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Environmental Geophysics and Sequential Aerial Photo Study at Sunfish and Marsden Lakes, Twin Cities Army Ammunition Plant

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by

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Abstract

Geophysical studies at Site H of Twin Cities Army Ammunition Plant have delineated specific areas of dumping and waste disposal. Anomalous areas noted in the geophysical data sets have been correlated with features visible in a chronological sequence of aerial photos. The photos aid in dating the anthropogenic changes and in interpreting the geophysical anomalies observed at Site H and across Sunfish Lake. Specifically, two burn cages and what has been interpreted as their surrounding debris have been delineated. The areal extent of another waste site has been defined in the southwest corner of Area H-1. Depth estimates to the top of the Area H-1 anomalies show that the anomalies lie below lake level, indicative of dumping directly into Sunfish Lake. Except for these areas along the northwestern shore, there is no evidence of waste disposal along the shoreline or within the present-day lake margins. Magnetic, electromagnetic, and ground-penetrating-radar data have pinpointed the locations of mounds, observable in aerial photos, around the first burn cage. The second burn cage and its surrounding area have also been clearly defined from aerial photos, with support from further geophysical data. Additional analysis of the data has yielded volumetric estimates of the amount of material that would need removal in the event of excavation of the anomalous areas. Magnetic and electromagnetic profiles were also run across Marsden Lake. On the basis of these data, it has been concluded that no large-scale dumping has occurred in or around Marsden Lake.

1 Introduction

The Twin Cities Army Ammunition Plant (TCAAP) is a Department of the Army facility located near New Brighton and Arden Hills, Minnesota, approximately 8 mi north of Minneapolis/St. Paul (Figure 1). The New Brighton/Arden Hills area, including TCAAP, is number 43 on the National Priorities List of the U.S. Environmental Protection Agency (EPA), with a score of 59 (Biang et al. 1991). Argonne National Laboratory (ANL) has completed a program of nonintrusive geophysical measurements at Sunfish and Marsden Lakes within TCAAP's 4-mi^2 area to examine environmental concerns related to past activities. The lakes are contained in a lowland basin extending north-south along the eastern quarter of TCAAP.

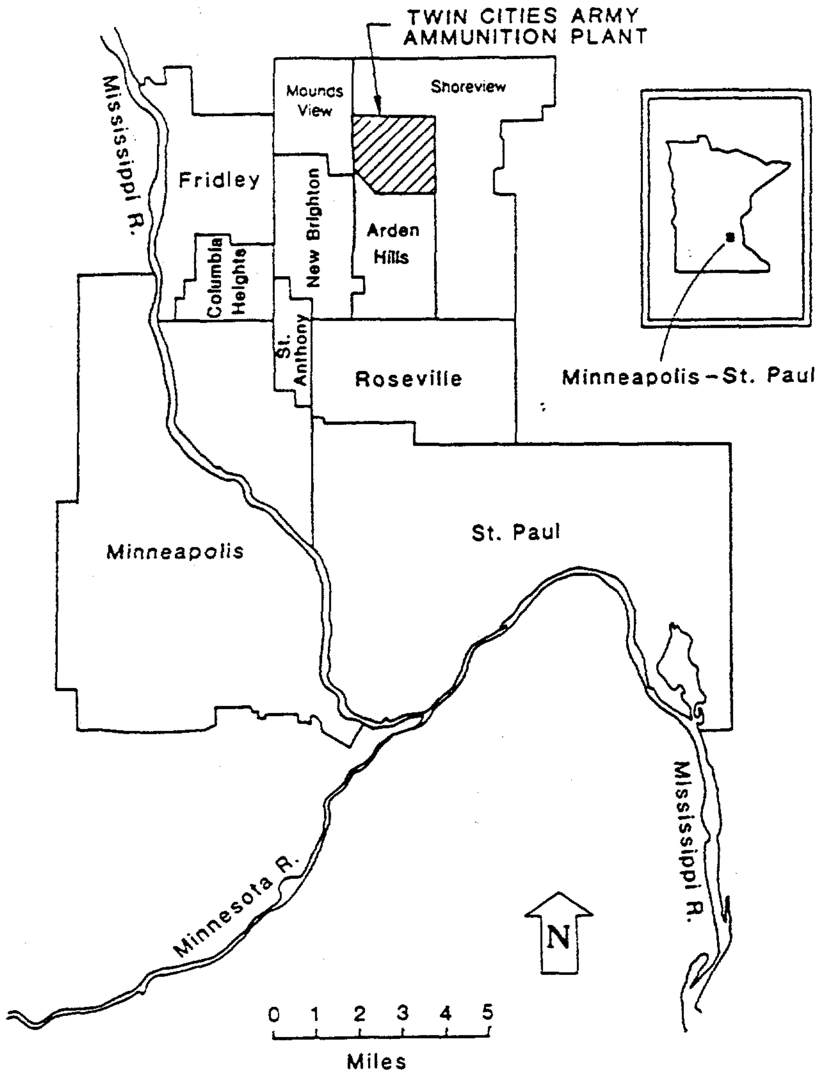


FIGURE 1 Map of TCAAP, Arden Hills, Minn.

Construction of the TCAAP site commenced on August 28, 1941, and was essentially completed on January 15, 1943. Primary responsibilities of the installation were to manufacture small-arms ammunition and related materials, proof-test small-arms ammunition and other items as required, and handle and store strategic and critical materials for other governmental agencies. The TCAAP facility is a government-owned, contractor-operated installation. The Federal Cartridge Company has been the primary operating contractor, except for a period (1946-1950) when the plant was operated by the federal government. Currently, most of TCAAP is in modified caretaker status. Two major lessees have also occupied the site since the late 1950s.

Prior to the initiation of the geophysics program, Argonne conducted a review of the historical record, technical publications, aerial photos, and previous geological and geophysical studies. The major part of the field-study effort was initiated in late February 1995 and concluded on March 10, 1995, to take advantage of ice cover on the lakes. Field-data acquisition was concluded June 26 to 30, 1995.

1.1 Site Background — Sunfish Lake

Sunfish Lake is located in the southeast corner of TCAAP. The northwest shoreline, including a former bay of Sunfish Lake, is referred to as Site H (Figure 2) and has been identified as a waste disposal site (USATHAMA 1978). Inspection of a sequence of aerial photos indicates that between 1940 and 1945 the bay was filled in. Geophysical surveys were conducted to determine whether munitions or other metallic debris were discarded anywhere in the lake.

The Sunfish Lake site consists of two subareas, H-1 and H-2 (Figure 3). Area H-1 is located immediately north of Sunfish Lake and immediately east of Hamline Avenue. It is approximately 820 ft × 500 ft in plan dimensions and is oriented with its major axis in an east-west direction. The northern margin of Sunfish Lake occupies the southeastern corner of Area H-1. Area H-2 is located north of the northeast corner of area H-1. It extends 200 ft from north to south and 260 ft from east to west.

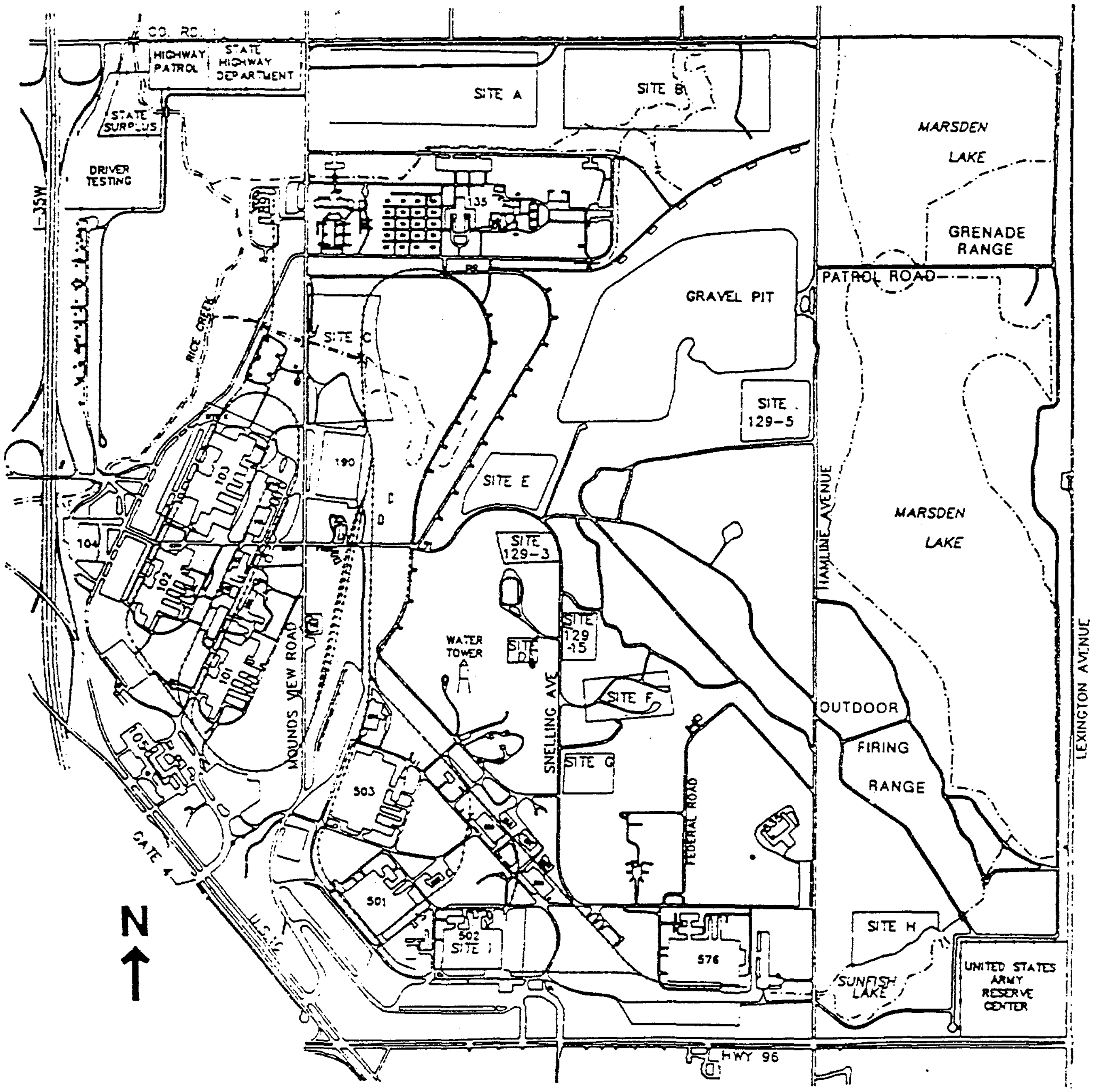
The eastern portion of Area H-1 was used as a burning area from early 1940 until late 1946, primarily to burn such combustible waste as wood, paper, cardboard, and other miscellaneous refuse. Between 1947 and 1953, a large burning cage was replaced with a smaller one. The new cage was used primarily for burning paper. Other materials, including solvent-contaminated maizo (corn cobs), were also burned in the vicinity of the new cage (Biang et al. 1991). The southwest corner of Area H-1, in the area of the former bay, may have been used for burial and dumping of industrial sludge, paint residue, incineration ash, and solvents.

Site H has been tentatively identified as the location of the Hamline Avenue Dump. Dumping activities were initiated at the end of World War II and continued until 1967, when Waste Control Incorporated was contracted to collect rubbish and scrap for off-site disposal. The history of activities in Area H-2 is unknown; however, Area H-2 is suspected to be part of a former waste disposal area (Biang et al. 1991).

1.2 Site Background — Marsden Lake

An environmental geophysical investigation was conducted at Marsden Lake within the boundaries of the TCAAP to determine whether past munitions testing and/or disposal activities may have resulted in disposal areas being located within or near the lake margins. According to available records (Biang et al. 1991), Marsden Lake was not used for waste activities at TCAAP; however, it is bounded by a gunnery, mortar, and small-arms testing range.

Marsden Lake occupies the eastern fourth of TCAAP, between Hamline and Lexington Avenues (Figure 2). The lake lies in the center of a marshy wetland of approximately 460 acres lying immediately east of the Rice Creek basin. A coarse-grained uplands associated with end moraines and glacial outwash separates the Marsden and Rice Creek basins.



SCALE 1" = 880'

FIGURE 2 Location of Site H

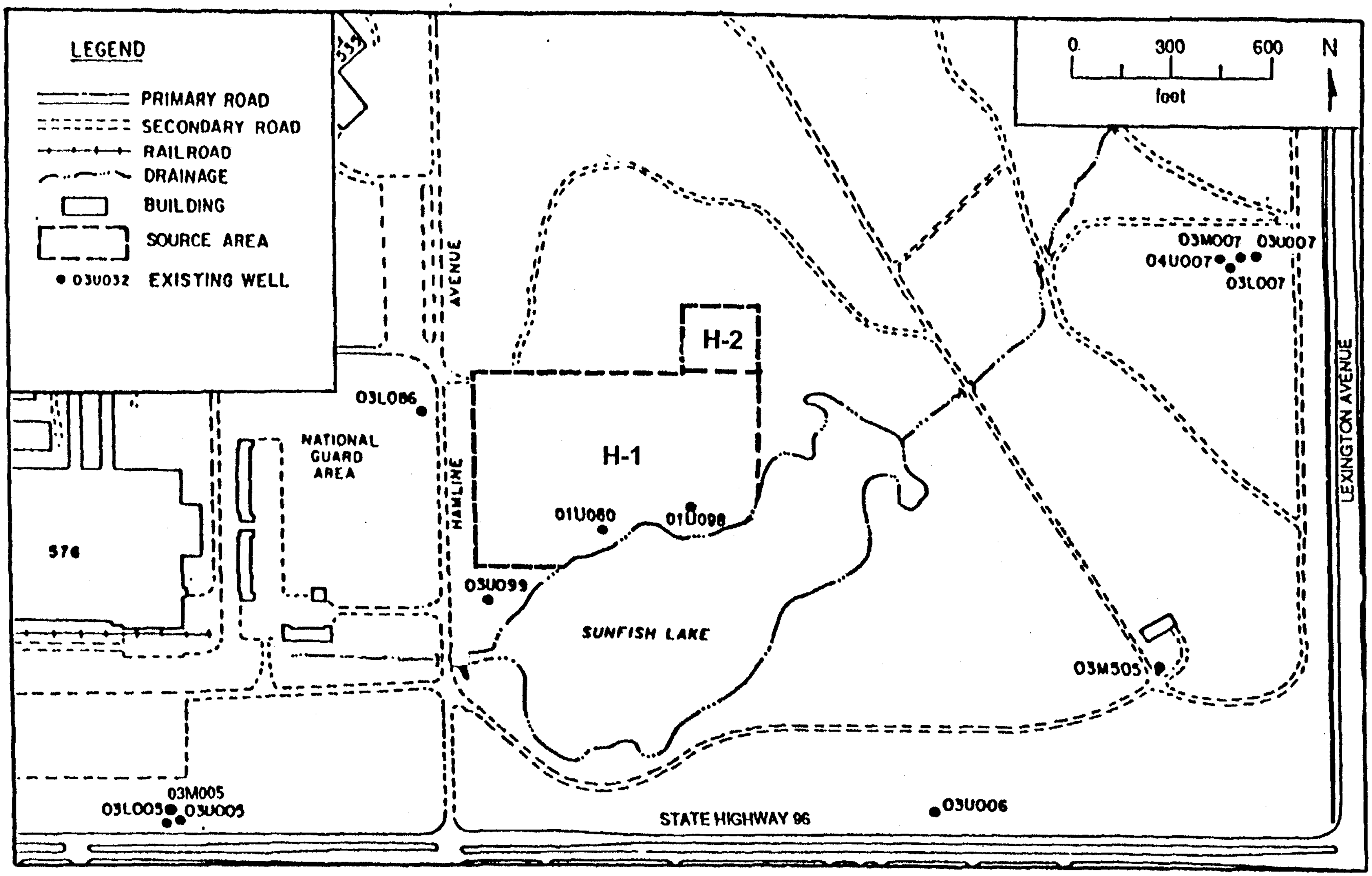


FIGURE 3 Location of Sites H-1 and H-2

Prior to the establishment and operation of TCAAP, much of what is now the Marsden Lake basin consisted of wetlands, floating marsh, and bordering, small farmsteads. Remnants of wire fencing discovered during the course of this work indicate that farm fields extended very near the water's edge.

Although TCAAP manufacturing activities were concentrated in the western half of the installation, munitions were tested in the eastern, open-range area. From 1941 to 1974, .30- and .50-caliber small-arms ammunition manufactured at TCAAP was tested for accuracy and performance on the Outdoor Firing Range located between Marsden and Sunfish Lakes. In 1985, the bullet catchers, located at various down-range distances of up to 1,900 yards, were removed, and 55 tons of bullets were sifted from the bullet-catching hills. These bullets were shipped off-site for disposal/recycling.

From 1961 to 1967, Honeywell tested 40-mm grenades on the Outdoor Firing Range. The escalation of war in Vietnam served as the catalyst to cause Honeywell to construct a range designed specifically for the testing of grenades. The Grenade Range was constructed in the northeast corner of TCAAP on the shores of Marsden Lake and can be identified on an aerial photo by the three circular pads along the eastern Patrol Road. These pads, or mounds, are elevated less than 10 ft above the surface of the wetland and measure approximately 600 ft in diameter. The Grenade Range was most likely built up on the marshy banks of Marsden Lake by using sand and gravel from the nearby gravel pit. Honeywell operated the Grenade Range from 1967 to 1976.

The range areas of TCAAP were used as training grounds by a U.S Army Corps of Engineers explosive ordnance disposal (EOD) team during the 1970s and 1980s. TCAAP has also been used in the past by the U.S. Army National Guard and the U.S. Army Reserves for training purposes. No records exist to document the history of the activities associated with these training exercises.

CERCLA Site 129-5 is located near Marsden Lake on the west side of Hamline Avenue and is within the Marsden Lake drainage basin. In 1945 or 1946, pits were established for burning explosive waste; the locations of the pits are unknown at the present time (ANL 1988). In the 1957 and 1958 aerial photographs, two pits containing dark material suggestive of damp soil can be seen within a building foundation in the southeast quadrant of Site 129-5. Within this area, evidence of disposal of brass casings and other ammunition manufacturing debris is still visible (Overtoom and Whitman 1987).

In 1948, a new powder-burning plot, 300 ft from north to south by 260 ft from east to west, was developed north of the northeastern corner of Site 129-5. The plot was used for the destruction of .30- and .50-caliber small-arms ammunition and smokeless powder. There also appears to have been a burning pit where bullets were ignited by dry propellant powder, scrapwood, and solvent. A 4-ft demolition pit may also have been in or near the powder-burning site. The powder-burning area was mined for sand and gravel by a commercial operation in the early 1970s. Currently, a silt-settling pond for the gravel-washing operation overlies much of the suspected burn area near the northeast corner of Site 129-5.

The disposal activities associated with these sites are easily identified in historical TCAAP aerial photos. These aerial photos also document former access roads that bordered the shores of Marsden and Sunfish Lakes. The roads appear to have been most active during the years that TCAAP was in production to satisfy war efforts. The possibility exists that these roads also may have been used for disposal operations in the lakes.

The lack of thorough documentation regarding testing, training, and disposal activities on the firing ranges, coupled with the existence of former access roads along the Marsden and Sunfish Lakes, generated concern over the possible existence of munitions dumpsites in the lakes. Recent findings of numerous undetonated grenades during magnetometer surveys of the range areas further prompted investigation of the anthropogenic content of the lakes.

1.3 Physiographic Setting

The TCAAP site is located in an area of intersecting terminal moraines, one formed by an ice tongue flowing to the southwest out of the Lake Superior lowland and the other by a second, smaller lobate tongue that flowed northeast and extended into the area from a large continental ice sheet in the southwest (USATHAMA 1978). The site contains typical ice-marginal, geomorphic features, including outwash plains, eskers, kettle lakes, and nonintegrated drainage. Marsden Lake and associated wetlands occupy the eastern fourth of TCAAP with Sunfish Lake, a small kettle lake, located southwest of Marsden Lake (see Figure 2). A northeast-trending kame hill is located northeast of the center of TCAAP, whereas the western half of TCAAP is characterized by primarily flat terrain, marshes, and streams. Rice Creek flows southward across the northwest portion of the site. Topography at TCAAP ranges from a low of 880 ft above mean sea level (MSL) along Rice Creek to a high of 1,100 ft above MSL at the crest of the kame.

1.4 Glacial Geology, Stratigraphy, and Hydrogeology

1.4.1 Glacial Geology

Multiple glaciation has dominated the development of the landscape of Minnesota, including TCAAP, leaving an almost continuous cover of till and such related sediments as glaciofluvial gravels, glacial-lake deposits, and upland loess (Wright and Ruhe 1965). Bedrock is extensively exposed only in northeasternmost Minnesota, near Lake Superior and the Canadian border, although the drift has been locally stripped from the deep postglacial valleys of the Mississippi River and its tributaries in southeastern Minnesota.

