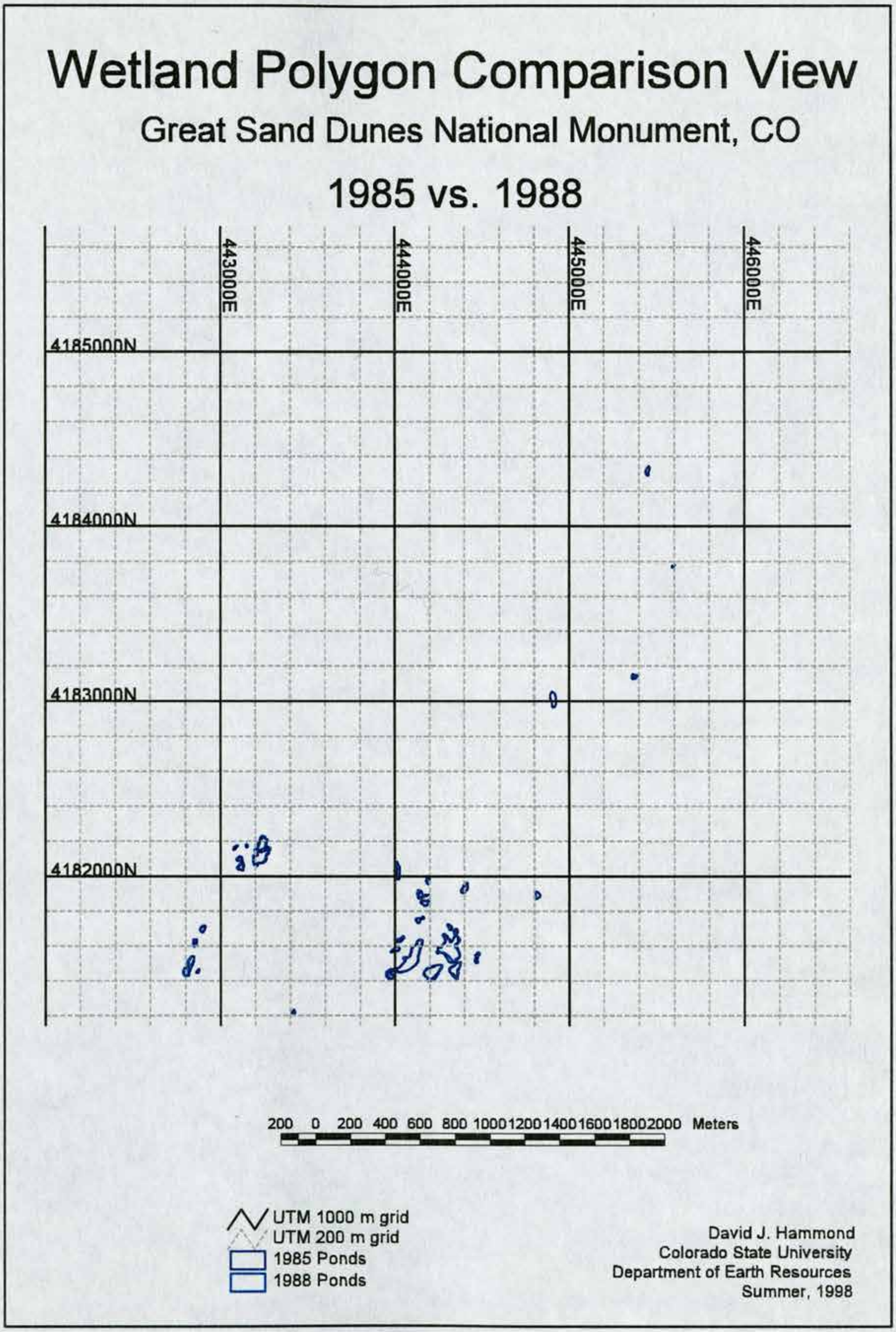

Wetland Polygon Comparison View
Great Sand Dunes National Monument, CO
1985 vs. 1988
443000E
444000E
445000E
446000E
4185000N
4184000N
4183000N
4182000N
200 0 200 400 600 800 1000 1200 1400 1600 1800 2000 Meters
UTM 1000 m grid
UTM 200 m grid
1985 Ponds
1988 Ponds
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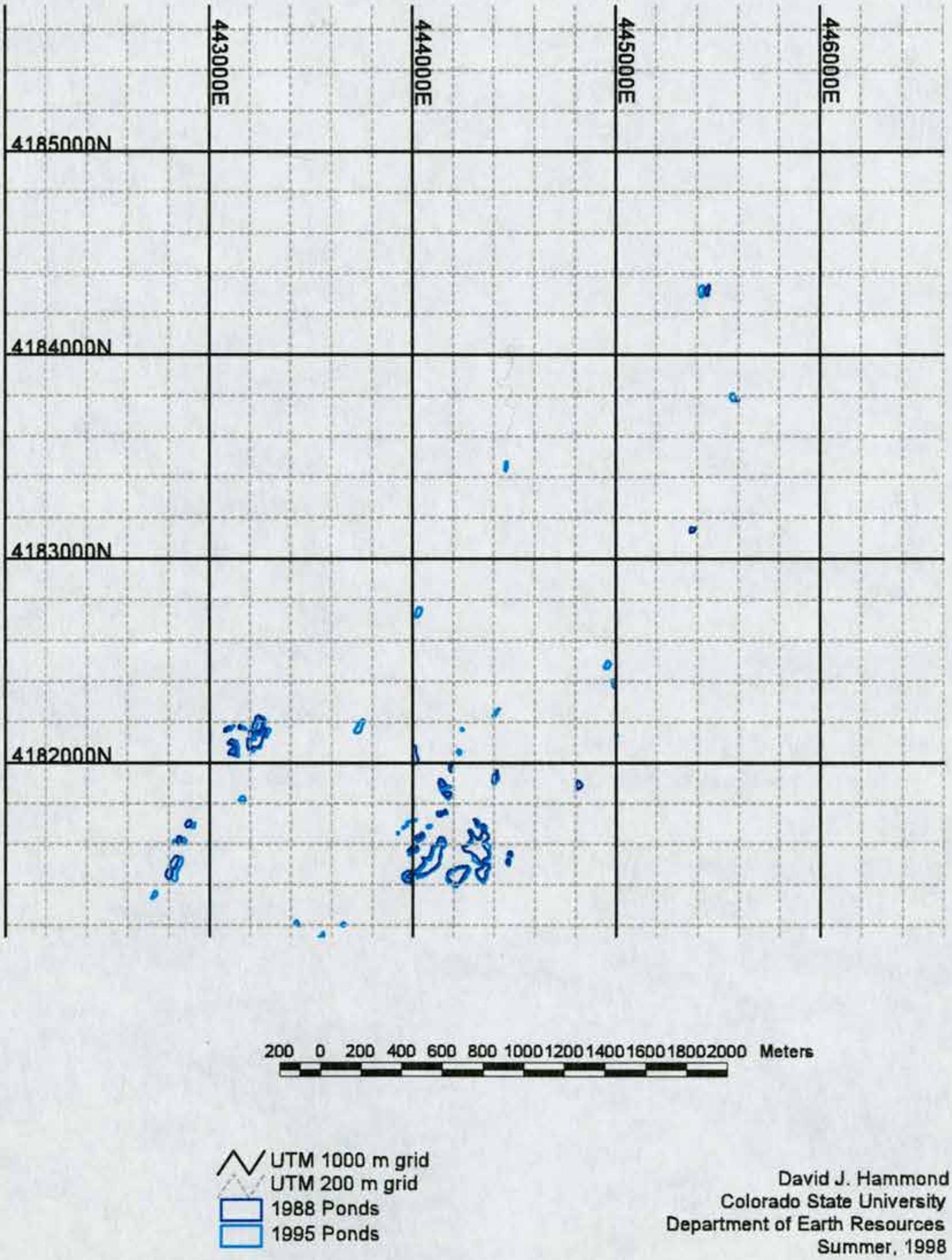
Wetland Polygon Comparison View

Great Sand Dunes National Monument, CO

1988 vs. 1995



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Appendix 6

Wetland Polygon ID Numbers and Wetland Attributes

ID #	1936 Wetlands Present	Pond Name	Soil	Acres	Surface h2o	1937 Wetlands Present	Pond Name	Soil	Acres	Surface h2o
5557	Y		Dun	0.10	No	Y		Dun	0.24	No
5555	Y		Dun	0.31	No	Y		Dun	0.25	Yes
5453	Y		Dun	0.22	No	N				
5353	Y		Dun	0.65	No	Y		Dun	1.32	Yes
5254	Y		Dun	0.44	No	Y		Dun	0.48	Yes
5253	N					Y		Dun	0.05	Yes
5153	Y		Dun	0.60	No	Y		Dun	0.99	Yes
5052	N					N				
4954	N					Y		Dun	3.49	Yes
4953	Y		Dun	2.14	No	N				
4952	Y		Dun	0.70	No	Y		Dun	0.80	Yes
4857	N					Y		Dun	1.66	Yes
4856	Y		Dun	1.65	Yes	N				
4854	Y		Dun	0.99	Yes	N				
4852	Y		Dun	0.36	No	Y		Dun	2.46	Yes
4852	Y		Dun	1.56	Yes	N				
4851	N					N				
4755	N					Y		Dun	0.14	Yes
4750	N					Y		Dun	0.13	Yes
4651	Y		Dun	2.47	Yes	Y		Dun	2.68	Yes
4454	N					Y		Dun	0.31	No
4452	Y		Dun	1.35	No	Y		Dun	0.30	No
4452	N					Y		Dun	0.06	No
4450	N					Y		Dun	0.04	Yes
4357	Y		Dun	0.26	No	N				
4354	Y		Dun	1.19	No	Y		Dun	0.96	Yes
4353	N					Y		Dun	0.48	Yes
4352	N					Y		Dun	0.50	Yes
4350	N					Y		Dun	1.59	Yes
4349	Y		Dun	1.68	Yes	N				
4257	N					Y		Dun	0.37	Yes
4250	N					N				
4248	N					N				
4151	Y		Dun	1.97	Yes	Y		Dun	2.80	Yes
4149	Y		Dun	0.29	No	N				
4148	Y		Dun	0.06	No	N				
4148	Y		Dun	0.07	No	N				
4055	Y		Dun	0.73	No	Y		Dun	0.25	No
4052	N					N				
4051	Y		Dun	1.14	Yes	N				
4049	N					Y		Dun	0.08	No
4048	N					Y		Dun	1.48	Yes
4047	Y		Dun	0.78	No	N				
3953	Y		Dun	0.38	No	N				
3952	N					Y		Dun	1.65	Yes
3949	N					N				
3853	N					Y		Dun	0.56	Yes
3849	Y		Dun	1.76	Yes	Y		Dun	2.94	Yes
3847	Y		Dun	0.95	Yes	Y		Dun	0.87	Yes

ID #	1936 Wetlands					1937 Wetlands				
	Present	Pond Name	Soil	Acres	Surface h2o	Present	Pond Name	Soil	Acres	Surface h2o
3755	N					N				
3755	N					N				
3753	N					Y		Dun	0.06	No
3748	N					Y		Dun	0.05	No
3747	N					N				
3746	N					N				
3548	N					Y		Dun	0.14	No
3544	N					Y		Dun	0.26	No
3447	N					N				
3446	Y		Dun	0.09	No	N				
3445	N					Y		Dun	0.47	Yes
3444	Y		Dun	0.15	No	N				
3347	N					Y		Dun	2.31	Yes
3346	Y		Dun	0.83	Yes	Y		Dun	0.55	Yes
3330	Y		Dun	0.50	Yes	N				
3251	N					N				
3249	Y		Dun	0.91	Yes	Y		Dun	0.82	Yes
3247	N					N				
3153	N					N				
3151	N					N				
3147	N					Y		Dun	0.23	No
3146	Y		Dun	0.28	No	N				
3144	N					N				
3139	N					Y		Dun	0.03	No
3129	Y		Dun	0.19	Yes	Y		Dun	0.07	Yes
3129	Y		Dun	0.26	Yes	N				
3128	Y		Dun	0.08	Yes	N				
3069	Y		Dun	0.17	Yes	N				
3051	Y		Dun	2.05	Yes	Y		Dun	2.14	Yes
3049	N					N				
3048	N					Y		Dun	0.14	No
3046	Y		Dun	2.06	Yes	N				
3044	N					N				
3043	N					Y		Dun	2.94	Yes
3039	N					Y	Alice?	Dun	0.79	Yes
3028	Y		Dun	0.07	Yes	N				
2948	Y		Dun	0.22	Yes	Y		Dun	0.65	Yes
2944	N					Y		Dun	0.20	Yes
2943	Y		Dun	0.11	No	N				
2929	N					N				
2846	N					N				
2845	Y		Dun	0.27	Yes	Y		Dun	0.65	Yes
2746	Y		Dun	0.06	No	Y		Dun	0.46	Yes
2740	Y	Alice?	Dun	1.01	Yes	Y		Dun	0.89	Yes
2646	Y		Dun	0.02	No	Y		Dun	0.12	No
2640	N					Y		Dun	0.07	No
2549	Y	Elm?	Cte	0.55	No	N				
2548	N					Y	N Elm?	Cte	0.16	No
2449	Y	Cow?	Cte	0.49	No	Y	Elm	Cte	0.28	No

ID #	1936 Wetlands Present	Pond Name	Soil	Acres	Surface h2o	1937 Wetlands Present	Pond Name	Soil	Acres	Surface h2o
2449	N					N				
2448	N					Y	N Elm?	Cte	0.08	No
2448	N					Y		Cte	0.32	Yes
2447	Y		Cte	0.06	No	N				
2439	Y		Dun	0.10	Yes	Y		Dun	0.66	Yes
2350	N					Y	Cow	Cte	0.34	Yes
2349	N					N				
2344	Y		Dun	1.10	No	Y		Dun	0.58	Yes
2341	N					Y		Dun	0.40	Yes
2247	N					Y		Dun	0.53	No
2244	N					N				
2244	N					N				
2244	N					N				
2243	N					N				
2237	N					Y		Cte	0.23	No
2232	N					N				
2150	N					N				
2147	Y		Dun	0.41	Yes	Y		Dun	0.56	Yes
2145	N					Y		Dun	0.47	Yes
2144	Y		Dun	0.18	No	N				
2142	N					N				
2137	N					Y		Cte	0.31	No
2132	Y	Corner E	Cte	0.49	No	Y	Corner E	Cte	1.93	Yes
2132	Y	Corner E	Cte	0.23	No	N				
2131	Y		Cte	0.05	No	N				
2130	N					Y		Cte	0.11	No
2050	Y		Dun	0.29	No	Y		Dun	0.28	No
2049	Y		Dun	1.27	No	Y		Cte	0.22	No
2042	N					Y		Cte	0.20	No
2041	N					N				
2040	N					Y		Cte	0.18	No
2033	N					Y		Cte	0.17	No
2032	N					N				
2031	N					Y	Corner W	Cte	0.50	No
1950	Y		Dun	0.33	No	Y		Dun	0.12	No
1948	N					Y		Dun	2.44	Yes
1947	Y		Dun	3.12	No	N				
1946	N					Y		Dun	0.12	No
1944	N					Y	Bones	Dun	0.67	Yes
1943	Y	Bones	Dun	0.43	Yes	N				
1941	N					Y		Cte	0.18	No
1941	N					Y		Cte	0.39	No
1940	N					N				
1850	Y		Dun	0.16	No	N				
1848	N					N				
1846	Y		Dun	0.51	No	Y		Dun	0.09	No
1844	N					Y		Dun	0.05	No
1841	Y		Dun	0.06	No	Y		Cte	0.17	Yes
1841	N					N				

