Wetland Delineation of Camp Ripley in Minnesota

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WETLAND DELINEATION OF CAMP RIPLEY IN MINNESOTA

by

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Richard A. Spencer

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CHAPTER 1

INTRODUCTION

The Department of Defense (DoD) maintains approximately 25 million acres of land that is used for military training in the continental United States. Currently, federal and state laws and regulations require that the DoD land be managed so that any activity, including training, will have a minimal effect on the natural environment.

One concern of land management at installations such as Camp Ripley is the location and extent of wetlands. This is because (1) wetlands are protected by many federal, state, and local regulations, including The Food, Agriculture, Conservation, and Trade Act FACTA (USDA 1990), Section 404 of the Clean Water Act (EPA 1989), the National Environmental Policy Act NEPA (1969), and the Minnesota State Wetland Conservation Act of 1991 (Want 1990; Meeks and Runyon 1990); (2) military activities could adversely affect wetlands if not properly implemented; (3) wildlife could also be affected by the noise produced by live munitions fire and troop and vehicle movement; and (4) Wharton et al. (1982) have found that, in general, 80% of America's breeding bird population and more than 50% of the 800 species of protected migratory birds rely on wetland habitats in their life cycle.

Appropriate land management of wetlands requires the availability of current maps that contain sufficient detail to permit the monitoring and protection activities mandated by law.

Utah State University has a research agreement to create a standardized national database for the protection and management of natural resources data for national guard training areas. Management of training on national guard facilities requires an efficient natural resources database that must be continually updated.

This project will produce a current wetland-status map to meet the specifications of the training and environmental managers. The map will be used to define areas that are unsuitable for training because of the presence of wetlands.

This thesis is a case study for land managers in which wetland boundaries can be delineated and their total area measured from aerial photography. The areas and boundaries shown on the National Wetland Inventory (NWI) map are compared to maps and photography from a number of years to determine the dynamics of wetlands and the effects of rainfall and seasonal changes.

A standard definition of a wetland has not yet been adopted and each organization concerned with wetlands has definitions that include: length of time that saturated conditions must exist to produce anaerobic conditions, the interval between saturated and unsaturated conditions, and the physical evidence under which wetland conditions exist. The definition of wetlands depends on the objectives and the area of interest of the user (Dahl 1992). The definition of wetlands used in this study is the definition used by the NWI. Due to the varied definitions mentioned above, there may be areas that are not included in this study that could be described as wetlands.

> Wetlands are dynamic ecosystems that can be defined by most federal regulating agencies as having three essential characteristics: hydrophitic vegetation, hydric soils (soils with anaerobic conditions in the upper part), and wetland hydrology, which are the requirements for the creation of wetlands. (Federal Interagency Committee for Wetland Delineation 1989, p. 76).

The most effective way to map and document wetlands is to use remote sensing, especially aerial photography. Four main types of photographic medium are used in aerial photography: black-and-white, black-and-white-infrared, color, and color-infrared (CIR). Although black-and-white and black-and-white-infrared photography provide a satisfactory means to delineate wetland areas, color and CIR airphotos provide a much improved delineation because patterns of darker soil and vegetation can be more easily detected by the human eye. This is because the human eye can discern millions of colors, but only 100 shades of gray (Avery and Berlin, 1992). Of the photographic materials available, CIR photography provides the best means of delineation of wetlands because damp ground, water, and vegetation are recognized much more easily (Wilen and Pywell 1992).

The most recent photography of Camp Ripley is CIR photography taken in 1994. Also, the Environmental Office at Camp Ripley has archival photography which was compared to the present data to analyze changes in wetlands over time. Table 1 explains the types of photography that were available.

Table 1. Dates and scale of archival photography

DATE	5-12-1954	10-30-1978	7-03-1990	4-25-1991
TYPE	BLACK & WHITE	BLACK & WHITE IR	BLACK & WHITE IR	COLOR IR
SCALE	APPROX. 1:15,000	APPROX. 1:10,000	APPROX. 1:15840	APPROX. 1:40,000

CIR film is manufactured to record green (0.5 to 0.6 micrometer), red (0.6 to 0.7 micrometer), and the photographic portion (0.7 to 0.9 micrometer wavelength) of the near-infrared scene energy in its three emulsion layers instead of the blue, green, and red light that standard color film records. The negative color of the dyes developed in each of these layers are yellow, magenta, and cyan. The resulting image is a "false-color" in which blue colors result from objects reflecting primarily green light, green colors result from objects reflecting primarily red light, and red or yellow colors result from non-thermal emission and reflectance of objects primarily in the near-infrared portion of the spectrum (Lillesand and Kiefer 1987). This "false-color" image makes healthy, chlorophyll-rich vegetation appear red so vegetation condition can be assessed by "redness" and water appears black so wet areas are easier to detect by their "blackness" (see Table 2).

As is shown in Table 2, damp ground has distinct darker tones and water is dark blue to black. This provides a superior method of delineation compared to natural color or black-and-white where damp ground is only slightly darker and silty water can be confused with vegetation.

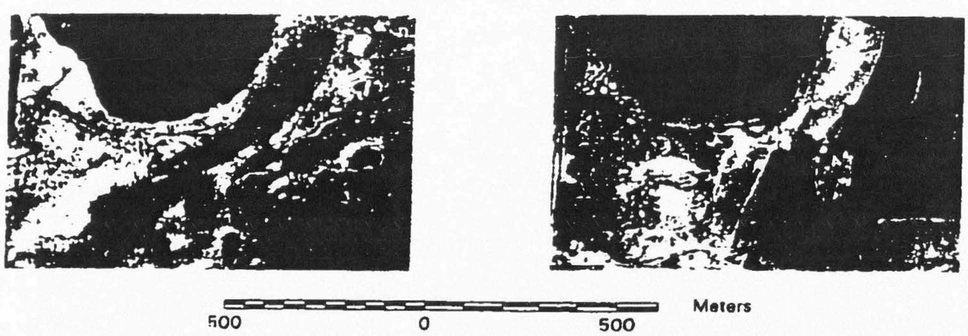
Table 2. Terrain signatures on normal color and CIR film (from Sabins 1978).

Subject	Signature on normal color film	Signature on CIR film
Healthy vegetation:		
Broadleaf type	Green	Red to magenta
Needle-leaf type	Green	Reddish brown to purple
Stressed vegetation:		
Previsual stage	Green	Darker red
Visual stage	Yellowish green	Cyan
Autumn leaves	Red to yellow	Yellow to white
Clear water	Blue-green	Dark blue to black
Silty water	Light green	Light blue
Damp ground	Slightly darker	Distinct dark tones
Shadows	Blue with details visible	Black with few details
Water penetration	Good	Green and red bands: good IR band: poor
Contacts between land and water	Poor to fair discrimination	Excellent discrimination
Red bed outcrops	Red	Yellow

Figure 1 is a comparison of the appearance of wetlands in CIR and panchromatic (B&W) photography. In both cases wetlands were delineated from the light and dark areas. The wetlands appear generally darker in both cases with a purplish color in the CIR image and black in the black-and-white image.

As this example shows, black-and-white photography is quite suitable for the delineation of wetlands. However, CIR film provides greater discrimination due to the millions of colors that are displayed, and the darker tones shown by the wet areas are much easier to detect.

Soils in the wetland areas are described as hydric soils, which are defined by the U.S. Soil Conservation Service (1985, p. 1) as "soil that is saturated, flooded or ponded long enough during the growing season to develop anaerobic conditions in the upper part. Wetland soils



1994 CIR 1954 B&W

Figure 1. A comparison of color to black-and-white photography

are of two types: (1) mineral soils, or (2) organic soils (*Histosols*)."

Histosols (from the Greek word *histos* [tissue]) are organic soils that are primarily made up of large amounts of plant and sometimes animal remains in various stages of decomposition. These components have accumulated under water or under very wet conditions, which slows the decomposition process. This process is further slowed by cooler temperatures (Fanning and Fanning 1989). This process yields a large A or Organic Horizon in the soil (Harpstead, Hole, and Bennet 1988). Everett (1983) indicates that cool to cold climates seem to favor Histosol formation due to a reduction or even prevention of decomposition. An example of this is when the soil freezes.

The parent materials of a Histosol are plant and animal remains. This material is usually deposited by alluviation and will usually collect in low areas where flowing water begins to slow down and lose its capacity to carry material. The topography of an area favoring Histosol formation is one that provides a flat or bowl-shaped terrain and a saturated or near-saturated environment (Fanning and Fanning 1989). Figure 2 shows a topographic sequence of the effects of water and run-off of soils on a slope in a humid temperate climatic zone.

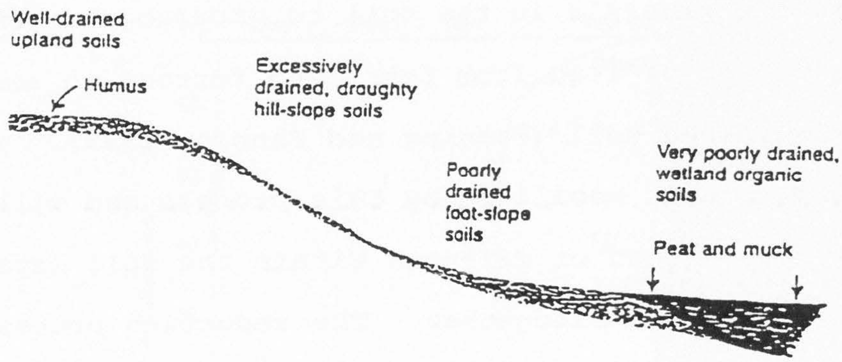


Figure 2. A topographic sequence of soils in a humid temperate climatic zone (from Harpstead, Hole, and Bennet 1988).

Once the material is deposited, there must be sufficient water present to form anaerobic conditions (Everett 1983). In continuously saturated environments, the formation of organic soils is likely due to the rate of organic matter production and addition to the soil, or the amount of soil parent material (humus) is much greater than the loss of organic matter by decomposition (Fanning and Fanning 1989).

Other wetland soils are mineral soils that have little plant material (humus) available. These mineral soils turn a greenish or blue-gray color when saturated long enough to develop anaerobic conditions. This is because of reduction and oxidation (Mitsch and Gosselink 1993). This type of wetland soil goes through a process called gleization (from the Russian word *glei* [clay] also close to the Polish word *glej* [muddy ground]). This process occurs because saturated conditions exist for a sufficient amount of time to cause the minerals in the soil to undergo changes caused by a reduction of iron from ferric to ferrous in some or all parts of the soil (Fanning and Fanning 1989). The available iron is mobilized by this process and will probably be leached or diffused within the soil layers or may be leached out altogether. The reduction process is typically followed by the reverse process of oxidation of ferrous to ferric, which is precipitated to other parts of the soil horizons (Fanning and Fanning 1989).

When clay or silty-clay soils are deposited in the bottom of a valley or ravine, the soil tends to have lower drainage characteristics and favor the formation of wetlands.

As a result of the processes described above, the soil is relatively dark compared to surrounding areas. This is due to low reflectance of almost all wavelengths of the water present in wet soils (see Figure 3). This provides a sufficient difference in the scene to delineate wetland areas, especially when using CIR film. Figure 3 describes the characteristics of different wavelengths of reflected electromagnetic radiation from various materials.

Since the photography was taken in the fall of 1994, the vegetation is a less obvious component of the scene because the spongy mesophyll cells of the senescent vegetation reflect less infrared energy (Avery and Berlin 1992), and

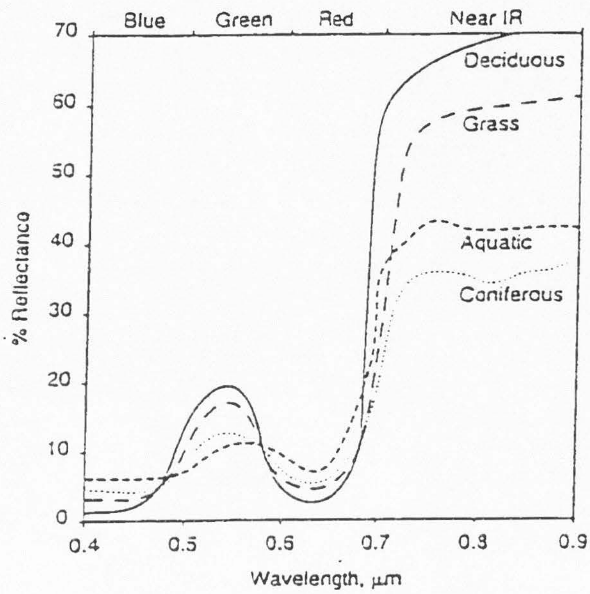


Figure 3. Average spectral-response curves for six materials (from Sabins 1978).

the delineation is more soil-dependent. However, some vegetation is visible. Hydrophytic vegetation is present, but, there is some reduction in color of this vegetation due to the time of year. In general, the detection of wetlands from airphotos can be achieved with both leaf-on and leaf-off. Permanent wetlands are more precisely delineated in the fall season. This is due to the minimum stream flow and less precipitation occurring in the fall season at Camp Ripley. Since less water is available to the wetlands in the fall, they become smaller or dry up. As stream flow increases in late winter and spring, the wetlands recharge. As Figure 4 indicates, the maximum stream flow in Minnesota is in the early spring, and the minimum is in the winter.