Glacial features of Wisconsinan age form the surface of TCAAP, and their relations reveal a complex history of ice advance and retreat. The Wisconsinan drifts have a highly varied lithology and complex stratigraphy, which reflect the sources of several ice lobes that protruded from the ice-sheet margin during various intervals of advance and retreat. This lobation of the ice margin was controlled by the major bedrock topography of the area over which the ice moved (Wright and Ruhe 1965). The TCAAP area is underlain by a shallow bedrock lowland that extends northeast through Minneapolis, en echelon with the Superior lowland.

1.4.2 Glacial Stratigraphy

The Twin Cities area was covered by the Superior Lobe and Grantsburg Sublobe extending from a late Pleistocene ice sheet. The St. Croix Phase of the Superior Lobe flowed from the northeast and covered the eastern and southern parts of the area. When it retreated about 14,000 years ago, a reddish-brown drift was deposited (Stone 1966). The Superior Lobe followed the Superior and Minneapolis lowlands, bringing generally red sandy till with pebbles of red sandstone and slate.

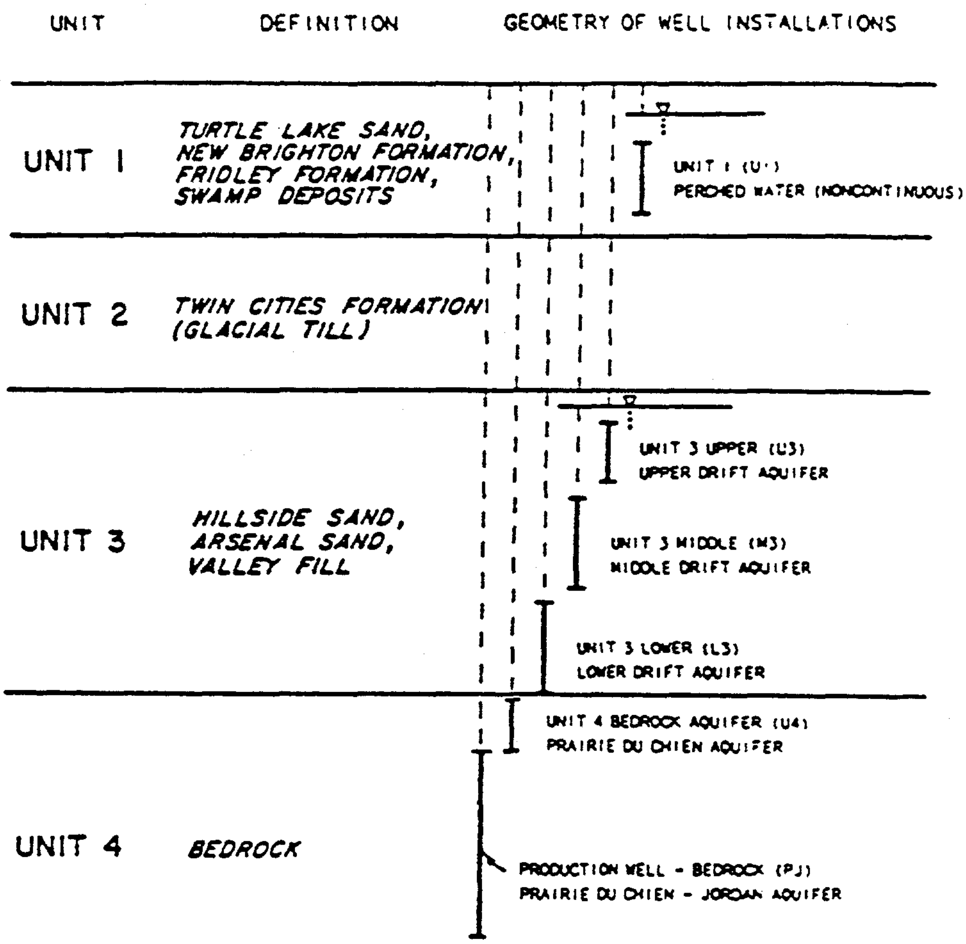
In western Minnesota, the Des Moines Lobe followed a major topographic lowland to central Iowa and sent a sublobe, called the Grantsburg Sublobe, eastward across southern Minnesota, bringing gray (buff where oxidized) calcareous silty till with fragments of Cretaceous shale into the Minneapolis lowland.

Glacially derived sediments from two sources, which range up to 447-ft thick at TCAAP, have been divided into four major formations: Hillside Sand, Arsenal Sand, Twin Cities Formation, and Lacustrine deposits (see Table 1) (Stone 1966). Hillside Sand overlies the bedrock formations throughout the TCAAP area. The sand is very-pale-brown to brown, poorly sorted, and medium- to coarse-grained and contains some pebbles and cobbles. It ranges in thickness from about 25 to 450 ft. The Hillside Sand is a glacial outwash, derived from both the Superior Lobe and the Grantsburg Sublobe. A dual origin or reworking of this unit is indicated, because it contains red sandstone, basalt, gabbro, and felsite pebbles from the Superior lowland as well as Cretaceous shale and clay, which indicate a western origin.

The Hillside Sand is overlain either by the Arsenal Sand or the Twin Cities Formation. It has an unusually rough and irregular upper surface. The contact of the Hillside Sand with the overlying Twin Cities Formation varies from sharp to gradational to interlayered. There is no distinct lithologic break between the Hillside Sand and the Arsenal Sand.

The Arsenal Sand occurs in the kame in the center of TCAAP and is light-gray to brown, well-sorted, and fine- to coarse-grained. Stone (1966) interpreted this deposit as a kame that formed at the edge of the retreating Grantsburg Sublobe.

TABLE 1 The Four Hydrologic Units at TCAAP and Their Associated Lithostratigraphic Units (adapted from CRA 1985)



The Twin Cities Formation is Grantsburg Sublobe Till, although its base is currently believed to be Superior Lobe Till. The Twin Cities Formation is a complex mixture of gray and reddish-brown drift of both western and northeastern origin. It is up to 125 ft thick at TCAAP and contains a mixture of sand, silt, clay, pebbles, cobbles, boulders, and lenses of silt or sand (Stone 1966). It also contains several small lake deposits and moderate-sized sand deposits. The clay and silt content of the formation, averaging about 50%, causes the formation to act as an aquitard to vertical migration of groundwater, although sand and silt lenses may allow some horizontal water flow.

Lacustrine deposits, lying above the Twin Cities Formation, are a series of lake sediments deposited ice-marginally to the Grantsburg ice sheet, which retreated to the southwest. The Lacustrine deposits consist of the Turtle Lake Sand, the New Brighton Formation, and the Fridley Formation. The Turtle Lake Sand is pale-brown sand with occasional laminae of silt and some gravel. It is present in the eastern portion of TCAAP and ranges from 0 to 49 ft in thickness. Stone (1966) interpreted this sand as a deltaic deposit laid down by meltwater streams running directly off the ice into a lake. Additional near-surface deposits, including the New Brighton and Fridley Formations, are not found in the southeastern areas of TCAAP.

1.4.3 Hydrogeologic Units

Hydrogeologic units at TCAAP are divided into Units 1, 2, 3, and 4 (Table 1). Unit 1 consists of all the material above the Twin Cities Formation. Groundwater in this unit is perched and discontinuous and exhibits seasonal fluctuation. The presence of an aquifer in Unit 1 depends on the thickness of the Unit 1 deposits, which attain a maximum of 60 ft above the underlying Unit 2 aquitard. Unit 2 includes all the till and interbedded sand and gravel lenses above the Hillside and Arsenal Sands. In all other portions of the site, the Twin Cities Formation (Unit 2) is exposed near the surface and is expected to be approximately 20-ft thick. Unit 3 is very thick at Site H and is composed primarily of outwash, fluvial sands, and gravels. Unit 3 was found to be over 270-ft thick in the northwestern corner of Site H. The thickness tends to decrease toward the east. Unit 4 is the bedrock of the Prairie du Chien Group (Durham 1991).

Surface water flow at Site H is to the south. Groundwater flow in Unit 3 is to the west-southwest (Durham 1991).

1.5 Instrumentation and Software

Nonintrusive surveys were conducted on shore and over lake ice. Continuously recording instrumentation provided 100% areal coverage. Instrumentation was selected to detect both ferrous and nonferrous metals. Identification of fill geometry and natural sediment layering was accomplished by using conductivity measurements and ground-penetrating-radar (GPR) data. Instruments used in the study include the devices described in the following sections.

1.5.1 Magnetometer/Gradiometer

The Schonstedt MAC-51B magnetic gradiometer is a dual-mode instrument for detecting shallow-buried iron and steel objects and tracing underground cables and pipes. The system consists of a transmitter and a dual-function receiver designed to detect anomalous magnetic gradients. The MAC-51B is an audio device for rapid detection of magnetic materials for further analysis with complementary instrumentation. Maps or models are not constructed from observations made with this instrument because the MAC-51B does not contain a permanent recording system. Anomalies are identified by changes in sound amplitude and frequency.

The MAC-51B in its receiver mode was used to visually identify anomaly-producing features around the lake perimeter. A qualitative description of the site perimeter, with

100% ground coverage, was achieved. The results obtained by other techniques, although more quantitative, are spatially limited to continuous readings along spaced profiles.

1.5.2 Magnetometer

A magnetometer survey was conducted to identify ferromagnetic metals by using the EG&G Geometrics G-822L cesium vapor magnetometer, a continuously recording total-field instrument. Data were acquired, with the sensing head held approximately 1 ft above the ground surface, at a rate of 10 readings per second. Average station spacing was 0.5 ft along transects spaced 10-ft apart. The instrument is capable of resolving anomalies to less than 1 nT.

Because of their dipolar field, magnetic anomalies due to a source having a simple geometric shape display a characteristic configuration, consisting of a positive magnetic peak and at least one negative magnetic trough. If symmetrically shaped iron-rich waste is buried in the northern hemisphere, a positive anomaly with a negative offset to the north will occur over the body. The horizontal distance between the paired peak and trough is directly proportional to the depth of burial, the size, and the shape of the source, whereas the amplitude of the anomaly is inversely proportional to the depth of burial. Metallic debris at or just below the ground surface produces strong, closely spaced magnetic peaks and troughs separated by high-gradient areas.

Data sets measured by using the G-822L and contoured by using software developed both in-house and by non-ANL sources were used to identify potential sources of contaminants and to distinguish them from background. Daily map outputs were available for observation and interpretation. Following data processing and gridding, anomalies were enhanced by using the color-coded software COLMX developed in-house by Thompson (1994).

1.5.3 EM-61 Time-Domain Millivolt Meter

Electromagnetic field data can be obtained in millivolts with a Geonics EM-61 meter, a portable, time-domain, electromagnetic induction instrument that transmits an electrical pulse into the ground and measures secondary magnetic fields caused by metallic objects beneath the instrument. Maximum target depth for the EM-61 is approximately 10 ft. The instrument is sensitive to all metals, making it a valuable complement to the magnetic gradiometer, which only detects ferrous metals.

Data were collected with the EM-61 at a rate of three readings per second and were stored on the OMNI 720 data logger. Output from three channels was generated, consisting of the responses from the upper coil (CH1), the lower coil (CH2), and the coil difference (CH3). Internal software permits downloading directly to an on-site computer.

The dual-coil arrangement allows the instrument to be operated in modes designed to reduce its sensitivity to interference from metallic sources at the surface. The instrument is tuned such that the upper coil is more sensitive than the lower coil to targets buried at greater depths. For metallic debris at the surface, both coils register approximately the same response. Surface debris can be discriminated from buried metals by comparing the lower coil and coil difference maps. Those anomalies observed on both maps are most likely caused by buried items.

The ratio between the upper and lower coil output can be used to estimate the depth to the top of the buried target. In this case, the anomaly peak is determined and the ratio, R, between the responses at the peak from the upper and lower coils is inserted into the following formula (Pawloski et al. 1995):

$$\text{Depth (cm)} = -2{,}229.57 + (7{,}288.13 \times R) - (9{,}635.75 \times R^2) + (6{,}458.69 \times R^3) - (2{,}158 \times R^4) + (292.118 \times R^5)\ .$$

1.5.4 EM-31 Conductivity Meter

The Geonics EM-31 is an electromagnetic induction meter that measures mean terrain conductivity to depths of approximately 20 ft. In electromagnetic profiling, electrical current flow is induced into the ground by an induction coil, and a receiver measures the secondary magnetic field caused by the low-intensity "eddy" currents induced in the subsurface. Because the instrument operates at low induction numbers, the transmitter and receiver coils are magnetically separate, and the magnetic-field strength of the induced eddy currents is nearly linearly proportional to the terrain conductivity (McNeill 1980).

The transmitter and receiver coils are housed in a nonconductive boom and are separated by 3.66 m. The coils are normally oriented in a vertical-dipole geometry, which provides the maximum depth penetration for the instrument.

The conductivity measurements provided by the EM-31 are an algebraic sum involving the thicknesses and conductivities of all geo-electric layers (or bodies) from the ground surface to the maximum depth of exploration. True bulk conductivities will only be observed where the subsurface consists of homogeneous and isotropic materials. Locations where the measured conductivity deviates from the background levels indicate points where further investigation is warranted.

Data were collected with the EM-31 at 0.5-s intervals and were stored on the OMNI 720 data logger. Only quad-phase, vertical-dipole, electrical-conductivity data were acquired. Internal software permits downloading directly to an on-site computer. Conductivity contouring is incorporated into the field acquisition procedure, so daily map outputs can be available for observation and interpretation.

1.5.5 Bistatic Ground-Penetrating Radar

Ground-penetrating-radar surveying and data processing were accomplished by using Geophysical Survey Systems, Inc., Radan III software and a model SIR-2 radar instrument. Data were digitally recorded directly to the internal hard drive to permit playback. A computer was located in a field office, so that the radar operator could download data, check data quality, and do preliminary processing after a day's run. Wave-velocity characteristics of near-surface materials were derived from representative sediment types. Internal calibration was performed daily to ensure that the graphic record of the range setting is consistent.

Ground-penetrating radar is the best method available to determine depth and geometry of natural and foreign objects. The weakness of the method is its limited depth of exploration due to wave-propagating constraints imposed by the electrical properties of soils. The maximum depth of penetration with GPR at TCAAP was approximately 20 ft, and it varied depending on near-surface geology. Greater penetration will be achieved where clays and conductive soils are absent. Good penetration was generally observed over the lake and near the shore.

2 Sunfish Lake

Data sets for Sunfish Lake were arranged in X,Y coordinates coincident with a grid overlaid on the survey transects, as shown in Figure 4. Transects were surveyed, flagged, and coded for ease of reference. Following the study, all survey markers were removed from the lake proper, but markers on land were left intact for possible future reference. A combination of magnetic, EM-61, EM-31, and ground-penetrating-radar data was used for the interpretation presented below.

2.1 Magnetic Gradiometry Measurements

A sequence of magnetic measurements, including gradiometer scans and total-field magnetic surveying, was made over and around the perimeter of Sunfish Lake to establish the presence of ferromagnetic metals. A gradiometer sweep around the lake perimeter and at occasional sites on land was conducted to provide visual identification of obvious anomaly sources. Where identification of a magnetic source, such as a magnetite-rich boulder, can be achieved, interpretative procedures are vastly improved. It was recognized through this study that some of the low-amplitude anomalies observed on the south shore of Sunfish Lake are caused by large boulders referred to as glacial erratics.

Gradients were detected at sites shown in Figure 5. A series of "hits" was observed along the north-central lakeshore, where landfill materials were dumped. Other than the north-central fill sites, one site was detected at the approximate coordinates (360,930) on the western shore and other sites were observed in a noncontinuous series of hits along the long axis of the south shore. Most of these south-shore hits are caused by such anthropogenic features as a culvert, a metal stake, and waste rubble. A large boulder generated the moderate-amplitude gradient at (840,540). The sources of additional low-intensity gradients along the southern shore are not visible, but the gradients are probably caused by buried iron-rich boulders or cobbles of natural origin.

2.2 Total-Field Magnetics Measurements

The total-field magnetic map (Figure 6) was constructed from 419,727 data points. A teardrop-shaped zone of higher amplitude magnetic anomalies north of the central lake margin is interpreted to be caused by ferromagnetic waste. This zone trends northwest from approximately (1100-1200,850) to (850,1650). Localized anomalies of lower amplitude, up to 100 nT above background, are caused by natural iron-rich sediments of glacial origin. They are displayed in Figure 6 by lighter colored browns and greens. The magnetic low seen along the western edge of the survey is caused by a metal fence that runs parallel to Hamline Avenue.

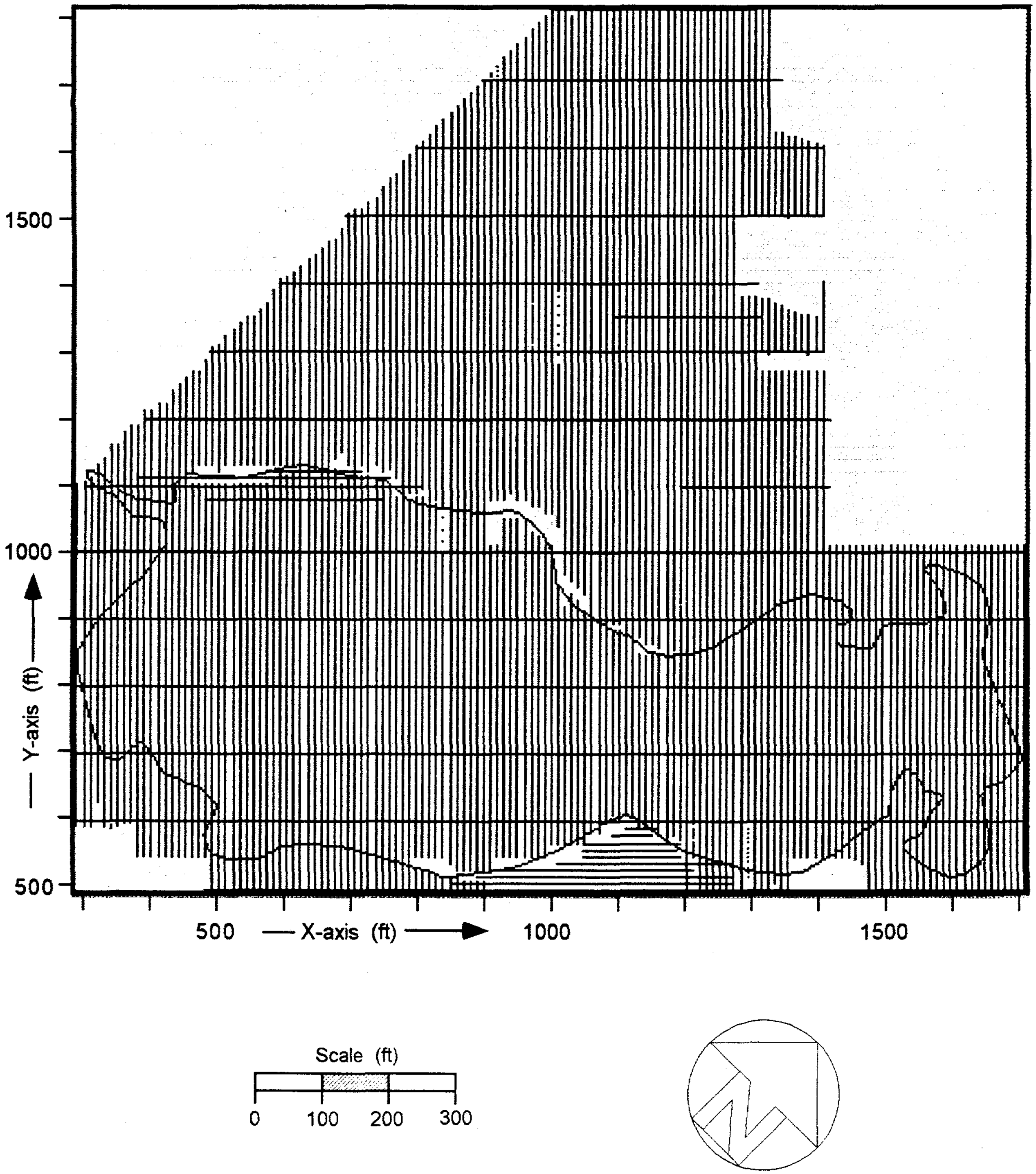


FIGURE 4 Location of Sunfish Lake Data Transects

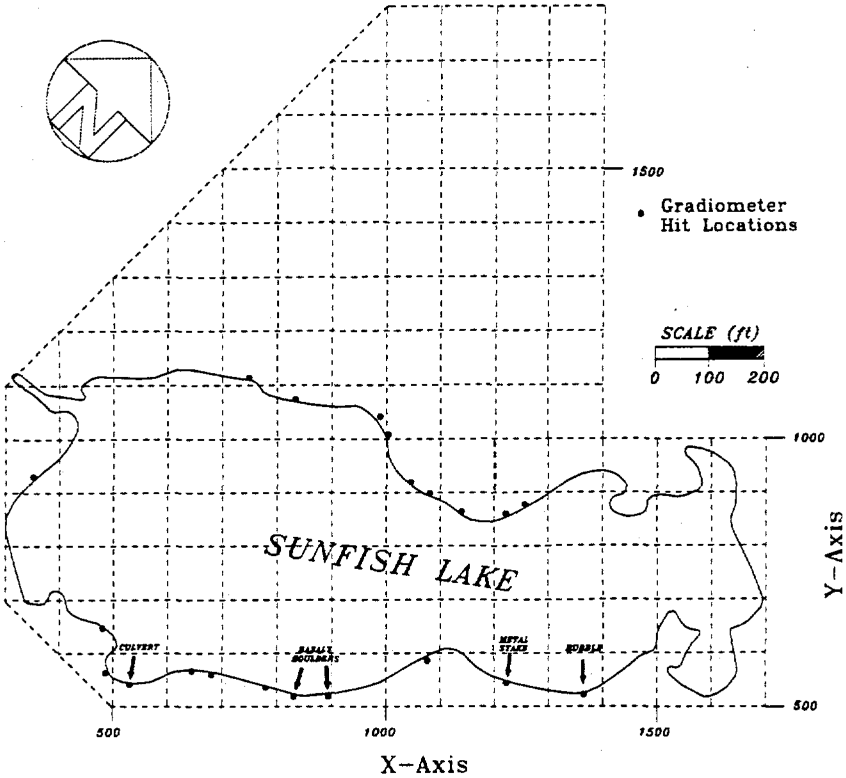


FIGURE 5 Gradiometer Hits around Sunfish Lake

The north-central magnetic zone does not include the former bay except for the far northeast bay edge and a northeast-to-southwest trending lineament along the northern lake edge along Y = 1100, from X = 700 to X = 900. The anomalous zone is truncated at the present lakeshore by a marked drop in magnetic intensity and continuity of magnetic signatures. The amplitude of anomalies within the anomalous north-central zone is approximately 300 nT above background, whereas to the southwest of the anomalous north-central zone, in the area once occupied by the former bay, background values of approximately 57,700 nT are observed. The fill in the bay consists, for the most part, of nonferromagnetic material.