ID #	1936 Wetlands Present	Pond Name	Soil	Acres	Surface h2o	1937 Wetlands Present	Pond Name	Soil	Acres	Surface h2o
1840	N					Y		Cte	0.19	Yes
1840	N					N				
1839	Y		Dun	0.06	No	N				
1831	Y		Cte	0.13	No	Y		Dun	0.41	No
1828	N					N				
1749	Y		Dun	0.69	No	Y		Dun	0.51	No
1746	Y		Dun	0.20	No	Y		Dun	0.09	No
1746	N					Y		Dun	0.24	No
1743	N					Y		Dun	0.09	No
1741	N					Y		Cte	0.03	No
1740	N					N				
1739	N					Y		Cte	0.05	No
1739	N					N				
1731	Y		Cte	0.11	No	N				
1729	N					N				
1728	N					N				
1648	N					Y		Dun	0.12	Yes
1647	Y		Dun	0.66	Yes	N				
1643	N					N				
1640	N					Y		Cte	0.02	No
1640	N					Y		Cte	0.12	No
1639	Y		Cte	0.05	No	N				
1639	N					N				
1639	N					N				
1638	N					Y		Cte	0.07	No
1629	N					Y		Cte	0.20	No
1628	N					N				
1628	N					N				
1551	N					Y		Dun	0.39	No
1546	Y		Dun	0.18	No	Y		Cte	0.24	No
1544	N					Y	E Elk Spr	Cte	0.46	No
1544	N					N				
1543	N					Y	N Elk Spr	Cte	3.69	Yes
1542	Y	N Elk Spr	Cte	1.40	Yes	N				
1540	Y	W Elk Spr	Cte	0.90	Yes	Y		Cte	0.20	Yes
1540	N					N				
1539	N					N				
1529	N					Y		Cte	0.15	No
1528	N					N				
1444	N					Y	E Elk Spr	Cte	0.02	No
1444	N					Y	E Elk Spr	Cte	0.04	No
1443	N					N				
1443	N					N				
1442	Y	S Elk Spr	Cte	0.16	Yes	Y	S Elk Spr	Cte	1.56	Yes
1441	Y	S Elk Spr	Cte	1.05	Yes	N				
1440	N					Y	W Elk Spr	Cte	2.97	Yes
1439	Y	W Elk Spr	Cte	0.06	No	Y	W Elk	Cte	0.12	No
1438	N					Y		Cte	0.10	No
1428	Y		Cte	0.30	No	Y		Cte	0.83	No

ID #	1936 Wetlands Present	Pond Name	Soil	Acres	Surface h2o	1937 Wetlands Present	Pond Name	Soil	Acres	Surface h2o
1428	N					Y		Cte	0.07	No
1327	N					N				
1236	N					Y		Cte	0.10	No
1234	N					N				
1135	N					Y		Cte	0.05	No
1134	N					N			0.05	
1034	N					Y		Cte	0.33	No
950	N					Y		Dun	0.09	No
944	Y		Cte	0.07	No	Y		Dun	0.11	No
849	Y		Cte	0.02	No	N				
749	N					N				

ID #	1953 Wetlands Pres ent	Pond Name	Soil	Acres	Surface h2o	1957 Wetlands Pres ent	Pond Name	Soil	Acres	Surface h2o
5557	N					N				
5555	N					N				
5453	N					N				
5353	N					N				
5254	N					N				
5253	N					N				
5153	N					N				
5052	N					Y		Dun	0.08	Yes
4954	N					N				
4953	N					N				
4952	N					N				
4857	N					N				
4856	N					N				
4854	Y		Dun	0.05	No	N				
4852	N					N				
4852	N					N				
4851	N					Y		Dun	0.06	Yes
4755	N					N				
4750	N					N				
4651	N					N				
4454	N					N				
4452	N					N				
4452	N					N				
4450	N					N				
4357	N					N				
4354	Y		Dun	0.10	Yes	Y		Dun	0.39	No
4353	N					N				
4352	N					N				
4350	N					N				
4349	N					N				
4257	N					N				
4250	Y		Dun	0.61	Yes	N				
4248	N					Y		Dun	0.14	Yes
4151	N					Y		Dun	0.27	No
4149	N					N				
4148	N					N				
4148	N					N				
4055	N					N				
4052	Y		Dun	0.28	Yes	Y		Dun	0.25	Yes
4051	N					N				
4049	N					N				
4048	N					N				
4047	N					N				
3953	Y		Dun	0.18	Yes	N				
3952	N					N				
3949	N					N				
3853	N					Y		Dun	0.22	Yes
3849	N					N				
3847	N					N				

ID #	1953 Wetlands					1957 Wetlands				
	Present	Pond Name	Soil	Acres	Surface h2o	Present	Pond Name	Soil	Acres	Surface h2o
3755	N					N				
3755	N					N				
3753	N					N				
3748	N					N				
3747	N					N				
3746	N					Y		Dun	0.17	Yes
3548	N					N				
3544	N					N				
3447	Y		Dun	0.66	No	N				
3446	N					N				
3445	N					N				
3444	N					N				
3347	N					N				
3346	N					N				
3330	Y		Dun	0.32	Yes	N				
3251	N					N				
3249	N					N				
3247	Y		Dun	0.33	No	N				
3153	N					Y		Dun	0.16	No
3151	Y		Dun	0.50	Yes	Y		Dun	0.93	Yes
3147	N					N				
3146	N					N				
3144	Y		Dun	0.72	Yes	N				
3139	N					N				
3129	N					N				
3129	N					N				
3128	N					N				
3069	N					N				
3051	N					N				
3049	N					N				
3048	Y		Dun	0.50	No	N				
3046	N					N				
3044	N					Y		Cte	0.54	Yes
3043	N					N				
3039	N					N				
3028	N					N				
2948	N					Y		Dun	0.42	No
2944	N					N				
2943	N					N				
2929	Y		Dun	0.58	No	N				
2846	Y		Dun	0.25	Yes	Y		Dun	0.21	Yes
2845	N					N				
2746	N					N				
2740	Y	Alice?	Dun	0.38	Yes	N				
2646	N					N				
2640	Y		Cte	0.35	No	N				
2549	Y	Elm	Dun	0.30	No	N				
2548	N					N				
2449	Y	Cow	Dun	0.33	No	N				

ID #	1953 Wetlands					1957 Wetlands				
	Present	Pond Name	Soil	Acres	Surface h2o	Present	Pond Name	Soil	Acres	Surface h2o
2449	N					Y	Elm	Dun	0.59	No
2448	N					N				
2448	N					N				
2447	N					N				
2439	Y		Cte	0.12	Yes	N				
2350	N					N				
2349	N					Y	Cow	Dun	0.62	No
2344	N					N				
2341	N					N				
2247	N					N				
2244	N					N				
2244	N					N				
2244	N					N				
2243	N					N				
2237	N					N				
2232	Y	Corner E	Cte	0.51	No	N				
2150	N					N				
2147	N					N				
2145	N					N				
2144	N					N				
2142	N					N				
2137	N					N				
2132	Y		Cte	0.04	No	N				
2132	Y	Corner E	Cte	0.56	No	N				
2131	N					N				
2130	N					N				
2050	N					N				
2049	N					N				
2042	N					N				
2041	N					N				
2040	N					N				
2033	N					N				
2032	N					N				
2031	Y	Corner W	Cte	0.43	No	N				
1950	N					N				
1948	N					N				
1947	N					N				
1946	N					N				
1944	Y	Bones	Cte	0.30	Yes	N				
1943	N					N				
1941	Y		Cte	0.78	No	N				
1941	N					N				
1940	N					N				
1850	N					N				
1848	N					N				
1846	N					N				
1844	N					N				
1841	N					N				
1841	N					N				

ID #	1953 Wetlands Present	Pond Name	Soil	Acres	Surface h2o	1957 Wetlands Present	Pond Name	Soil	Acres	Surface h2o
1840	Y		Cte	0.28	No	N				
1840	Y		Cte	0.15	No	N				
1839	N					N				
1831	N					N				
1828	N					N				
1749	N					N				
1746	N					N				
1746	N					N				
1743	N					N				
1741	N					N				
1740	N					N				
1739	N					N				
1739	N					N				
1731	N					N				
1729	N					N				
1728	Y		Cte	0.16	No	N				
1648	N					N				
1647	N					N				
1643	N					N				
1640	N					N				
1640	N					N				
1639	N					N				
1639	N					N				
1639	N					N				
1638	N					N				
1629	Y		Cte	0.22	No	N				
1628	N					N				
1628	N					N				
1551	N					N				
1546	N					N				
1544	Y	E Elk Spr	Cte	0.78	No	Y	E Elk Spr	Cte	0.78	No
1544	N					N				
1543	Y	N Elk Spr	Cte	4.69	Yes	N				
1542	N					N				
1540	Y	W Elk Spr	Cte	2.38	Yes	N				
1540	N					N				
1539	N					N				
1529	Y		Cte	0.07	No	N				
1528	Y		Cte	0.66	No	N				
1444	Y	E Elk Spr	Cte	0.22	No	N				
1444	Y	E Elk Spr	Cte	0.08	No	N				
1443	N					N				
1443	N					N				
1442	Y	S Elk Spr	Cte	1.38	Yes	N				
1441	N					N				
1440	N					N				
1439	N					N				
1438	N					N				
1428	N					N				

	1953 Wetlands					1957 Wetlands				
ID #	Present	Pond Name	Soil	Acres	Surface h2o	Present	Pond Name	Soil	Acres	Surface h2o
1428	N					N				
1327	N					N				
1236	Y		Cte	0.25	No	N				
1234	N					N				
1135	N					N				
1134	Y		Cte	0.36	No	N				
1034	N					N				
950	N					N				
944	N					N				
849	N					N				
749	N					N				

ID #	1966 Wetlands Present	Pond Name	Soil	Acres	Surface h2o	1975 Wetlands Present	Pond Name	Soil	Acres	Surface h2o
5557	N					N				
5555	N					N				
5453	N					N				
5353	N					N				
5254	N					N				
5253	N					N				
5153	Y		Dun	0.20	No	N				
5052	N					N				
4954	N					N				
4953	N					N				
4952	N					N				
4857	N					N				
4856	N					N				
4854	N					N				
4852	N					N				
4852	N					N				
4851	N					N				
4755	N					N				
4750	Y		Dun	0.25	No	N				
4651	N					N				
4454	N					N				
4452	N					N				
4452	N					N				
4450	N					N				
4357	N					N				
4354	N					N				
4353	N					N				
4352	N					N				
4350	N					N				
4349	N					N				
4257	N					N				
4250	N					N				
4248	Y		Dun	0.26	No	N				
4151	N					N				
4149	N					N				
4148	N					N				
4148	N					N				
4055	N					N				
4052	N					N				
4051	N					N				
4049	N					N				
4048	N					N				
4047	N					N				
3953	Y		Cte	0.15	No	N				
3952	N					N				
3949	Y		Cte	0.11	No	Y		Cte	0.37	No
3853	N					N				
3849	N					N				
3847	N					Y		Cte	0.26	No

ID #	1966 Wetlands Present	Pond Name	Soil	Acres	Surface h2o	1975 Wetlands Present	Pond Name	Soil	Acres	Surface h2o
3755	N					N				
3755	N					N				
3753	Y		Cte	0.55	No	N				
3748	N					N				
3747	Y		Dun	0.17	No	N				
3746	N					N				
3548	N					N				
3544	N					N				
3447	N					N				
3446	N					N				
3445	N					N				
3444	N					N				
3347	N					N				
3346	N					N				
3330	Y		Dun	0.18	No	N				
3251	N					N				
3249	N					N				
3247	N					N				
3153	Y		Dun	0.02	No	Y		Dun	0.10	No
3151	Y		Dun	0.86	No	Y		Dun	0.21	No
3147	Y		Cte	0.74	No	N				
3146	N					N				
3144	N					N				
3139	N					N				
3129	N					N				
3129	N					N				
3128	N					N				
3069	N					N				
3051	N					N				
3049	N					N				
3048	Y		Cte	0.42	No	N				
3046	N					N				
3044	N					N				
3043	N					N				
3039	N					N				
3028	N					N				
2948	N					Y		Cte	0.36	No
2944	Y		Cte	1.02	No	N				
2943	N					N				
2929	N					N				
2846	N					N				
2845	Y		Dun	0.44	No	N				
2746	N					N				
2740	N					N				
2646	N					N				
2640	N					Y		Cte	0.36	No
2549	N					N				
2548	N					N				
2449	N					N				

ID #	1966 Wetlands					1975 Wetlands				
	Present	Pond Name	Soil	Acres	Surface h2o	Present	Pond Name	Soil	Acres	Surface h2o
2449	N					N				
2448	N					N				
2448	N					N				
2447	N					N				
2439	N					N				
2350	N					N				
2349	N					N				
2344	N					N				
2341	N					N				
2247	N					N				
2244	N					N				
2244	N					N				
2244	N					N				
2243	Y		Cte	0.19	No	N				
2237	N					N				
2232	N					N				
2150	N					N				
2147	N					N				
2145	N					N				
2144	N					N				
2142	N					N				
2137	Y		Cte	0.11	No	Y		Cte	0.79	No
2132	Y	Corner E	Cte	1.85	No	Y	Corner E	Cte	2.18	No
2132	N					N				
2131	Y	Corner W	Cte	0.48	No	N				
2130	N					Y		Cte	0.05	No
2050	N					N				
2049	N					N				
2042	N					N				
2041	N					N				
2040	N					N				
2033	N					N				
2032	N					N				
2031	N					Y	Corner W	Cte	0.37	No
1950	N					N				
1948	N					N				
1947	N					N				
1946	N					N				
1944	Y	Bones	Cte	0.11	No	Y	Bones	Cte	0.51	No
1943	N					N				
1941	N					Y		Cte	0.15	No
1941	N					N				
1940	N					N				
1850	N					N				
1848	N					N				
1846	N					N				
1844	N					N				
1841	Y		Cte	0.29	No	Y		Cte	1.06	No
1841	Y		Cte	0.14	No	N				

