GROUND WATER INVESTIGATIONS AND DATA AUTOMATION

1985 - 1987

REPORT
TO THE
LEGISLATIVE COMMISSION
ON
MINNESOTA RESOURCES

DEPARTMENT OF NATURAL RESOURCES
DIVISION OF WATERS

Report to the

Legislative Commission on Minnesota Resources

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1985-1987

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Project Manager

Department of Natural Resources

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Executive Summary

The work plan approved for this project consolidated three proposals: geophysical exploration, nitrate isotope analyses and data automation. The Department of Natural Resources, Division of Waters (DOW) was lead agency and the Minnesota Geological Survey (MGS), Pollution Control Agency (PCA), and U.S. Geological Survey (USGS) were cooperating agencies. Four staff positions were provided to DNR and two to PCA. A measure of the success of this project is that the Department was able to convert the four positions to complement positions as a result of legislative action and the PCA was also able to keep their staff using federal Superfund dollars to expand its site assessment program.

GEOPHYSICAL EXPLORATION

Cooperative work with PCA was initiated this biennium to apply geophysical methods to the investigation of solid and hazardous waste sites. The geophysical equipment used in this portion of the study was predominantly electromagnetic induction (EM). The objective of the EM field investigations was to determine the capabilities of the electromagnetometer as a reconnaissance tool at a wide range of solid and hazardous waste site environments.

Forty-seven (47) sites have been investigated utilizing EM techniques. The sites can be grouped into the following categories: buried drum sites, underground storage tank sites, landfill dump sites, surface spills/waste pit sites and arsenic burial sites. The EM equipment proved very successful in detecting locations of buried drums, locating and determining the orientation of underground storage tanks, detecting and mapping contamination plumes and defining buried lagoons and trenches. The results at arsenic burial sites were inconclusive. The EM equipment was, however, able to detect buried foundation structures (i.e., silo, barn, shed foundations) near which the arsenic sacks are often located.

To date, follow-up investigations based upon the geophysical data have been conducted at three sites:

1. EM successfully detected the burial location of 19 metal drums which were then excavated as evidence in a criminal investigation.

2. EM successfully defined a leachate plume emanating from a former household dump. Monitoring wells installed at target areas identified in the EM survey revealed elevated chloride concentrations.

3. EM detected a buried foundation near which arsenic grasshopper bait was buried. Soil borings taken nearby revealed high arsenic concentrations.

The results of the program show that geophysical surveys can provide a rapid, cost-effective reconnaissance tool for both preliminary and in-depth investigations of potential hazardous waste sites. Chapter 1 provides greater detail on this phase of the project.

A presentation of the EM work was made at the annual meeting of the North Central Section of Geological Society of America in May. A copy of the abstract "Electromagnetic Exploration of Hazardous Waste Sites in Various Minnesota Settings", by Jay R. Frischman and James R. Lundy, is presented in Appendix A.

The seismic exploration portion of this project was a continuation of work started the previous biennium. Development work continued on adapting the seismic equipment and a variety of energy sources for use in water resource investigations. We have worked closely with Bison Instruments, Inc., the Minnesota firm that manufactures the seismic equipment, in the furtherance of technological development. We gratefully acknowledge their technical advice and assistance and look forward to continuing this productive relationship in the future.

The objectives of the seismic investigations were both delineation of aquifer boundaries, in cooperation with the USGS, and delineation of bedrock features, in cooperation with the DNR-Division of Minerals and the MGS. The work with Minerals and MGS included mineral potential description; additional work aided MGS's county atlas program.