Scattered iron-rich objects, exhibited as anomalies above background, are located along the southwest shore and just south of the western outlet of the lake. These anomalies are point sources and do not appear to be caused by a landfill or trench, which cause the anomalies in the north-central areas. The eastern and southeastern shores also contain anomalous magnetic features that are within the magnetic background range and result from naturally magnetic glacial sediments. These shore areas display the normal, rather noisy, low-amplitude background common in a gravel and cobble terrain consisting of crystalline rock derived from the Superior lowland, a magnetite-rich complex contained within the broad crystalline shield of North America. Verification of naturally magnetic gravels as the source of these anomalous features is supported by observations made with the gradiometer over boulders observed at the surface. Several random metallic hits are recognized as point sources along the northwest and south shore. Some of these sources are iron stakes or drainage lines. Others are unidentified.

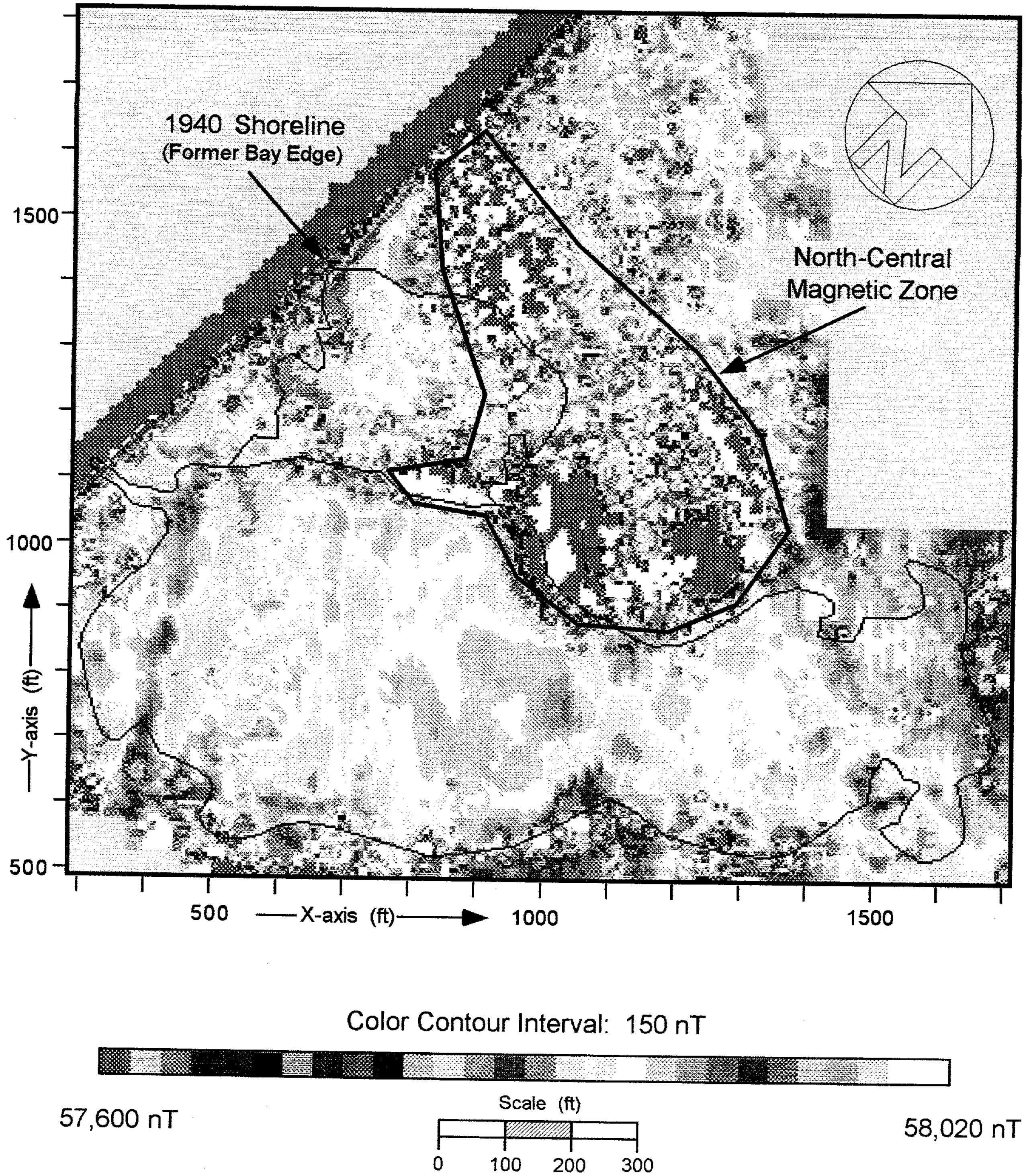


FIGURE 6 Map of the Total-Field Magnetics Data at Sunfish Lake

In general, magnetic field strength decreases over the lake because of the inverse square law, which states that field strength is inversely proportional to the square of the distance from the measuring point to the magnetic object.

Other magnetic objects of interest include

- A northwest-southeast magnetic lineament in the southwest end of the lake from coordinates (400,550) to (450,1150);
- A low-amplitude magnetic lobe extending into the northeast end of the lake, and then trending in a more northwesterly direction, that may be associated with magnetite-rich outwash (along X = 1400, from Y = 1000 to Y = 1350); and
- A thin band of magnetic features that extends along the southern shore and diverges from the shore to the southwest.

2.3 Time-Domain Electromagnetic Induction Measurements

The EM-61 meter was used to detect metallic objects buried at depths of up to 10 ft. Interpretation and analysis of the lower coil voltages, coil-difference voltages, and depth/volume estimates are discussed in the following sections.

2.3.1 Lower Coil Data

Figure 7 represents an induction map of secondary voltages received from the lower coil of the EM-61 meter. The lower coil output is a response to all metals buried between the surface and a depth of 10 ft. The map is produced from 139,066 data points. Background response is indicated by the light- and dark-blue areas, whereas anomalous regions, representing high concentrations of metals, are indicated by red and white. Gray tones show no-data areas.

Many of the anomalies displayed on the lower coil induction map have equivalent features on the magnetic anomaly map (Figure 6); however, the magnetic map also contains characteristics not detected with the EM-61. The dominant metal signatures are in clusters centered on and north of the northern shoreline of Sunfish Lake. A prominent west-northwest-striking lineament, north of the former bay and centered at about (925,1500), has its counterpart on the magnetic map, although the magnetic anomalies are much broader and more diffuse. The sinuous white line bordering the northern shoreline represents the most concentrated cluster of metals. Edges of additional anomalous areas are clearly marked. The fence line to the northwest is displayed as a white anomalous stripe.

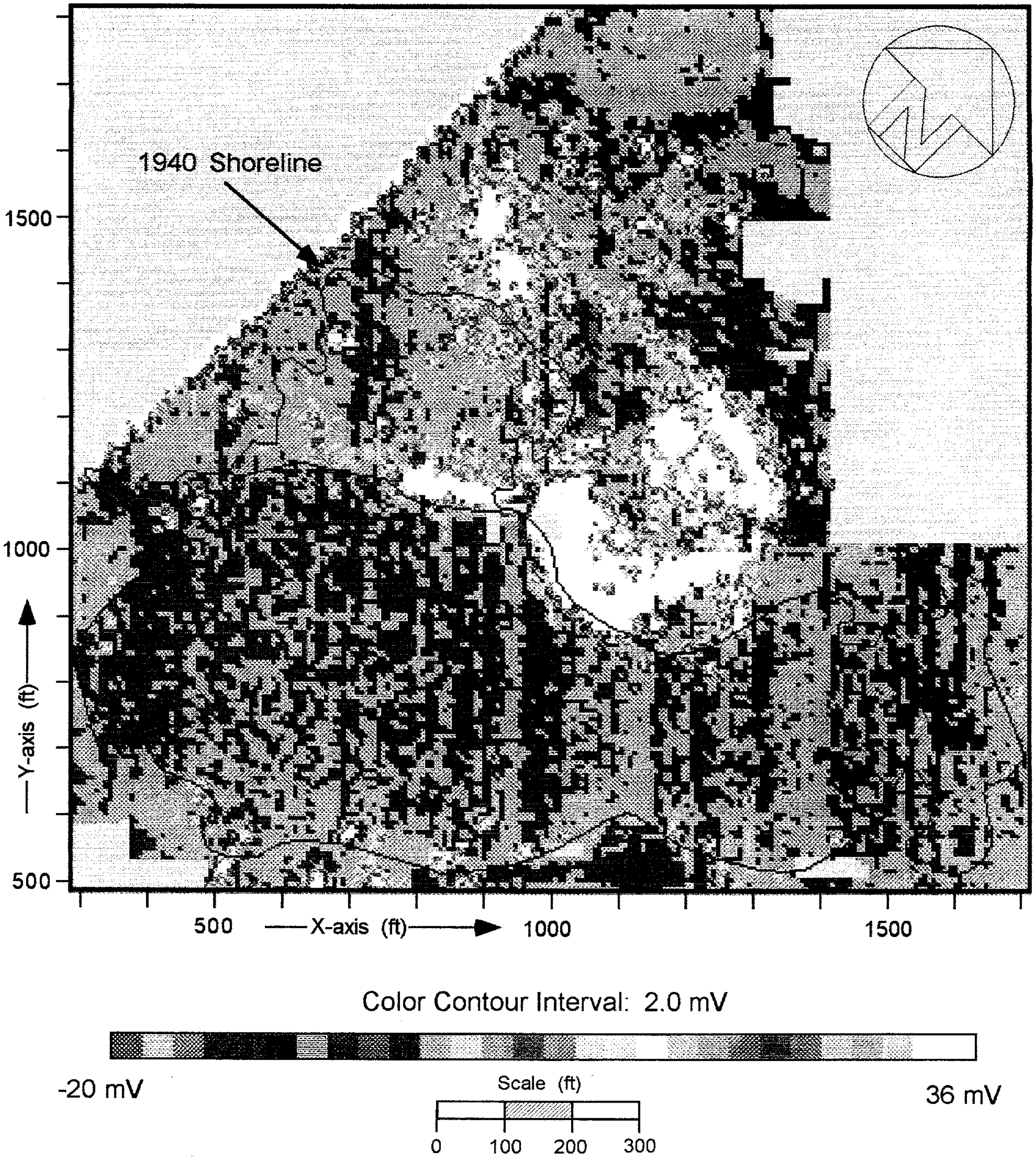


FIGURE 7 Map of the EM-61 Lower Coil Electromagnetics Data at Sunfish Lake

2.3.2 Coil-Difference Data

Figure 8 represents the potential field remaining after subtracting data acquired with the upper coil from data acquired with the lower coil. The purpose of this map is to discriminate between metallic sources at the surface and buried sources. This map was produced from 278,132 data points and represents secondary voltages from metals buried below the ground surface to depths of up to 10 ft. The light- to dark-blue signature covering most of the site is representative of background. Major anomalies are represented by the sinuous trend extending along the north-central lakeshore and the lineament striking northwest to southeast at coordinates (1250,1150).

The anomaly trends are similar to those displayed on the magnetic and lower coil data maps (Figures 6-7); however, the area of anomalous magnetic and lower coil data north of the former bay is not a prominent feature on the difference map, suggesting that these anomalies are caused by surficial or very shallow-buried (<1 ft) metal waste. Once again, the fenceline appears in the data along the far western edge of the survey area.

2.3.3 Depth and Volume Estimates

Approximate depths to the top of geophysical anomalies were calculated by using the theory given by Pawlowski et al. (1995). These depth calculations, along with the calculated area of the anomalous regions, enabled us to estimate of the volume of material that may need to be removed in an environmental cleanup effort. The area to the northwest, around the second burn cage, is approximately 34,700 ft^2. The average depth to the top of the anomalies is about 3.8 ft. The true depth to the base of the metallic fill cannot be determined from geophysical data, but if we overestimate and assume that the excavated depth will need to extend to the current lake surface level, then approximately 22,500 yd^3 of material will need to be excavated: 4,900 yd^3 of overburden and 17,600 yd^3 of waste material. The anomalous area surrounding the original burn cage is approximately 80,000 ft^2. With an average depth to the top of anomalies of approximately 6.2 ft, similar calculations show that approximately 49,000 yd^3 of material will need to be removed, 30,500 yd^3 of which is expected to be waste product. Part of this area directly to the south is of concern because many anomalies lie offshore at an average depth of about 6.5 ft.

A volume estimate for the southwest portion of Area H-1 cannot be made by using the same assumptions because the estimated average distance to the top of the anomaly is already approximately 2 ft below the current lake surface level, an indication that waste was probably dumped directly into the lake in this area. The anomalous area covers about 8,200 ft^2 along the shore. Almost 1,400 yd^3 of material would have to be removed just to lower the surface to lake level. If we assume that waste product extends to the maximum depth of the present lake (about 6 ft), then a total volume of 1,800 yd^3 of waste product would require removal.

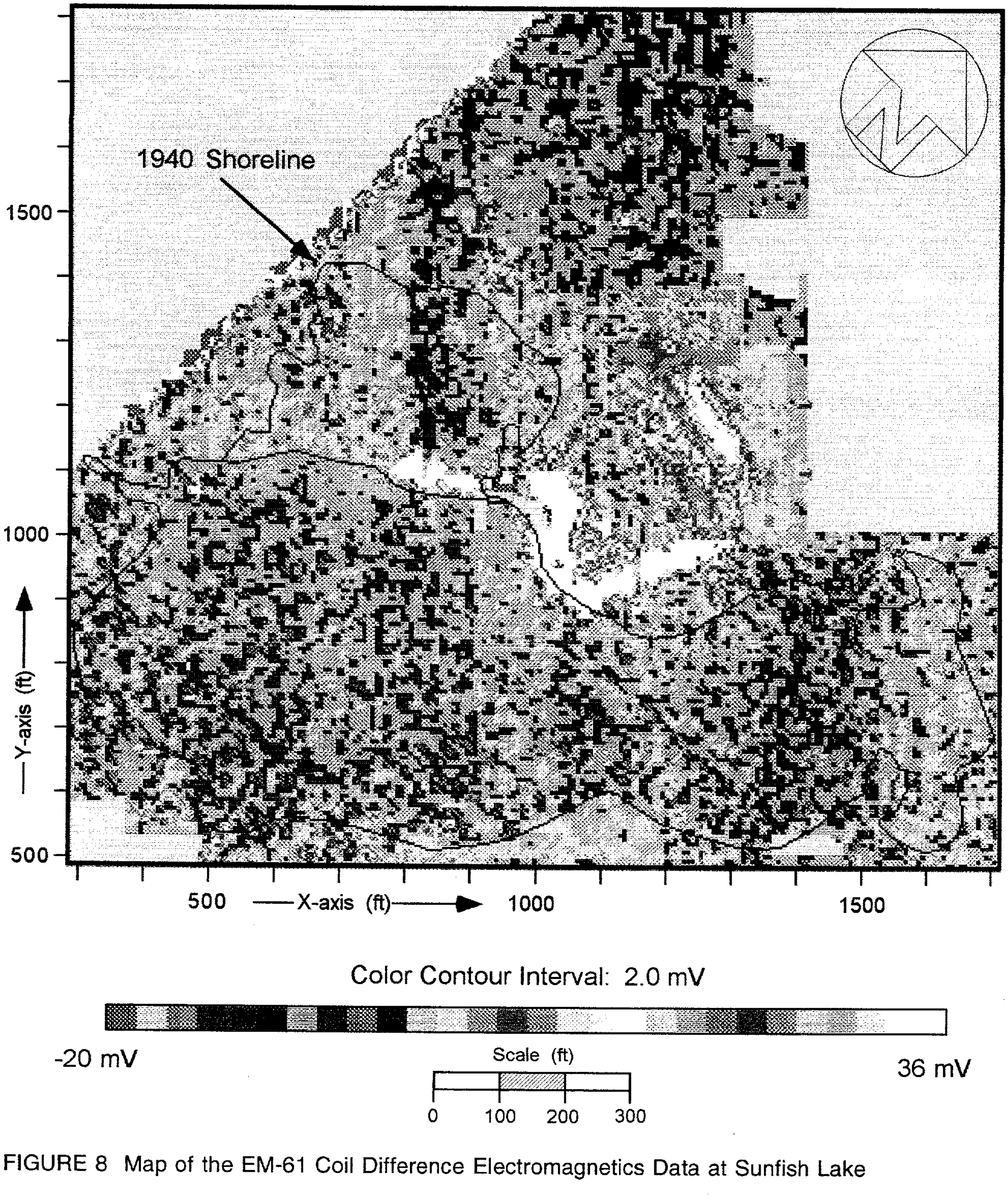


FIGURE 8 Map of the EM-61 Coil Difference Electromagnetics Data at Sunfish Lake

2.4 Terrain Conductivity Measurements

Figure 9 was constructed by gridding and contouring the 79,678 electrical conductivity measurements obtained in the Sunfish Lake survey. Areas of high conductivity are represented by white and red colors. Lower conductivity areas are dark blue and purple, whereas intermediate zones contain the lighter blues, greens, and yellows. For reference purposes, a clean sand and gravel saturated with freshwater has a conductivity on the order of 10 mS/m (blue), whereas a saturated, freshwater, silty clay has a conductivity on the order of 30 mS/m (pale yellow). Where metals are contained in soils, as in landfills, the conductivity is a function of the volume content of the metals, percent saturation, and pore water chemistry.

Sunfish Lake is characterized by a prominent conductive anomaly in the north-central part of the survey area, in the western half of the former H-1 waste disposal site. The conductive zone is spatially coincident with the former bay, as indicated by the bay outline drawn on Figure 9; therefore, conductivity data provide a distinctive electrical signature of fill material relative to background. Since the EM-61 coil difference map (Figure 8) indicates that the former bay is free of deep-seated metals, the electrical signature must be primarily a function of the soils and pore water chemistry of the fill material. The fill material was probably soil removed from other areas of the base during construction. Soil analyses should be conducted in the red zone of Figure 9, because previous work indicates that the southwest corner of Area H-1 may have been used for burial and dumping of industrial sludge, paint residue, incineration ash, and solvents. Some of these materials, particularly industrial sludge, may be good conductors. In this data set, the far western edge of the survey contains a conductivity high associated with the fenceline.

Three conductive zones associated with magnetic and electromagnetic (EM-61) anomalies are located (1) north of the former bay, (2) along the northwest lake margin, and (3) in the trench-like lineaments in the central map area southeast of the bay. A narrow band of conductive materials is also located along the southeastern lakeshore, where magnetic and electromagnetic anomalies indicate the presence of point-source metals.

A moderately conductive zone is present in the shallow waters of the southwestern lakeshore. It is probable that this feature is caused by shallowing of the clay/organic mud bottom.