ID #	1966 Wetlands Present	Pond Name	Soil	Acres	Surface h2o	1975 Wetlands Present	Pond Name	Soil	Acres	Surface h2o
1840	N					N				
1840	N					N				
1839	N					N				
1831	N					N				
1828	N					N				
1749	Y		Dun	0.51	No	N				
1746	N					N				
1746	N					N				
1743	N					N				
1741	N					Y		Cte	0.08	No
1740	N					N				
1739	N					N				
1739	N					N				
1731	N					N				
1729	Y		Cte	0.10	No	N				
1728	N					N				
1648	N					N				
1647	N					N				
1643	N					N				
1640	N					Y		Cte	0.18	No
1640	N					Y		Cte	0.06	No
1639	N					N				
1639	N					N				
1639	N					N				
1638	N					N				
1629	N					N				
1628	Y		Cte	0.06	No	Y		Cte	0.08	No
1628	N					Y		Cte	0.13	No
1551	N					N				
1546	N					N				
1544	N					Y	E Elk Spr	Cte	1.01	No
1544	N					N				
1543	Y	N Elk Spr	Cte	4.08	Yes	Y	N Elk Spr	Cte	5.78	Yes
1542	N					N				
1540	Y	W Elk Spr	Cte	2.22	No	N				
1540	N					N				
1539	N					Y		Cte	0.19	No
1529	Y		Cte	0.09	No	N				
1528	N					N				
1444	N					N				
1444	N					N				
1443	N					N				
1443	N					N				
1442	Y	S Elk Spr	Cte	1.31	Yes	N				
1441	N					Y	S Elk Spr	Cte	2.47	No
1440	N					Y	W Elk Spr	Cte	3.96	No
1439	N					N				
1438	N					N				
1428	Y		Cte	0.66	No	Y		Cte	0.55	No

ID #	1966 Wetlands Present	Pond Name	Soil	Acres	Surface h2o	1975 Wetlands Present	Pond Name	Soil	Acres	Surface h2o
1428	Y		Cte	0.04	No	N				
1327	N					N				
1236	N					N				
1234	N					Y		Cte	0.12	No
1135	N					N				
1134	N					N				
1034	Y		Cte	0.24	No	Y		Cte	0.32	No
950	N					N				
944	N					N				
849	N					N				
749	N					N				

ID #	1979 Wetlands					1985 Wetlands				
	Present	Pond Name	Soil	Acres	Surface h2o	Present	Pond Name	Soil	Acres	Surface h2o
5557	N					N				
5555	N					N				
5453	N					N				
5353	N					N				
5254	N					N				
5253	N					N				
5153	N					N				
5052	N					N				
4954	N					N				
4953	N					N				
4952	N					N				
4857	N					N				
4856	N					N				
4854	N					N				
4852	N					N				
4852	N					N				
4851	N					N				
4755	N					N				
4750	N					N				
4651	N					N				
4454	N					N				
4452	N					N				
4452	N					N				
4450	N					N				
4357	N					N				
4354	N					Y		Cte	0.18	No
4353	N					N				
4352	N					N				
4350	N					N				
4349	N					N				
4257	N					N				
4250	N					N				
4248	N					N				
4151	N					N				
4149	N					N				
4148	N					N				
4148	N					N				
4055	N					N				
4052	N					N				
4051	N					N				
4049	N					N				
4048	N					N				
4047	N					N				
3953	N					N				
3952	N					N				
3949	Y		Cte	0.37	No	N				
3853	N					N				
3849	N					N				
3847	Y		Cte	0.26	No	N				

ID #	1979 Wetlands Present	Pond Name	Soil	Acres	Surface h2o	1985 Wetlands Present	Pond Name	Soil	Acres	Surface h2o
3755	N					Y		Cte	0.01	No
3755	N					Y		Cte	0.01	No
3753	N					N				
3748	N					N				
3747	N					N				
3746	N					N				
3548	N					N				
3544	N					N				
3447	N					N				
3446	N					N				
3445	N					N				
3444	N					N				
3347	N					N				
3346	N					N				
3330	N					N				
3251	Y		Dun	0.21	No	N				
3249	N					N				
3247	N					N				
3153	Y		Dun	0.10	No	Y		Dun	0.11	No
3151	N					N				
3147	N					N				
3146	N					N				
3144	N					N				
3139	N					N				
3129	N					N				
3129	N					N				
3128	N					N				
3069	N					N				
3051	N					N				
3049	N					Y		Cte	0.49	No
3048	Y		Dun	0.36	No	N				
3046	N					N				
3044	N					N				
3043	N					N				
3039	N					N				
3028	N					N				
2948	N					N				
2944	N					N				
2943	N					N				
2929	N					N				
2846	N					N				
2845	N					N				
2746	N					N				
2740	N					N				
2646	N					N				
2640	N					N				
2549	N					N				
2548	N					N				
2449	N					N				

ID #	1979 Wetlands Present	Pond Name	Soil	Acres	Surface h2o	1985 Wetlands Present	Pond Name	Soil	Acres	Surface h2o
2449	N					N				
2448	N					N				
2448	N					N				
2447	N					N				
2439	N					N				
2350	N					N				
2349	N					N				
2344	N					N				
2341	N					N				
2247	N					N				
2244	N					N				
2244	N					N				
2244	N					N				
2243	N					N				
2237	Y		Cte	0.79	No	N				
2232	N					N				
2150	N					N				
2147	N					N				
2145	N					N				
2144	N					N				
2142	N					N				
2137	N					N				
2132	Y	Corner E	Cte	1.54	Yes	Y	Corner E	Cte	2.03	No
2132	N					N				
2131	Y	Corner W	Cte	0.37	No	Y		Cte	0.04	No
2130	Y		Cte	0.05	No	Y		Cte	0.07	No
2050	N					N				
2049	N					N				
2042	N					N				
2041	Y		Cte	0.09	No	N				
2040	N					Y		Cte	0.43	No
2033	N					N				
2032	N					N				
2031	N					Y	Corner W	Cte	0.42	No
1950	N					N				
1948	N					N				
1947	N					N				
1946	N					N				
1944	Y	Bones	Cte	0.44	No	N				
1943	N					Y	Bones	Cte	0.21	Yes
1941	Y		Cte	0.23	No	Y		Cte	0.15	No
1941	N					N				
1940	N					N				
1850	N					N				
1848	N					Y		Dun	0.20	No
1846	N					N				
1844	N					N				
1841	Y		Cte	0.13	No	Y		Cte	0.23	No
1841	N					Y		Cte	0.20	Yes

	1979 Wetlands					1985 Wetlands				
ID #	Present	Pond Name	Soil	Acres	Surface h2o	Present	Pond Name	Soil	Acres	Surface h2o
1840	N					N				
1840	N					N				
1839	N					N				
1831	N					N				
1828	N					Y		Cte	0.72	No
1749	N					N				
1746	N					N				
1746	N					N				
1743	N					Y		Cte	0.08	No
1741	N					Y		Cte	0.17	No
1740	N					N				
1739	N					N				
1739	N					N				
1731	N					N				
1729	N					N				
1728	Y		Cte	0.18	No	N				
1648	N					N				
1647	N					N				
1643	Y	N Elk Spr	Cte	3.44	Yes	N				
1640	N					Y		Cte	0.14	No
1640	N					N				
1639	N					N				
1639	N					N				
1639	N					N				
1638	N					N				
1629	N					N				
1628	Y		Cte	0.06	No	Y		Cte	0.17	No
1628	N					Y		Cte	0.15	No
1551	N					N				
1546	N					N				
1544	Y	E Elk Spr	Cte	0.11	No	Y		Cte	0.07	No
1544	N					N				
1543	N					Y	N Elk Spr	Cte	2.63	Yes
1542	Y	S Elk Spr	Cte	0.95	Yes	N				
1540	Y	W Elk Spr	Cte	2.08	Yes	Y		Cte	0.21	No
1540	N					Y	W Elk Spr	Cte	2.97	Yes
1539	N					N				
1529	N					N				
1528	Y		Cte	0.55	No	N				
1444	N					N				
1444	N					N				
1443	N					Y	N Elk Spr	Cte	0.69	No
1443	N					N				
1442	N					Y	S Elk Spr	Cte	1.37	Yes
1441	N					N				
1440	N					N				
1439	N					N				
1438	N					N				
1428	N					Y		Cte	0.05	No

ID #	1979 Wetlands					1985 Wetlands				
	Present	Pond Name	Soil	Acres	Surface h2o	Present	Pond Name	Soil	Acres	Surface h2o
1428	N					N				
1327	N					N				
1236	N					N				
1234	Y		Cte	0.06	No	Y		Cte	0.05	No
1135	N					N				
1134	N					N				
1034	Y		Cte	0.32	No	Y		Cte	0.30	No
950	N					N				
944	N					N				
849	N					N				
749	N					Y		Cte	0.02	No

ID #	1988 Wetlands Present	Pond Name	Soil	Acres	Surface h2o	1995 Wetlands Present	Pond Name	Soil	Acres	Surface h2o
5557	N					N				
5555	N					N				
5453	N					N				
5353	N					N				
5254	N					N				
5253	N					N				
5153	N					N				
5052	N					N				
4954	N					N				
4953	N					N				
4952	N					N				
4857	N					N				
4856	N					N				
4854	N					N				
4852	N					N				
4852	N					N				
4851	N					N				
4755	N					N				
4750	N					N				
4651	N					N				
4454	N					N				
4452	N					N				
4452	N					N				
4450	N					N				
4357	N					N				
4354	Y		Cte	0.18	No	Y		Cte	0.28	No
4353	N					N				
4352	N					N				
4350	N					N				
4349	N					N				
4257	N					N				
4250	N					N				
4248	N					N				
4151	N					N				
4149	N					N				
4148	N					N				
4148	N					N				
4055	N					N				
4052	N					N				
4051	N					N				
4049	N					N				
4048	N					N				
4047	N					N				
3953	N					N				
3952	N					N				
3949	N					N				
3853	N					N				
3849	N					N				
3847	N					N				

ID #	1988 Wetlands Present	Pond Name	Soil	Acres	Surface h2o	1995 Wetlands Present	Pond Name	Soil	Acres	Surface h2o
3755	Y		Cte	0.01	No	Y		Dun	0.19	No
3755	N					N				
3753	N					N				
3748	N					N				
3747	N					N				
3746	N					N				
3548	N					N				
3544	N					N				
3447	N					N				
3446	N					N				
3445	N					N				
3444	N					Y		Cte	0.12	No
3347	N					N				
3346	N					N				
3330	N					N				
3251	N					N				
3249	N					N				
3247	N					N				
3153	Y		Dun	0.11	No	N				
3151	N					N				
3147	N					N				
3146	N					N				
3144	N					N				
3139	N					N				
3129	N					N				
3129	N					N				
3128	N					N				
3069	N					N				
3051	N					N				
3049	N					N				
3048	N					N				
3046	N					N				
3044	N					N				
3043	N					N				
3039	N					N				
3028	N					N				
2948	N					N				
2944	N					N				
2943	N					N				
2929	N					N				
2846	N					N				
2845	N					N				
2746	N					N				
2740	N					Y	Alice	Dun	0.26	Yes
2646	N					N				
2640	N					N				
2549	N					N				
2548	N					N				
2449	N					N				

ID #	1988 Wetlands Present	Pond Name	Soil	Acres	Surface h2o	1995 Wetlands Present	Pond Name	Soil	Acres	Surface h2o
2449	N					Y	Elm	Cte	0.18	No
2448	N					N				
2448	N					N				
2447	N					N				
2439	N					N				
2350	N					N				
2349	N					Y	Cow	Cte	0.16	No
2344	N					N				
2341	N					N				
2247	N					N				
2244	N					Y		Cte	0.02	No
2244	N					Y		Cte	0.03	No
2244	N					Y		Cte	0.02	No
2243	N					N				
2237	N					N				
2232	N					N				
2150	N					Y		Cte	0.02	No
2147	N					N				
2145	N					N				
2144	N					N				
2142	N					Y		Cte	0.04	No
2137	N					Y		Cte	0.39	No
2132	Y	Corner E	Cte	2.03	Yes	Y	Corner E	Cte	1.74	No
2132	N					N				
2131	Y	Corner	Cte	0.04	No	Y	Corner	Cte	0.07	No
2130	Y	Corner	Cte	0.07	No	Y	Corner	Cte	0.05	No
2050	N					N				
2049	N					N				
2042	N					Y		Cte	0.06	No
2041	N					N				
2040	Y		Cte	0.43	No	Y		Cte	0.43	No
2033	N					N				
2032	N					N				
2031	Y	Corner W	Cte	0.42	No	Y	Corner W	Cte	0.35	No
1950	N					N				
1948	N					N				
1947	N					N				
1946	N					N				
1944	Y	Bones	Cte	0.21	Yes	Y	Bones	Cte	0.29	Yes
1943	N					N				
1941	Y		Cte	0.15	No	Y		Cte	0.15	No
1941	N					N				
1940	N					N				
1850	N					N				
1848	Y		Dun	0.20	Yes	Y		Dun	0.20	No
1846	N					N				
1844	N					N				
1841	Y		Cte	0.23	No	Y		Cte	0.32	No
1841	Y		Cte	0.20	No	Y		Cte	0.20	No

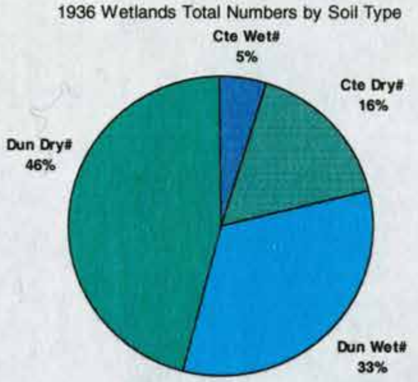
ID #	1988 Wetlands Present	Pond Name	Soil	Acres	Surface h2o	1995 Wetlands Present	Pond Name	Soil	Acres	Surface h2o
1840	N					N				
1840	N					N				
1839	N					N				
1831	N					Y		Cte	0.13	No
1828	N					N				
1749	N					N				
1746	N					N				
1746	N					N				
1743	Y		Cte	0.08	No	Y		Cte	0.14	No
1741	Y		Cte	0.17	No	Y		Cte	0.10	No
1740	N					Y		Cte	0.02	No
1739	N					Y		Cte	0.03	No
1739	N					Y		Cte	0.01	No
1731	N					N				
1729	N					N				
1728	N					N				
1648	N					N				
1647	N					N				
1643	N					N				
1640	Y		Cte	0.14	No	Y		Cte	0.06	No
1640	N					Y		Cte	0.13	No
1639	N					Y		Cte	0.01	No
1639	N					Y		Cte	0.03	No
1639	N					Y		Cte	0.01	No
1638	N					N				
1629	N					Y		Cte	0.08	No
1628	Y		Cte	0.17	No	Y		Cte	0.10	No
1628	Y		Cte	0.15	No	Y		Cte	0.05	No
1551	N					N				
1546	N					N				
1544	Y	E Elk Spr	Cte	0.06	No	Y	E Elk Spr	Cte	0.11	No
1544	Y	E Elk Spr	Cte	0.07	No	Y	E Elk Spr	Cte	0.08	No
1543	Y	N Elk Spr	Cte	2.63	Yes	Y	N Elk Spr	Cte	3.23	Yes
1542	N					N				
1540	Y		Cte	0.21	No	Y		Cte	0.18	No
1540	Y	W Elk Spr	Cte	2.97	Yes	Y	W Elk Spr	Cte	2.59	Yes
1539	N					N				
1529	N					N				
1528	N					N				
1444	N					N				
1444	N					N				
1443	Y	N Elk Spr	Cte	0.69	No	Y	N Elk Spr	Cte	0.86	Yes
1443	N					Y	S Elk Spr	Cte	1.61	Yes
1442	Y	S Elk Spr	Cte	1.37	Yes	N				
1441	N					N				
1440	N					N				
1439	N					N				
1438	N					N				
1428	Y		Cte	0.72	No	Y		Cte	0.67	No