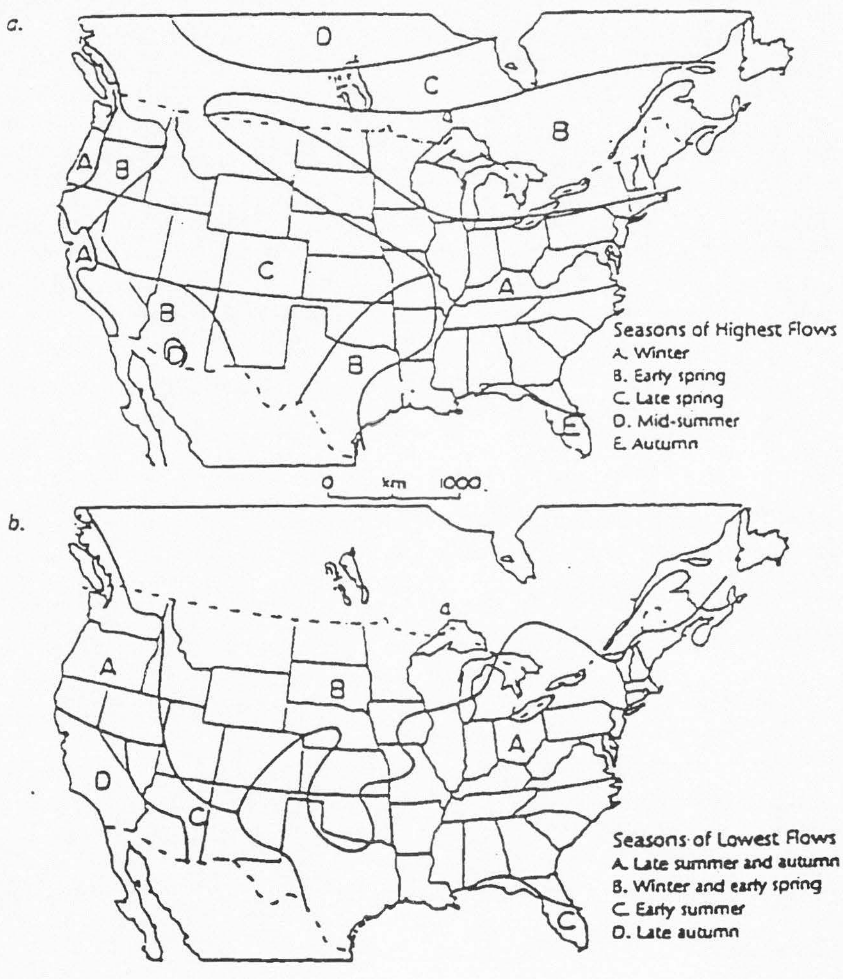


Figure 4. Maximum and minimum streamflow in North America (from Sabins 1978)

In compiling maps for any wetlands study, it is important to establish a mapping standard. The base map selected for this project is the National Wetlands Inventory map (NWI). The NWI classification scheme for discerning wetland areas is the 1979 U.S. Fish and Wildlife Service's definition. Other national agencies dispute the accuracy of these maps because different mapping procedures and definitions have been employed. However, airphoto interpretation to accurately map specific wetland areas is the method most commonly used by federal, state, and local agencies (Lee and Lunetta 1995). This study is based the following NWI classification:

> Wetlands are lands transitional between terrestrial and aquatic systems where the water table is usually at or near the surface or the land is covered by shallow water. For purposes of this classification, wetlands must have one or more of the following three attributes: (1) At least periodically, the land supports predominantly hydrophytes, (2) The substrate is predominantly undrained hydric soil and (3) The substrate is nonsoil and is saturated with water or is covered by shallow water at sometime during the growing season of each year. (Cowardin et al. 1979, p. 3)

CHAPTER 2

LITERATURE REVIEW

In a memo given in the manual of the 1995 Department of Defense (DoD) National Conservation/Legacy Workshop, Secretary of Defense Dr. William J. Perry (1995) stated:

> Now, DoD has an aggressive environmental program because it is critical to the defense mission. Why? Because it protects the quality of life of our forces and their families from environmental health and safety hazards where they live and work. Careful use of our lands and waters also preserves our access to these resources for training, which is key to military readiness. DoD's environmental programs are an investment in the readiness and quality of life of our forces. Moreover, investment in sound environmental practices and compliance now will save us much higher costs later for cleanup. (p. 3)

This statement summarizes the DoD commitment to protecting the environment. The DoD has implemented the following programs to ensure military lands are protected and to comply with the laws and regulations that govern each installation:

1. Integrated Training Area Management (ITAM) which is described as a program which provides a management and decision-making process to integrate Army training and other mission requirements for land use with sound natural resource management of that land. This includes inventorying and monitoring land condition, integrating training requirements with consideration of land capacity, educating land users to minimize adverse effects, and providing for rehabilitation and maintenance of land. (Macia 1995, p. 3).

2. Land Conditioning-Trend Analysis (LCTA) is a program which uses consistent methods to collect, analyze, and report data on natural resources. The two basic objectives of LCTA are to inventory and monitor the ecological

> health of Army lands and determine the carrying capacity of Army lands. The data is collected from transects originating from permanent plots which are allocated by a stratified random sampling design. These plots provide land managers with comparable data from throughout an installation and through time. LCTA provides inventory and monitoring data for NEPA documentation, integrated natural resources management plans, environmental impact statements, master planning, and scheduling of training operations. (Kowalski and Shaw 1995, p. 9)

These two programs in conjunction with the DoD's commitment to protecting the environment cause military land managers to adopt more orderly procedures to monitor current conditions and trends in natural resources, including wetland areas.

A military land manager will use the techniques stated above; however, each installation will have a unique environment where specific natural phenomena will occur. The management of these will require a variety of monitoring techniques. The following are some case studies where wetland boundaries and trends are analyzed. These studies should be used as examples of how others have monitored wetlands in the past.

Jensen et al. (1993) performed a study on the Evaluation of the CoastWatch Change Detection in South Carolina using slope, exposure, soil type, and temperature to produce a model for wetland development and preservation. This project used LANDSAT Thematic Mapper (TM) and CIR airphotos to delineate wetland boundaries and monitor the condition of wetland areas. Ferguson, Wood, and Graham (1993) studied changes in sea-grass habitat in North Carolina using photo-interpretive techniques to delineate seagrass areas to monitor coastal wetland locations. Welch, Remillard, and Alberts (1992) used historical aerial photographs from 1953 and 1974 for mapping past conditions in marshlands and surrounding upland areas of Spelo Island using digital image processing and photo-interpretive methods to delineate wetland areas in Georgia. Lyon and Greene (1992) used aerial photographs to quantify change in the Lake Erie Coastal wetlands and used a water-level method to delineate wetland areas by photo-interpretation. All of the projects mentioned above used CIR aerial photography. Dahl (1992) stated that the preferred source of remotely sensed data for mapping wetland areas is color infrared, leaf-off, high-altitude photography. However, this is slowly being replaced with satellite imagery.

Wetland mapping is becoming more important as land managers realize the reliance of fauna and flora dependence on wetland areas (Wilen and Pywell 1992). Dahl (1992, p. 223) stated, "There is an increasing demand to provide more information on the status and trends of wetlands." The significance of producing wetland boundary maps when aerial photography is taken should be realized and these maps should utilized by land managers in all phases of land use.

The methods of delineating wetlands vary due to the data available and the different characteristics of the area being managed. Vegetation boundaries are a good source of delineation. Brown (1978) studied and compared methods used by the Earth Satellite Corporation (ESC) for a coastal wetland inventory in New Jersey and New York. This was done by evaluating where the emergent vegetation starts and drawing a line. Using these data, Brown delineated an upper wetland boundary line just below the emergent vegetation line. However, Civico, Kennard, and Lefore (1978) suggest that accurate boundary delineation requires a combination of multiseasonal photography.

A map of the ecoregions within a specific area assists managers of aquatic and terrestrial resources in understanding the regional patterns of the area to be able to maintain the quality of these resources (Omernik 1987). One of the major requirements for predictive modeling of an area is an identification of the ecosystems that the study area exhibits (Bailey 1988). The mean precipitation and temperature become important in the determination of the ecosystem in the area that is managed. Bailey (1983) divided the continental United States into two major divisions: dry and humid temperate. This was divided along roughly the 100th West Meridian where a general increase of average precipitation is noted. Camp Ripley (located at 46 04′20″ North and 94 21′ 05″ West) is east of the humid temperate boundary. This climate, along with the topography of the area, is ideal for the formation of lakes and wetland areas. Wetland locations and trends are very important to the training activities in Camp Ripley.

CHAPTER 3

STUDY SITE

Camp Ripley (21,500 hectares) is located in the north-central part of Minnesota about eight kilometers north of Little Falls. The Mississippi River borders it on the east side. It is located in the Mississippi-Great Lakes section of the Central Lowland Physical Province (see Figure 5).

The topography of Camp Ripley suggests the area was formed by glaciers. Lobeck (1948) describes the formation and characteristics of the area of Camp Ripley as follows:

> A lobe of the Wisconsin ice sheet moved southward across Minnesota and reached Iowa around 10,000 years ago and left numerous moraines and plains of drift. The glacier stopped the flow of the northern-flowing Red River and also cut off the outlet of Lake Winnipeg to Hudson Bay. It caused one of the largest pro-glacial lakes in North America called Lake Agassiz. When the lake retreated, it left several basins with highly fertile soil and knob and kettle topography. There are thousands of lakes which characterize this area. This topology combined with a continental type of climate, combine to render this region the heart of the spring wheat area of North America. (p. 1)

The area is ideally suited to wheat production, the major activity, because of the mineral soils and climate. Much of the area is low-lying and water tends to collect in the lowest areas leading to the formation of wetland areas.

The camp is situated in an area of rolling hills with a mixture of pines and hardwoods. Figure 6 shows areas of woodlands which merge into dense growth.