A circular, low-amplitude, positive conductive feature is observed in the east-central half of the lake. The source of this feature is interpreted to be a clay-filled depression within a gentle rise in the lake bottom produced by a remnant of a fossil pingo. The rise in the lake bottom is shown in Figure 10, which is part of a 1945 aerial photo taken when lake water levels were low. Pingos form where mean annual surface temperatures reach -2° to -3°C and remain at those temperatures for extended periods of time. They are particularly prevalent in areas where shallow lakes freeze inward, causing the expulsion of water upward. An ice core centrally located at the crest of the pingo will eventually collapse as climates moderate, and a small depression will form in place of the ice core. In a fossil pingo environment, the central depression will contain

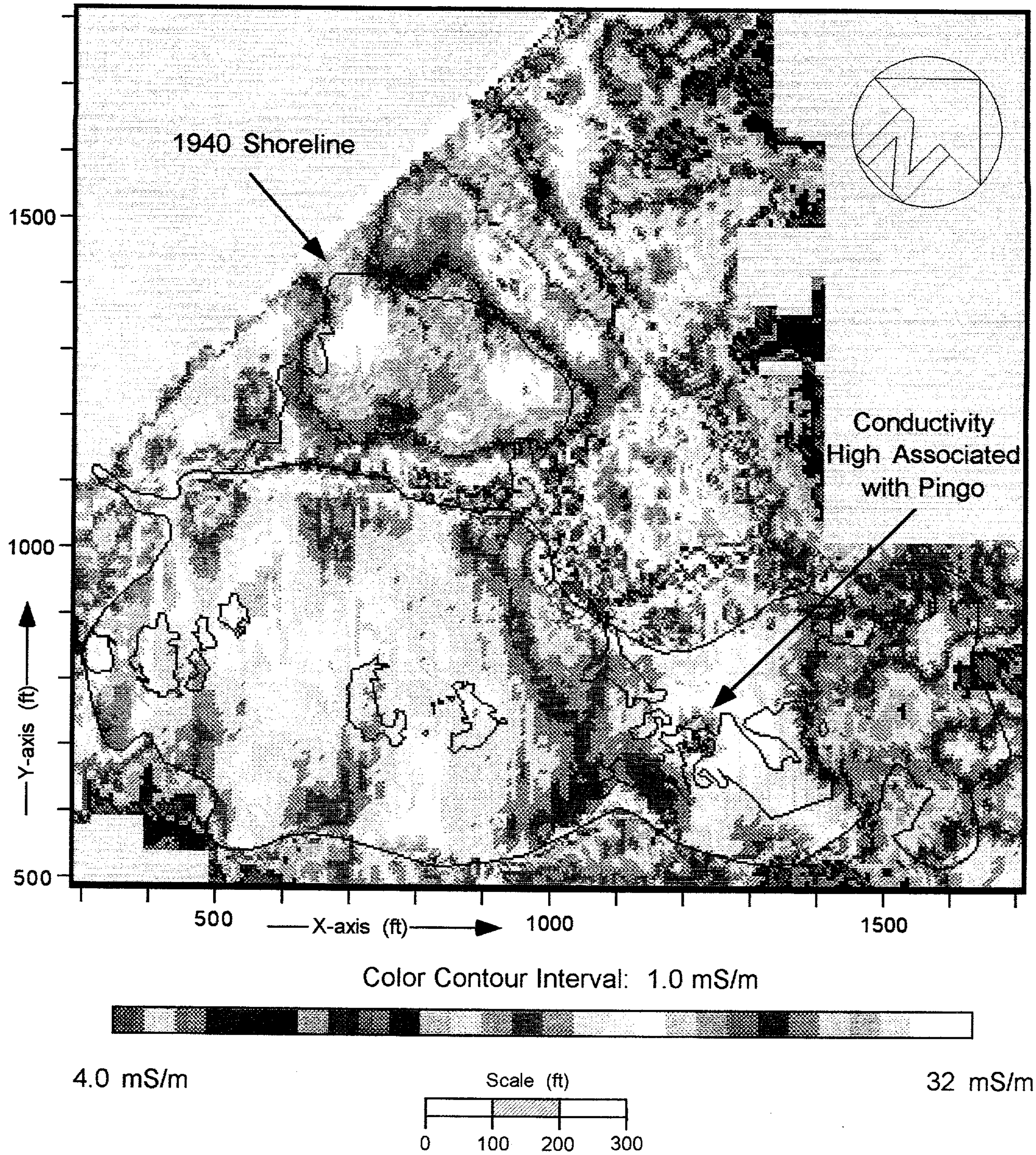


FIGURE 9 Map of the EM-31 Electromagnetics Data at Sunfish Lake

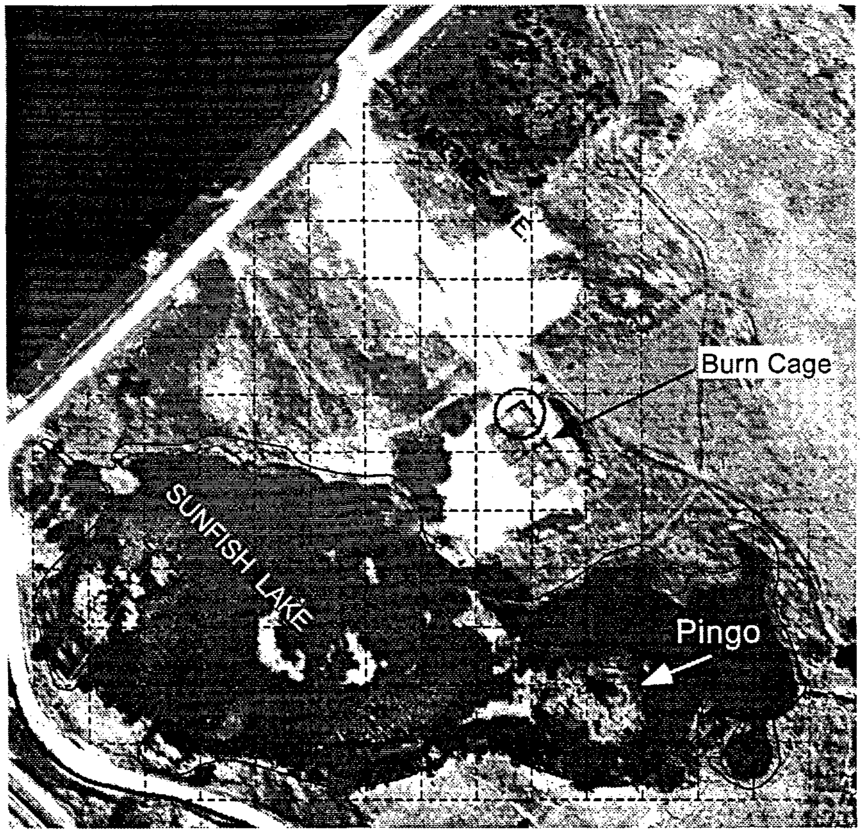


FIGURE 10 Geophysical Survey Grid Superimposed on a 1945 Aerial Photo of Sunfish Lake

organic sediments, lake-bottom muds, and perhaps a core of clay silt. The anatomy of a pingo provides the explanation for the conductivity anomaly in the eastern third of the lake. Fossil pingo fields have been observed as far south as the DeKalb mounds in northern Illinois (Flemal et al. 1976).

2.5 Bistatic Ground-Penetrating Radar Measurements

A GPR profile detailing the shallow stratigraphy under Sunfish Lake is shown in Figure 11. The profile is oriented parallel to the Y survey axis, and extends from Y = 500 to Y = 855 along X = 1220. Both the uninterpreted and interpreted profiles are shown. Radar images are observed at depths of about 20 ft, where a strong multiple obscures any signal energy from deeper objects. Water bottom is seen at approximately 32 ns. Subbottom reflectors are seen rising northward toward the northern lakeshore. This rise follows the original basin of the lake that has filled with sediment from the surrounding uplands. Below this rise, a sandy clay unit is present (inferred from a near-shore trench log) (ANL 1988). Stratigraphy indicated in this profile is representative of most Sunfish Lake profiles crossing the lake.

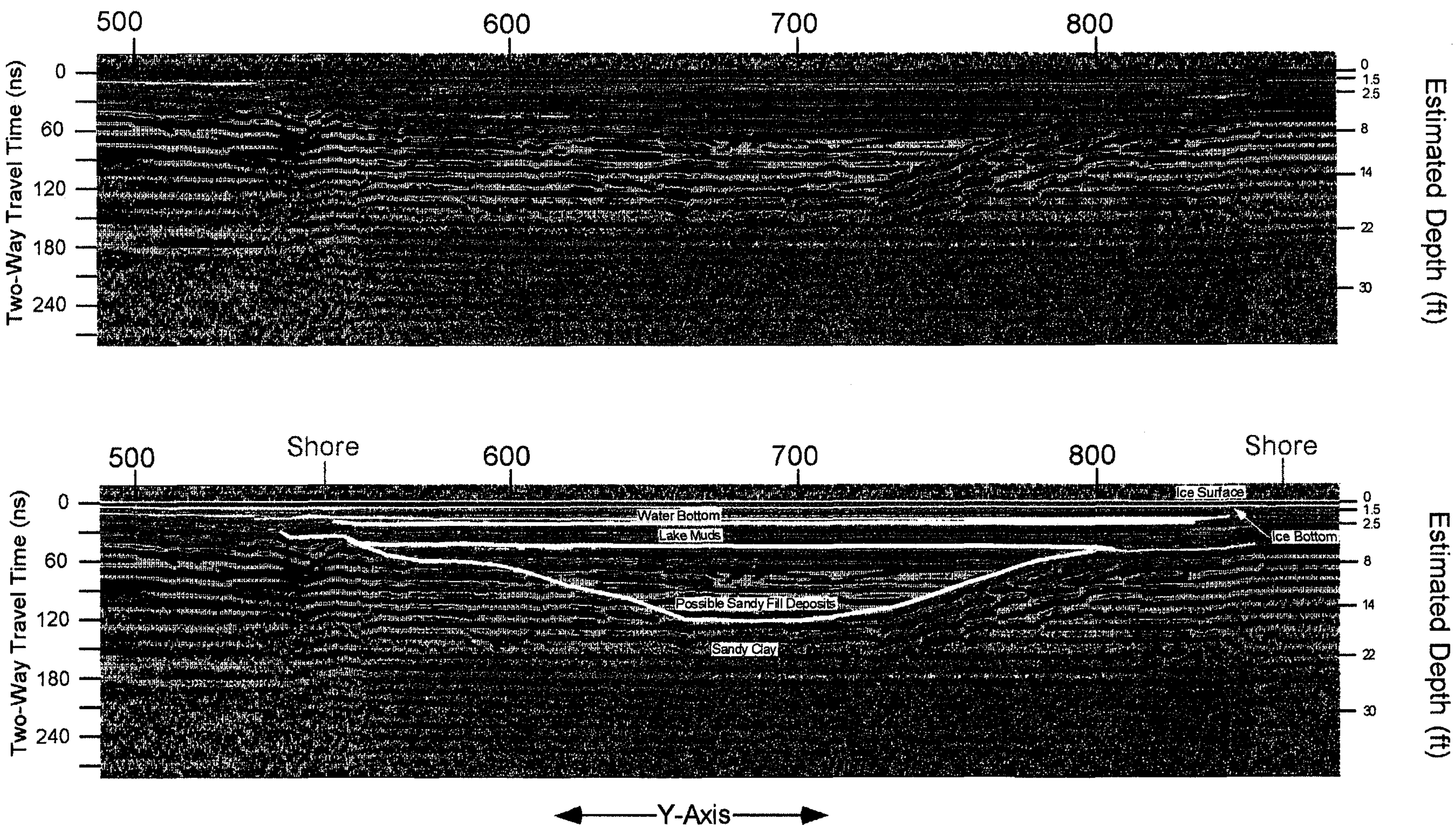


FIGURE 11 GPR Profile along X = 1220 Showing Lake Bottom and Lake Basin

Two GPR profiles are shown in Figure 12. Both profiles are oriented along the Y survey axis. Profile A is located along X = 1160 and extends from Y = 885 to Y = 1200. Profile B is located along X = 1200 and stretches from Y = 880 to Y = 1200. Both profiles show an anomalous region from approximately Y = 955 to Y = 975. This anomalous area is characterized by a stronger signal return (less attenuation) than background. The red and white areas in Figure 12 delineate the anomalies. The location of the anomaly is coincident with the location of a mound identified in the 1945 aerial photo (Section 3.1.2). The strong reflection in the GPR data is most likely due to the presence of shallow metal at depths of 2.5-5.5 ft.

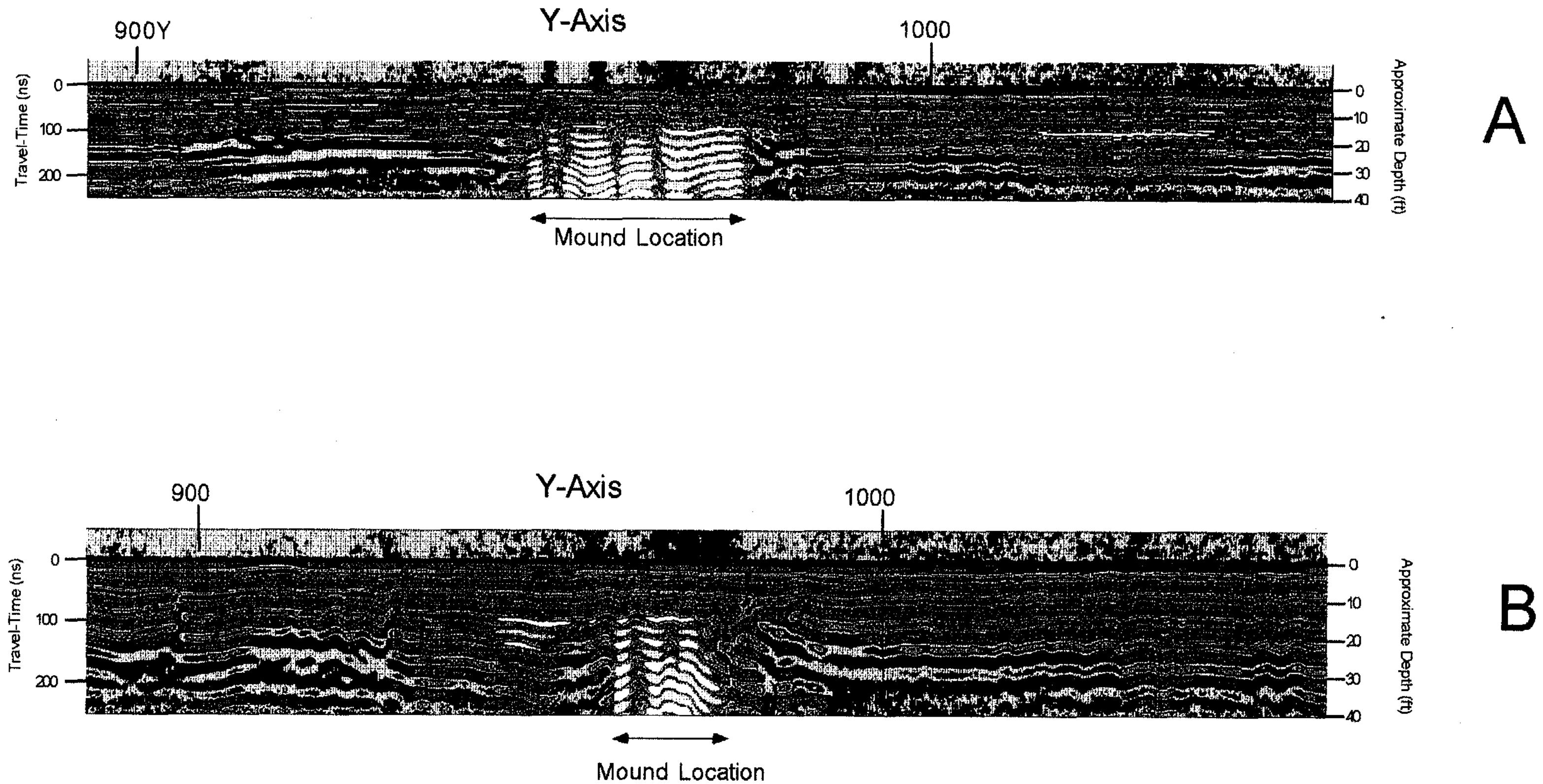


FIGURE 12 Location of the Mound 2 Anomaly along (A) the GPR Profile at X = 1160 and (B) the GPR Profile at X = 1200

3 Correlation of Aerial Photographs of Sunfish Lake with the Geophysical Analysis

3.1 Interpretation of Aerial Photographs

In order to establish the chronology of events that took place around Sunfish Lake, a sequence of aerial photographs taken between 1940 and 1993 have been studied. These photos aid in dating the anthropogenic alterations to Sunfish Lake and its surrounding area, as well as aid in interpreting the observed geophysical anomalies. Historical records detailing activities at different times indicate probable source materials for the geophysical anomalies observed. Figures A.1–A.12 in the Appendix are scanned images of the photos utilized in this study. The scanned photos have been traced and their significant physical features noted. These tracings appear as figures in the main text to aid in correlating the physical characteristics of the area with the results of the geophysical analysis.

The following description of the modification of Sunfish Lake and its surrounding parcel is limited to the geophysical survey area and to periods when significant changes to the lakeshore and the upland area can be observed from aerial photos. Specifically, the discussion centers on the changes that took place in the intervals between the taking of photos dated 1940, 1945, 1947, 1953, and 1966. The changes that took place in the years 1957-1958 and from 1970 through 1993 will be addressed in two sections, without a specific discussion of each photo taken during those time periods.

All coordinate locations are referenced to the local grid system established for the geophysical survey. The survey grid is rotated approximately 45° west of true north. However, directional descriptions will be made with respect to true north.

3.1.1 1940 Photo

The 1940 aerial photo (Figure A.1) shows the lakeshore as it appeared before the installation was built. Most of the surrounding land shows signs of agricultural use. From the northwestern edge of the southwestern half of the lake, the original shoreline is shown to be approximately 300 ft northwest of its current position (Figure 13). No alteration of the natural features is apparent in the 1940 photo.

3.1.2 1945 Photo

The most dramatic changes to Sunfish Lake itself took place between 1940 and 1945, as can be seen in the 1945 aerial photo (Figure A.2). The northern embayment was filled in, reducing

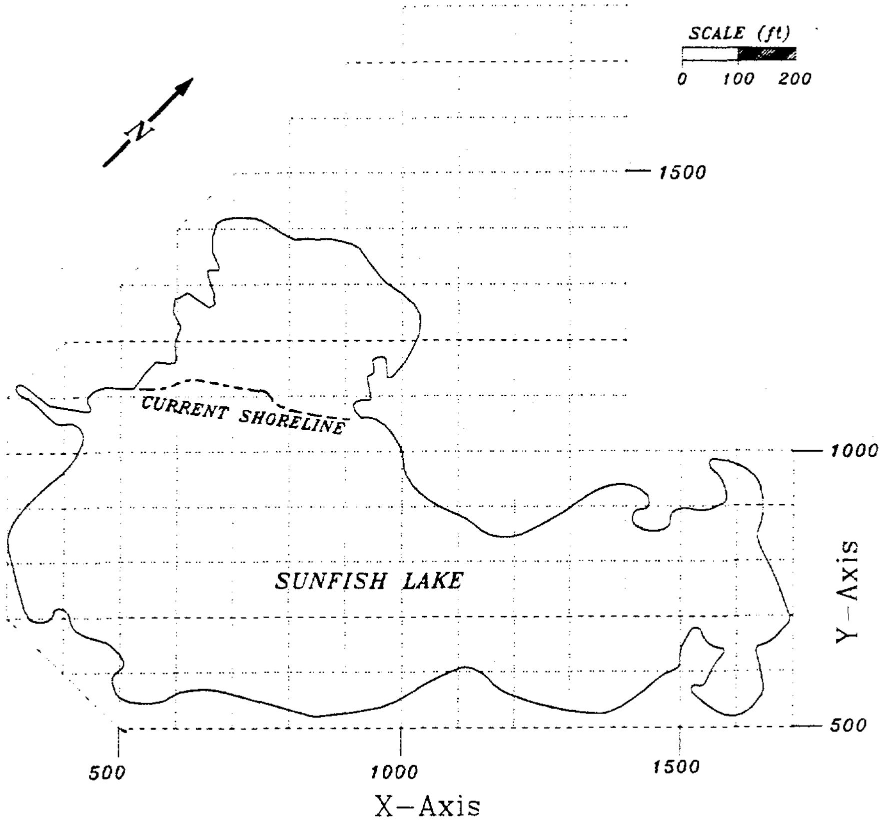


FIGURE 13 Sunfish Lake as it Appeared in 1940

the lake to its approximate present size and shape. A narrow channel was constructed on the eastern shore at about Y = 700. This channel was probably created to drain into Marsden Lake the water that was displaced when the northwest corner of Sunfish Lake was filled. A heavy-duty road about 40-ft wide enters the survey area at about coordinates (875,1675) and crosses east-southeast to a large cleared area. A 170 ft × 85 ft burn cage, oriented east-west, is centered near coordinates (1185,1135). Two mounds observed in this photo are thought to contain debris from the burn cage (Figure 14). Mound 1 is about 185 ft × 35 ft. Mound 2 is 150 ft × 30 ft.