ID #	1988 Wetlands					1995 Wetlands				
	Present	Pond Name	Soil	Acres	Surface h2o	Present	Pond Name	Soil	Acres	Surface h2o
1428	N					N				
1327	N					Y		Cte	0.13	No
1236	N					Y		Cte	0.06	No
1234	N					Y		Cte	0.08	No
1135	N					Y		Cte	0.14	No
1134	N					N				
1034	Y		Cte	0.29	No	Y		Cte	0.37	No
950	N					N				
944	N					Y		Cte	0.24	No
849	N					N				
749	Y		Dun	0.02	No	N				

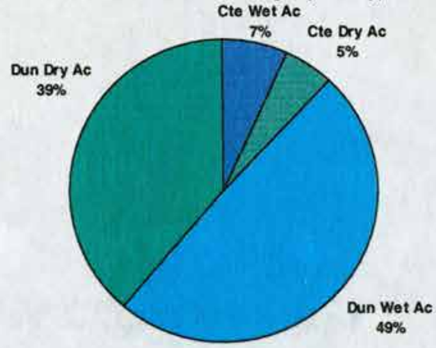
Appendix 7

Wetlands Analysis by Soil Type

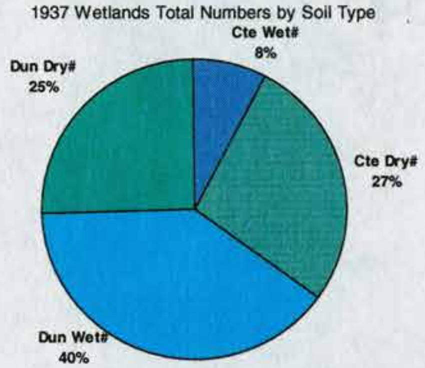
1936 Wetlands Total Numbers by Soil Type



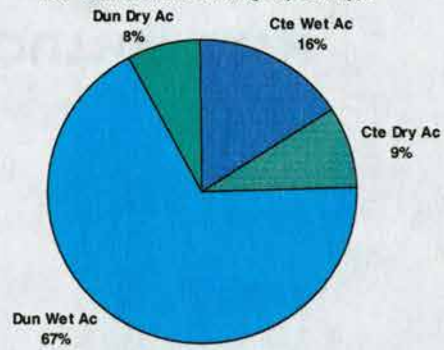
1936 Total Wetlands Acreage by Soil Type



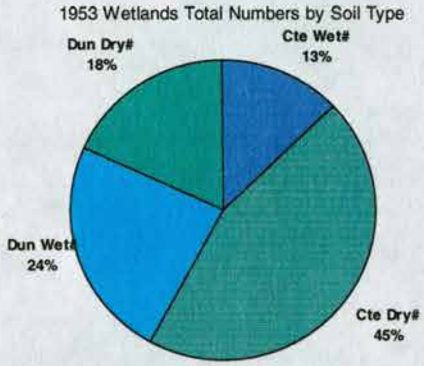
1937 Wetlands Total Numbers by Soil Type



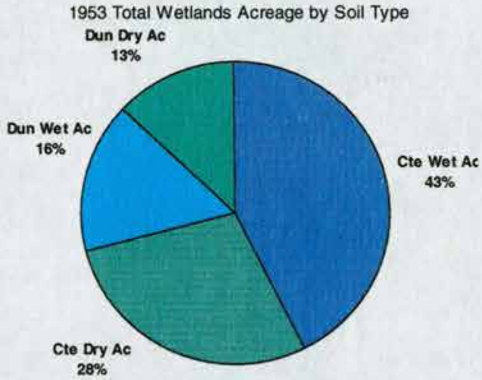
1937 Total Wetlands Acreage by Soil Type



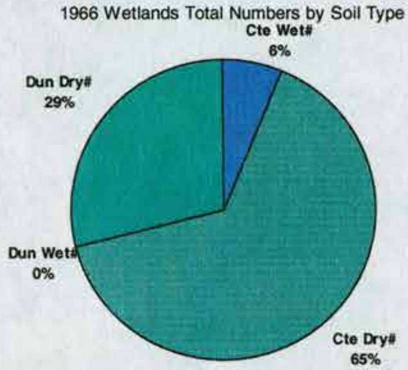
1953 Wetlands Total Numbers by Soil Type



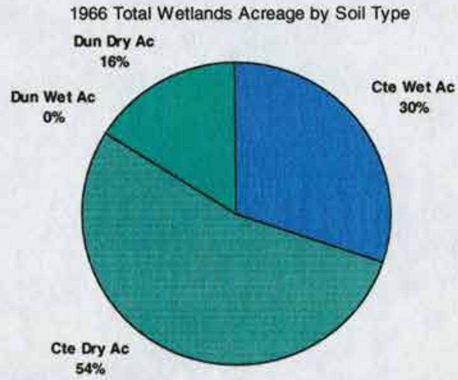
1953 Total Wetlands Acreage by Soil Type

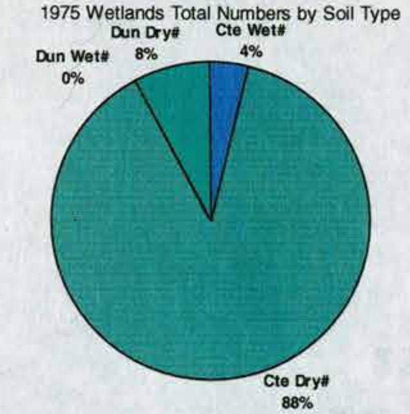


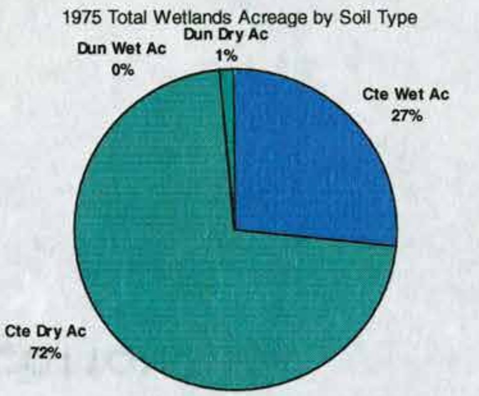
1966 Wetlands Total Numbers by Soil Type

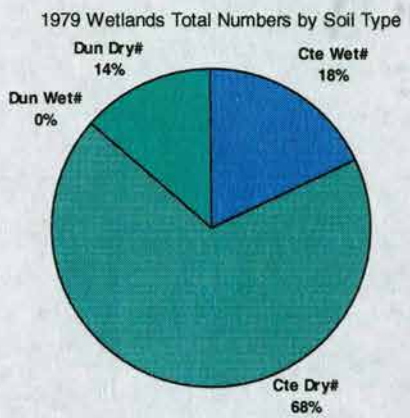


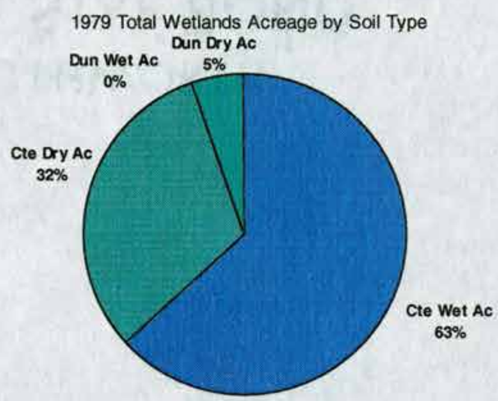
1966 Total Wetlands Acreage by Soil Type