A total of twenty-five (25) study areas were investigated using seismic methods. Chapter 1 contains brief description of the study areas and findings is included in Chapter 2. Appendix B contains copies of papers and abstracts that have been presented at professional meetings, including a paper entitled "Off-End Surface Seismic Reflection Sounding with Vertical Seismic Profiling in Glacial Terrain" by Andrew R. Streitz. This paper was presented at a conference sponsored by the National Water Well Association in May, 1987 and is a detailed discussion of seismic applications for water supply investigation done near Belgrade, Minnesota. An abstract of "Locating Confined Aquifers in Glacial Drift with Seismic - Reflection Methods, Western, Minnesota" by Jeff Stoner and Andrew Streitz, which was presented at the Annual Meeting of the North Central Section of the Geological Society of America, is also included. A Water Supply Paper, "Locating Confined Aquifers in Glacial Drift with Seismic Reflection and Borehole Geophysical Methods, Minnesota" by Jeff Stoner and Andrew Streitz is being published by USGS. Copies will be provided when it is published.

NITRATE ISOTOPE ANALYSES

Nitrate concentrations have increased in ground water in surficial-sand aquifers in Minnesota. Previous aquifer studies have shown a correlation between certain land use practices and elevated nitrate concentrations. Residential septic tanks and intensively cultivated areas, especially those being irrigated, have been shown to have nitrate concentrations that are significantly above background levels. The objective of the isotope study was to determine, at least qualitatively, the relationship between various land uses and high nitrate concentrations.

Samples were collected from 33 wells representing 5 land-use settings: non-irrigated cultivated areas, irrigated areas, downgradient of residential areas with septic systems, downgradient from feed lots or cattle yards and undeveloped areas. Results indicate that each setting has a "typical range" of isotope values but that sampling, analysis and interpretation must be done with care.

Chapter 3, written by Henry Anderson of the U.S. Geological Survey, summarizes the work on this project. An expanded report is currently under review for publication in a professional journal.

DATA AUTOMATION

The data automation project was designed by DNR and MGS with advice and assistance from the Groundwater Subcommittee of the SWIM Users Committee. The objective was to develop an automated index of water well records. The data base developed is the Well Log Listing System (WELLS). This natural resources data base has common value and was designed to be integrated into MLMIS. A copy of the database has been delivered to the Planning Information Center. The Department and the MGS are working on a plan to update and maintain the system.

The information in WELLS is from water well construction records supplied by water well contractors in fulfillment of Department of Health (DOH) requirements. Copies of these logs are then provided to MGS, DNR, the Soil and Water Conservation District, the well owner, and the driller. Data on these records include information about well location and construction, the rock or sediment type encountered during drilling, hydrologic characteristics of the aquifer, and, very importantly, the unique number for that well. Budget considerations precluded automation of all the data; the format ultimately selected was based upon recommendations of the SWIM subcommittee.

WELLS is essentially an index or clearinghouse database. By entering as many well records as possible and including the unique number and location for each record, it is then possible to reference additional information from other state databases. A total of 95,000 water well records were automated. This database will aid all state, local and federal agencies who need information about geology or ground water. Chapter 4 contain a detailed description of the WELLS.

Late in the biennium, PCA notified the Project Manager that there was an unencumbered balance of $30,000 due to salary savings. After consultation with LCMR staff, the Department proposed a work plan change to move those funds to the Data Automation project for the purpose of enabling the Department, MGS and USGS to develop better capabilities to respond to requests for ground water data for local water planning. The work plan change was approved by LCMR on March 5, 1987.

A team representing DNR, MGS, USGS and PIC guided this pilot project to compile data from established databases and to develop a brochure for local water planning on how to use ground water data. Data were compiled for an area of Hubbard and Becker Counties. Although there were some difficulties and frustrations, intergration and transfer of this data set was accomplished. A discussion of the use of these types of data sets, with a clear description of their limitations, is presented in the brochure entitled "Using Ground-Water Data for Water Planning". This brochure was prepared by staff of MGS with guidance from the team and other state agencies with ground water data and an interest in water planning. The brochure is being printed and copies will be distributed as soon as it is available.

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Chapter 1

Geophysical Applications

Electromagnetic Induction Techniques

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Introduction

In areas of ground water or soil contamination, a method of delineating the area affected by pollution without drilling is particularly desirable because drilling into or through contaminated materials can be dangerous to investigators, can contribute to the spread of pollutants, and often yields a very limited picture of what is actually present. In 1985, the Legislative Commission on Minnesota Resources (LCMR) funded a joint Minnesota Department of Natural Resources (MDNR) and Minnesota Pollution Control Agency (MPCA) project to develop the capability to use geophysical tools in preliminary investigations of potential hazardous waste sites. This investigation is a portion of the project entitled Ground Water Investigations and Data Automation.