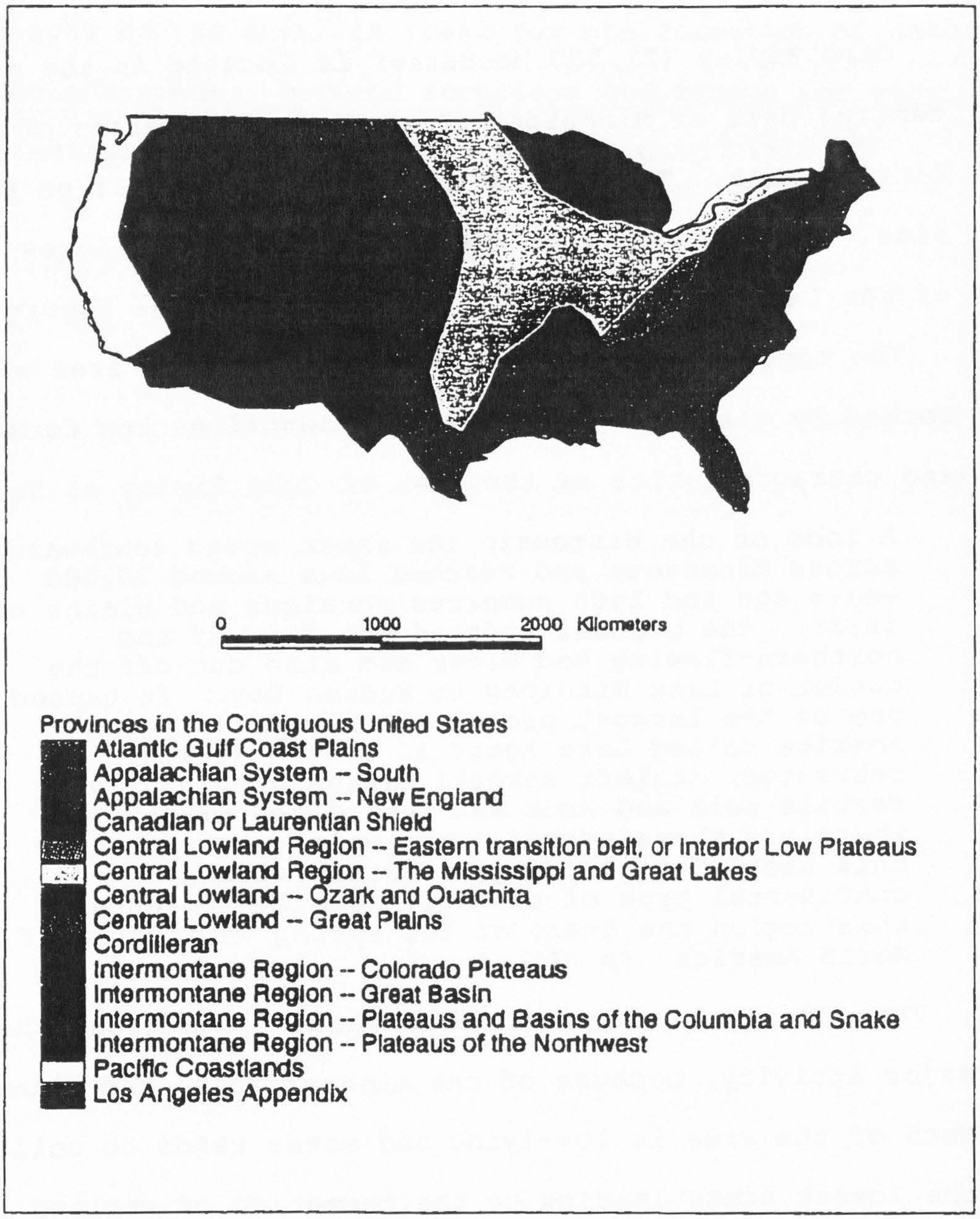


Figure 5. The physical provinces of North America (based on Patterson 1994)

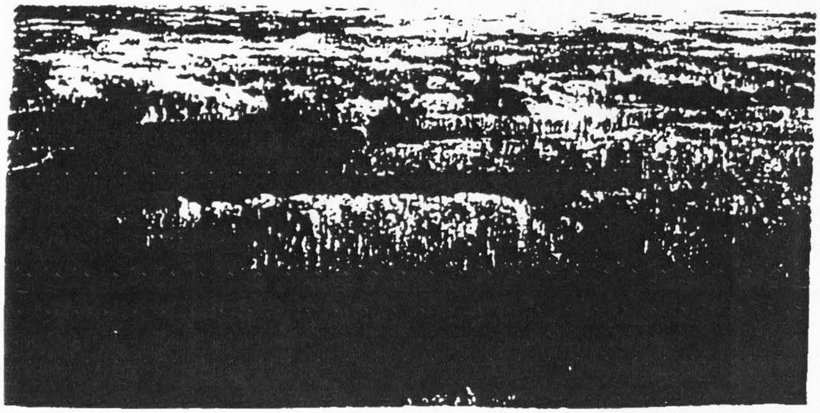


Figure 6. An area of northern Minnesota.

In Figure 7, airphotos reveal interspersed patterns of wooded hills surrounded by bottomlands, rivers, and lakes, some of which exhibit wetland characteristics. The photo-mosaic is overlaid with a polygon coverage of delineated wetland areas. The study area is located in the northeast part of Camp Ripley in an area surrounding Mud Lake. Figure 7 also indicates where Camp Ripley is in the state of Minnesota.

As was mentioned in the preceding chapter, Camp Ripley is in Bailey's Humid Temperate Domain (see Figure 8). The climate of this vast Domain varies depending on latitude, altitude, and proximity to large bodies of water. The climate of this domain is

> governed by both tropical and polar air masses. Much of the precipitation in this domain comes from rising moist air along fronts. Pronounced seasons are the rule, with strong annual cycles of temperature and precipitation. The seasonal fluctuation of solar energy and temperature is greater than the diurnal. The climates of the mid

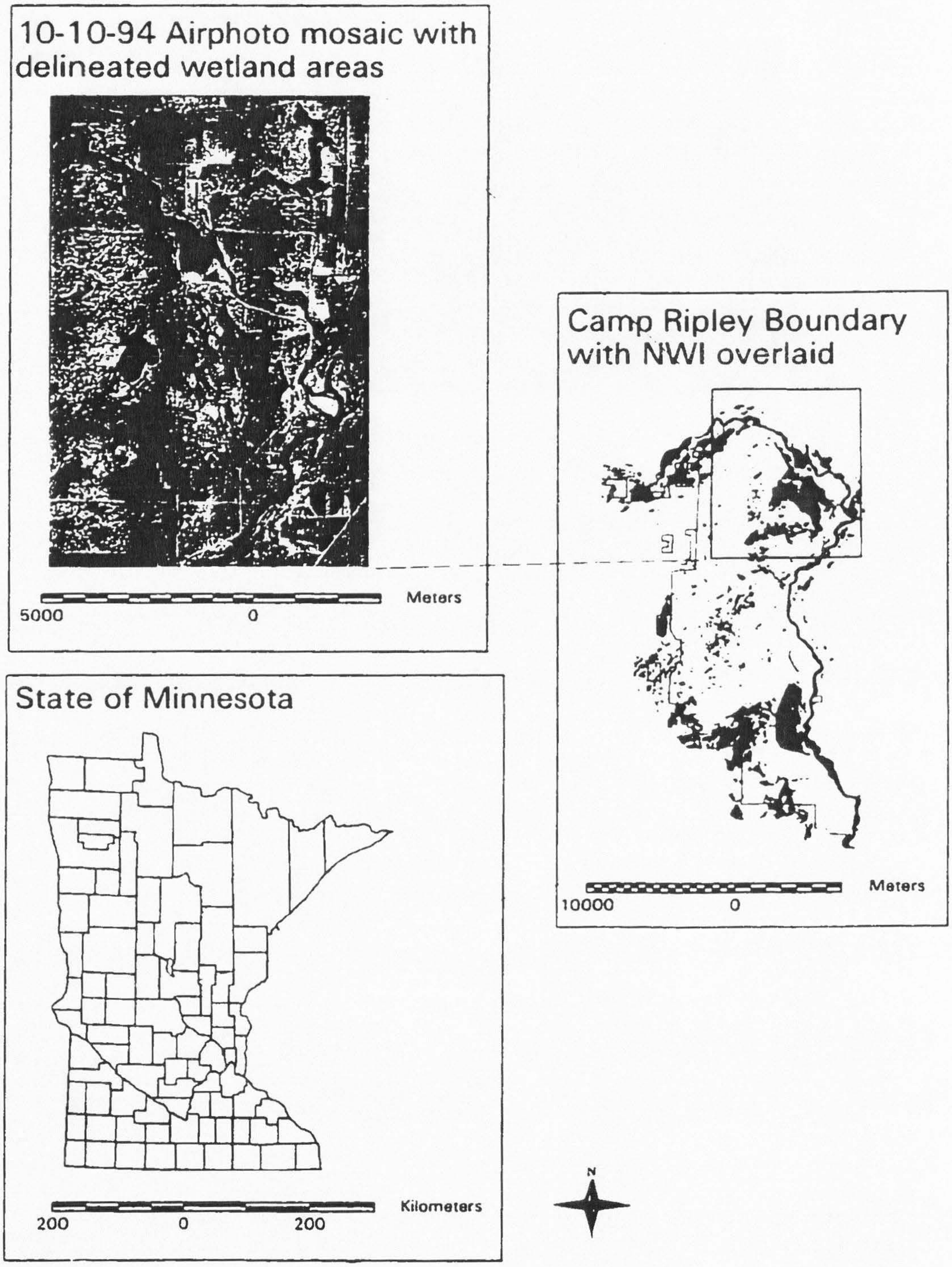


Figure 7. Location of Camp Ripley with a photo-mosaic of the northeast area with the NWI map overlaid on the installation boundary

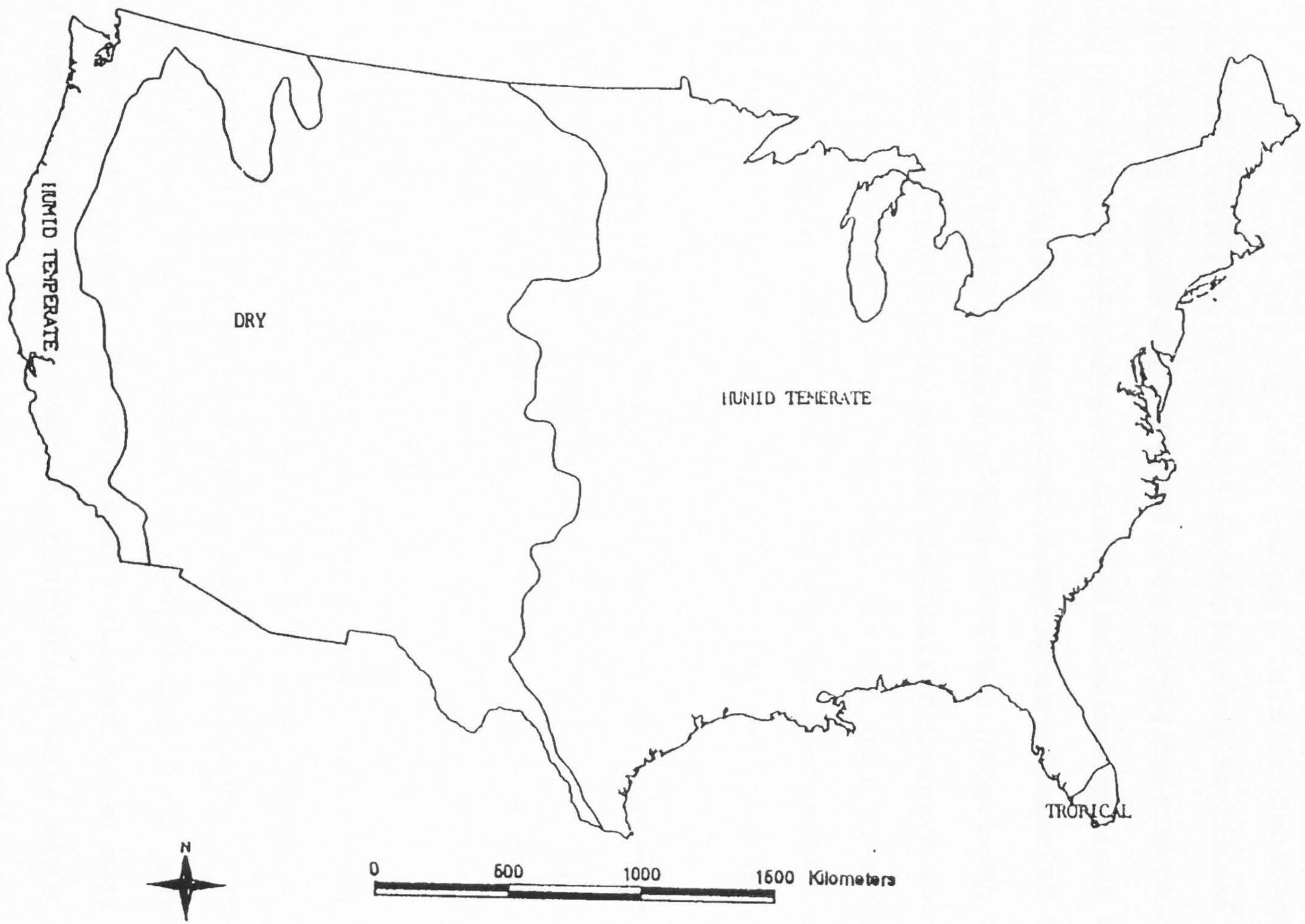


Figure 8. Bailey ecoregions--domain level
(from Bailey 1983)

> latitudes have a distinctive winter season. Broadleaf deciduous and needleleaf forests are contained within. (Bailey 1996, p. 78)

The amount of precipitation (twenty-five inches per year), with most precipitation falling in the summer season, and warm summers and cold winters combine to produce a climate that favors the development of wetland areas. Bogs and fens develop in the bottomlands because precipitation exceeds evapotranspiration (Mitsch and Gosselink 1993).