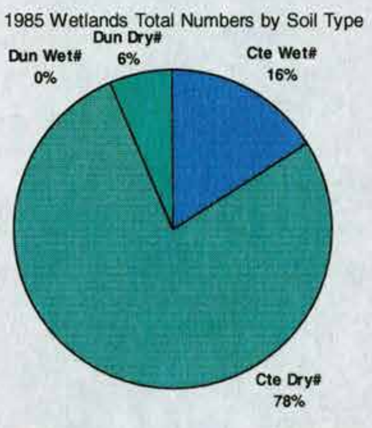


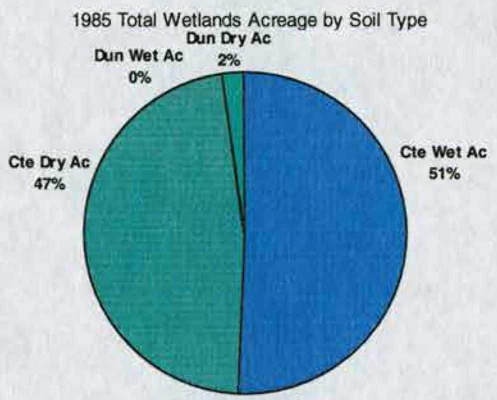

1975 Wetlands Total Numbers by Soil Type
Dun Dry#
8%
Cte Wet#
4%
Dun Wet#
0%
Cte Dry#
88%

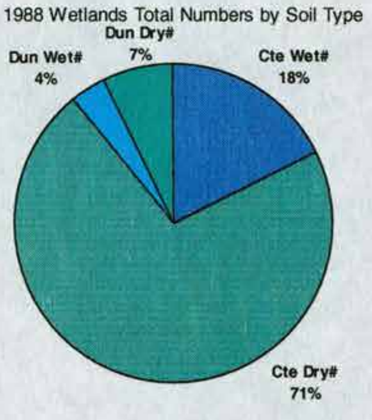

1975 Total Wetlands Acreage by Soil Type
Dun Dry Ac
1%
Dun Wet Ac
0%
Cte Wet Ac
27%
Cte Dry Ac
72%

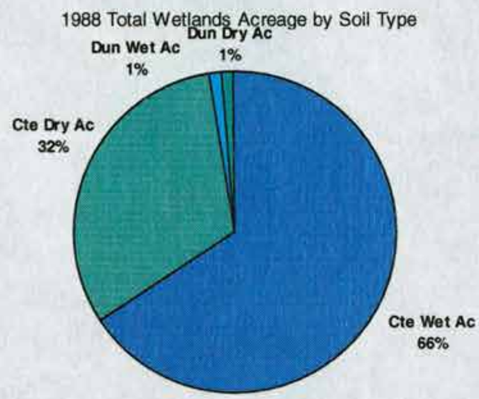

1979 Wetlands Total Numbers by Soil Type
Dun Dry#
14%
Cte Wet#
18%
Dun Wet#
0%
Cte Dry#
68%

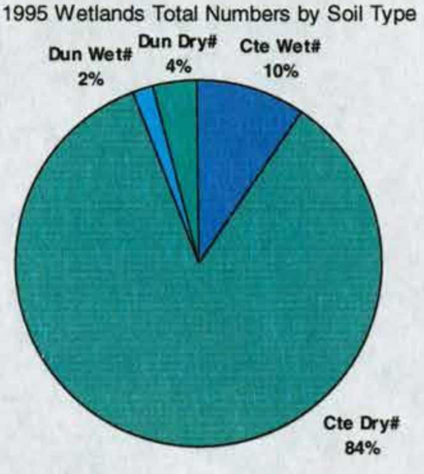

1979 Total Wetlands Acreage by Soil Type
Dun Dry Ac
5%
Dun Wet Ac
0%
Cte Dry Ac
32%
Cte Wet Ac
63%

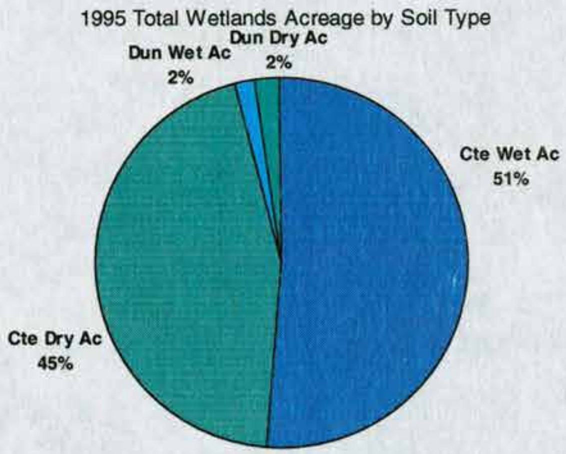

1985 Wetlands Total Numbers by Soil Type
Dun Dry#
6%
Dun Wet#
0%
Cte Wet#
16%
Cte Dry#
78%


1985 Total Wetlands Acreage by Soil Type
Dun Dry Ac
2%
Dun Wet Ac
0%
Cte Dry Ac
47%
Cte Wet Ac
51%


1988 Wetlands Total Numbers by Soil Type
Dun Dry#
7%
Dun Wet#
4%
Cte Wet#
18%
Cte Dry#
71%


1988 Total Wetlands Acreage by Soil Type
Dun Dry Ac
1%
Dun Wet Ac
1%
Cte Dry Ac
32%
Cte Wet Ac
66%


1995 Wetlands Total Numbers by Soil Type
Dun Wet#
2%
Dun Dry#
4%
Cte Wet#
10%
Cte Dry#
84%


1995 Total Wetlands Acreage by Soil Type
Dun Wet Ac
2%
Dun Dry Ac
2%
Cte Wet Ac
51%
Cte Dry Ac
45%

Appendix 8

Regression Results

	Linear Regression Results					
	Wet Wetland Acres vs.					
	Slope	Intercept	r2	rse	df	p
Regressions results from GRSA (3541) Annual Precipitation Totals, 1951 - 1995						
GRSA 1 Yr Precipitation Total	0.338	4.696	0.109	2.376	5	0.469
GRSA 2 Yr Precipitation Total	0.097	6.140	0.039	2.468	5	0.673
GRSA 3 Yr Precipitation Total	0.014	7.749	0.002	2.515	5	0.932
GRSA 5 Yr Precipitation Total	0.088	2.848	0.316	1.484	4	0.245
GRSA 10 Yr Precipitation Total	0.018	5.635	0.015	1.782	4	0.820
GRSA 20 Yr Precipitation Total	0.002	7.450	0.000	1.582	3	0.980
Total Precip Previous 1 Month	-1.604	10.372	0.383	1.977	5	0.138
Total Precip Previous 2 Months	-0.478	9.405	0.080	2.415	5	0.539
Total Precip Previous 3 Months	0.163	7.555	0.013	2.501	5	0.810
Total Precip Previous 6 Months	0.421	5.706	0.161	2.307	5	0.373
Total Precip Previous 9 Months	0.494	4.436	0.155	2.314	5	0.382
Total Precip Previous 12 Months	-0.097	9.257	0.024	2.487	5	0.742
Total Precip Previous 24 Months	0.050	7.072	0.018	2.495	5	0.775
Total Precip Previous 36 Months	-0.009	8.469	0.001	2.516	5	0.952
Total Precip Previous 60 Months	0.077	3.353	0.255	1.550	4	0.308
Total Precip Previous 120 Months	0.021	5.282	0.022	1.775	4	0.778
Regressions results from Mangimeli Dendrochronology Indices - 1650 - 1979						
Pinyon Pine Chronology - 1 Yr	10.606	7.592	0.038	22.970	4	0.711
PPC - 1 Yr Total offset by 20 Yrs	29.890	-14.244	0.538	12.690	7	0.024
PPC - 9 Yr Mn	-0.721	20.406	0.000	23.420	4	0.989
PPC - 9 Yr Mn offset by 5 Years	21.254	-1.290	0.034	0.140	4	0.727
PPC - 9 Yr Mn offset by 10 Years	39.974	-25.082	0.371	15.800	6	0.109
PPC - 9 Yr Mn offset by 15 Years	37.845	-24.359	0.613	12.390	6	0.022
PPC - 9 Yr Mn offset by 16 Years	37.687	-24.268	0.633	11.320	7	0.010
PPC - 9 Yr Mn offset by 17 Years	35.664	-21.617	0.586	12.010	7	0.016
PPC - 9 Yr Mn offset by 18 Years	43.841	-19.666	0.678	12.110	7	0.006
PPC - 9 Yr Mn offset by 19 Years	46.811	-22.736	0.660	12.440	7	0.008
PPC - 9 Yr Mn offset by 20 Years	37.466	-22.653	0.479	13.490	7	0.039
PPC - 9 Yr Mn offset by 21 Years	30.721	-15.692	0.408	14.370	7	0.064
Regressions results from Rio Grande Annual Discharge Totals, 1908 - 1995						
Rio Grande Annual Acre Feet	0.000	32.603	0.105	17.660	7	0.394
RG Ann AcFt 3 Yr Mean	0.000	47.075	0.120	17.510	7	0.360
RG Ann AcFt 5 Yr Mn	0.000	68.063	0.223	16.460	7	0.199
RG Ann AcFt 10 Yr Mn	0.000	53.942	0.042	18.280	7	0.596
RG Ann AcFt 20 Yr Mn	0.000	-134.193	0.548	12.550	7	0.022
Regression results from Blanca Annual Precip, 1948 - 1995						
Blanca (0776) Annual Precip	0.857	0.864	0.586	1.621	7	0.045
Regressions results from USGS Stream Gaging						
Site 08227500, N Crestone Creek, May 1936 - Sept 1980						
Crestone Creek 1 Month Discharge	-0.006	26.809	0.124	21.930	4	0.494
Crestone Crk - 2 Month Discharge	-0.005	32.530	0.230	20.560	4	0.336
Crestone Crk - 3 Month Discharge	-0.005	40.487	0.353	18.840	4	0.214
Crestone Crk - 6 Month Discharge	-0.001	29.788	0.023	23.150	4	0.773
Crestone Crk - 9 Month Discharge	-0.002	34.725	0.041	22.940	4	0.702
Crestone Crk - 12 Month Discharge	-0.002	33.385	0.013	26.370	3	0.855

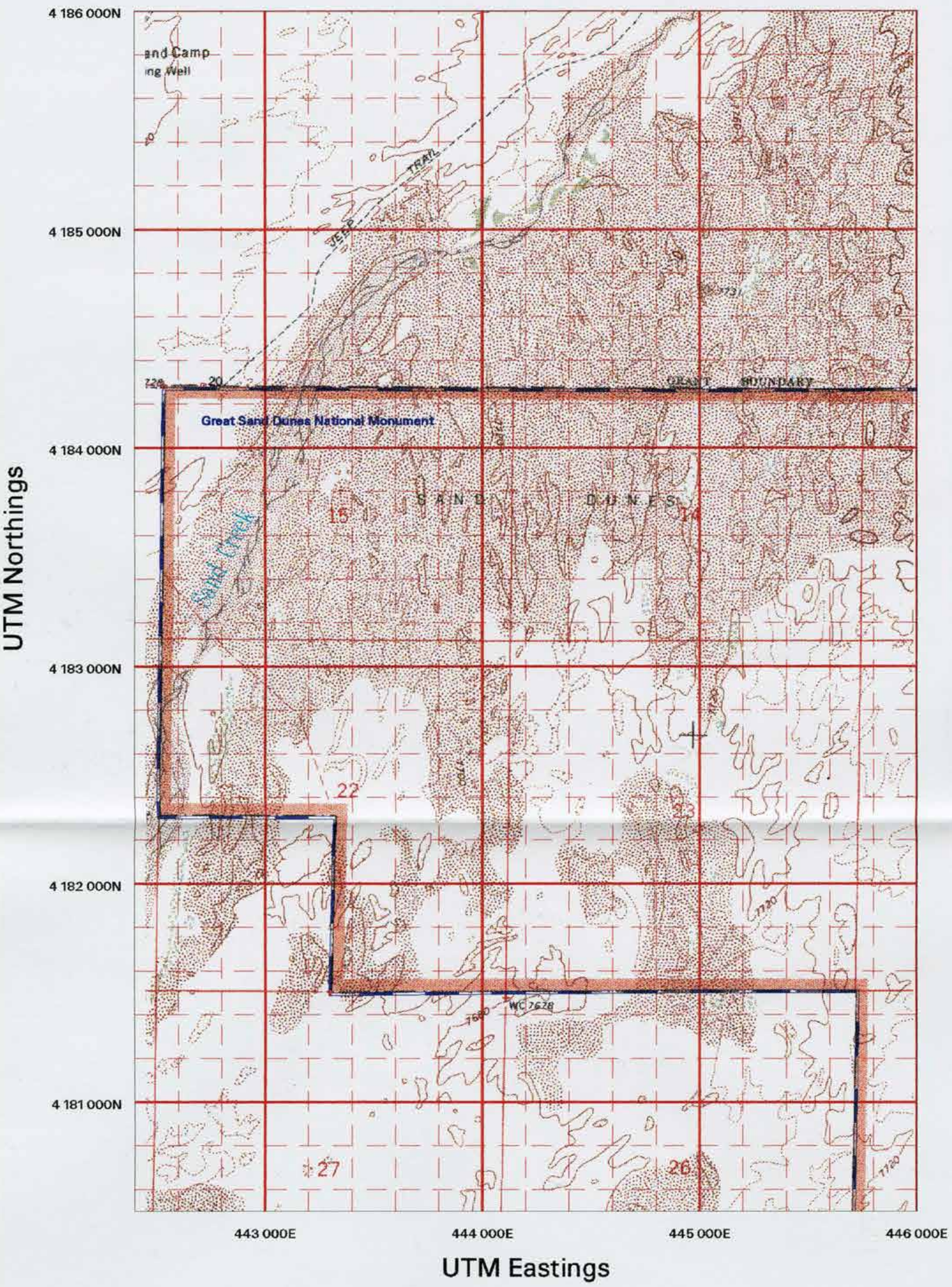
	Linear Regression Results					
	Total Wetland Acres vs.					
	Slope	Intercept	r2	rse	df	p
Regressions results from GRSA (3541) Annual Precipitation Totals, 1951 - 1995						
GRSA 1 Yr Precipitation Total	0.268	14.186	0.032	3.640	5	0.702
GRSA 2 Yr Precipitation Total	0.157	13.651	0.047	3.612	5	0.642
GRSA 3 Yr Precipitation Total	-0.096	19.998	0.036	3.633	5	0.685
GRSA 5 Yr Precipitation Total	-0.060	19.511	0.037	3.510	4	0.714
GRSA 10 Yr Precipitation Total	0.131	2.577	0.195	3.210	4	0.381
GRSA 20 Yr Precipitation Total	0.148	-15.009	0.160	3.687	3	0.505
Total Precip Previous 1 Month	-1.877	19.515	0.243	3.218	5	0.261
Total Precip Previous 2 Months	-0.863	19.159	0.121	3.468	5	0.445
Total Precip Previous 3 Months	-0.232	17.852	0.012	3.677	5	0.816
Total Precip Previous 6 Months	-0.022	17.089	0.000	3.699	5	0.975
Total Precip Previous 9 Months	-0.087	17.615	0.002	3.695	5	0.920
Total Precip Previous 12 Months	-0.088	17.934	0.009	3.682	5	0.839
Total Precip Previous 24 Months	-0.034	17.704	0.004	3.692	5	0.896
Total Precip Previous 36 Months	-0.117	20.740	0.065	3.576	5	0.580
Total Precip Previous 60 Months	-0.034	18.137	0.012	3.555	4	0.835
Total Precip Previous 120 Months	0.115	3.960	0.172	3.256	4	0.414
Regressions results from Mangimeli Dendrochronology Indices - 1650 - 1979						
Pinyon Pine Chronology - 1 Yr	-0.936	33.336	0.000	25.530	4	0.976
PPC - 1 Yr Total offset by 20 Yrs	33.854	-7.679	0.528	14.660	7	0.027
PPC - 9 Yr Mn	-3.895	36.084	0.001	25.510	4	0.947
PPC - 9 Yr Mn offset by 5 Years	-0.039	32.305	0.000	25.530	4	1.000
PPC - 9 Yr Mn offset by 10 Years	41.849	-16.128	0.315	18.750	6	0.148
PPC - 9 Yr Mn offset by 15 Years	45.608	-21.900	0.689	12.630	6	0.011
PPC - 9 Yr Mn offset by 16 Years	45.556	-22.106	0.708	11.540	7	0.005
PPC - 9 Yr Mn offset by 17 Years	43.842	-19.666	0.678	12.110	7	0.006
PPC - 9 Yr Mn offset by 18 Years	38.578	-24.639	0.586	12.010	7	0.016
PPC - 9 Yr Mn offset by 19 Years	39.147	-24.039	0.539	12.680	7	0.024
PPC - 9 Yr Mn offset by 20 Years	49.073	-24.053	0.628	13.020	7	0.011
PPC - 9 Yr Mn offset by 21 Years	41.134	-15.860	0.560	14.170	7	0.020
Regressions results from Rio Grande Annual Discharge Totals, 1908 - 1995						
Rio Grande Annual Acre Feet	0.000	48.115	0.136	19.850	7	0.329
RG Ann AcFt 3 Yr Mean	0.000	70.924	0.188	19.240	7	0.243
RG Ann AcFt 5 Yr Mn	0.000	97.094	0.313	17.690	7	0.117
RG Ann AcFt 10 Yr Mn	0.000	85.690	0.078	20.500	7	0.466
RG Ann AcFt 20 Yr Mn	0.000	-148.591	0.571	13.990	7	0.019
Regression results from Blanca Annual Precip, 1948 - 1995						
Blanca (0776) Annual Precip	-0.850	24.219	0.267	3.168	5	0.235
Regressions results from USGS Stream Gaging						
Site 08227500, N Crestone Creek, May 1936 - Sept 1980						
Crestone Creek 1 Month Discharge	-0.003	36.465	0.036	25.060	4	0.717
Crestone Crk - 2 Month Discharge	-0.004	42.663	0.127	23.850	4	0.488
Crestone Crk - 3 Month Discharge	-0.006	54.543	0.341	20.720	4	0.224
Crestone Crk - 6 Month Discharge	-0.004	58.891	0.136	23.730	4	0.472
Crestone Crk - 9 Month Discharge	-0.005	65.845	0.171	23.250	4	0.416
Crestone Crk - 12 Month Discharge	-0.004	60.541	0.054	26.440	4	0.708

List of Abbreviations

AML – Arc Macro Language
CBD – Closed Basin Division, U.S. Bureau of Reclamation
CIR - Color Infrared
DEM - Digital Elevation Model
dpi – dots per inch
ESIC – USGS Earth Science Information Center
GCP – Ground Control Point
GRSA - National Park Service acronym for Great Sand Dunes National Monument
Lx,ly or Rx,ry – X,y values from Left or Right side of image
MSS – Landsat Multi Spectral Scanner data
NAPP - National Aerial Photography Program
NHAP – National High Altitude Photography Program
NPS – National Park Service
NWI – National Wetland Inventory, U.S. Fish and Wildlife Service
RMS – Root Mean Square error
TM – Landsat Thematic Mapper data
SCFZ - Sangre de Cristo Fault Zone
SLV – San Luis Valley
USDA – U.S. Department of Agriculture
WRMP – Water Resources Management Plan
NCDC – National Climatic Data Center
USGS - U.S. Geological Survey

Wetlands Study Area Base Map

Great Sand Dunes National Monument, CO
Plotted on USGS Topographic Map
Showing UTM Zone 13 Grid, NAD 27



Map Scale = 1:24,000

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Plate 1

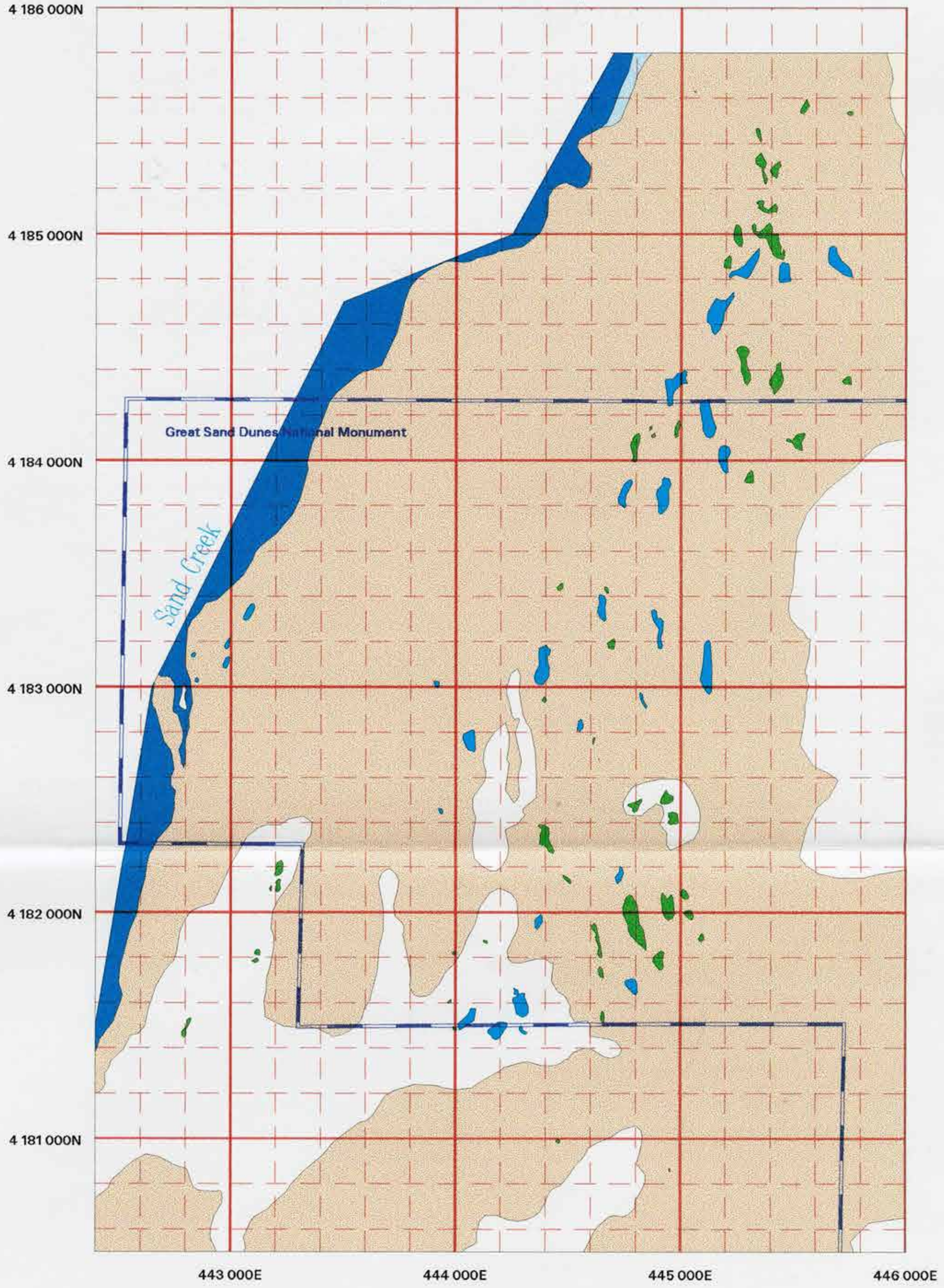
Summer, 1998

1936 Distribution of Wetland and Sand Types
Great Sand Dunes National Monument, CO

Photo Date: August 12, 1936

Photo Scale 1:31,680

X RMS = 5.54 meters, Y RMS = 4.34 meters, Total RMS = 7.04 meters



1936 Wetlands Statistics	Count	Acres: Total	Mean	Maximum	Minimum	Std. Dev
"Wet" Wetlands	30	27.89	0.93	2.47	0.07	0.71
"Dry" Wetlands	50	22.44	0.45	3.12	0.02	0.57
Total Wetlands	80	50.33	0.63	3.12	0.02	0.66