Site Selection

Initial site selection for the LCMR project consisted of extensive file searches and inquiries by MDNR and MPCA staff. The U. S. Environmental Protection Agency's (EPA) Comprehensive Environmental Response, Compensation, and Liability Information System (CERCLIS) inventory of potential hazardous waste sites provided the source of potential sites. The CERCLIS inventory was most beneficial because of the number of potential sites available (about 300), and the fact some information (Preliminary Assessments (PA), Executive Summaries, soil testing information, etc.) was usually already available in the files. Later search efforts for suitable sites focused on citizen Hotline Complaints and investigative assistance requests from MPCA staff for sites presently involved in active "cleanup" and remedial investigation efforts.

A ranking system was established to determine each site's potential for geophysical study. The most crucial factor considered was whether a "target" (object or condition detectable by the geophysical method) was present on or near the site. Examples of these might be: buried drums; past trenching activities; plumes of heavy metals, solvents, etc. or any condition that causes a change in ground conductivities at the site. Other factors considered included: access; proximity to power lines, buildings, railroad tracks, and other sources of cultural noise that could affect or prevent a successful survey; and soil or ground water conditions (e.g., clay soils, or deep ground water in a porous soil) that may mask the target.

Site Visits

Early in the program, it was discovered that site visits prior to doing actual fieldwork were beneficial in assessing the site conditions and developing a site work plan. Many sites that appeared to be suitable on paper for geophysical study were rejected on the basis of a site visit for reasons not readily apparent in the files (e.g. files out of date, excessive vegetation, unforeseen cultural interference, etc.)

Site Access

Prior to site visits or field work on any site, permission was sought to gain access to the property. In some cases, this involved the drafting of a formal Access Agreement document. However, in most cases an informal telephone conversation sufficed.

Electromagnetic Method

The electromagnetic method (EM) was chosen for use at every site investigated, and a description of it follows below. In addition, two sites required the use of electrical resistivity (ER) and its description can be found in the references (Mooney, 1980). The equipment utilized in this project were: a) the Geonics Ltd. EM-31D, b) the Geonics Ltd. EM-34, and c) the Bison Instruments, Inc. Model 2390 Resistivity System and a Bison Model 2365 Offset Sounding System. The use of brand names in this report is for descriptive purposes only and does not constitute endorsement by either the MDNR or MPCA.

The EM method measures the electrical conductivity of subsurface materials. Electrical conductivity is a function of rock or soil type, porosity, permeability, saturation, and pore fluid characteristics. Since pore fluids commonly contribute the greatest influence to the measured conductivity values, the EM method is an effective technique for mapping ground water and contaminant plumes. Additionally, trench boundaries, buried wastes, and drums, as well as metallic utility lines can be located with EM techniques.

Many contaminants cause an increase or decrease in the free ion concentration of the soil or ground water containing them. This deviation from natural or "background" conductivity values makes the detection and mapping of contaminated soil and ground water at hazardous waste sites, landfills, and impoundments possible. Though absolute conductivity values for geological material (and contaminants) are not necessarily diagnostic in themselves, lateral and vertical variations in conductivity allow delineation of conductivity anomalies.

The EM principal of operation is quite simple (Figure 1.1). The transmitter coil is energized with an alternating voltage which causes a current to flow through the coils. This current in turn generates a primary magnetic field which, according to Farraday's Law, causes electrical currents to be induced into the earth. The induced current in the earth generates a secondary magnetic field. Both primary and secondary fields are detected by the receiver. The resulting ratio of the two fields are proportional to the target's conductivity and is expressed in millimhos/meter (mmhos/m) on the equipment's analog meter. The instrument reading represents the combined effects of the thickness of the soil or rock layers, their depths, and the specific conductivities of the materials.