Features observed near the burn cage on the 1945 aerial photo were overlain onto the color images for the total-field magnetics and EM-61 coil-difference maps (see Figure 15). What is clearly demonstrated in Figure 15 is the spatial coincidence of observed geophysical anomalies and past anthropogenic activities. Specifically, both Mounds 1 and 2 have direct geophysical counterparts, although the extent of the waste debris inferred from the limits of the geophysical anomalies is considerably greater than suggested by the aerial photos. In addition, the GPR profiles shown in Figure 12 also detected the presence of Mound 2.

Geophysical data suggest that the southern portion of the clearing, at about coordinates (1025,950), contains debris (Mound 3). Although Mound 3 is not as clearly defined in the photograph, the geophysical data help locate its position. Another open area exists at about

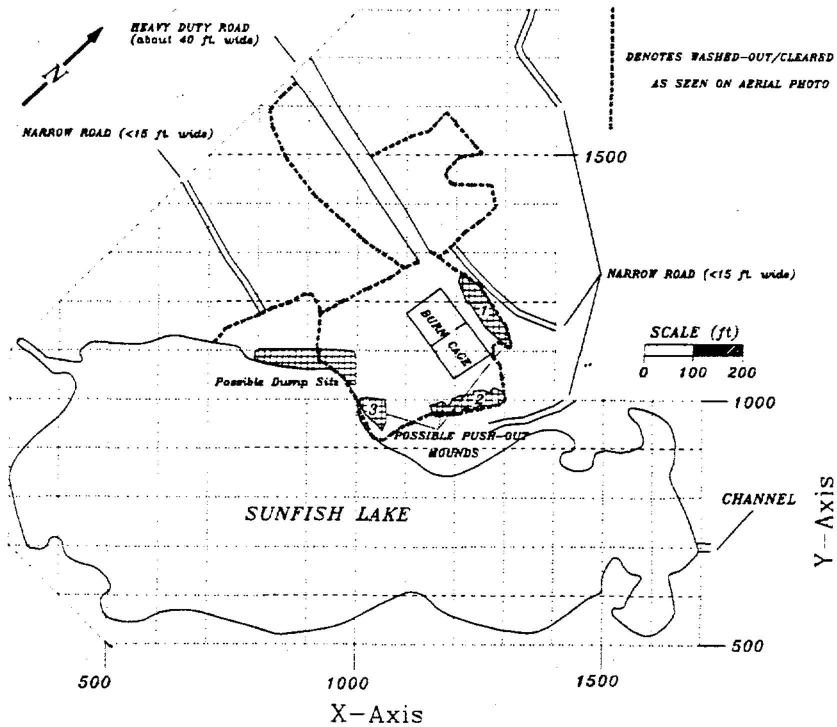


FIGURE 14 Anthropogenic Features at Sunfish Lake Traced from 1945 Aerial Photo

coordinates (850,1100). It is accessed by two roads, one from the north and the other from the west. It is unclear from the photo whether any dumping occurred here, but the magnetic and electromagnetic data clearly indicate the presence of buried metals. The importance of geophysical surveying data, specifically the EM-61 coil-difference data, cannot be minimized; although some of the anomalous areas appear in the aerial photos, the exact location and boundaries of the contaminated areas are delineated by the data sets.

3.1.3 1947 Photo

According to the site background description and 1947 aerial photo (Figure A.3), the burn cage was removed by 1947. The mounds visible in the 1945 photograph are also absent. The washed-out area where the burn cage was previously located now covers a larger area. These observations are significant for two reasons. First, the new larger area extends southeast of where Mound 2 was previously located, explaining the anomaly in the geophysical data set. Second, the cleared area now abuts the shoreline to the south. The area appears to be fairly flat, and it is possible that the size of this area was increased by leveling of the site. As a result, debris was probably pushed to the outer limits of this area. The geophysical data sets delineate the edge of this area (Figure 16).

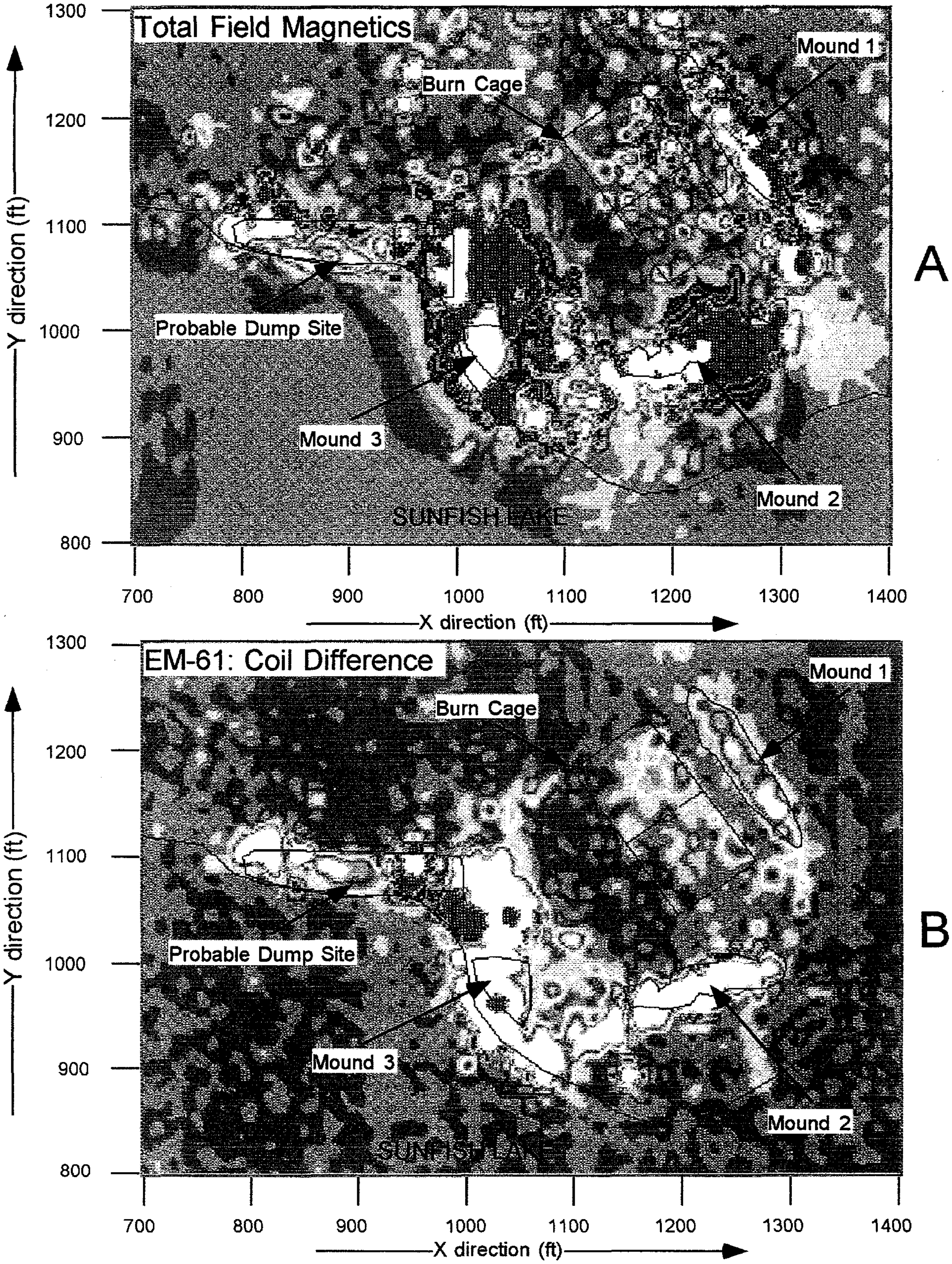


FIGURE 15 Correlation of Observed Mound Locations with (A) Total-Field Magnetics Data and (B) EM-61 Coil-Difference Data

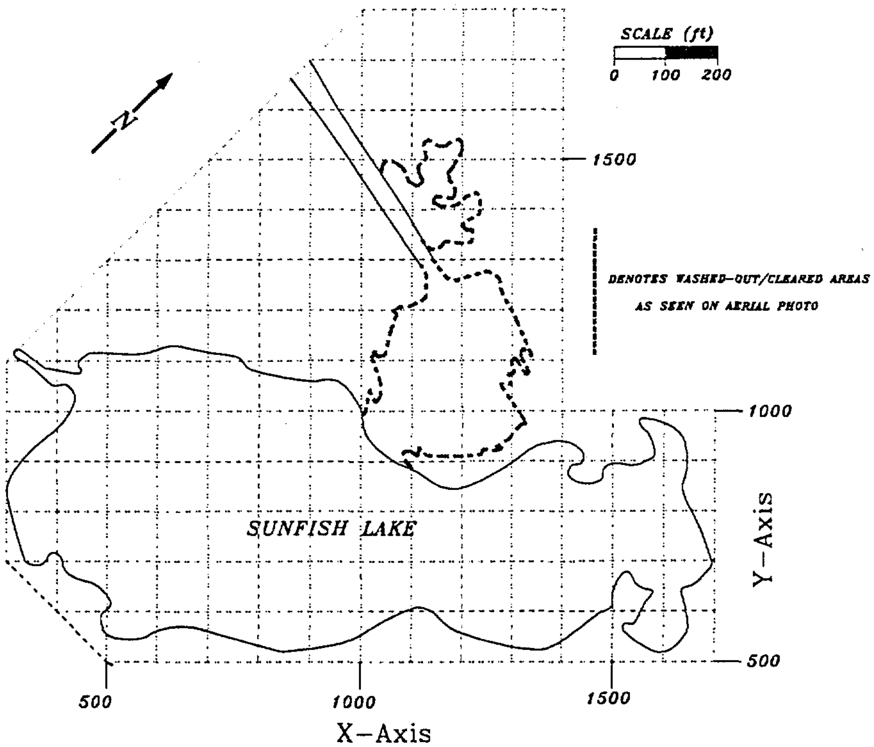


FIGURE 16 Anthropogenic Features at Sunfish Lake Traced from 1947 Aerial Photo

3.1.4 1953 Photo

Although Biang et al. (1991) indicated that a smaller burn cage had been installed in 1962, a new cage-like feature appears clearly on the 1953 aerial photo (Figure A.4). This probable 25 ft × 60 ft burn cage is centered near coordinates (930,1425), with its long axis oriented 30 degrees west of the Y-axis. The cage lies in a teardrop-shaped clearing off the main road. It is possible that a mound or pile of debris lies about 100 ft southwest of the cage (Figure 17). The entire clearing was delineated by the magnetic data, while the electromagnetic (EM-61) data set located only the apparent burn cage (Figure 18). As shown in the photo, the heavy-duty road that led to the clearing which previously contained the burn cage now extends to the lakeshore. The clearing is overgrown, with the exception of about 40 ft of mowed grass on either side of the road. On the basis of the aerial photos, it is unclear whether any dumping took place at the end of this road near the lakeshore.

3.1.5 1957 and 1958 Photos

The 1957 and 1958 aerial photos (Figures A.5 and A.6) show an enlarged cleared area around the second burn cage (Figure 19). This larger area correlates well with the magnetic anomalies for this area. From 1953 to 1958, plant production was probably increased to satisfy

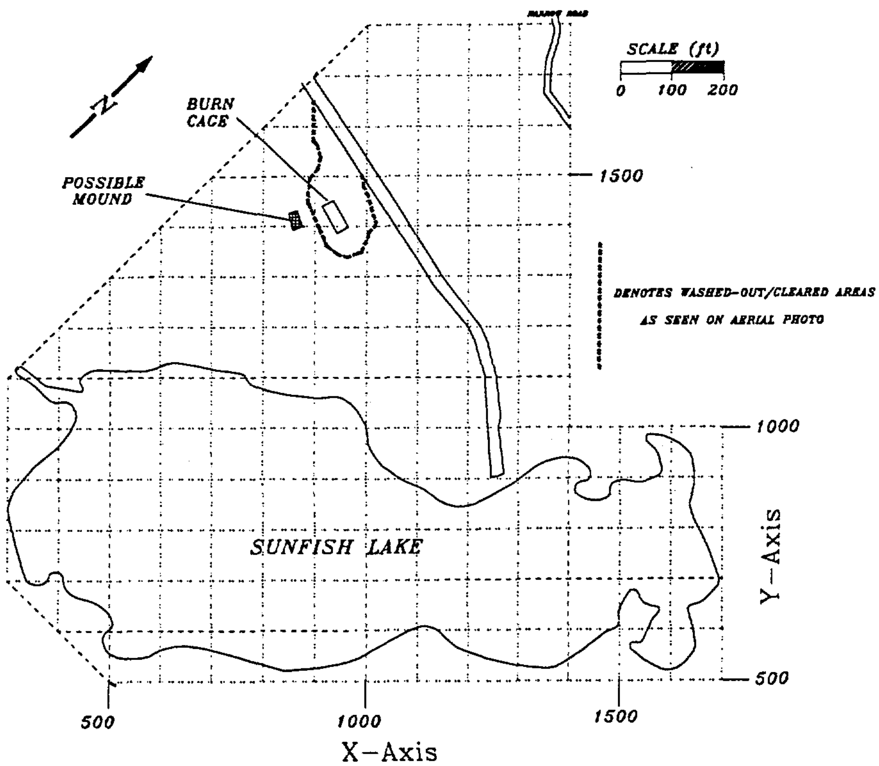


FIGURE 17 Anthropogenic Features at Sunfish Lake Traced from 1953 Aerial Photo

the military's expanded needs. In the 1958 photo, a road extending south from the burn cage to the lakeshore is visible. Approximately 14 to 18 small piles, each a few feet in diameter, are present within 80 ft of the shore. Because this area seems to have been in continuous use, it is unclear whether the geophysical anomalies are caused by material dumped here in the late 1950s or are related to activities in the 1940s.

3.1.6 1966 Photo

The 1966 photo (Figure A.7) shows that the burn cage is still active; however, the road leading to the shore is not visible and probably had not been used for some time. Even the clearing by the shore is no longer visible.

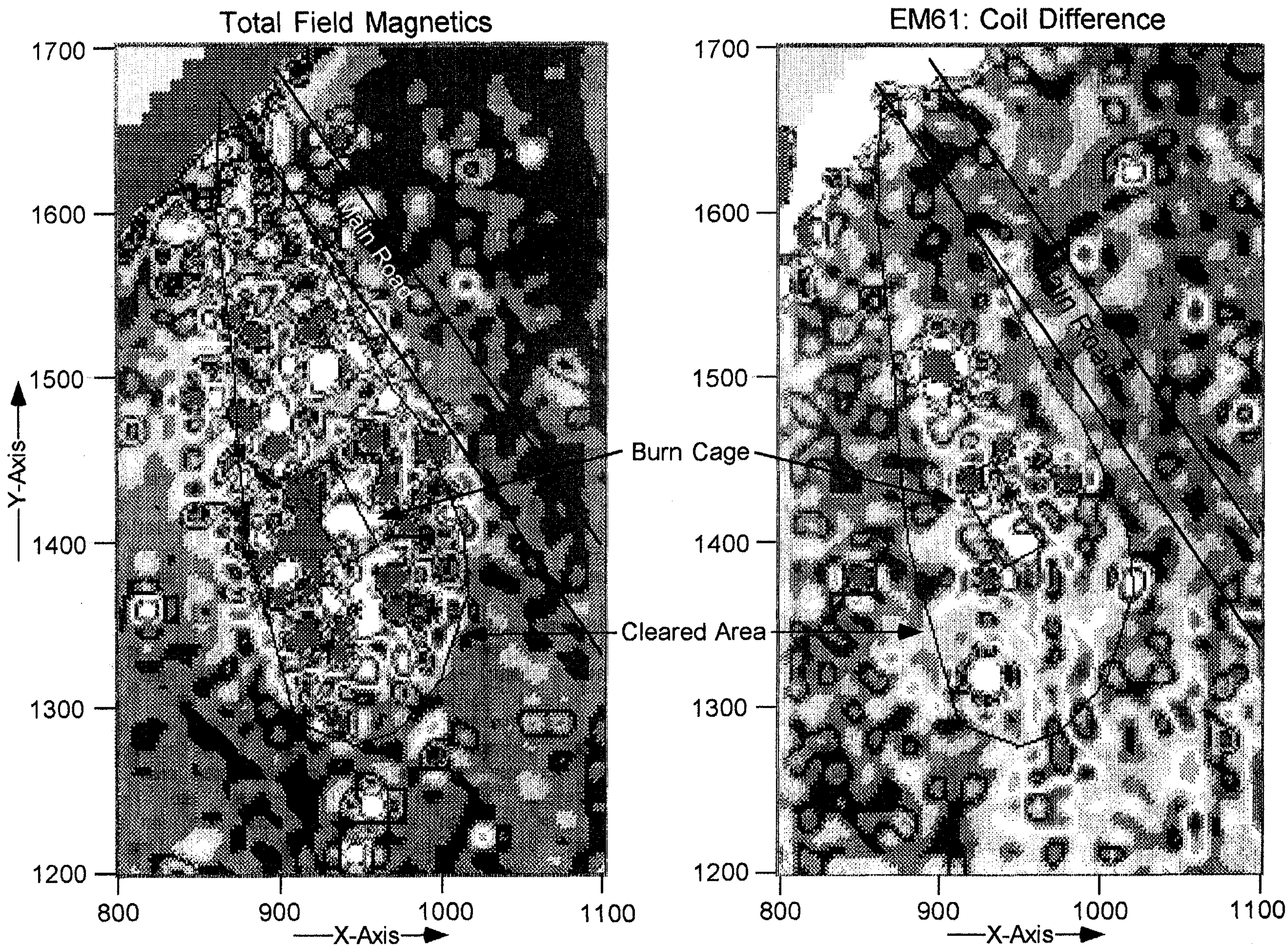


FIGURE 18 Geophysical Data Sets Overlaid on a Map of the Open Area and Second Burn Cage

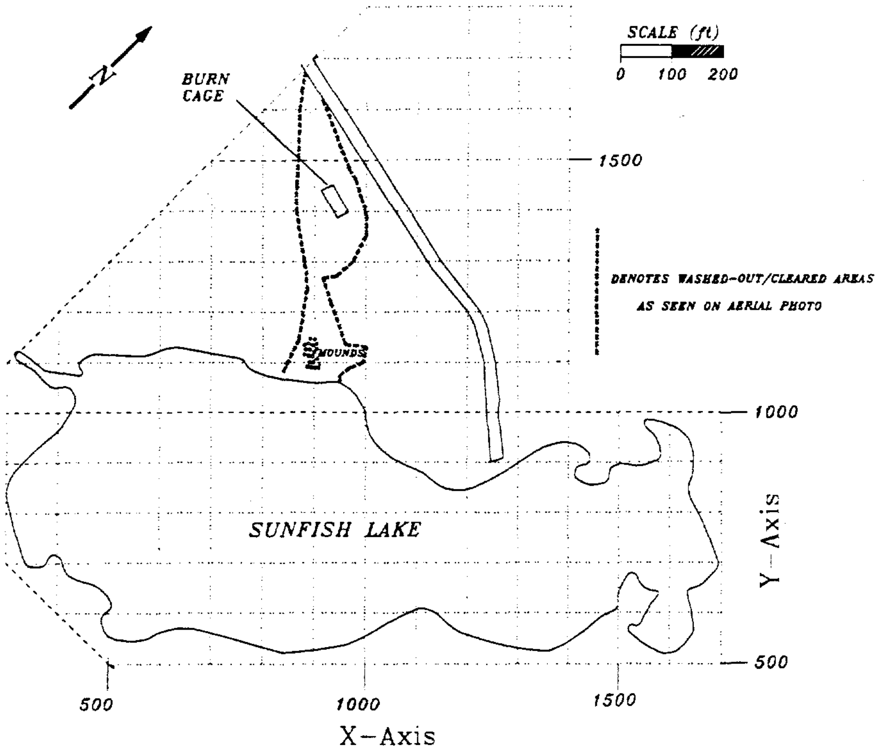


FIGURE 19 Anthropogenic Features at Sunfish Lake Traced from 1957 and 1958 Aerial Photos

3.1.7 1970-1993 Photos

In the 1970 photo (Figure A.8), the burn cage is not visible and has most likely been removed. The main road (to the original burn cage and lake shore) appears overgrown. No dump sites are apparent. The only open area left is the clearing where the second burn cage once stood. All successive aerial photos show the roads and the clearing becoming increasingly overgrown, until they are practically indistinguishable. In the 1993 photo, the road around Sunfish Lake appears much smaller than in previous photos and is probably seldom used (Figure 20).