Map Scale = 1:24,000

Sand Classification

- Main Dune Field
- Unvegetated Sand Sheet
- Vegetation/Covered Sand
- Sand Creek Streambed - Dry
- Sand Creek Streambed - Wet

Wetlands Classification

- Wetland w/ Water at Surface
- Wetland w/o Water at Surface

- GRSA Boundary
- UTM 1000 Meter Grid
- UTM 200 Meter Grid

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Plate 2

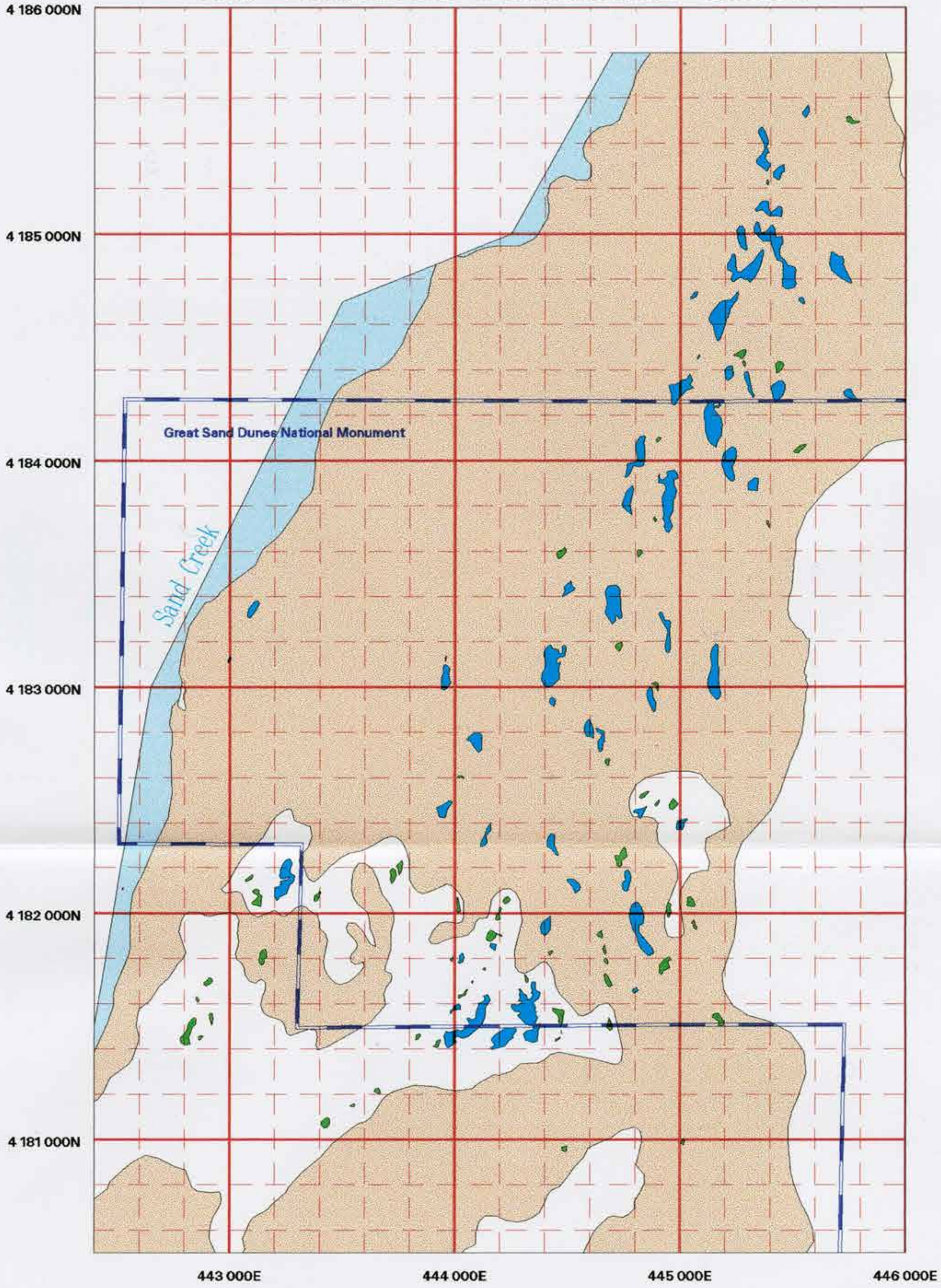
Summer, 1998

1937 Distribution of Wetland and Sand Types
Great Sand Dunes National Monument, CO

Photo Date: September 26, 1937

Photo Scale 1:20,000

X RMS = 1.44 meters, Y RMS = 1.25 meters, Total RMS = 1.90 meters



1937 Wetlands Statistics	Count	Acres: Total	Mean	Maximum	Minimum	Std. Dev
"Wet" Wetlands	54	58.86	1.09	3.69	0.04	1.00
"Dry" Wetlands	60	11.43	0.19	0.83	0.02	0.16
Total Wetlands	114	70.29	0.62	3.69	0.02	0.83

Map Scale = 1:24,000

Sand Classification

- Main Dune Field
- Unvegetated Sand Sheet
- Vegetation/Covered Sand
- Sand Creek Streambed - Dry
- Sand Creek Streambed - Wet

Wetlands Classification

- Wetland w/ Water at Surface
- Wetland w/o Water at Surface
- GRSA Boundary
- UTM 1000 Meter Grid
- UTM 200 Meter Grid

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Plate 3

Summer, 1998

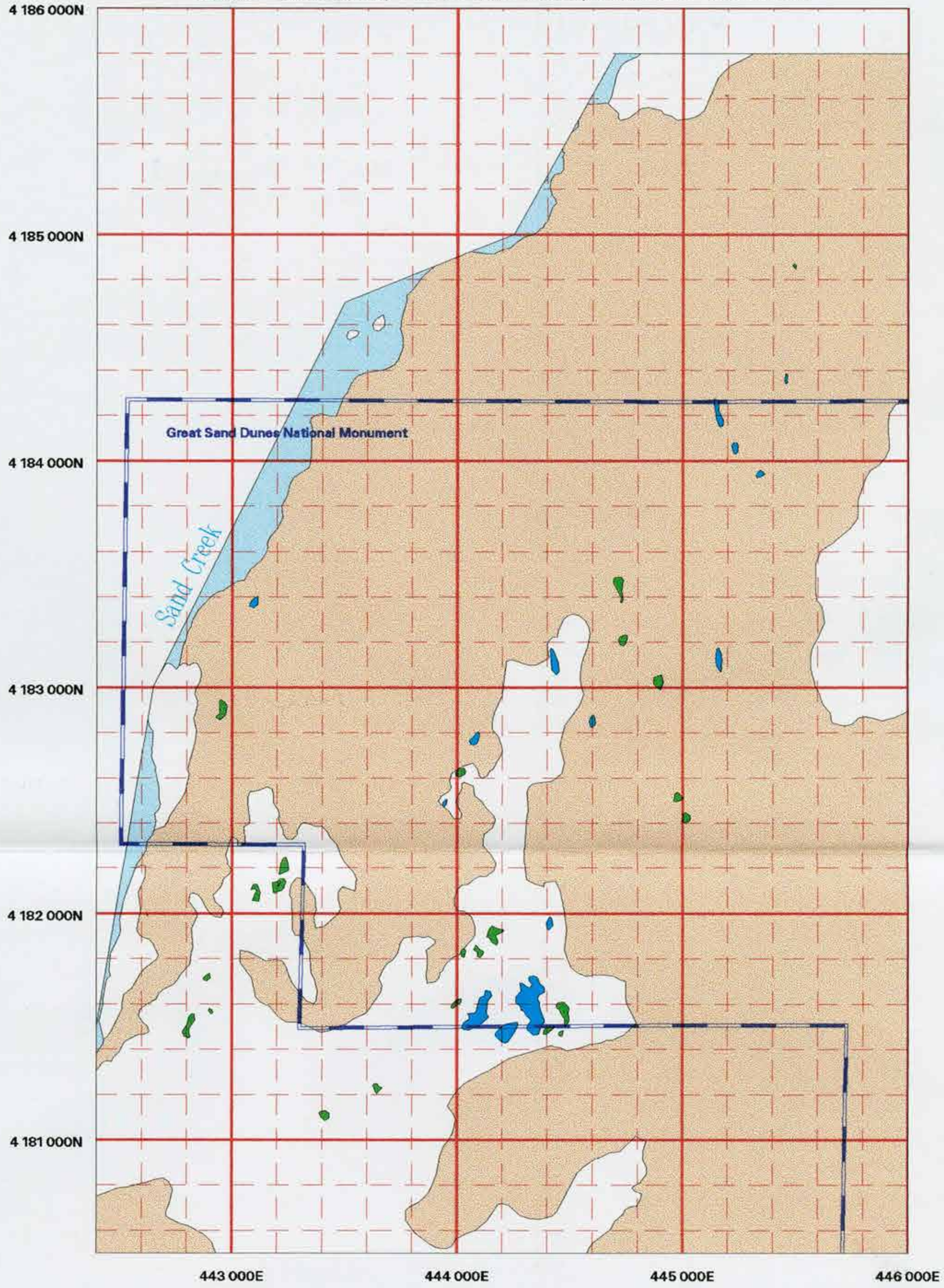
1953 Distribution of Wetland and Sand Types

Great Sand Dunes National Monument, CO

Photo Date: October 9, 1953

Photo Scale 1:53,000

X RMS = 3.28 meters, Y RMS = 5.04 meters, Total RMS = 6.01 meters



1953 Wetlands Statistics	Count	Acres: Total	Mean	Maximum	Minimum	Std. Dev
"Wet" Wetlands	14	12.20	0.87	4.69	0.10	1.26
"Dry" Wetlands	24	8.63	0.36	0.78	0.04	0.23
Total Wetlands	38	20.83	0.55	4.70	0.04	0.81

Map Scale = 1:24,000

Sand Classification

- Main Dune Field
- Unvegetated Sand Sheet
- Vegetation/Covered Sand
- Sand Creek Streambed - Dry
- Sand Creek Streambed - Wet

Wetlands Classification

- Wetland w/ Water at Surface
- Wetland w/o Water at Surface
- GRSA Boundary
- UTM 1000 Meter Grid
- UTM 200 Meter Grid

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Plate 4

Summer, 1998

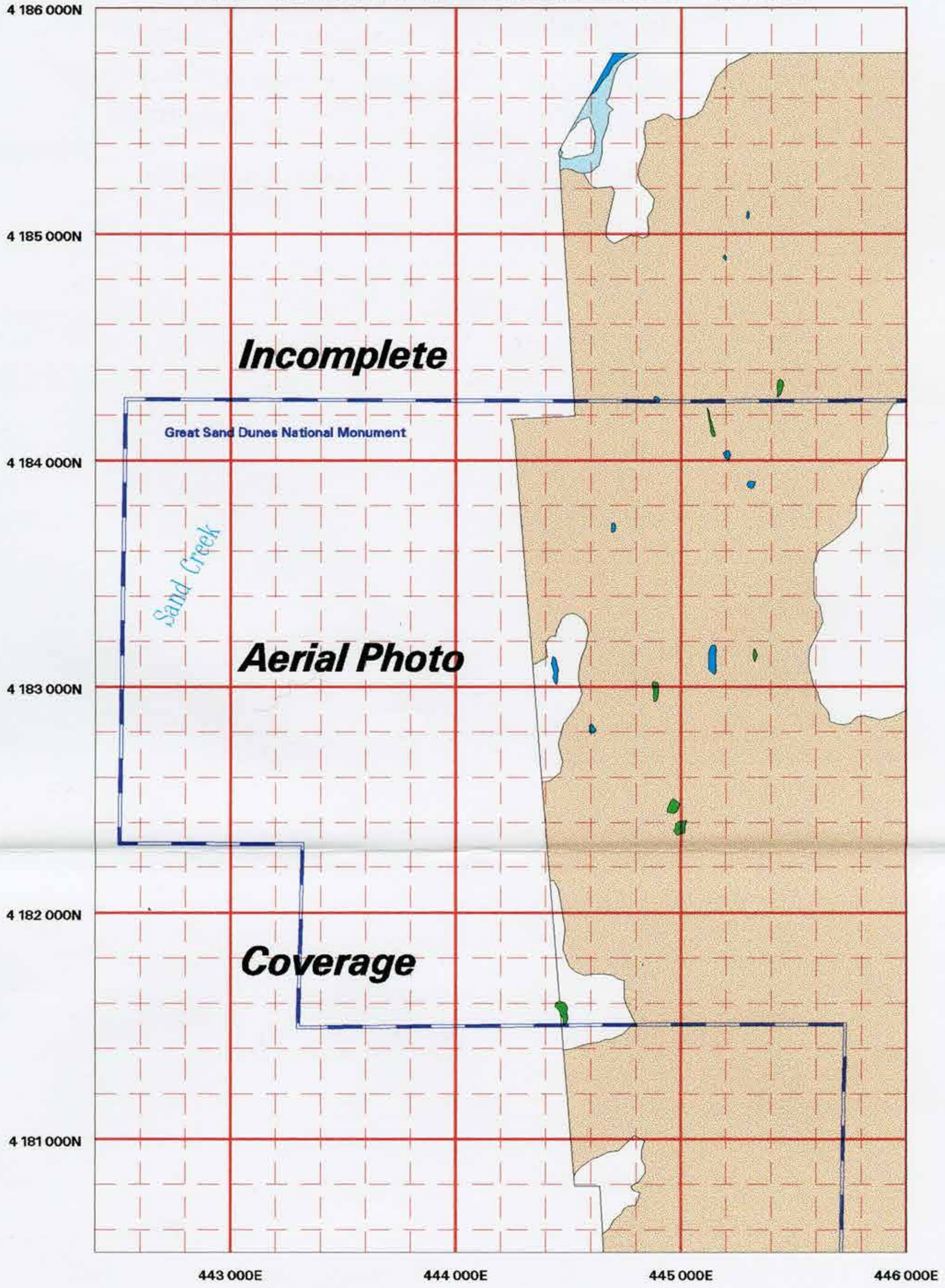
1957 Distribution of Wetland and Sand Types