There are two components of the induced magnetic field measured by the Geonics EM-31D. The first is the quadrature-phase component which gives the ground conductivity measurement as described above. The second is the inphase component which is significantly more sensitive to large metallic objects, and hence is very useful when looking for buried metal drums. The Geonics EM-34 measures the quadrature-phase component only.

The sampling depth of an electromagnetometer is related to the instrument's coil spacing (distance between transmitter and receiver coils). The nominal sampling depth of the EM system is approximately 1.5 times the coil spacing. The EM-31D provides penetration to about six meters while the EM-34, which has three coil spacings, allows surveys to depths of approximately 15, 30, and 60 meters.

A recoverable grid origin (0,0 point) is chosen, carefully surveyed in, and parallel survey lines are laid out according to the chosen spacing. Since the electromagnetometer does not require ground contact, measurements can be made

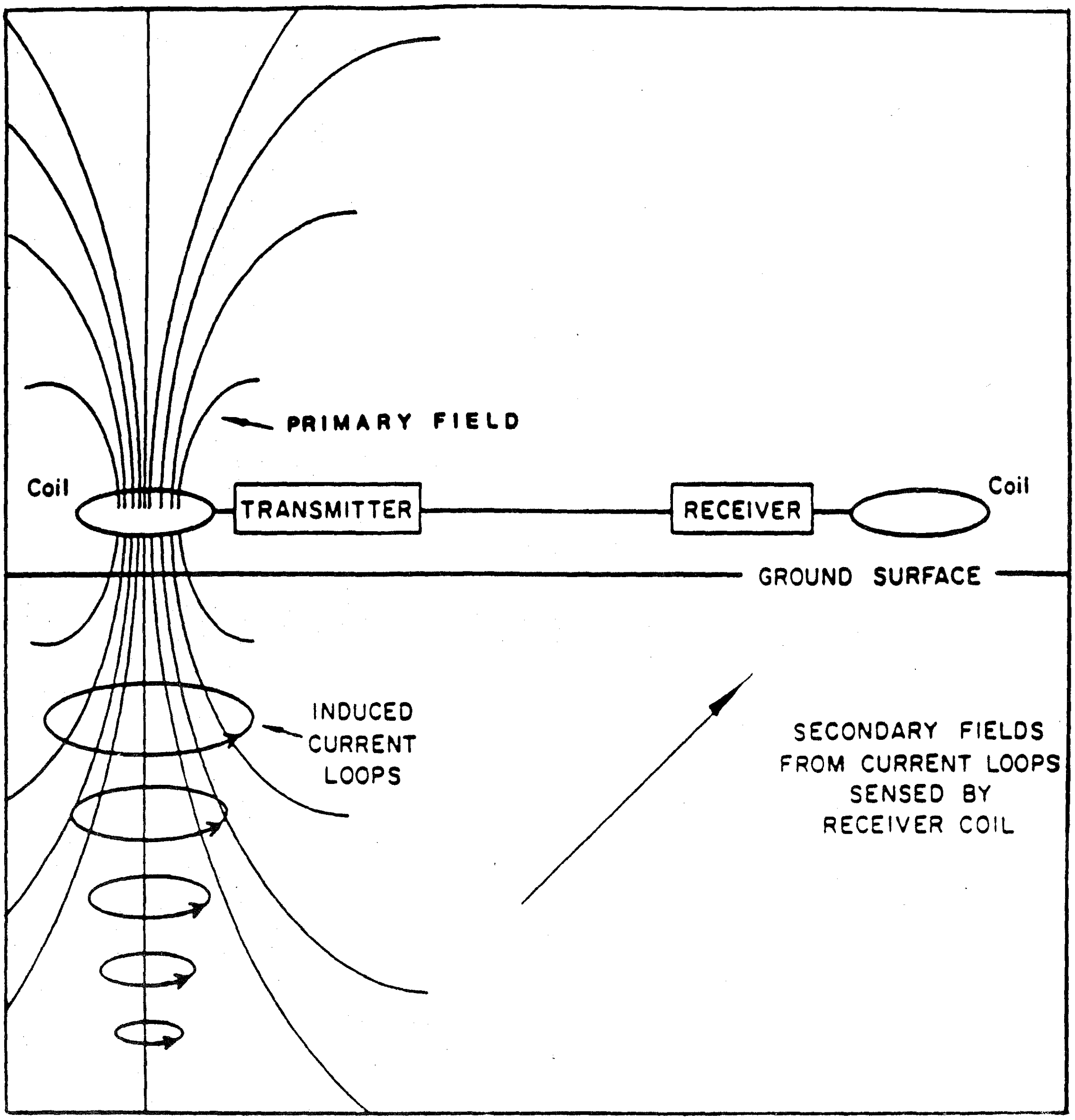


FIGURE 1.1 THE EM PRINCIPAL OF OPERATION. MODIFIED FROM BENSON, GLACCUM, AND NOEL.

quite rapidly. Lateral conductivity variations are detected and mapped (profiling). Profiling is effective for outlining burial pits, contaminant plumes, or delineating fracture patterns in bedrock. By varying coil spacings (sounding) over the same survey area, vertical conductivity variations can be detected.

Field data may be presented for interpretation in a variety of ways. Two presentations used are the isopleth plan view (Figure 1.2) and the three-dimensional (3-D) perspective plot (Figure 1.3). The 3-D plot provides at a glance a complete graphic view of major trends in the data. The plan view format facilitates accurate location, determination of size and estimation of the magnitude of contamination.

General Site Introduction

Forty seven (47) sites were investigated utilizing EM techniques for this project. The locations of the sites are shown on Figures 1.4 and 1.5. An LCMR site list has also been constructed (Table 1) to provide a quick overview of the sites and some general information regarding them. Summaries of the site categories and individual sites appear in the same chronological order as listed on the LCMR site list and are presented in the following Attachments.