CHAPTER 4

METHODS

The delineation of wetland areas was accomplished by the integration of remotely sensed data, GIS, and photo-interpretive techniques. The primary software used for geopositioning and image processing is the Image Interpreter and Modeler in ERDAS IMAGINE. The polygon coverages were produced using ESRI ARC/INFO vector software. The procedure followed was (1) download the NWI map of the Camp Ripley area from the World-Wide Web in NETSCAPE, convert into an ARC/INFO coverage, and input into the GIS system; (2) scan the aerial photography into a GIS using a Hewlett-Packard ScanJet IIc optical laser scanner; (3) georegister the images to a UTM projection; (4) overlay the images and coverages; (5) map visible wetlands; (6) analyze the differences between 4 and 5; and (7) provide a map that the training managers can use.

The minimum mapping unit was determined to be four square meters for the 1:40,000 scale photography and two square meters for the 1:15,840 scale photography. This study required a fine resolution due to the small size of some wetland areas. The resolution allowed an accurate delineation because the wetland boundaries were visible.

The scanned image resolution at the 1:15,840 scale was determined to be 400 dots per inch (DPI) to produce a ground resolution of 1.0058 meters per dot (Formula 1).

$$\frac{1.0058\ \text{m}}{\text{dot}} = \frac{15840}{1}\ \frac{1\ \text{meter}}{39.37\ \text{in}}\ \frac{1\ \text{inch}}{400\ \text{dots}}$$

Formula 1. Determines DPI for larger-scale imagery

At smaller scales, a finer resolution of 600 DPI should be used for 1:40,000 photography. This gives a ground resolution of 1.69 meters per dot (Formula 2).

$$\frac{1.69\ \text{m}}{\text{dot}} = \frac{40000}{1}\ \frac{1\ \text{meter}}{39.37\ \text{in}}\ \frac{1\ \text{inch}}{600\ \text{dots}}$$

Formula 2. Determines DPI for smaller-scale imagery

This procedure of making a mosaic requires the planimetric rectification of air photographs or satellite images (proper real-world scaled X, Y position) by the use of a USGS stable-base, 7.5 Minute-Quadrangle Map (Jensen 1995). The map should contain appropriate detail to position the images, for example, roads, man-made structures, river, stream and lake boundaries, farm borders, and so forth.

A USGS map was placed on a digitizer tablet. Four or five points (tics) of known location were entered into the geographical information system (GIS) from the corners and the middle of the map so that the GIS system could position the map into real-world coordinates.

Ground Control Points (GCPs) that were common to both the USGS map and each airphoto image were located and placed on the digitized map and image. The image pixel coordinates were matched to those of the map. The GCPs were chosen using road intersections, towers, bends in roads, parking areas, buildings, farm fields, and other man-made objects. Natural features were used less often due to the seasonal change in the characteristics of natural features. Prominent natural features were used when man-made features were not present and a GCP was required for the correct geopositioning of the image to maintain an even spread of points.

Positioning of the GCPs was difficult because the surface relief and local features do not show on the standard a:24,000 USGS map. Also, compilation dates of the USGS maps were twenty to thirty years ago and there is a need for revision of the standard USGS maps in this area.

Careful placement of GCPs was used minimize the total RMS error. If a low RMS error was not achieved with the initial placement of points, some adjustments to the position of the GCP were made. The points of natural features were the first to be adjusted. Then other points were reselected to reduce RMS error where possible.

Formula 3 shows how the RMS error is calculated for all points in an image. The points that generate the greatest error can be identified and the general accuracy of the

$$\text{RMS error} = \sqrt{(x' - x\ \text{orig.})^2 + (y' - y\ \text{orig.})^2}$$

Formula 3. RMS error calculation (from Jensen 1995)

transformation can be measured (Jensen 1995). ERDAS IMAGINE was used for calculation of RMS error using pixel measurement. Any reselection of a GCP was at the discretion of the interpreter who also selected the level of accuracy desired. Careful observation of the effects of moving a GCP (one pixel in an X, Y direction) on the total RMS error was necessary. This interpreter-driven process was used to register features to those of an adjacent image.

Once the transformation was completed, a trial overlay was done by bringing up two adjacent images in one viewer and observing how closely the roads, trees, or other features were aligned in the overlapping section. Figure 9 shows the road was 10-20 meters misregistered and natural features were fuzzy. (Note the road and the grove of trees in the middle of the photograph.) When ERDAS IMAGINE combines the images (mosaic), it will place features in the image that is to be positioned to a location that will be on the main (controlling) image according to the specific transformation chosen, then overlay the images, and the output is one continuous image (ERDAS 1994).

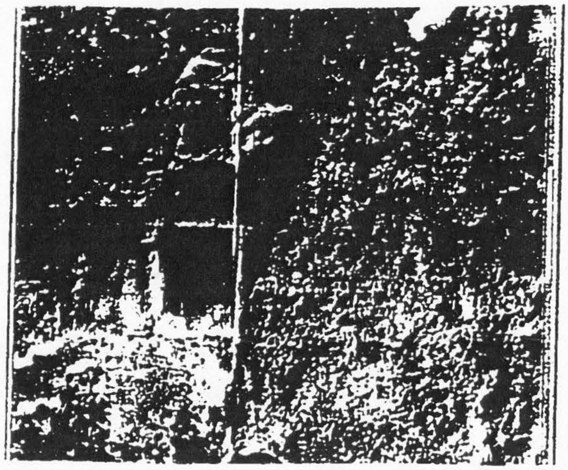


Figure 9. Misregistered mosaic

The problem was that only a small number of locations for GCPs were available. The process described above did not remove all distortion by topographic relief displacement and radial distortion in images. When three-dimensional data were converted to two-dimensional, size, relative location, and distance were changed depending on the type of projection used. The image was adjusted in the X, Y direction to make linear features register; however, this often produced misregistrations in other areas.

In this preceding procedure, the image and map were placed in real-world coordinates first, then mosaiced. A method for closer registration was provided by ERDAS Customer Service.

This procedure describes how to make a mosaic before the image is geopositioned. A solution to the problem in the previous method was to use unrectified or raw image data and a "false" coordinate system. This would eliminate transformation errors because the original positioning value of the pixel had not changed.

A center or controlling image was chosen and assigned a "false" coordinate system by adding this information to the Image header file. Subsequent images were not assigned a coordinate system until they were mosaiced to the center image using image-to-image registration. The next step was to identify features from the overlap zone between the center image and adjacent images and placing GCPs in this zone. A mosaic of the images was made using the GCPs. The center-image coordinate system was assigned to each adjacent image during the mosaic process.

This procedure allowed abundant locations of GCPs to be available because the interpreter looks at an image of the same area at the same time on two different photographs. The resulting transformation produced images with total RMS errors below two pixels and feature registration within three to five pixels in adjacent images.

Figure 10 describes the terminology explained in the text and shows how the imagery was mosaiced. The images with little or no common area to the center image (subsequent) were mosaiced to two of the images that had been mosaiced to the center image (adjacent) using the same procedure as described above. The transformation of images with little area in common with the center image was

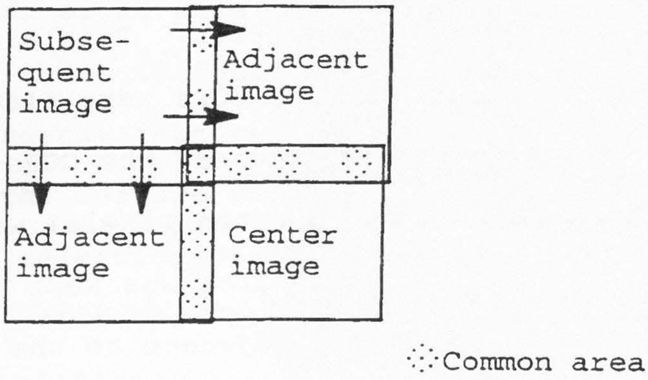


Figure 10. Explanation of terms used in the mosaic

registered within five to ten pixels and had total RMS errors below ten pixels.

The difference between feature registration and total RMS error is that total RMS error is calculated using Formula 3 (page 27), it is used to calculate the total error (pixel units) for both images and feature registration, and it measures how closely a certain feature will overlay in a mosaic of two images.

GCPs had to be correctly identified in the controlling and adjacent images. The use of a Chip-Extraction Window in both images (two Viewers) was required. Each was positioned to the same area and then zoomed in enough so that each pixel could be viewed. This allowed the interpreter to locate the GCP as closely as possible (hopefully within one pixel) in the subsequent image.

The Transformation Editor that displays the RMS Error was opened after four GCPs were placed to see if any one of the points contributed a large error. This allowed for any adjustments to be made. If many GCPs were placed before the Transformation Editor was opened, the GCPs that were causing the high RMS error (over ten pixels) was difficult to distinguish. The total RMS error was kept below two pixels when positioning images adjacent to the controlling image and seven pixels for images that did not have features in common with the center image.

This required careful selection of GCPs so that feature registration could be done. Each image mosaic required a different GCP selection to keep the RMS error low and features registered. The placement of ten to fifteen GCPs and the image adjustment using different transformation orders (discussed below) produced the best mosaics. For certain features that did not register, clusters of three to four GCPs were required to register roads or boundaries.

A good distribution of GCPs over the entire common area of each image is important to ensure the registration of features. The number of GCPs is not as important as the even distribution and amount of common area. ERDAS Customer Service instructed that ten GCPs or fewer was the best number of GCPs to use as long as they were distributed evenly. However, there were times where more or fewer GCPs were required. Many times, a transformation was tried and a critical feature, for example, a road, would not register properly. This was usually the result of a high RMS error (greater than eight pixels). This was corrected by the addition of three to four GCPs placed on or around the feature or nearby features and another transformation was done until the feature registered with the controlling image. The selection of GCP locations required careful observation using the Chip Extraction Window zoomed in to the individual pixels. An even distribution of points was normally used; however, there were occasions where groups or clusters of three or four GCPs were placed on the corners of an intersection, building, or farmland to register certain features. The method of moving GCPs depended on the outcome of the transformed image and resulting match.

If the total RMS error was less than five pixels, a linear or first-order transformation was attempted. The resulting image was compared to the controlling image.

If the total RMS error was greater than five pixels, a higher transformation order or nonlinear transformation was employed. ERDAS IMAGINE has the capabilities using different transformation **orders** according to the distortion of the imagery (ERDAS 1994). The order in the previous sentence is expressed as the order or highest exponent of the polynomial equation used in the calculation of the least-squares regression line to best fit the GCP locations. Higher transformation orders require more GCPs so that it is possible to calculate the number of coefficients required for the equation.

A first-order transformation was used to join images that only required scale, offset, or rotation correction. This was the primary order of transformation because no warping was involved and no distortion of the image took place in areas that were not in the overlap area. When a more complex transformation was required for the registration of features, and the total RMS error was greater than five pixels, a second or higher-order (non-linear) transformation was used to produce a lower RMS error and correct any nonlinear distortions of the photography. However, the further the features were away from the common area, the greater the distortion. An even distribution of GCPs over one-third of the image was required to correct the distortion. Many attempts were required to be able to know which combination of transformation order and GCP location was best suited for each image to make the best possible mosaic.

The mosaic of images was geopositioned by Digital Line Graphs of roads and hydrology. Correct positioning and a good match of colors and features in the mosaic of the aerial photography were important when detecting variances in the areas of interest. Histogram matching and geopositioning methods provided in ERDAS IMAGINE were employed (ERDAS 1994).

Since soil color and other topographic information were used to delineate the wetland areas in this study, Bennema and Gelens (1969, p. 87) suggest the following three elements for this type of analysis:

1. The area of study has a direct relationship to the soil, the color or gray-tone of the top soil and the drainage condition which can be used to detect different soil types.

2. If the features analyzed indicate specific conditions in soil formation (hydric and other soils), then changes in this indicate changing conditions of soil formation and probably different soil types.