Great Sand Dunes National Monument, CO

Photo Date: September 25, 1957

Photo Scale 1:20,000

X RMS = 2.99 meters, Y RMS = 4.99 meters, Total RMS = 5.82 meters



1957	< Partial Coverage >					
Wetlands		Acres:				
Statistics	Count	Total	Mean	Maximum	Minimum	Std. Dev
"Wet" Wetlands	9	2.59	0.29	0.93	0.06	0.28
"Dry" Wetlands	7	8.63	0.36	0.78	0.04	0.23
Total Wetlands	16	11.22	0.36	0.93	0.06	0.26

Map Scale = 1:24,000

Sand Classification

- Main Dune Field
- Unvegetated Sand Sheet
- Vegetation/Covered Sand
- Sand Creek Streambed - Dry
- Sand Creek Streambed - Wet

Wetlands Classification

- Wetland w/ Water at Surface
- Wetland w/o Water at Surface
- GRSA Boundary
- UTM 1000 Meter Grid
- UTM 200 Meter Grid

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Plate 5

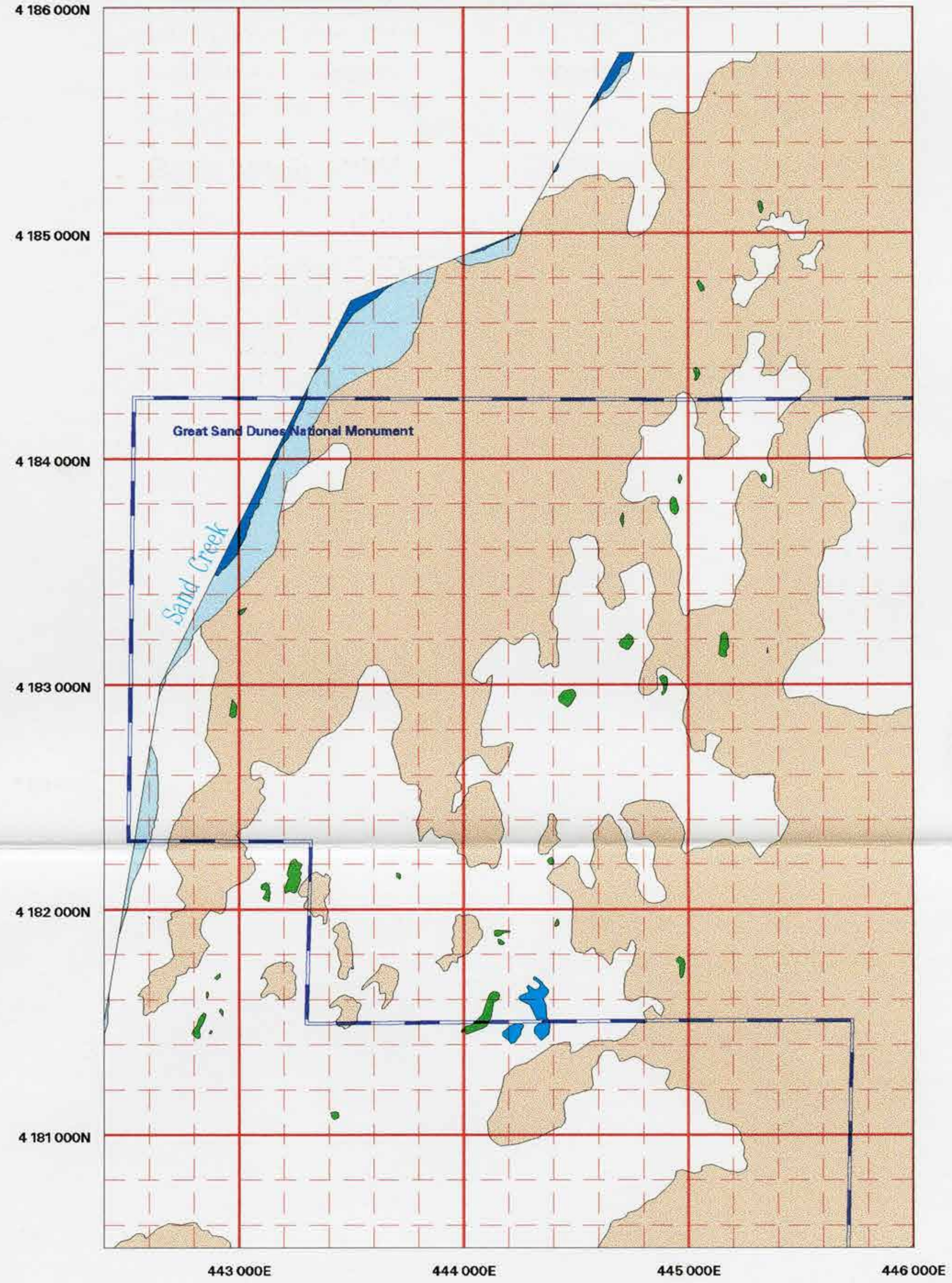
Summer, 1998

1966 Distribution of Wetland and Sand Types
Great Sand Dunes National Monument, CO

Photo Date: August 25, 1966

Photo Scale 1:20,157

X RMS = 2.36 meters, Y RMS = 3.89 meters, Total RMS = 4.55 meters



1966 Wetlands Statistics	Count	Acres: Total	Mean	Maximum	Minimum	Std. Dev
"Wet" Wetlands	2	5.38	2.69	4.07	1.31	1.96
"Dry" Wetlands	29	12.43	0.43	2.22	0.02	0.52
Total Wetlands	31	17.81	0.56	4.07	0.02	0.83

Map Scale = 1:24,000

Sand Classification

- Main Dune Field
- Unvegetated Sand Sheet
- Vegetation/Covered Sand
- Sand Creek Streambed - Dry
- Sand Creek Streambed - Wet

Wetlands Classification

- Wetland w/ Water at Surface
- Wetland w/o Water at Surface
- GRSA Boundary
- UTM 1000 Meter Grid
- UTM 200 Meter Grid

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Plate 6

Summer, 1998

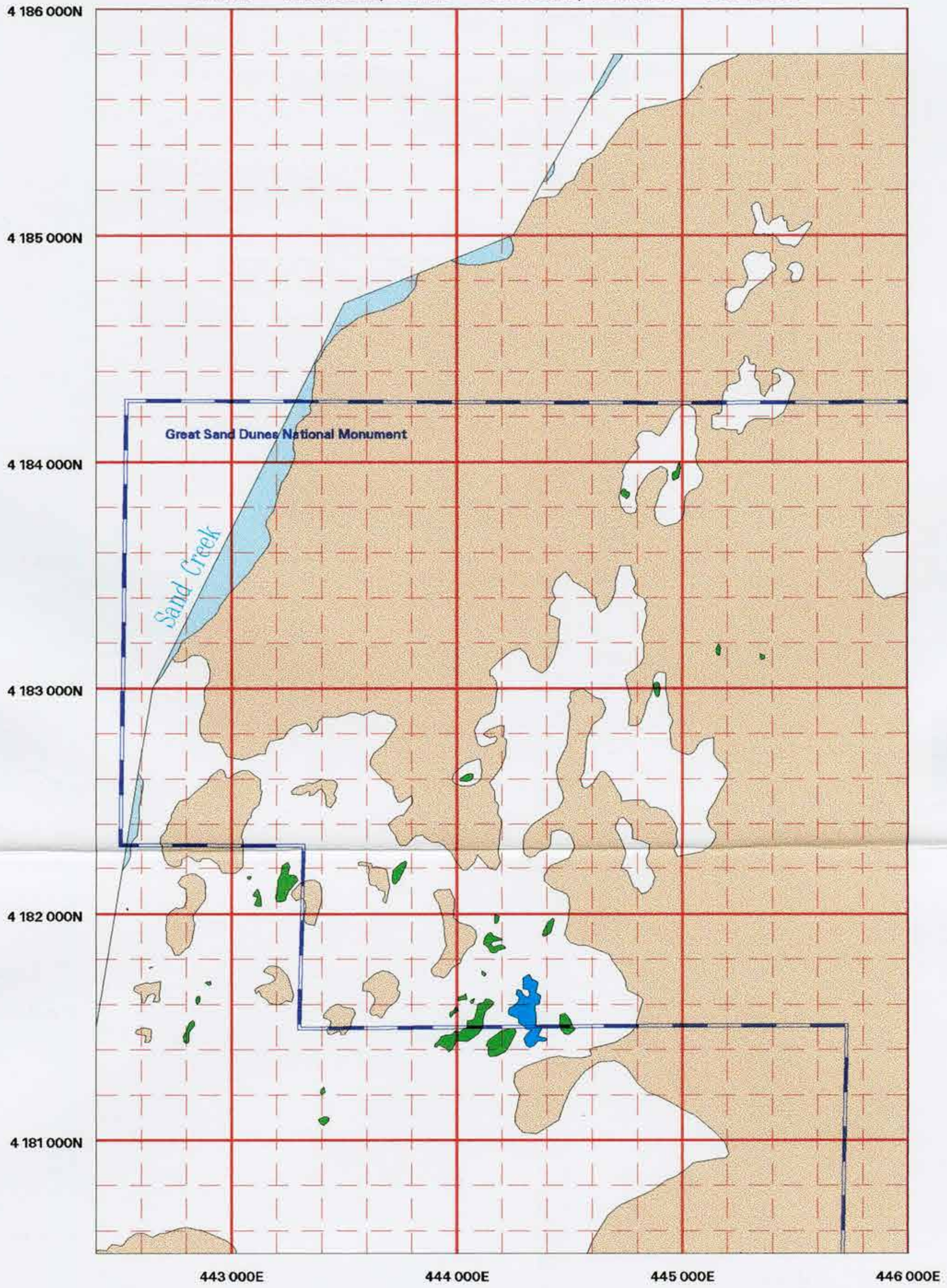
1975 Distribution of Wetland and Sand Types

Great Sand Dunes National Monument, CO

Photo Date: June 26, 1975

Photo Scale 1:80,000

X RMS = 8.78 meters, Y RMS = 4.66 meters, Total RMS = 9.94 meters



1975 Wetlands Statistics	Count	Acres: Total	Mean	Maximum	Minimum	Std. Dev
"Wet" Wetlands	1	5.78	5.78	5.78	5.78	
"Dry" Wetlands	25	15.91	0.64	3.96	0.05	0.93
Total Wetlands	26	21.69	0.80	5.78	0.05	1.34

Map Scale = 1:24,000

Sand Classification

- Main Dune Field
- Unvegetated Sand Sheet
- Vegetation/Covered Sand
- Sand Creek Streambed - Dry
- Sand Creek Streambed - Wet

Wetlands Classification

- Wetland w/ Water at Surface
- Wetland w/o Water at Surface
- GRSA Boundary
- UTM 1000 Meter Grid
- UTM 200 Meter Grid

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Plate 7

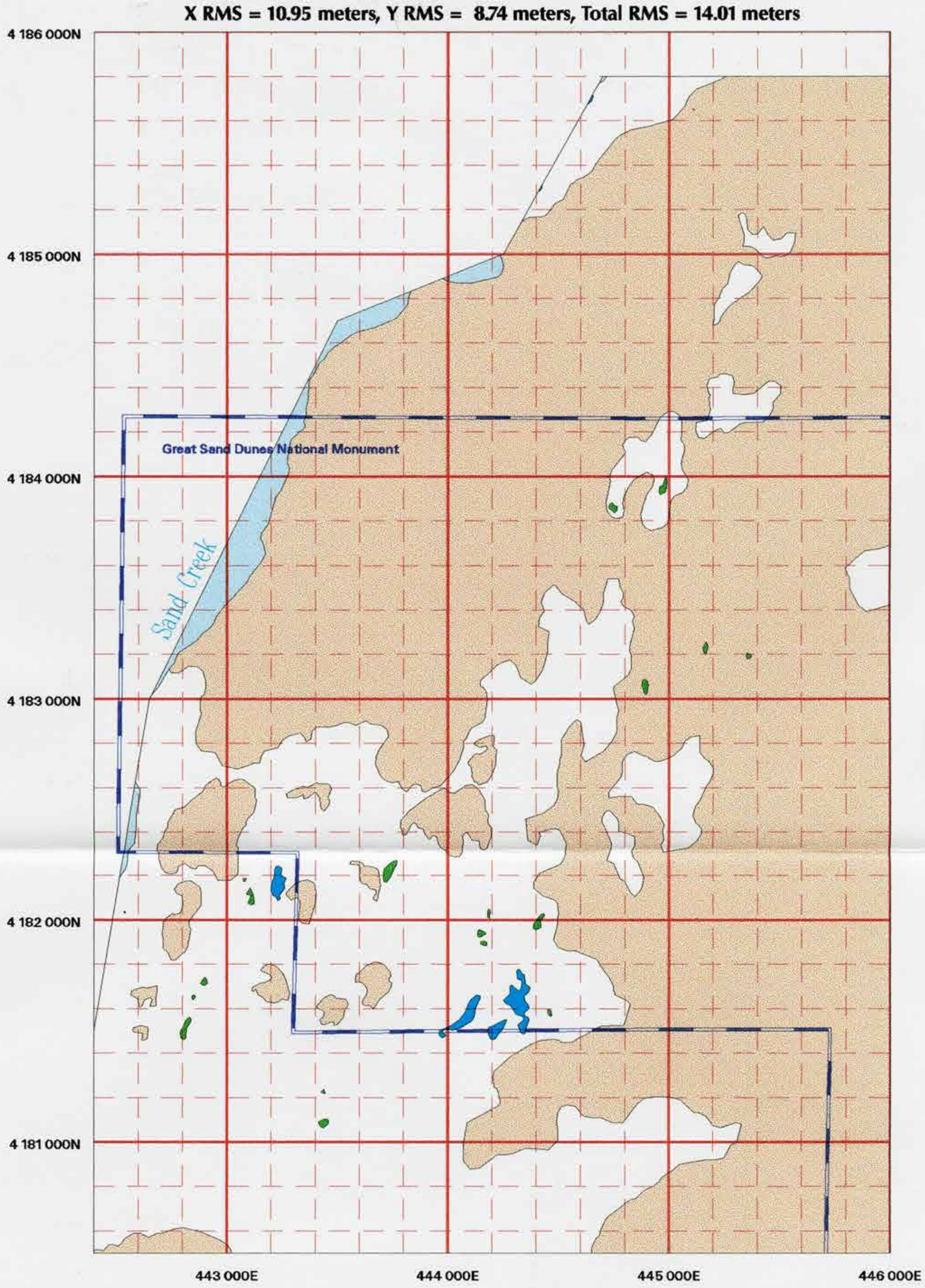
Summer, 1998

1979 Distribution of Wetland and Sand Types
Great Sand Dunes National Monument, CO

Photo Date: Sept 5, 1979

Photo Scale 1:78,000

X RMS = 10.95 meters, Y RMS = 8.74 meters, Total RMS = 14.01 meters



1979 Wetlands Statistics	Count	Acres: Total	Mean	Maximum	Minimum	Std. Dev
"Wet" Wetlands	4	8.01	2.00	3.44	0.94	1.06
"Dry" Wetlands	18	4.67	0.26	0.79	0.05	0.20
Total Wetlands	22	12.68	0.55	3.44	0.05	0.81