3.2 Discussion

By studying the aerial photographs taken from 1940 to 1993, activities and anthropogenic features can be correlated with geophysical anomalies delineated by the ANL study. The anomalous areas southwest of Y = 1100 near the lakeshore represent operation of the original burn cage and its debris. The location of the burn cage and the adjacent mounds around it are clearly delineated by the magnetic and electromagnetic data (Figure 15). In the magnetic data, the large, semicircular group of anomalies in the northern part of the survey area correlates with the location of the clearing around the second, smaller burn cage. The electromagnetic data in this area clearly shows the location of the burn cage itself. An item of historical significance extracted

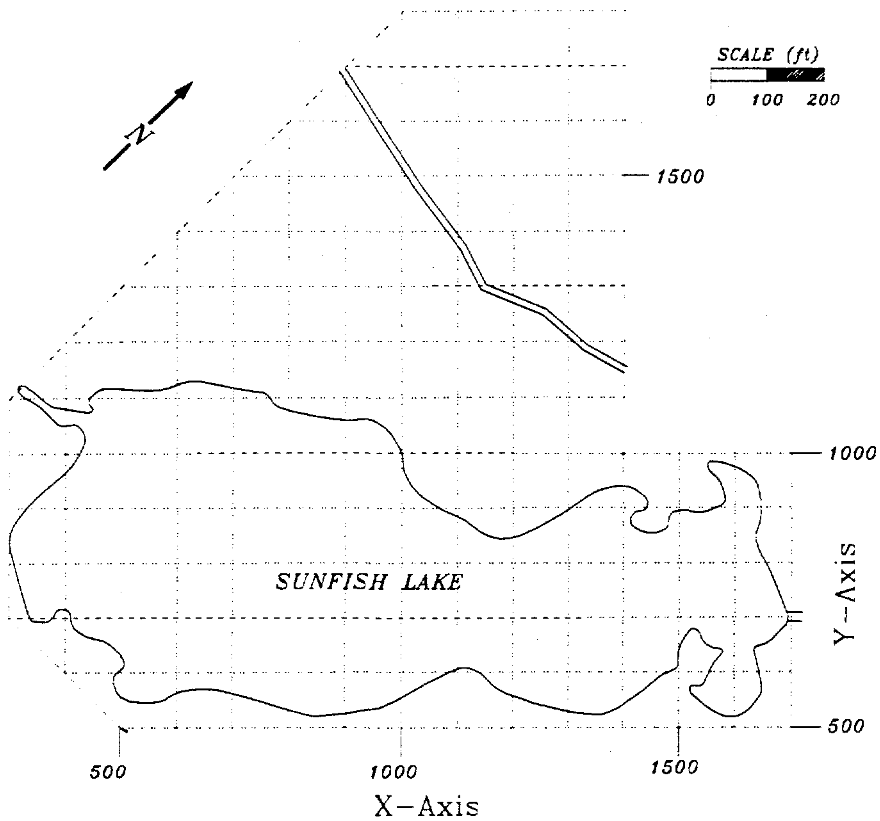


FIGURE 20 Anthropogenic Features at Sunfish Lake Traced from 1993 Aerial Photo

from this aerial photographic study is that the second, smaller burn cage was in use by 1953, rather than the 1962 date cited in previous literature.

4 Marsden Lake

Data sets for Marsden Lake were collected along diagonal transects spaced at various intervals across the lake (Figure 21). Each profile was connected with visible markers onshore. Lengths of data transects are known within a few tens of feet; however, precise end-point coordinates were not required because of the reconnaissance nature of the Marsden Lake geophysical survey. Magnetic gradiometry, total-field magnetic, and conductivity (EM-31) measurements provide data from which the degree of contamination by foreign objects can be estimated.

4.1 Magnetic Gradiometry Measurements

Prior to conducting total-field magnetic measurements across the Marsden Lake transects, a magnetic gradiometry scan was conducted around the lake perimeter. Three isolated sites of high iron concentrations, all of which were along the western shore of Marsden Lake, were observed: (1) north of Patrol Road due to unknown causes; (2) at the Homestead site, caused by rebar in concrete waste immediately south of Patrol Road; and (3) along the southwest shore at a location in alignment with Lexington Avenue to the east, which was caused by barbed wire.

4.2 Total-Field Magnetics Measurements

Total-field magnetics were measured along eight transects across Marsden Lake, from Lexington Avenue on the east to Hamline Avenue on the west (Figure 22). The magnetic field strength at Marsden Lake ranged from 45,868 to 58,848 nT. The high-end anomalies are due to the chain link fence at the ends of the transects in the northeast corner of the survey area. Except for the anomaly caused by the fence and a negative anomaly caused by buried barbed wire at the southwest end of the most southerly line, the entire magnetic-field range is essentially background noise. The range in background amplitudes is approximately 150 nT, which can be explained by natural variations in orientation or by magnetite concentrations in glacial debris common at TCAAP.

Two maps of the magnetic field at Marsden Lake, one with and one without the Patrol Road transect, are shown in Figures 22 and 23 to illustrate differences in magnetic intensities produced by cultural features associated with road grade, drainage pipes, and access fences. Except for small anomalies caused by these features, the maps are identical.

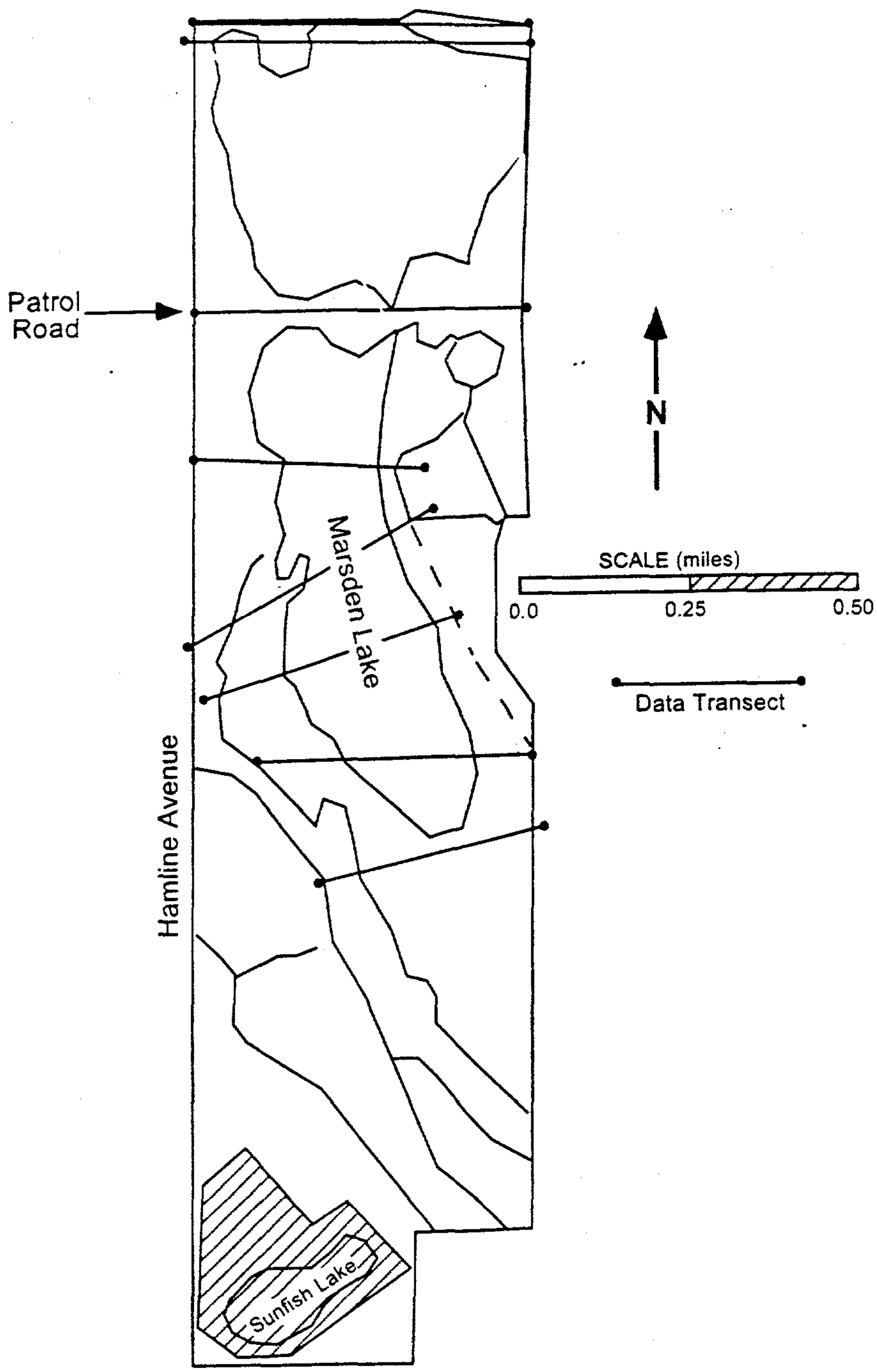


FIGURE 21 Transects for the Geophysical Survey at Marsden Lake

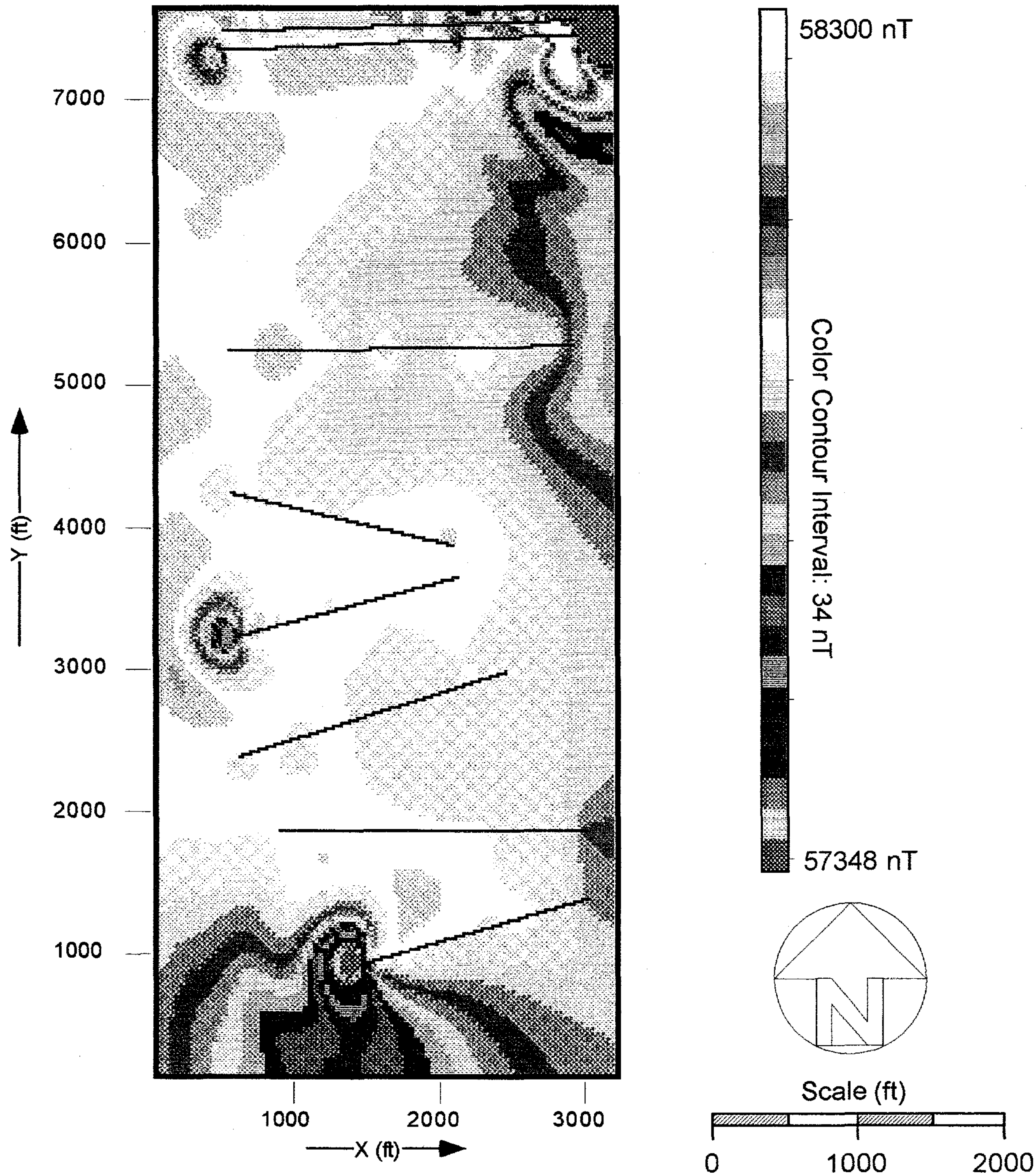


FIGURE 22 Magnetics Data at Marsden Lake including the Patrol Road Survey Line

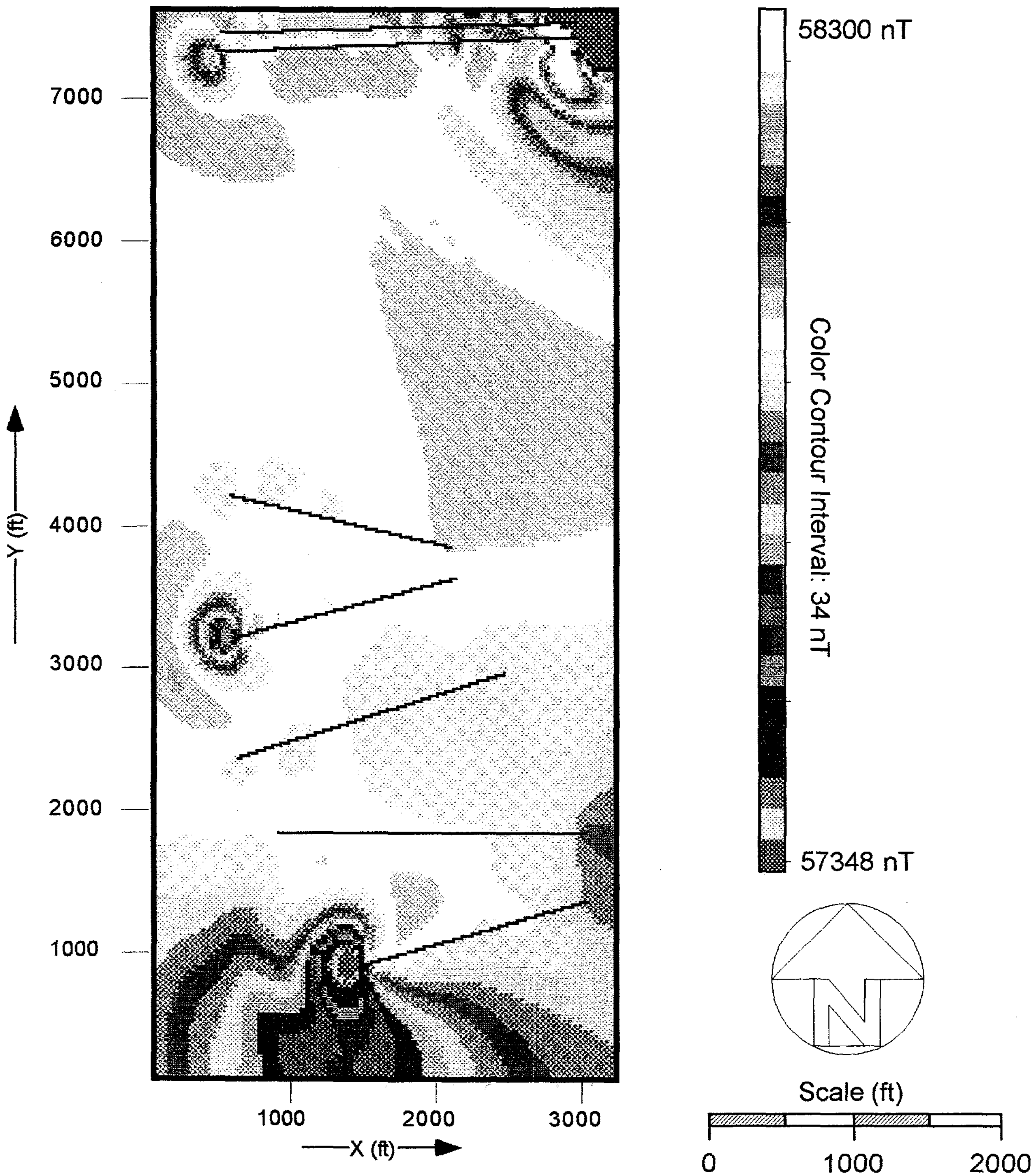


FIGURE 23 Magnetics Data at Marsden Lake without the Patrol Road Survey Line

4.3 Terrain Conductivity Measurements

Terrain conductivity measurements across Marsden Lake were made along 10 east-west transects, each of which was approximately 1,000 ft long. The average ground conductivity was measured to a depth of about 18 ft, as well as along the ground 10 ft to the left and to the right of the equipment boom. Two conductivity maps of Marsden Lake, one with and one without the Patrol Road transect, were constructed from the survey data and are shown in Figures 24 and 25. The map with the Patrol Road included is marked by a negative conductivity anomaly crossing the lake at the road. This anomaly is caused by the greater elevation of the EM-31 instrument on the road than on the lake and by the low conductivity of the road grade relative to the natural saturated sediments in the lake bed.

In general, conductivities in the lake center are higher than those observed on the shore. These differences are caused by high conductivities of saturated lake clays and organic muds relative to the frozen sediments on the terraces adjacent to the lake. All of the observed conductivities are produced by natural materials found in the glacial sediments of the lake basin.

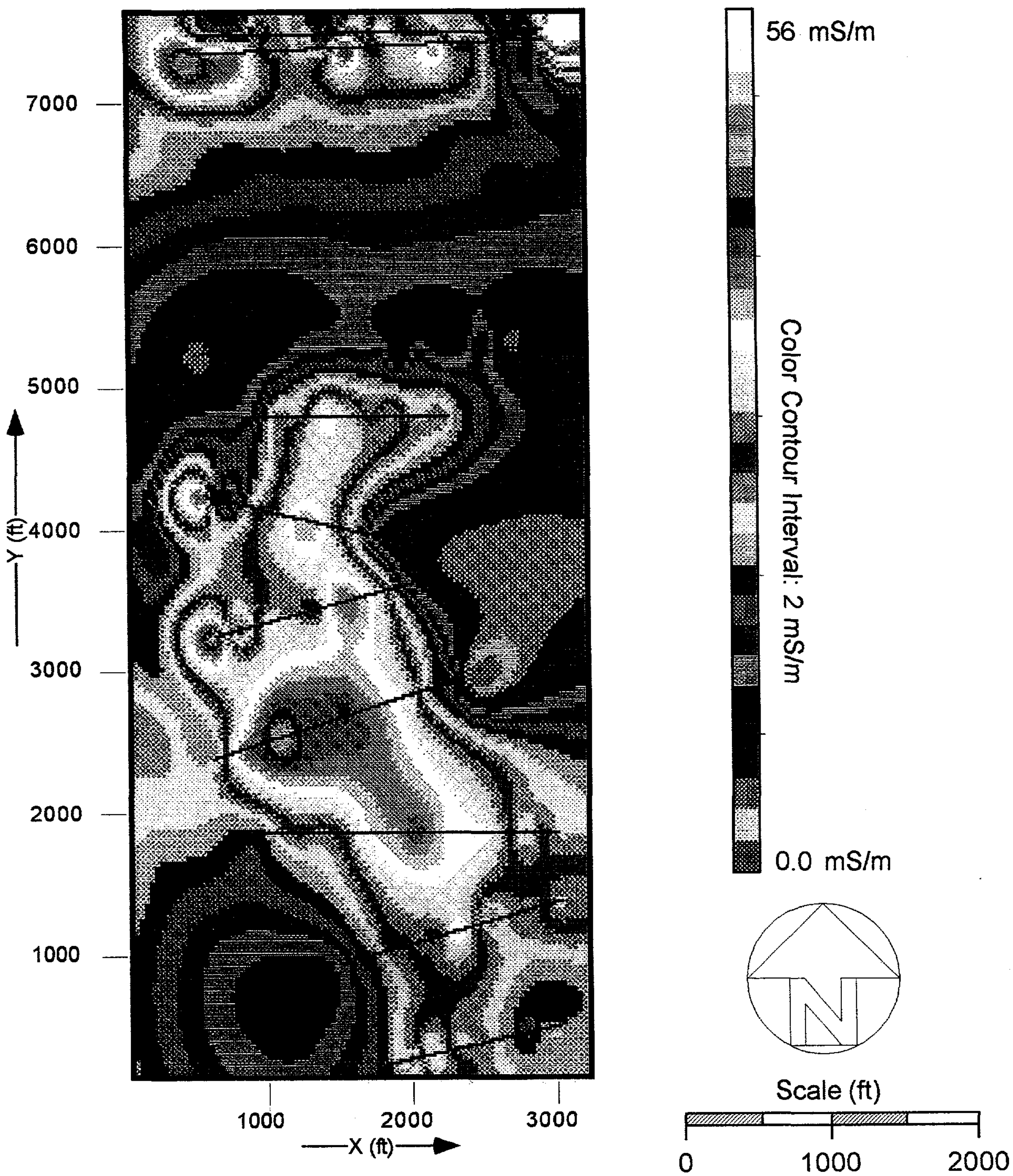


FIGURE 24 Conductivity Data at Marsden Lake including the Patrol Road Survey Line