Buried Drum Sites

The first type of site investigated with geophysics, included ones at which drummed wastes were buried in pits or trenches. For the past half century, drums have been the containers of choice for storing or hauling anything from liquid wastes, to radioactive materials, to general household trash. Unfortunately, although cheap to obtain, metal drums' life spans are a function of the conditions they are stored in.

Drummed wastes are found from ultra-urbanized areas to the remotest rural areas. When one thinks of drummed wastes, pictures of technicians in "moon suits" walking near thousands of stacked drums come to mind. Although these type of sites receive most of the publicity, a buried drum site may contain only a single barrel. Depending on the type of work involved, the structural integrity of the drums, site conditions, and proximity to humans, the environmental impact and cost of cleanup can vary widely. Leaking drums can taint drinking water, pollute soil, and release harmful gases to the atmosphere.

After several years, a buried drum site may have no surface expression; thus, unless an eyewitness account of the burial is available, the burial location may not be known. However, through a remote sensing technique such as EM, a burial site may be located and outlined, thus assisting in subsequent investigations. Buried drum site surveys had a twofold objective: 1) determine the applicability of EM in locating and defining buried drum wastes and 2) map the movement of contaminant leachates away from leaking drums.

EM surveys using the inphase or "metal detection" mode were conducted at seven (7) sites throughout Minnesota. The survey areas ranged from small 15 by 15 meter areas to several in the 100's of meters on a side. In most cases, some knowledge concerning burial location was known, and thus the surveys were meant to confirm suspected burial locations. Several cases, however, were reconnaissance type surveys where the survey was meant to locate alleged burial sites.