3. The area can indicate the conditions which result because of any soil difference and how an area may be used by humans.

These three relationships were used to determine the difference in wet and dry soil characteristics in the photography.

Avery and Berlin (1992) state that there are certain characteristics of features that can be thought of as recognition elements. These include shape, size, pattern, shadow, tone or color, texture, association, and site. The interpreter can use any one or any combination of these elements at a time that is necessary to delineate wetland areas.

Soil in areas that are wet exhibit a darker tone than surrounding areas. However, the same conditions exist for shadows. One method used for discerning shadows from wetlands is uneven terrain indicated by closely spaced contour lines. The circled area in Figure 11 shows this type of terrain. The boxed area in Figure 11 shows an area that has widely spaced or an absence of contour lines, i.e., the terrain is flat. Most wetland areas develop on lowlands, especially near water bodies or in the bottom of bowl-shaped areas. The area immediately left of the circled area in Figure 11 provides an example of this type of terrain.

Camp Ripley provided one-meter contour line data. The NWI map was overlaid with the contour data to assist in the delineation of the wetland areas of the airphotos. Shadows are discerned by closely spaced contour lines and subsequent darker shades, which appear opposite the sun angle. The circled area in Figure 11 shows this. However, wetland areas can be found in dark areas, which are bordered by closely spaced, oval, or round contour lines at the edge and an oval or round-flat bottom. The area to the left of the circle in Figure 11 shows this phenomenon. These areas were delineated as wetlands even if on the top of hills.

Another area of concern is shadows of trees and hills. These also appear dark like wetland areas. Usually, these areas have little topographic relief. These shadows are detected by the jaggedness along the edges. These shadows also follow the direction of the sun angle. Wetlands usually tend to have rounded edges. Figure 11 shows the

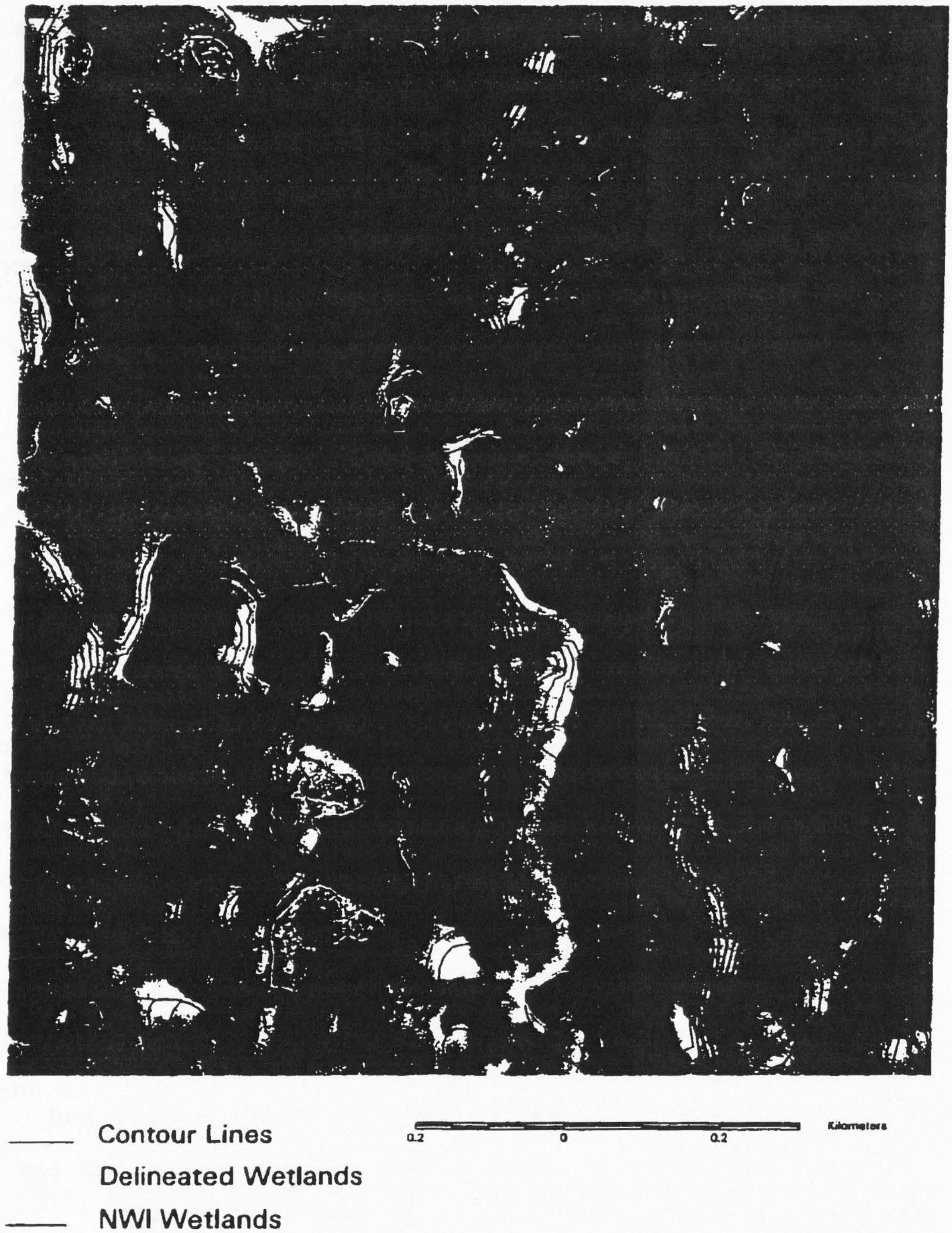


Figure 11. Image of delineated wetlands, NWI, and contour lines

round edges of delineated wetlands.

These techniques used with the conditions described above provided the interpreter with the ability to delineate wetland areas and differentiate between actual wet areas and shadows. The ancillary data, contour and NWI line maps, provided the best information.

Dark areas next to rivers or lakes were mapped as wetlands because of a constant water supply. These areas are generally flat. Rivers and lakes were considered to be wetland areas. There are underground rivers and streams, which can cause wetland areas to develop. These areas usually exhibit darker linear features.

In some wet years, or after a precipitation event, there are areas that are temporarily wet, and could be classified as wetland areas. These areas are included to analyze the effects of seasons and rainfall.

The NWI map was used as a training guide for the interpreter. If the NWI indicates a wetland, a wetland is delineated on the airphoto unless it no longer appears wet. The area is delineated as it appears on the airphoto. The NWI was used as a guide to locate wetland areas, and then the airphoto was carefully analyzed by the procedures mentioned above. The wetland areas were delineated according the procedures mentioned above.

The wetland areas were detected by visual interpretation. Recognition of the areas exhibiting darker tones than the surrounding area and the presence of wetland vegetation were important for the interpreter to map wetlands when using this technique. Wetland soils and ponded areas have a dark spectral signature and are usually near water bodies or streams. Once these areas were detected, a polygon was drawn around the perimeter of the area that exhibited wetland characteristics using the Vector Tool of ERDAS IMAGINE. One of the functions of the Vector Tool is to allow lines to be digitized on the screen, and a polygon coverage can be made (ERDAS 1994). The polygons, which were drawn to match the boundaries of wetland areas, were the basis for the analysis.

The NWI and airphoto-delineated maps were overlaid for comparison. Separate new polygons were created where there were differences in area or location of wetlands that occurred between the maps being compared. The polygon coverage of new polygons was the basis of the analyses from which a comparison was done. This was done using ARC/INFO software. The total area was generated for each year. This combined with climatological data to make a model for the effects that seasons and rainfall have on the area and extent of wetlands.

The maps showing the differences from the NWI to airphoto delineated wetlands were made by comparing the NWI with the new polygons. The map provided the basis for this study. The map shows the areas that have become dry or wet in comparison to the NWI. By using the ARC-INFO command UNION, all of the attributes and polygon data of the NWI and airphoto-delineated coverages can be joined together into one polygon coverage (ESRI 1991). The command RESELECT can be used to select the areas that have data or no data in the tabular (descriptive) database from the NWI or airphoto-delineated coverage and create a new coverage with each polygon having attributes of none, one, or both of the two coverages (ESRI 1991). If the tabular database contains data or no data from both coverages, then they are put into a "NO CHANGE" coverage. If the delineated-coverage attribute has data and the NWI attribute is empty, then the polygon is put into a "WETTER" coverage and if the opposite is true then it is put into a "DRIER" coverage. This will allow the location of changes to be visualized, and statistics generated so that exact differences can be examined.

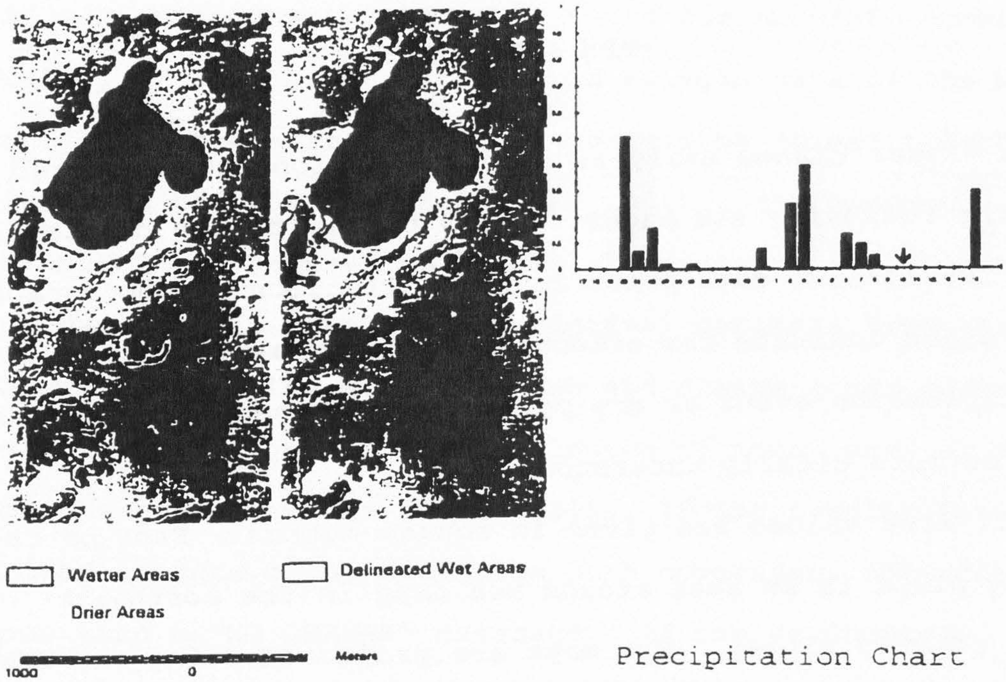
CHAPTER 5

MAPS AND CHARTS

A visual change analysis and explanation are presented in the following six pages. Daily precipitation charts for the twenty-five days prior to the collection of photography are given indicate the effects on wetland areas of a precipitation event or dry period. Also, seasonal changes can be more clearly understood.

All area values are given in square meters. Each of the study plots is an area around Mud Lake in the northeast part of Camp Ripley. The maps are projected using the UTM projection and are in UTM Zone 15. The Datum is NAD 83 and the spheroid is GRS1980. The lower-right corner coordinates are: X=392,681 (Easting) and Y = 5,124,016 (Northing). The upper-left coordinates are: X = 391,051 (Easting) and Y = 5,127,737 (Northing)

The maps of this chapter (Figures 12-16), depict the same image with two different vector coverages overlaid. The one on the left is areas that indicate change from the NWI map. The areas in blue are those that have become wet and the areas in yellow are those that have become dry. The arrow on the precipitation chart indicates the date of the photography. The precipitation chart is provided to show recent precipitation events. This provides information about the effects of precipitation on wetland areas.