Map Scale = 1:24,000

Sand Classification

- Main Dune Field
- Unvegetated Sand Sheet
- Vegetation/Covered Sand
- Sand Creek Streambed - Dry
- Sand Creek Streambed - Wet

Wetlands Classification

- Wetland w/ Water at Surface
- Wetland w/o Water at Surface
- GRSA Boundary
- UTM 1000 Meter Grid
- UTM 200 Meter Grid

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Plate 8

Summer, 1998

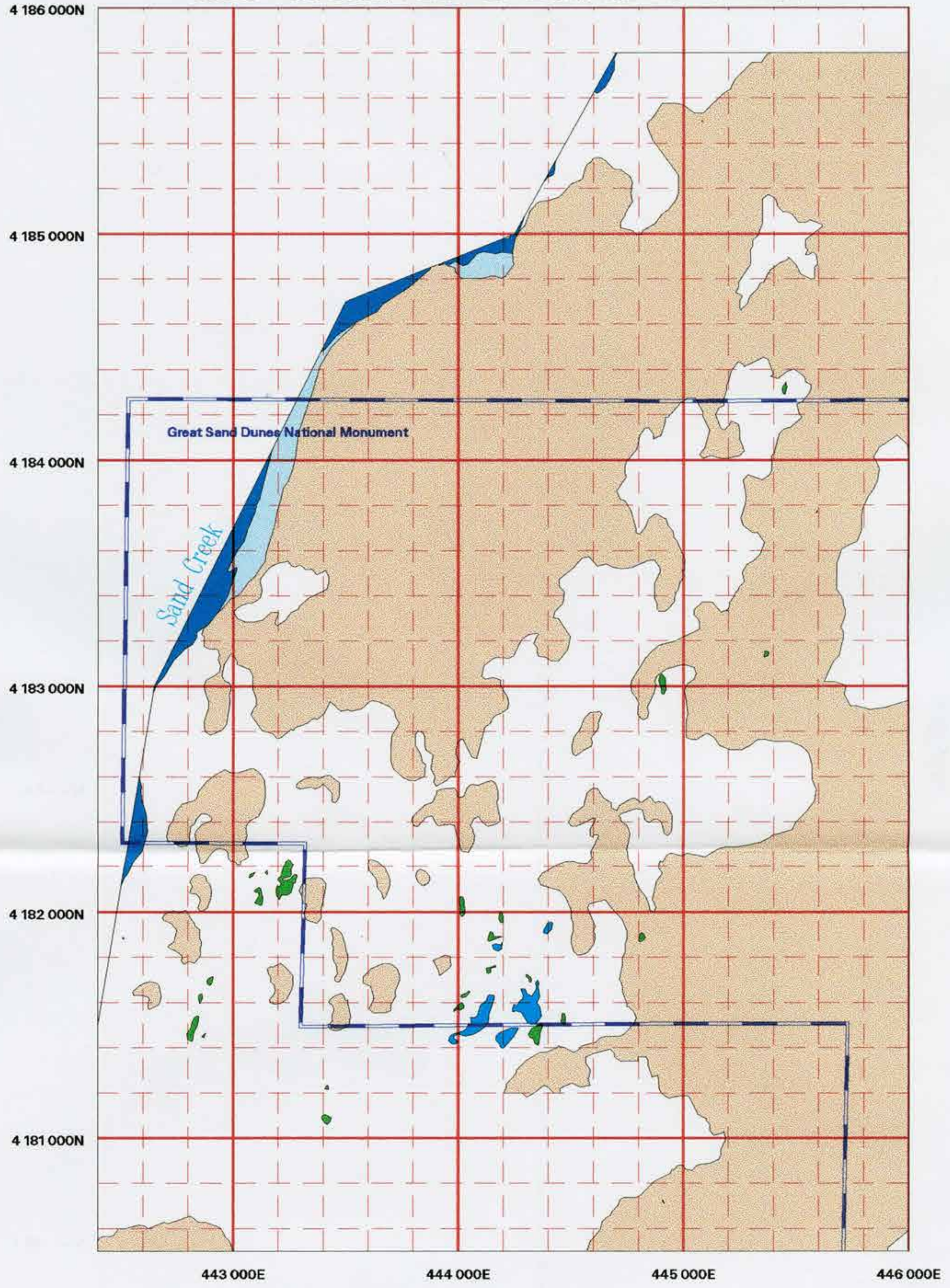
1985 Distribution of Wetland and Sand Types

Great Sand Dunes National Monument, CO

Photo Date: August 13, 1985

Photo Scale 1:53,000

X RMS = 4.08 meters, Y RMS = 3.07 meters, Total RMS = 5.10 meters



1985 Wetlands Statistics	Count	Acres: Total	Mean	Maximum	Minimum	Std. Dev
"Wet" Wetlands	5	7.71	1.54	3.00	0.27	1.34
"Dry" Wetlands	25	7.38	0.30	2.03	0.01	0.41
Total Wetlands	30	15.09	0.50	3.00	0.01	0.78

Map Scale = 1:24,000

Sand Classification

- Main Dune Field
- Unvegetated Sand Sheet
- Vegetation/Covered Sand
- Sand Creek Streambed - Dry
- Sand Creek Streambed - Wet

Wetlands Classification

- Wetland w/ Water at Surface
- Wetland w/o Water at Surface
- GRSA Boundary
- UTM 1000 Meter Grid
- UTM 200 Meter Grid

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Plate 9

Summer, 1998

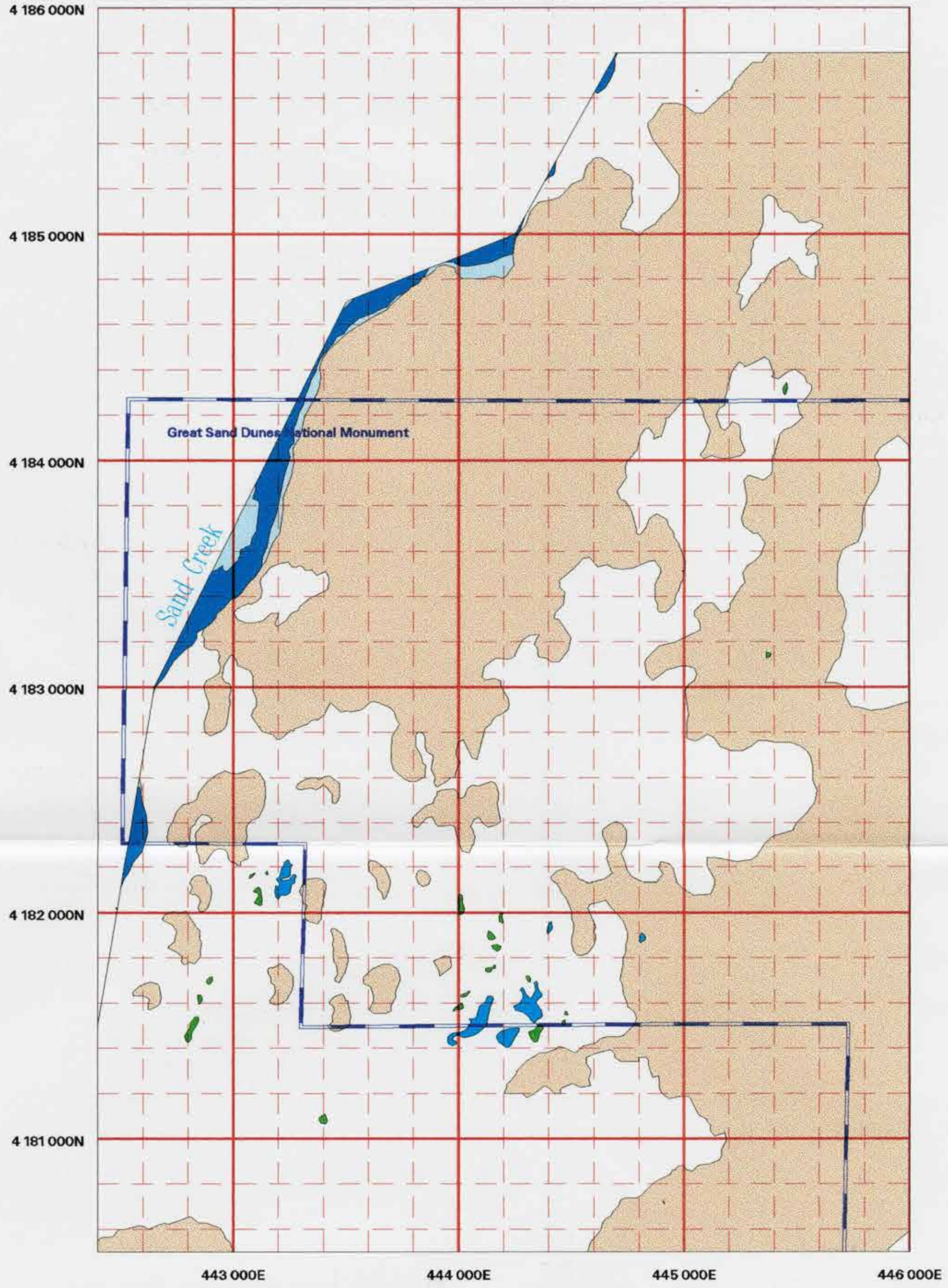
1988 Distribution of Wetland and Sand Types

Great Sand Dunes National Monument, CO

Photo Date: July 22, 1988

Photo Scale 1:40,000

Photos Orthorectified



1988 Wetlands Statistics	Count	Acres: Total	Mean	Maximum	Minimum	Std. Dev
"Wet" Wetlands	6	9.40	1.57	2.97	0.20	1.19
"Dry" Wetlands	22	4.60	0.21	0.72	0.01	0.20
Total Wetlands	28	14.00	0.50	2.97	0.01	0.78

Map Scale = 1:24,000

Sand Classification

- Main Dune Field
- Unvegetated Sand Sheet
- Vegetation/Covered Sand
- Sand Creek Streambed - Dry
- Sand Creek Streambed - Wet

Wetlands Classification

- Wetland w/ Water at Surface
- Wetland w/o Water at Surface
- GRSA Boundary
- UTM 1000 Meter Grid
- UTM 200 Meter Grid

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Plate 10

Summer, 1998

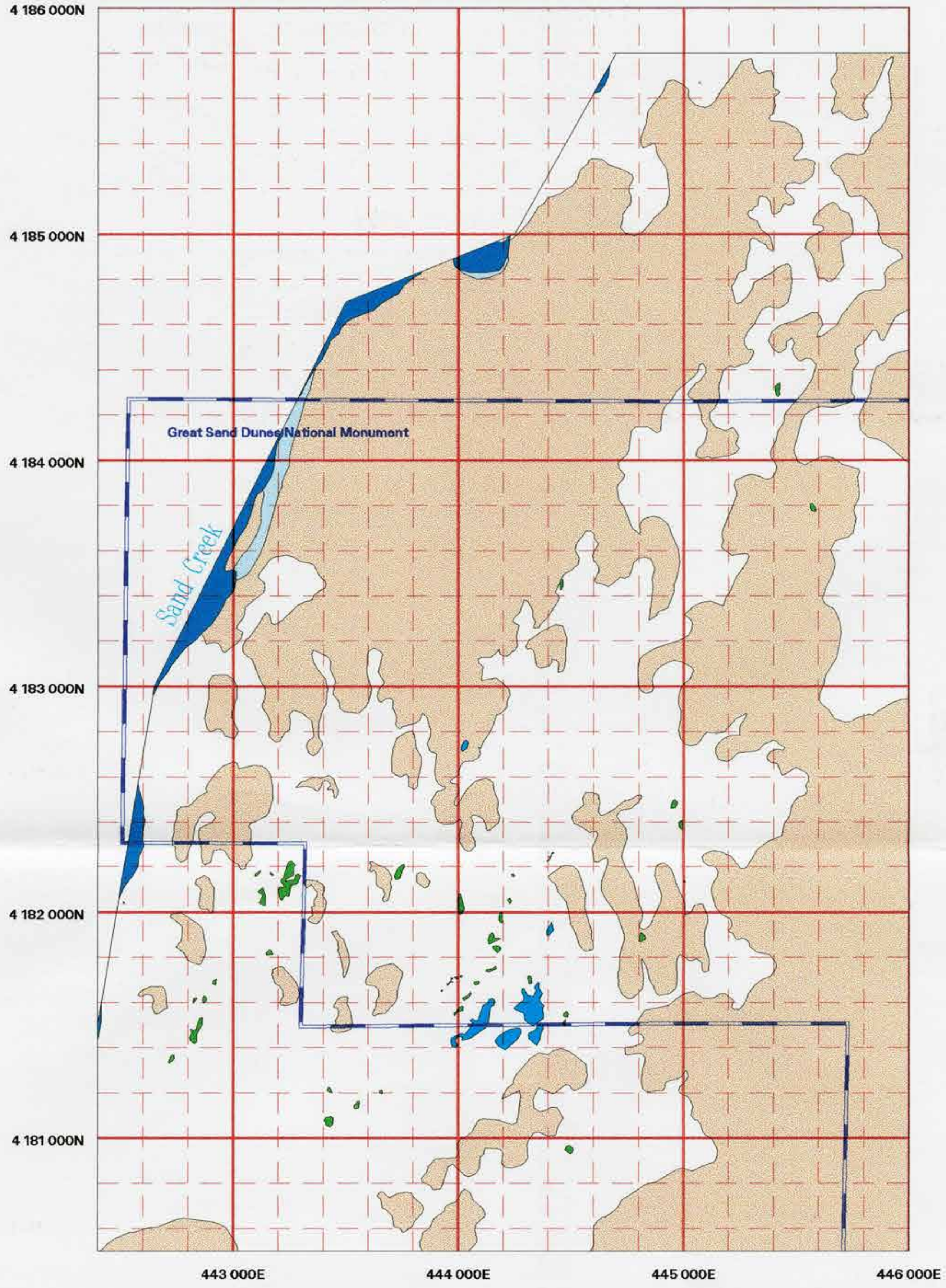
1995 Distribution of Wetland and Sand Types

Great Sand Dunes National Monument, CO

Photo Date: July 26, 1995

Photo Scale 1:24,000

X RMS = 2.73 meters, Y RMS = 2.20 meters, Total RMS = 3.50 meters



1995 Wetlands Statistics	Count	Acres: Total	Mean	Maximum	Minimum	Std. Dev
"Wet" Wetlands	6	8.81	1.47	3.22	0.26	1.23
"Dry" Wetlands	45	7.81	0.17	1.74	0.01	0.27
Total Wetlands	51	16.63	0.33	3.23	0.01	0.63

Map Scale = 1:24,000

Sand Classification

- Main Dune Field
- Unvegetated Sand Sheet
- Vegetation/Covered Sand
- Sand Creek Streambed - Dry
- Sand Creek Streambed - Wet

Wetlands Classification

- Wetland w/ Water at Surface
- Wetland w/o Water at Surface
- GRSA Boundary
- UTM 1000 Meter Grid
- UTM 200 Meter Grid

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Plate 11

Summer, 1998