FIGURE 1.2 ISOPLETH PLAN VIEW

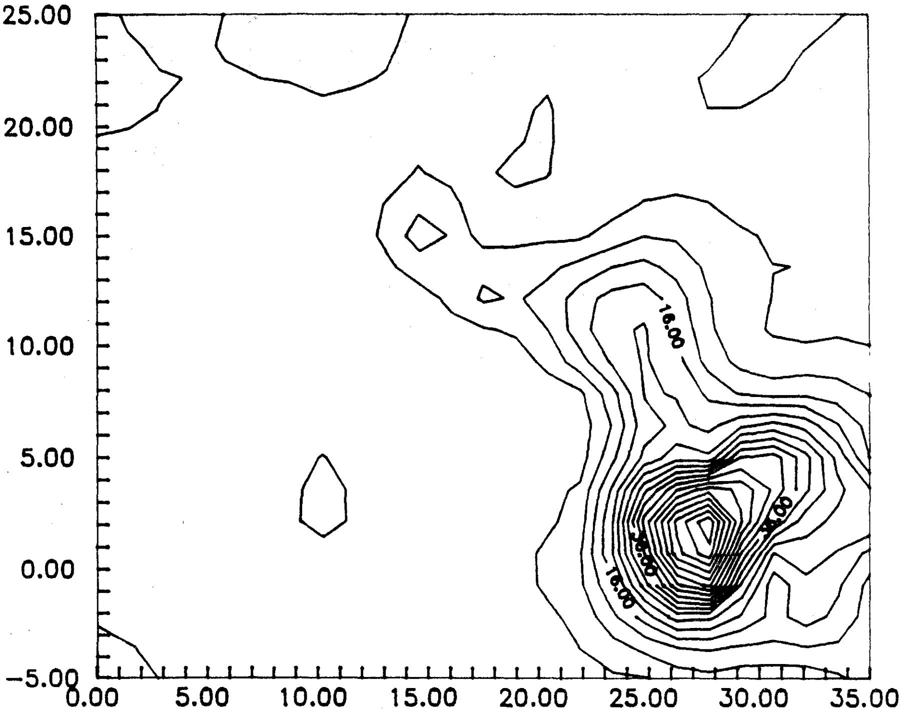
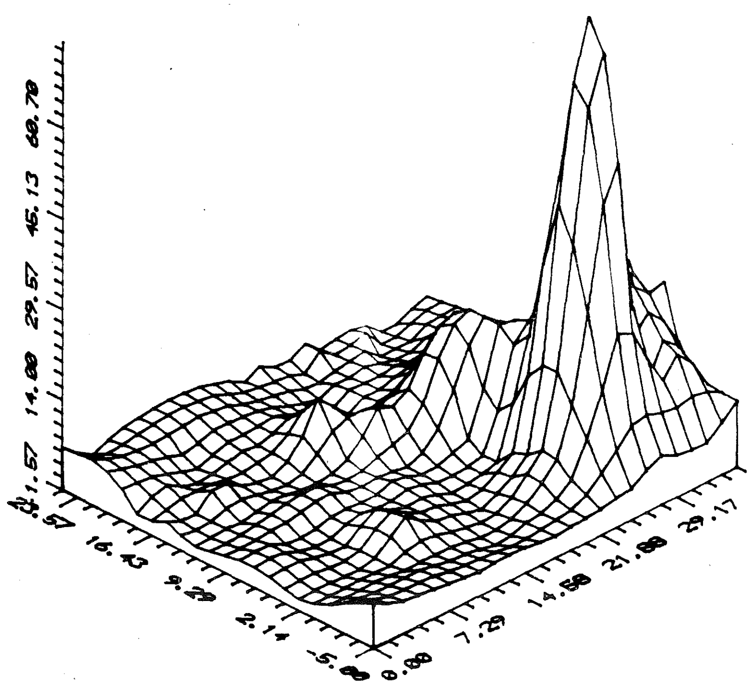