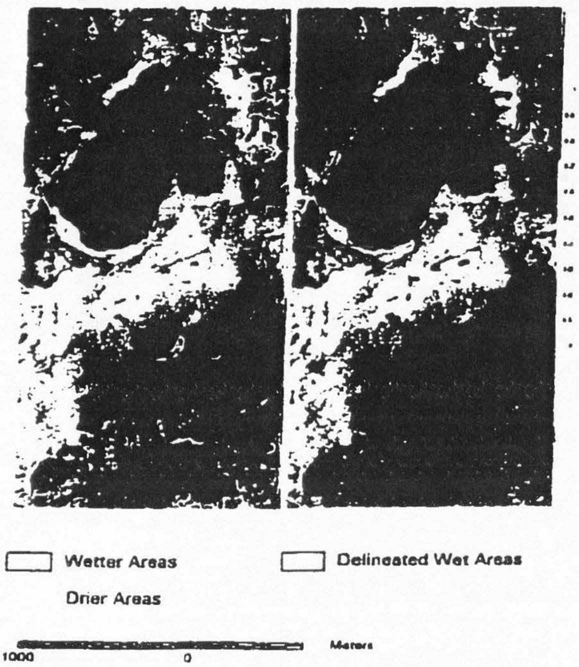


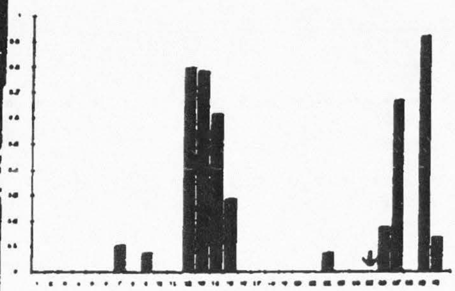
Precipitation Chart

Wetter Area	526,514
Drier Area	622,921
Delineated	2,147,335

Figure 12. Maps of delineated wetlands and areas of change since the NWI. Photo date: 10-10-1994.

Figure 12 shows the total area that became wetter on October 10, 1994 is 526,514 square meters and 622,921 square meters have become drier compared to the NWI at the time of the photography. There was a decrease of 96,407 square meters. The total area that was delineated (right image) is 2,147,335 square meters. The precipitation chart indicates three minor precipitation events occurring: two to four, seven to eight, and eighteen to twenty days prior to the date of the photography. The events produced less than three-quarters of an inch of precipitation.



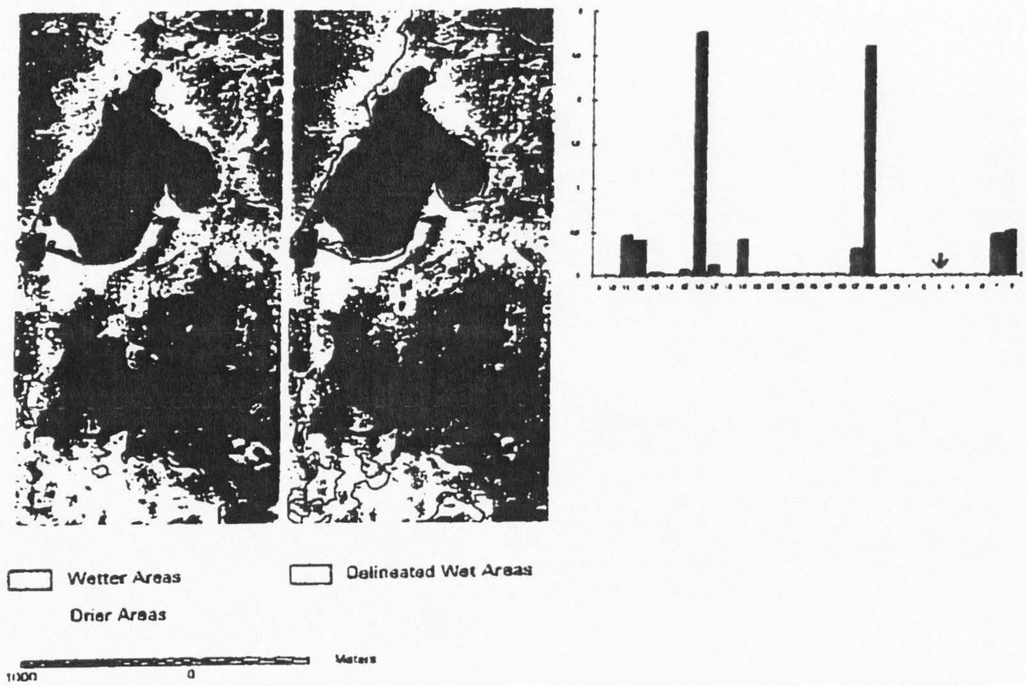


Precipitation Chart

Wetter Area	712,515
Drier Area	487,618
Delineated	2,147,335

Figure 13. Maps of delineated wetlands and areas of change since the NWI. Photo date: 4-25-1991.

Figure 13 shows the total area that became wetter on April 25, 1991 is 712,515 square meters and 487,618 square meters became dry compared to the total area of the NWI at the time of the photography. There was a net increase of 24,897 square meters. The total area of the delineated wetlands (right image) was 2,147,335 square meters. The precipitation chart indicates a precipitation event which occurred ten to thirteen days prior and produced two-and-a-half inches of precipitation.

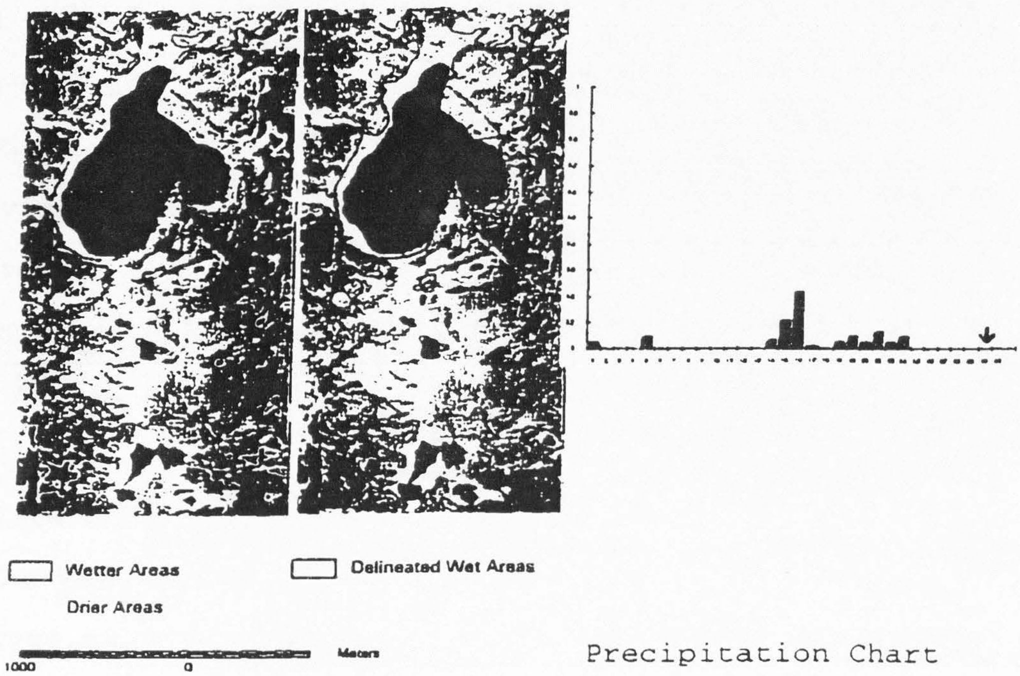


Precipitation Chart

Wetter Area	1,030,785
Drier	755,339
Delineated	2,610,405

Figure 14. Maps of delineated wetlands and areas of change since the NWI. Photo date: 7-03-1990.

In Figure 14, the image on the left indicates an increase in wetland area of 1,030,785 square meters and a decrease of 755,339 compared to the NWI. The total delineated area was 2,610,405, which is depicted in the image on the right. There was a 24,897 square-meter increase of total wetland area. The precipitation chart indicates two major precipitation events: five and seventeen days prior to the date of the photography. Each event produced over two-and-a-half inches of precipitation.

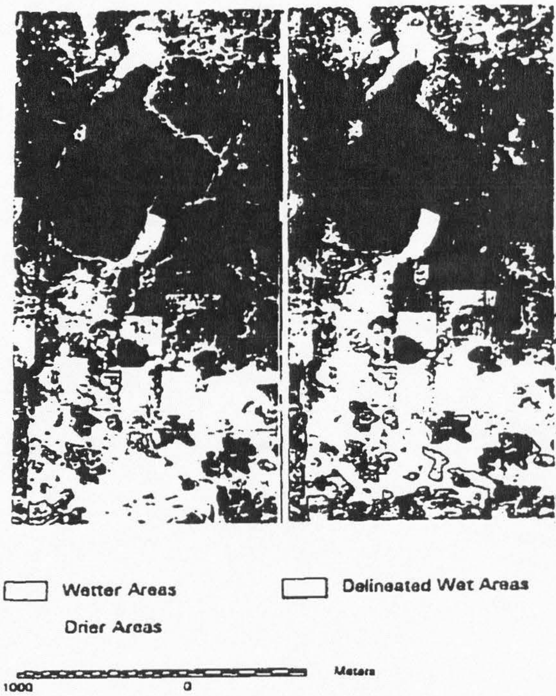


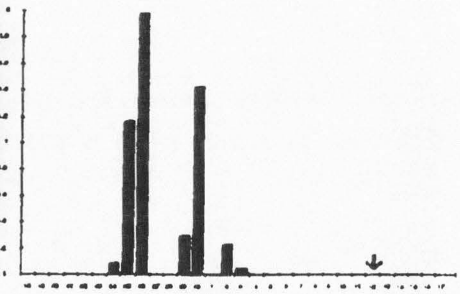
Precipitation Chart

Wetter Area	468,676
Drier Area	867,187
Delineated	1,999,701

Figure 15. Maps of delineated wetlands and areas of change since the NWI. Photo date: 10-30-1987.

In Figure 15, the left image indicates a total increase of 468,676 square meters and a 867,187 square meter decrease compared to the NWI. This is a total decrease of 395,896 square meters. The precipitation chart shows that very little precipitation fell before the photography was taken. One event occurred six to eleven days and the other thirteen to sixteen days prior to the photography. Each produced less than one-third of an inch of precipitation. This is the latest time in any year that data were available





Precipitation Chart

Wetter Area	282,082
Drier Area	788,190
Delineated	1,939,383

Figure 16. Maps of delineated wetlands and areas of change since the NWI. Photo date: 5-12-1954.

In Figure 16, the image on the left indicates the total area that became wetter is 282,082 square meters and 788,190 square meters became drier compared to the NWI. The right image indicates a total area delineated from the image was 1,939,383 square meters. There was a total decrease of 243,213 square meters of wetland area. The precipitation chart shows a precipitation event took place twelve to thirteen and sixteen to eighteen days prior to the date of the image. The event which happened twelve to thirteen days prior produced one-and-two-thirds of an inch and the one sixteen to eighteen days prior produced three-and-one-quarter inches of precipitation.

The following temperature charts, Figures 17 and 18, are provided to give the reader some indication of the effects of temperature on changes of wetland areas. Each month of each year that photography was available can be compared to the average for any extremes that affect the evaporation of soil moisture and the amount of run-off, which recharge or deplete wetlands.

The year 1994 had a colder than normal winter with average temperatures five degrees below normal. A slightly warmer than normal spring followed. A slightly cooler than normal summer occurred that year. The photography was taken in September of 1994. The average temperature was four degrees warmer than normal in October of 1994.

The year 1991 experienced a warmer than average winter and spring with temperatures two to ten degrees above normal. The photography was taken in April of 1990. April temperatures were two to three degrees above normal in 1991.

The year 1990 also experienced a warmer than average winter and spring. The temperatures ranged from one to ten degrees above normal. The summer was average. The photography was taken in July of 1990 and the temperature was average.