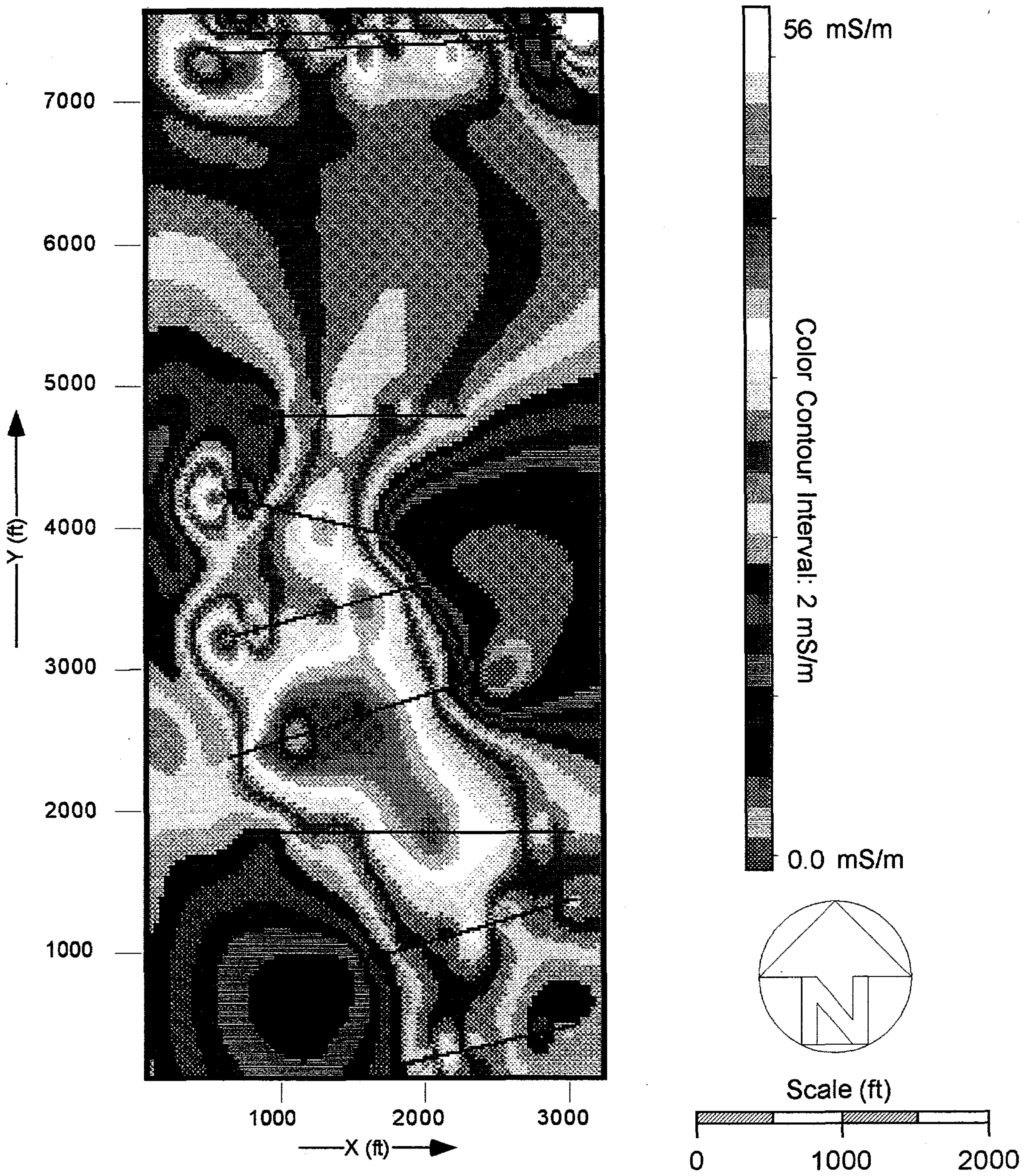


FIGURE 25 Conductivity Data at Marsden Lake without the Patrol Road Survey Line

5 Homestead Site

The Homestead site was investigated because of the presence of gradiometer hits. These hits were found during a gradiometer sweep around the margins of Marsden Lake.

5.1 Total-Field Magnetics Measurements

Data from 13 transects spaced at 10-ft intervals describe the magnetic field at the Homestead site. The magnetic field is featureless except for concentrations of anomalies in the center of the survey area (Figure 26). These anomalies correlate with the locations of gradiometer hits and are caused by rebar contained in concrete waste observed at the site.

5.2 Terrain Conductivity Measurements

Terrain conductivities were measured with the Geonics EM-31 instrument along 13 transects spaced at 10-ft intervals. The configuration of the conductivity map is caused by the proximity of the site to the shoreline of Marsden Lake. Higher conductivities are observed at lower elevations and are primarily due to the ground being frozen along the banks versus the unfrozen lake bottom sediments (Figure 27). Small anomalies are produced by rebar contained in concrete waste observed at the site.

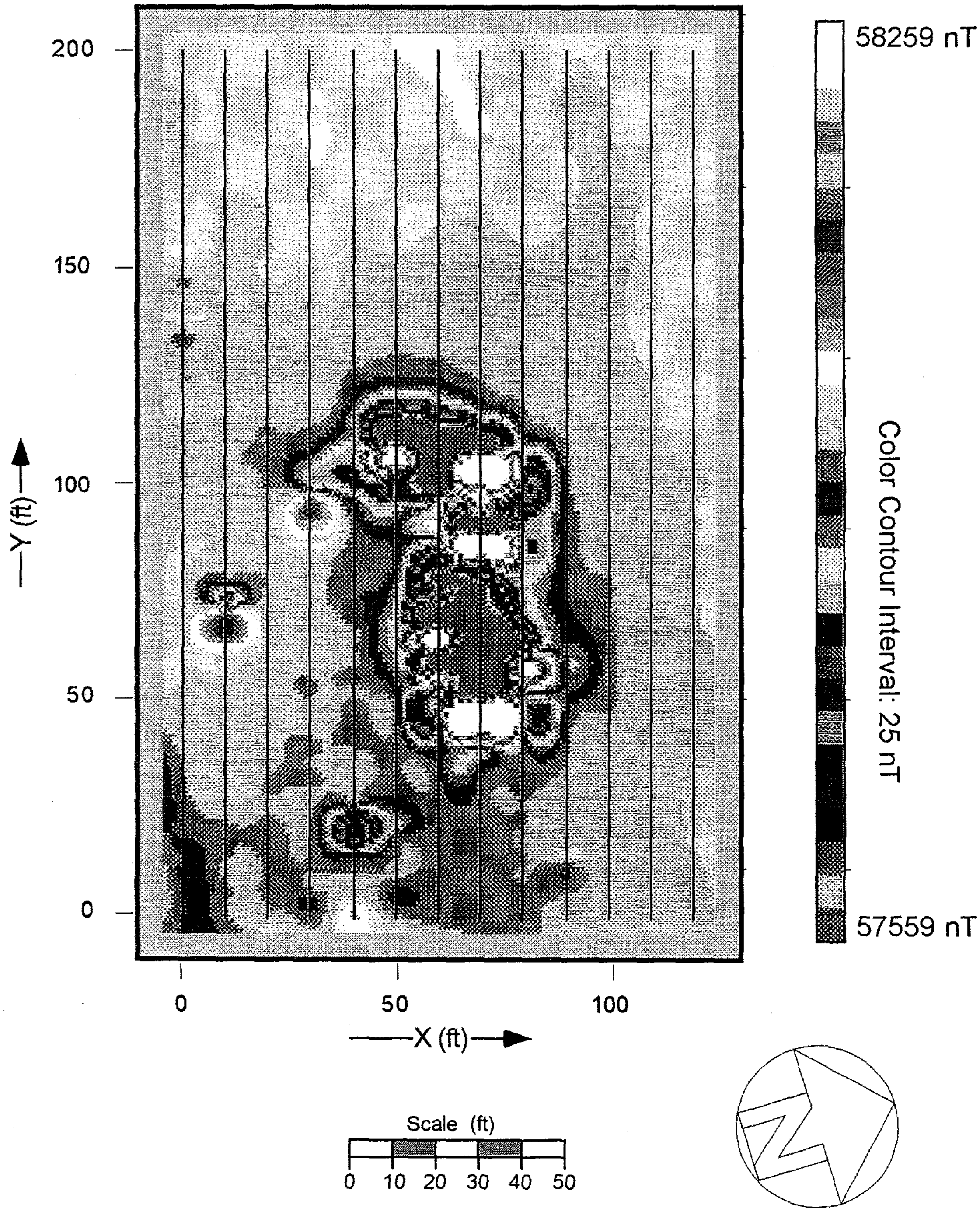


FIGURE 26 Map of the Total-Field Magnetics Data for the Homestead Site

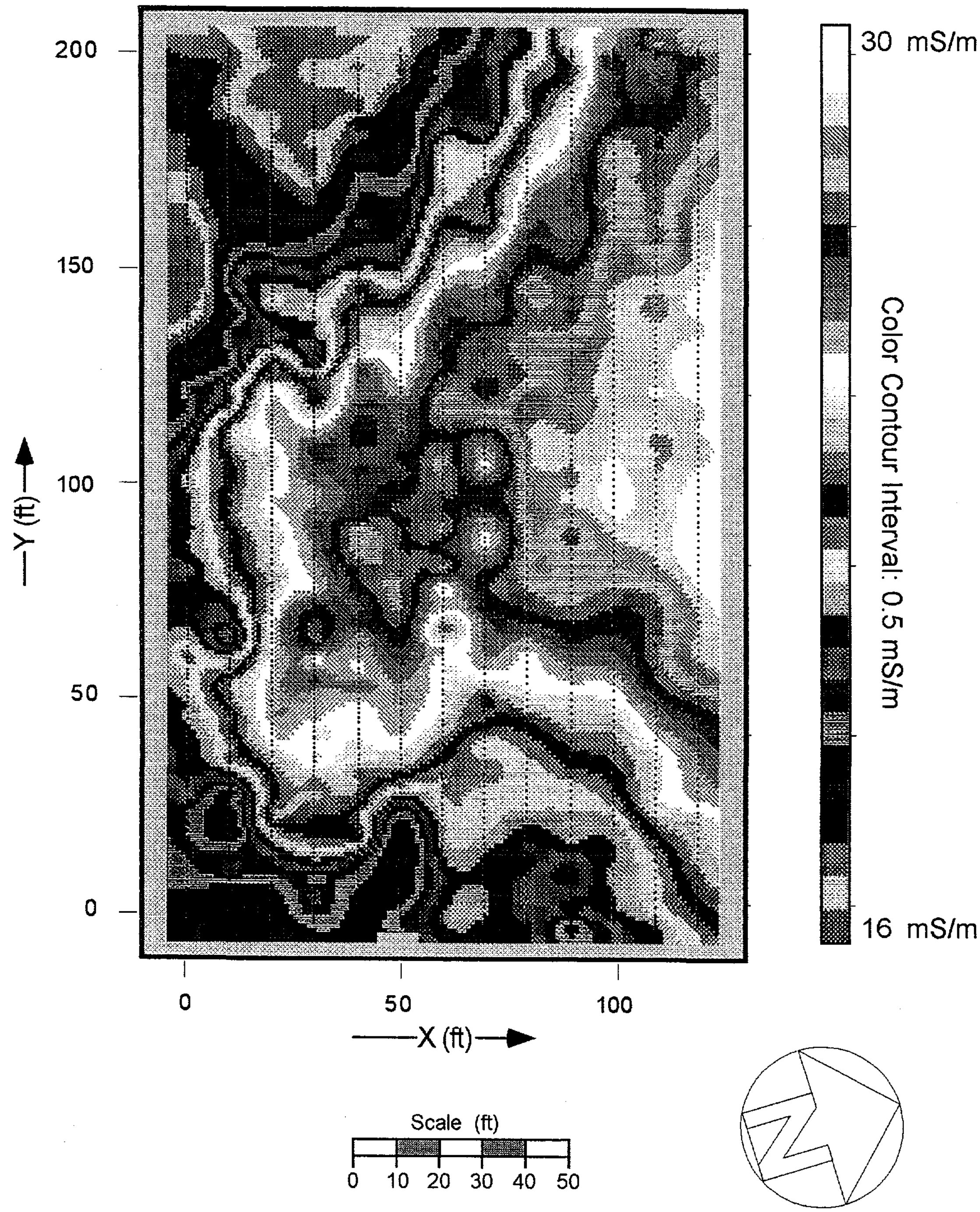


FIGURE 27 Map of the Conductivity Data for the Homestead Site

6 Summary and Conclusions

The construction of TCAAP resulted in the infilling of the northwestern arm of Sunfish Lake between 1940 and 1945. From the 1940s to the 1960s, Area H-1 was active with two distinct burn locations. The first burn-cage site, in operation between 1940 and 1946, was centered at geophysical survey coordinates (1150,1100); it was used to burn combustibles and other miscellaneous refuse. This burn site was replaced with a smaller burn cage between 1947 and 1953. The location of this new site was centered at about (950,1400). This second burn site was in use until 1967, when an outside contractor took over waste-disposal operations. The southwest corner of Area H-1 may also have been used as a disposal site for industrial sludge, paint residue, incineration ash, and solvents.

An extensive geophysical survey was conducted over and around Sunfish Lake in March and June of 1995. A chronological series of aerial photos was also analyzed in order to correlate anthropogenic features with the geophysical anomalies observed. The aerial photos were useful in dating events that may have caused these anomalies.

The area around Marsden Lake has been utilized for numerous activities throughout the history of TCAAP. Areas were used as a grenade testing range, EOD training grounds, and burn plots for the disposal of munitions. Not all of these activities, however, were well-documented, and the existence of numerous access roads around Sunfish and Marsden Lakes caused concern about the possibility of dumping around or within Marsden Lake. A preliminary survey was made along transects crossing Marsden Lake in an attempt to locate possible disposal sites. Areas containing metallic debris were mapped by using magnetic and electromagnetic methods.

Specific conclusions drawn from these two studies are as follows:

- The areal extent of the first burn-cage site at Sunfish Lake is clearly defined by both the aerial photos and the geophysical data.

- Three mounds identified from early aerial photos are spatially coincident with the magnetic, time-domain electromagnetic, and GPR data. Shallow-buried metallic debris probably exists at these locations. Subsequent photos show an enlargement of the burn-cage clearing and the absence of the mounds. The geophysical anomalies extend east and south toward the shore, indicative of the push-out of debris toward and into Sunfish Lake. This area was active between 1940 and 1947, and the materials causing the anomalies were emplaced at that time.

- The southwest corner of Area H-1 was used as a dumpsite at one time, although it is difficult to definitively date this activity. Anomalously high values in the magnetic and electromagnetic data are observed in this area, which is consistent with the presence of shallow-buried metallic debris.

- Except at the shoreline around the first burn cage and in the southwestern portion of Area H-1, it is believed that no dumping or waste disposal took place along the shore or within the present-day margins of Sunfish Lake.

- The clearing around the second burn cage is clearly delineated by the magnetic data, and the location of the burn cage itself is evident from the time-domain electromagnetic data. On the basis of aerial photos, the sources of the anomalies in this area date from the early 1950s to the late 1960s.

- The magnetic and conductivity surveys across Marsden Lake indicate no anomalous areas. Instrument measurements over Marsden Lake were consistent with normal background readings for glaciated terrains.

- The Homestead site contains rebar in concrete waste, which was discovered by magnetic gradiometry and visual observation. The concrete was part of a former building foundation. There is no other evidence of waste-disposal activity at this site except for random litter, probably associated with the occupation of the original farm site.

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Appendix:

Aerial Photographs of Sunfish Lake

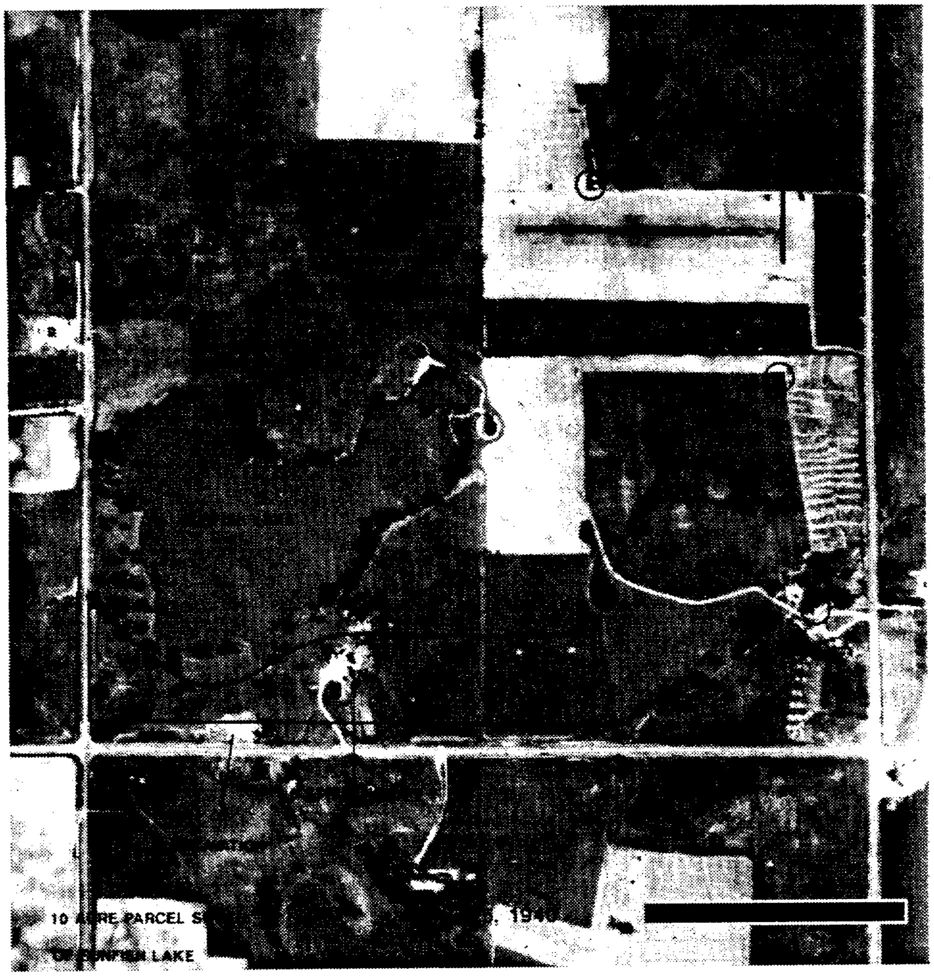

FIGURE A.1 1940 Photo of Sunfish Lake

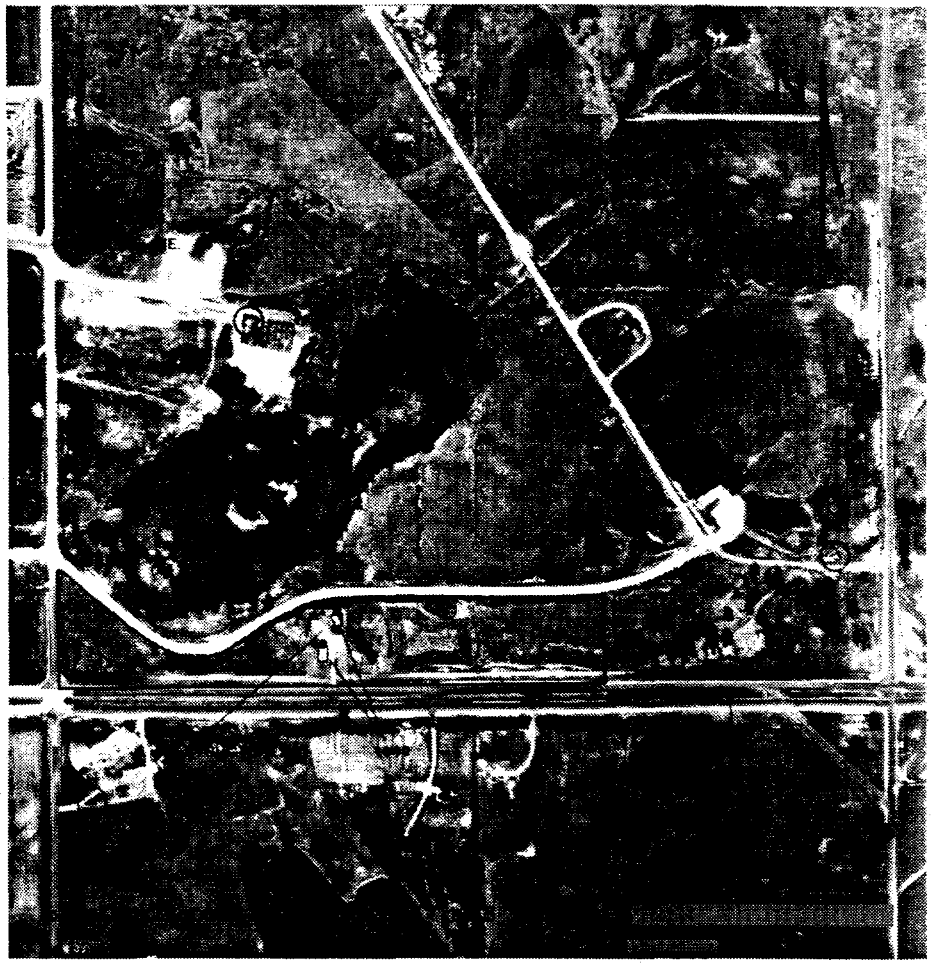

FIGURE A.2 1945 Photo of Sunfish Lake

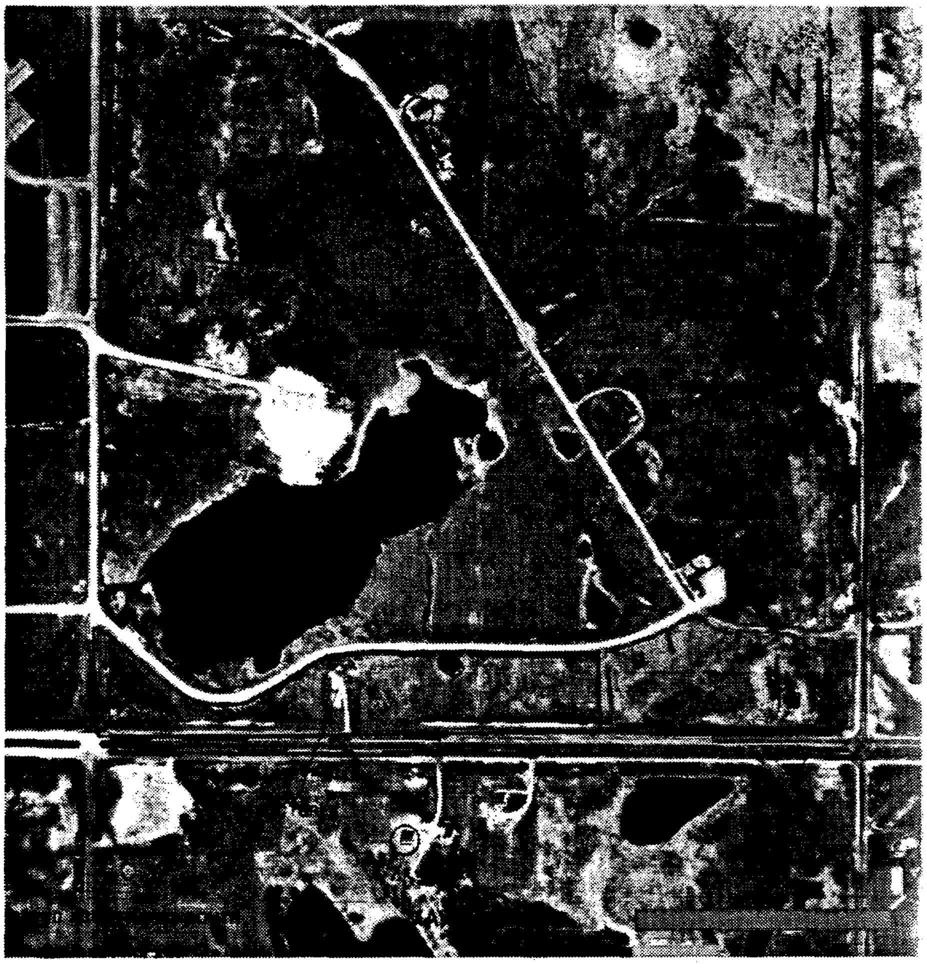

FIGURE A.3 1947 Photo of Sunfish Lake

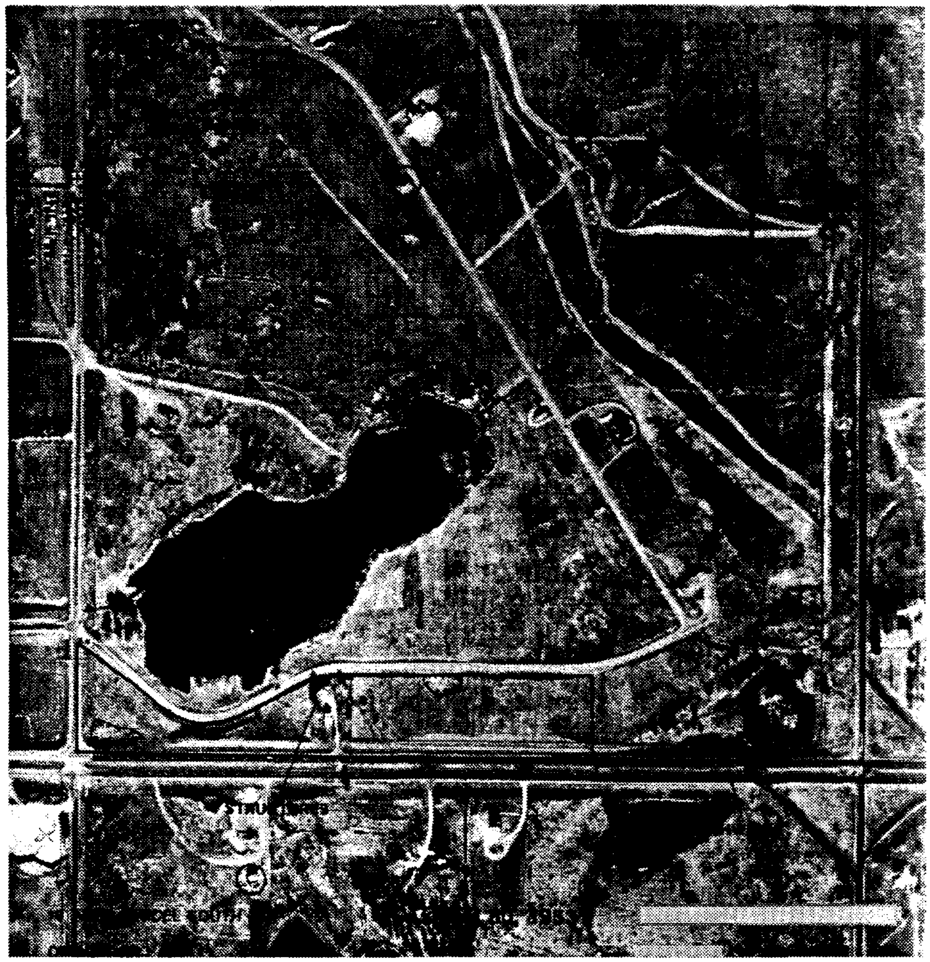

FIGURE A.4 1953 Photo of Sunfish Lake

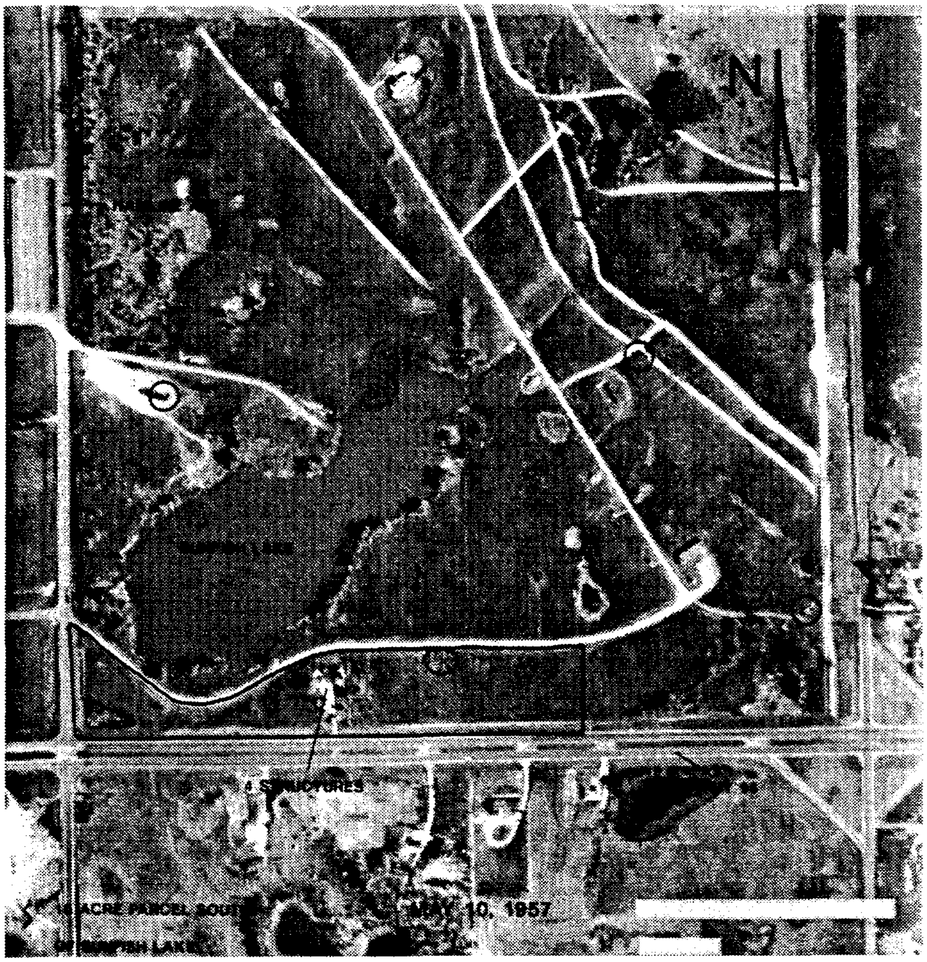

FIGURE A.5 1957 Photo of Sunfish Lake

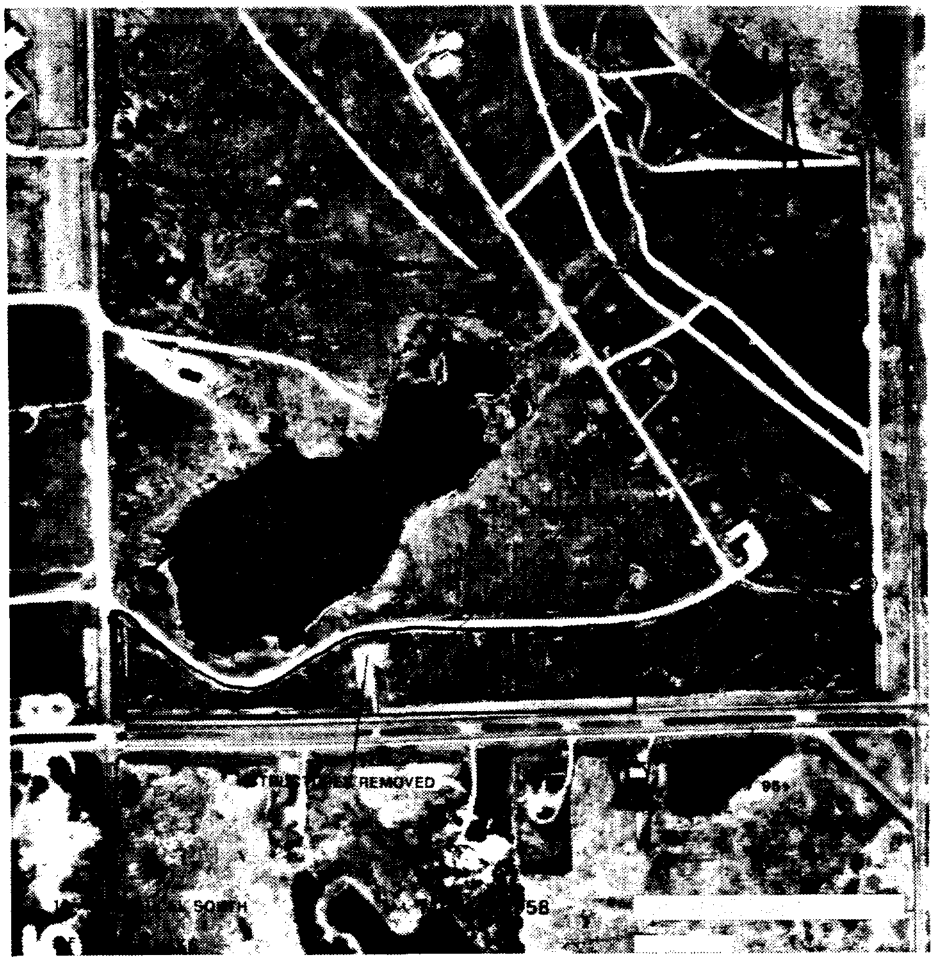

FIGURE A.6 1958 Photo of Sunfish Lake

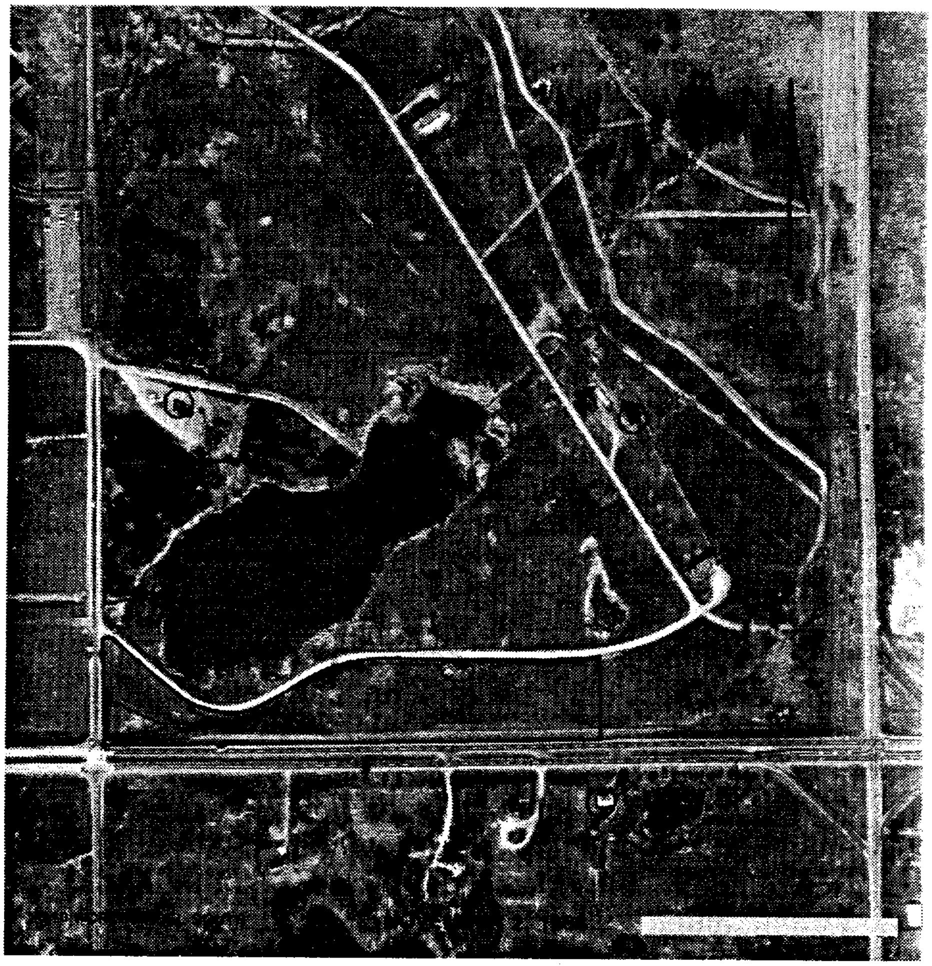

FIGURE A.7 1966 Photo of Sunfish Lake

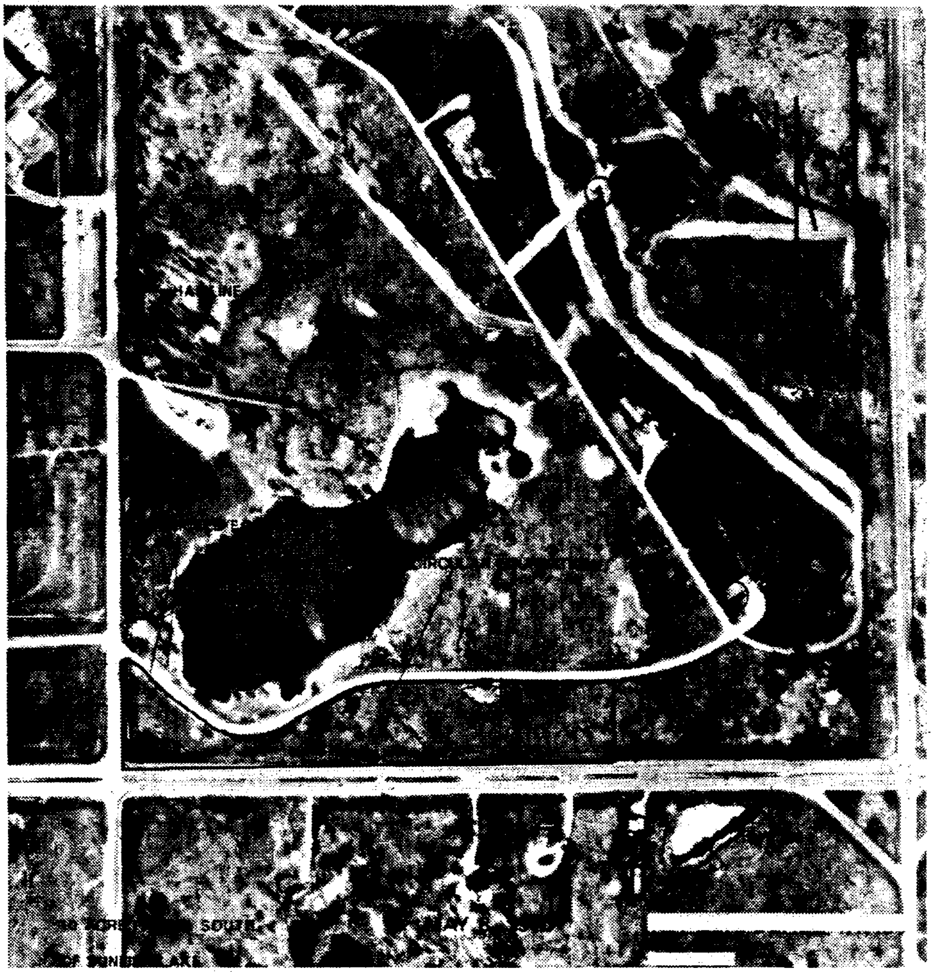

FIGURE A.8 1970 Photo of Sunfish Lake

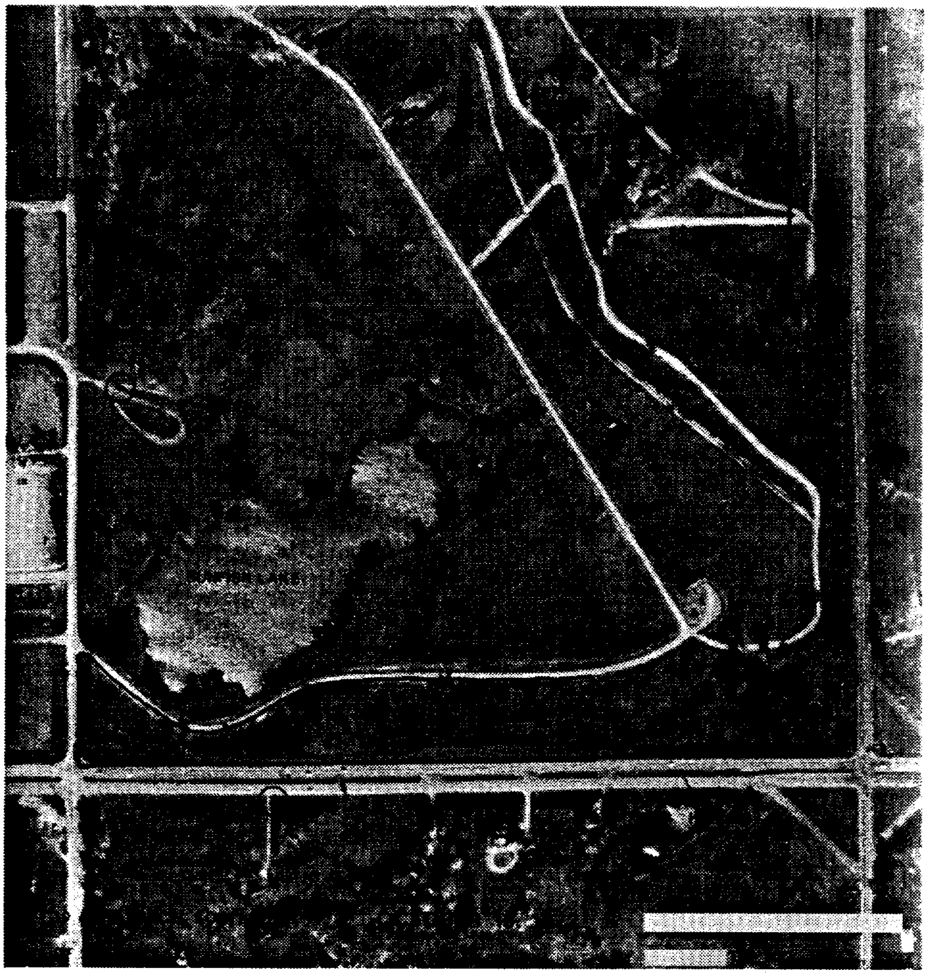

FIGURE A.9 1972 Photo of Sunfish Lake

FIGURE A.10 1982 Photo of Sunfish Lake

FIGURE A.11 1993 Photo of Sunfish Lake