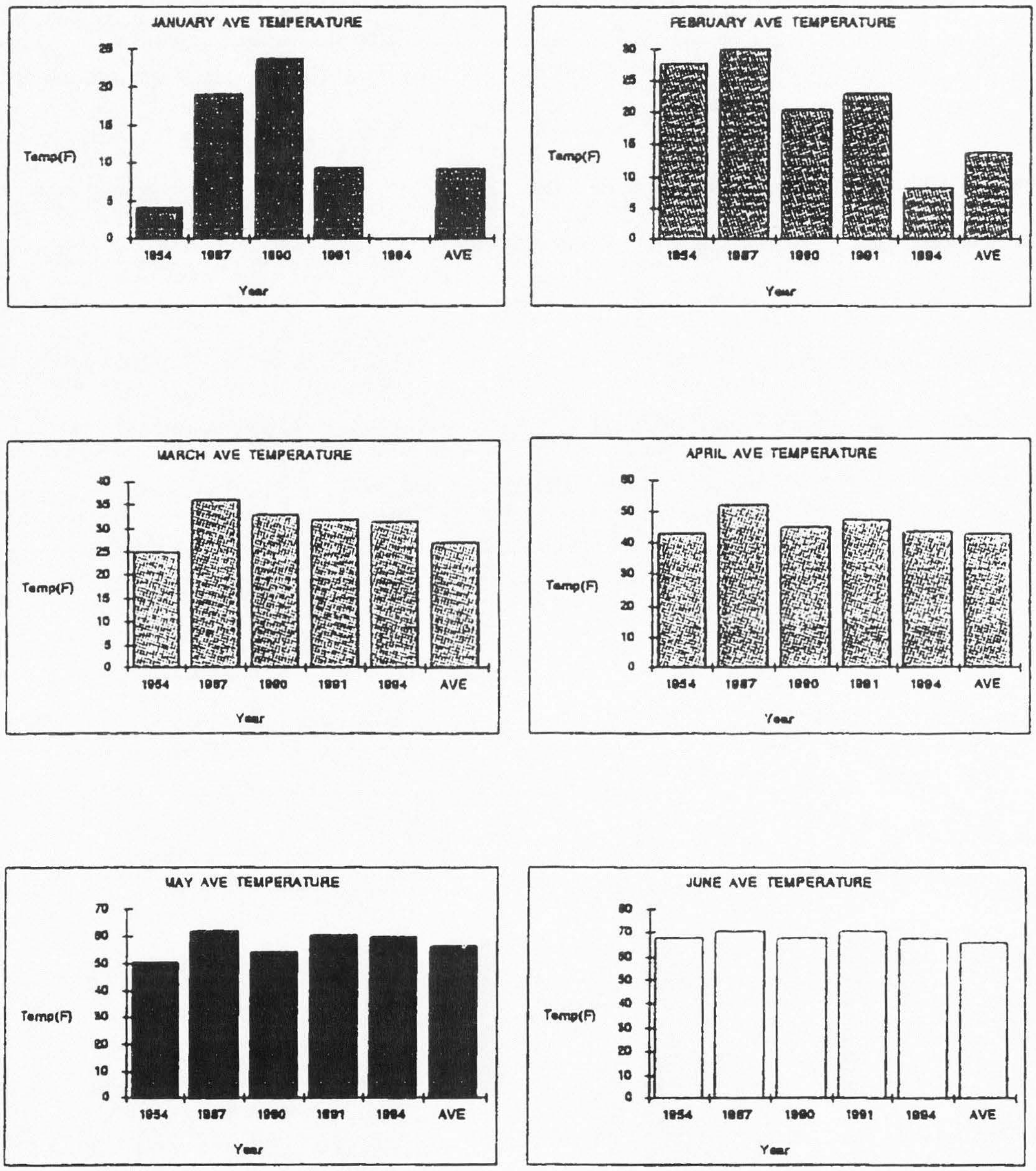


Figure 17. Camp Ripley Mud Lake area monthly temperature charts: January-June

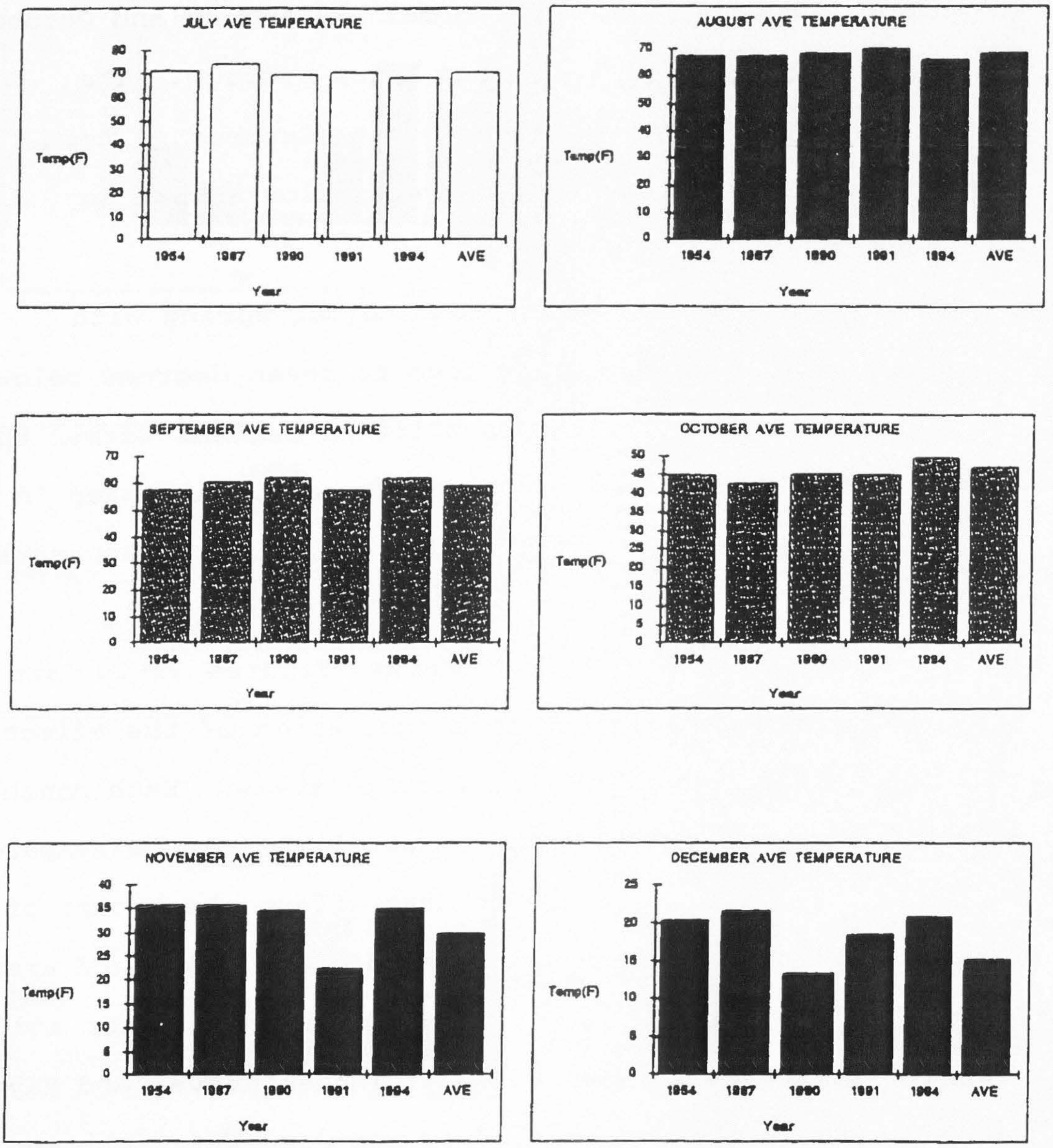


Figure 18. Camp Ripley Mud Lake area monthly temperature charts: July-December

The year 1987 was an unusually warm year. Most months were five to ten degrees warmer than average. The only months that were cooler than normal are August and October which were three to five degrees below average. The photography for 1987 was taken in late October. The average temperature was five degrees below normal in October of 1987.

The year 1954 had a cooler than normal spring with January, March, and May being five to seven degrees below normal. However, February was thirteen degrees warmer than normal. April was normal. The photography was taken in May of that year. May was five degrees cooler than normal in 1954.

The following precipitation charts, Figures 19-20, are provided to give the reader some indication of the effects of precipitation on changes of wetland areas. Each month of each year that photography was available can be compared to the average for any extremes that affect the amount of available water that can replace or deplete a wetland area.

The year 1994 had wet and dry months during winter and spring. April was one-and-one-half inches above, and May was two inches below normal. July was very wet with two inches above normal precipitation. August and September were slightly below normal. October was two inches above normal. The photography in Figure 12 was taken in October.

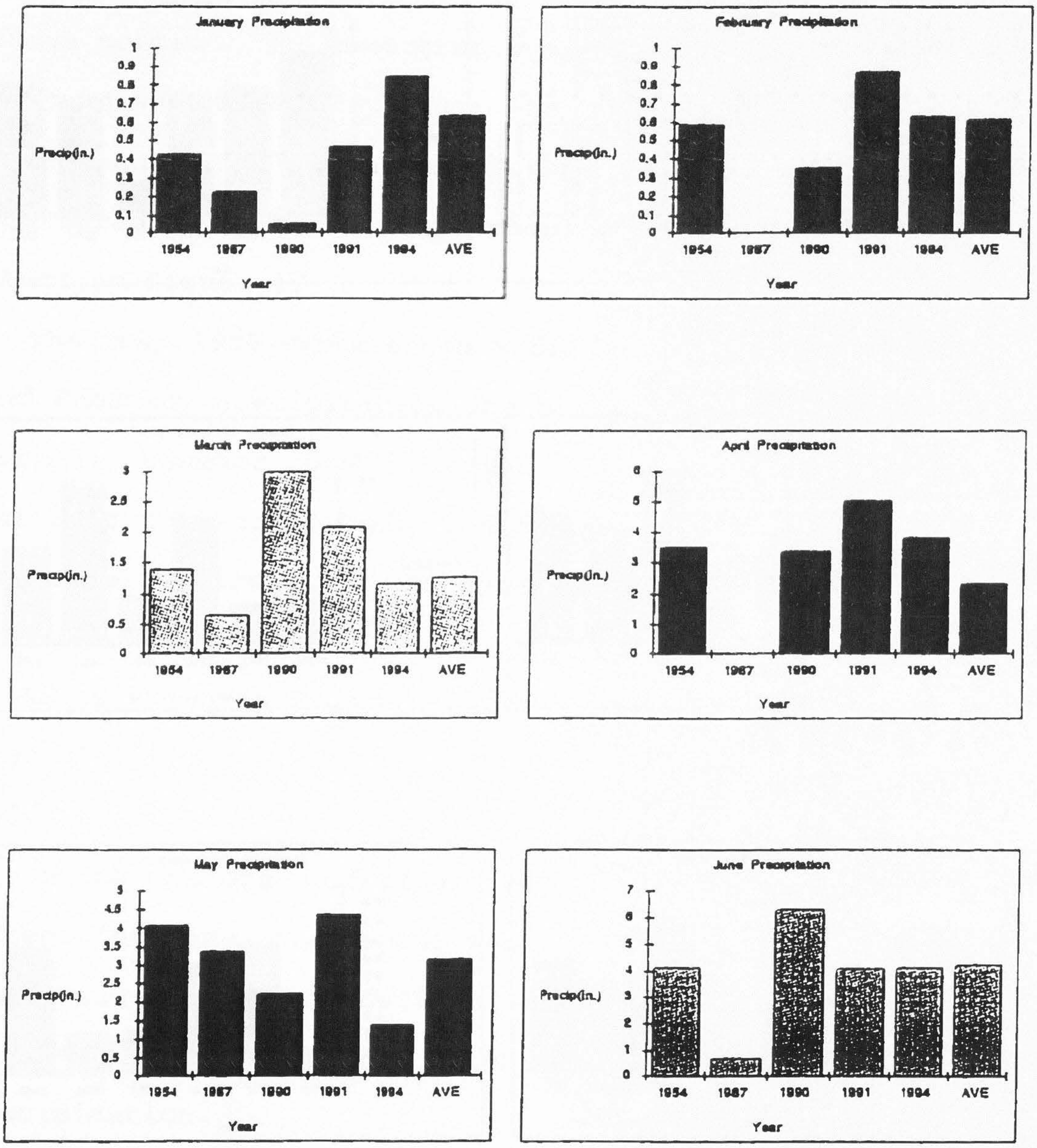


Figure 19. Camp Ripley Mud Lake area monthly precipitation charts: January-June

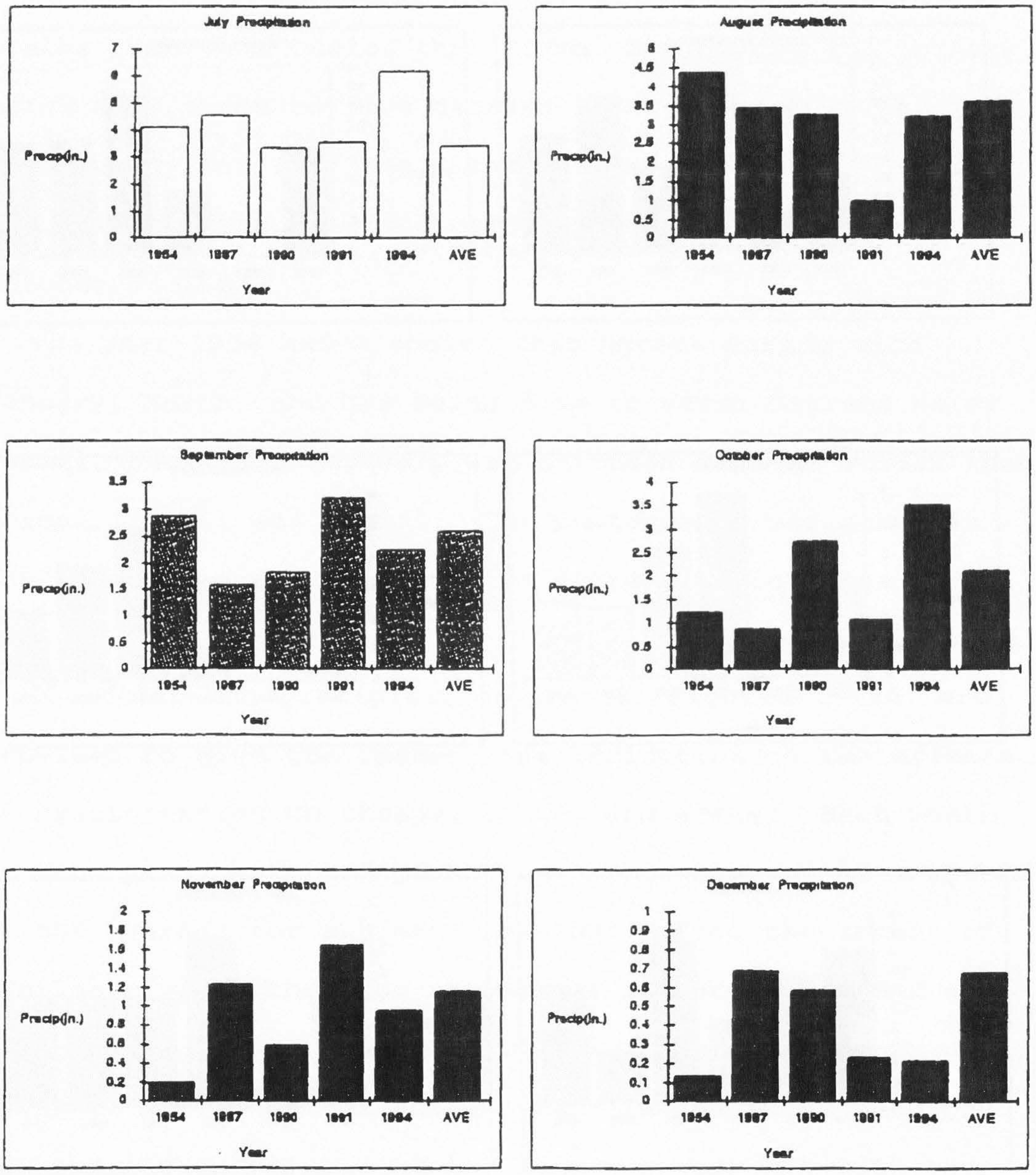


Figure 20. Camp Ripley Mud Lake area monthly precipitation charts: July-December

The year 1991 had a wet winter and spring. January was the only month below average with one-quarter inch less precipitation. Other months were one-half to two inches above normal. The photography was taken in April of that year in which over four-and-a-half inches of precipitation fell. However, two inches of this fell after the photography was taken as is shown in the precipitation chart on Figure 13.

The year 1990 experienced a dry winter with both January and February precipitation one-half of an inch below normal. However, precipitation in March, April, and June was over two inches higher than normal. May was an inch-and-a-half below. The photography in Figure 14 was taken in July.

As is shown in Figures 19 and 20, 1987 was the driest year that was studied. All months except May and July were below average. The spring was exceptionally dry except for May which was one-half of an inch wetter than normal. Except for June, the summer was normal. June experienced a three-and-a-half inch deficit. The photography in Figure 15, was taken in October, which had below normal precipitation.

The year 1954 had normal winter precipitation with variations of less than one-half of an inch. The amount of precipitation received in the spring was one-half to one inch greater than normal. The photography in Figure 16 was taken in May. Four inches of precipitation fell in May of 1954. May had one inch greater than normal precipitation.

CHAPTER 6

RESULTS

In Figure 12, the delineated coverage indicates a net decrease of wetland area of 96,407 square meters in comparison to the NWI. The major decreases were northeast of the lake and in the southern area of the map. Figure 18 indicates that there was a three-degree temperature difference in average temperatures in September and October of 1994 compared to the average for this month. Figure 20 indicates that the precipitation is two inches above normal. This will tend to produce temporary wetland areas; however, a major precipitation event occurred after the photography was taken. In the autumn, discernible wetland areas will tend to decrease as the river and stream flow is low as is indicated in Figure 4 (page 11). The highest stream flow is in the Spring. The greatest amount of precipitation normally falls from May to August.

The photography was taken in the spring of 1991 in Figure 13 and shows an increase of 24,897 square meters of wetland areas. As is indicated in Figure 19, the spring of 1991 was wetter than normal with March receiving one-half of an inch and April receiving almost two inches more. In Figure 17, the average temperature for March and April was six degrees above average. This likely accelerated the winter run-off and caused the wetland areas to grow. This caused an increase in delineated wetland areas in the spring of 1991. The wetland area was close to the same area as the NWI. This photography was taken during the highest river flow for the area, as is shown in Figure 4 (page 11). There was a decrease in wetland area to the east of the lake and a general increase to the west. This proves that wetland areas are dynamic and tend to vary in area from time to time. The increase is most likely due to the time of year and the precipitation events, which took place a few days before the photography was taken.

The photography in Figure 14 was taken in the summer of 1990. There is a net increase of 275,446 square meters in wetland area. The major area of increase was south of the lake. There was a decrease in wetland areas in the areas north of the lake. There were two major precipitation events, each producing two-and-a-half inches of rain five and seventeen days before the photography was taken. Since the highest precipitation falls during May through August, wetland areas may peak during this time of the year. This is the season of the highest river flows as is evident in Figure 4 (page 11). This is the largest increase in wetland areas of all the years studied.

The photography taken in Figure 15 is the latest time of year for which data were available. The major decreases were the northeast and northwest areas of the lake and in the southern areas of the map. There were two light precipitation events that occurred six to eleven days and thirteen through sixteen days before the photography was taken. This year was the driest year of data available, with an annual precipitation of sixteen-and-one-half inches compared to the normal twenty-five inches. In addition, stream flows for this time of year are also at the lowest according to Figure 4 (page 11). There was a total decrease of 395,896 square meters in wetland area in this photography. This was the largest decrease in all five years of data. The most likely cause of this decrease is that 1987 was a drought year and warmer than normal for most months, as is indicated in Figures 17-20.

The photography, in Figure 16, was taken in the spring and there is a decrease of 243,213 square meters of wetland area. The main areas of loss are northwest of the lake and the southern end of the map. The longest elapsed time between a precipitation event and photography taken was ten days. The most recent event produced less than one-third of an inch. The events that occurred twelve and fifteen days before produced one-and-one-half and three inches of precipitation. The major areas of loss are in the southern and northeastern parts of the map. The loss (second highest) of wetland area in this scene was unexpected. Precipitation was normal and temperatures were slightly higher than normal during the winter and spring months. The possible explanations could include a lower than normal snowfall for the previous year. This would produce a lower run-off. The elapsed time between a precipitation event and the time of photography would allow temporary wetland areas to dry up.

The main results of this study are that wetlands tend to be dynamic in their location, perimeter, and area. They are dependent on precipitation and seasons. They tend to be more numerous and larger in the spring and summer and smaller in the fall and winter seasons. Precipitation events can cause temporary wetlands to appear. However, these may disappear in several days or may become permanent wetlands depending on topography and amount and duration of precipitation.

CHAPTER 7

CONCLUSION

Figure 21 is a map of a compilation of the extent of areas of wetlands from the five years of photography. The coordinate and projection information for this map is the same as in Figures 12-16.

Training activities in the blue areas (permanent wetland areas) should be avoided at all times because these areas were wet in all five years of photography. The total blue area is 1,269,990 square meters. The red areas were wet at some time during the period of the study. The total for the red areas is 3,361,564 square meters. Precipitation and temperature data should be referred to if training activities are planned in any of the red areas as these areas may be wet during certain seasons depending on meteorological conditions. These areas are not considered permanent wetland areas in this study.

The accuracy of this study could be expanded by the addition of ground truthing supplemented by a global positioning systems (GPS) to position the photography with greater accuracy. Moreover, wetland locations could be mapped in situ using a GPS in the field, then having the interpreter overlay the GPS map to assist in the airphoto delineation. Ground truth collected through observable field plots (wetland areas) is needed to determine the

Figure 21. Camp Ripley Mud Lake area maximum and minimum extent of wetlands

accuracy of the map and provides any required information that is not discernible through remote sensing alone (Lund 1993). GPS instruments can be used to get points in the field, which would increase mapping accuracy (Jensen 1995). This is the preferred method to position GCPs because the accuracy could increase to within one meter of the actual world coordinates. A GPS map could also be used as an accuracy assessment to this project. All projects require accurate registration of the data layers. This is made possible by the establishment of a geometrically accurate ground control network on which all data sets are based (Welch, Remillard, and Alberts 1992). GPS would be ideal for setting up this network because it can be accurate to within one meter.

The type of medium used for this study and most other wetland detection projects is CIR photography. However, other types of medium are used. Jensen et al. (1993) used TM data for the entire coast of South Carolina. However, Wilen and Pywell (1992, p. 9) stated, "LANDSAT would not provide the needed data for classifica-tion detail and wetland determinations within the required level of accuracy". This is because LANDSAT TM data has 30-meter resolution. There are many wetland areas that cannot be seen at this resolution. Wood (1983) used many types of remote-sensing media to detect historical changes of wetlands in California, including: black-and-white photography, aerial color slides, CIR aerial photography, LANDSAT MSS, and TM simulator. The LANDSAT MSS classification showed much confusion compared to the CIR photography. The TM data were better. The CIR photography proved to be the best medium for mapping wetlands. Jacobson, Ritter, and Koelin (1987) generated a waterfowl habitat inventory in an area northeast of Anchorage using LANDSAT TM data. These data provided accurate wetland mapping of areas greater than one hectare.

As the resolution of satellite data becomes finer, this may become the medium of choice. Simultaneous use of MSS and panchromatic Systeme Pour l'Observation de la Terre (SPOT) data can provide an acceptable analysis for a statewide, wetland-mapping project (Lee and Lunetta 1995). At present, most wetland-mapping projects use satellite data to supplement aerial photography. In December of 1997, one-meter-resolution data will become available, which will allow a detailed analysis of wetland area and extent. The procedures described in this thesis would be applicable to a study done using satellite imagery.

Anther method that includes radar imaging can be used to classify wetlands over a large area for regions that are perpetually cloudy (Lee and Lunett, 1995). However, this method is used to complement conventional sources. Other sources include aircraft MSS and videography.

All of these techniques will make it possible to detect wetland areas. However, appropriate management of these wetland areas requires the land managers to make use of a GIS system with the remotely sensed data. Decision support is available through use of both raster and vector-based GIS software. Wei et al. (1992) suggests that the approaches above are "limited to monitoring, producing maps, and analyzing changes in wetland habitat, and indicate a need to integrate the knowledge of wetland experts into GIS techniques for decision support for managing wetland resources." This study should be used as an example of how wetland areas are delineated by aerial photography interpretation techniques.

The results of this project are important because there is little information available on the area of wetlands and the variations over time (Lyon and Greene 1992). Lee and Lunetta (1995, p. 250) stated:

> Baseline inventorying should consider climatological influences, and generally should have a multiseasonal approach .... If wetland maps are based on persistence and extent of surface water alone, their boundaries will vary seasonally.

The procedures described in this study would apply to any military installation or other areas where wetland management is required, and where recent or historical aerial photography or other remotely sensed data are available or have been recently acquired. Wetland areas can be accurately mapped and monitored by the methods described.

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