FIGURE 1.3 THREE-DIMENSIONAL VIEW



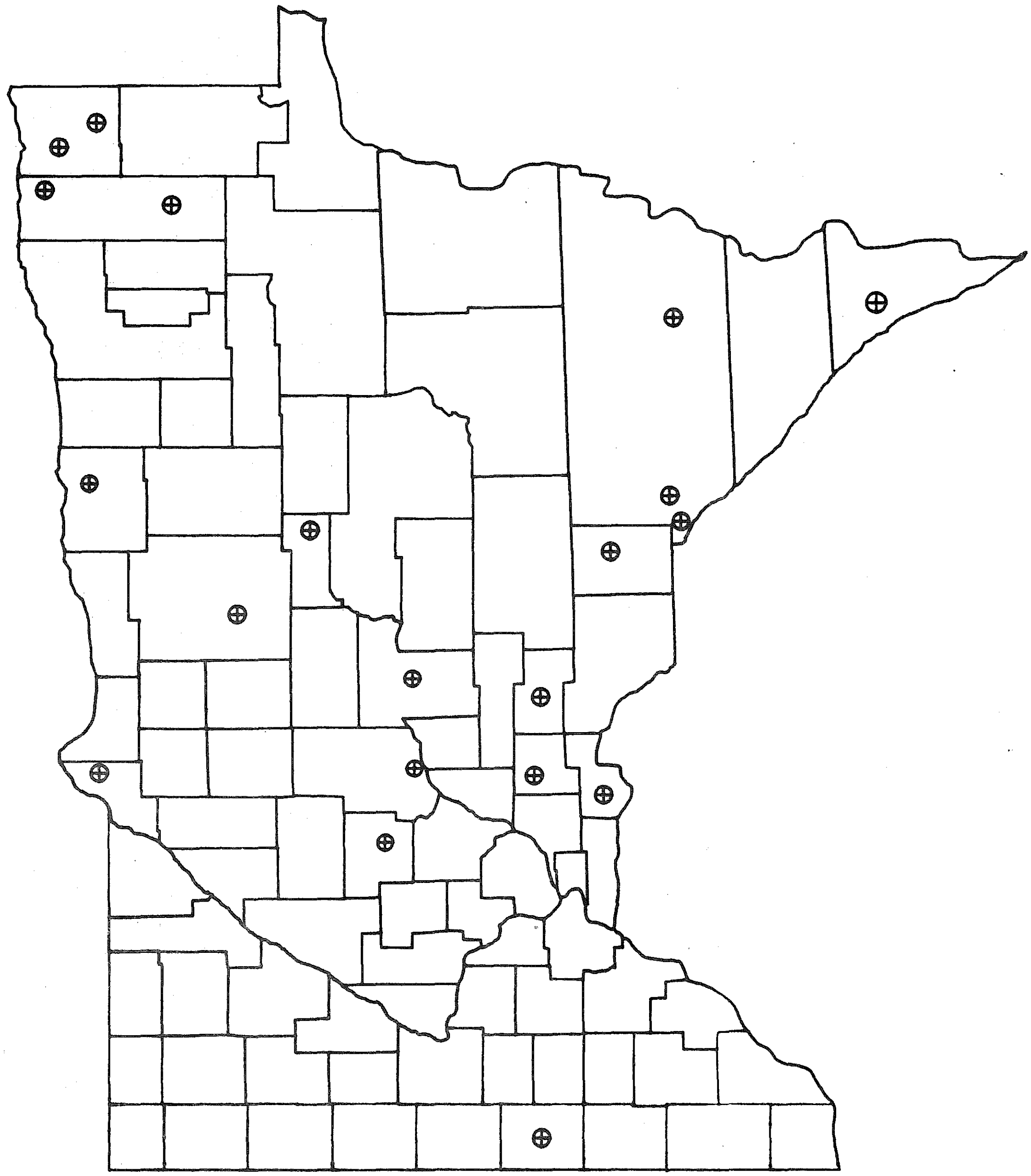


FIGURE 1.4 OUTSTATE GEOPHYSICAL TEST SITES

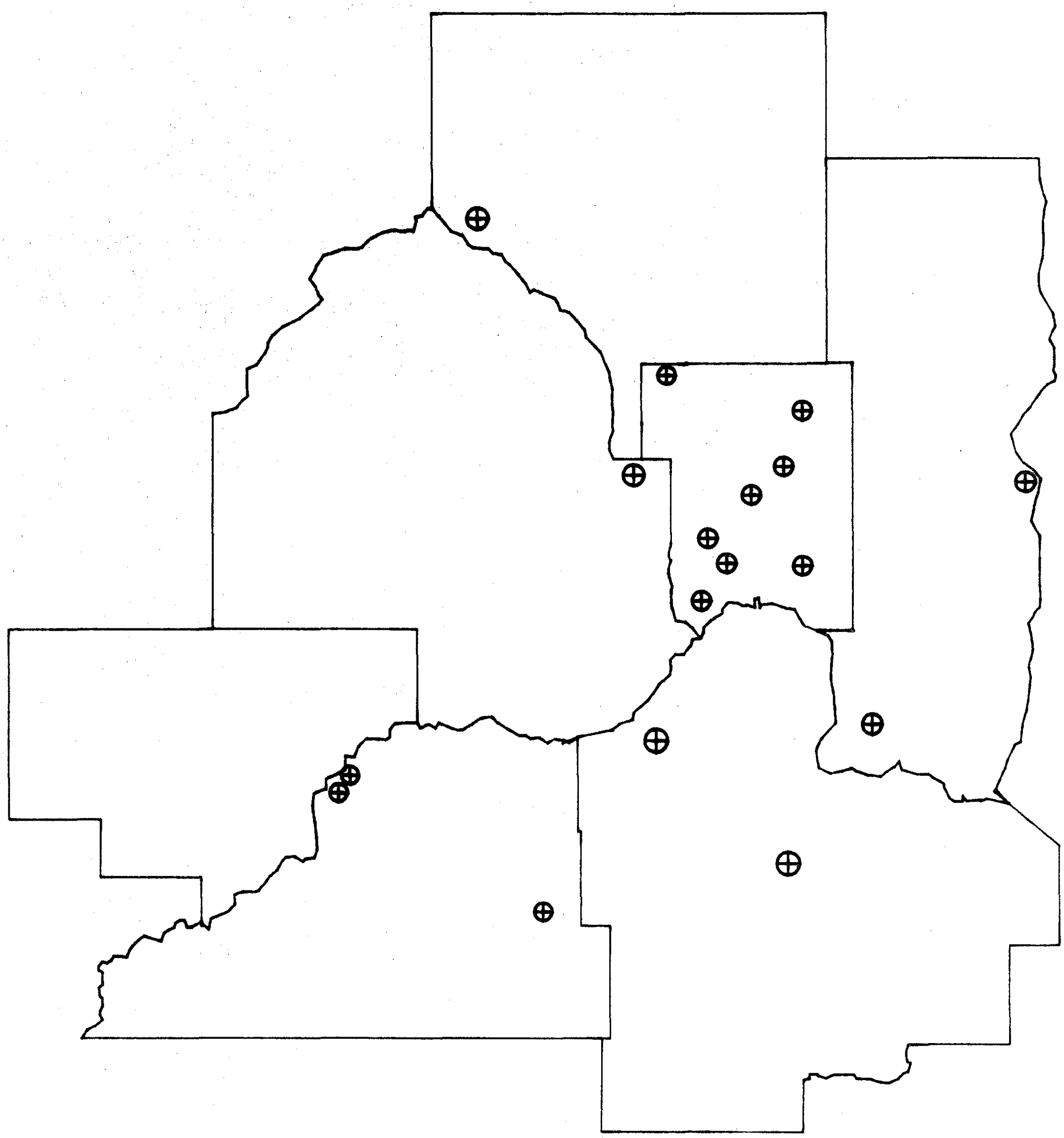


FIGURE 1.5 METRO-AREA GEOPHYSICAL TEST SITES

(Table 1)

LCMR Study - Electromagnetic Geophysical Investigations

CATEGORY: BURIED DRUMS - geophysical work performed

Site Name	County	MPCA Classification	Date of Survey	Site Discovery Origin	Cooperator	Access Method	Action Taken
1. Buried Drum Criminal Investigation	Scott	MPCA RCRA Enforcement Rules	5/26/87	MPCA HW Enforcement	Scott County Sheriff Dept.	Search Warrant	Excavation of Barrels
2. BN Waite Park	Stearns	PLP, NPL & CERCLIS	3/12-13/87	PCA Site Response	MPCA Site Resp./ Local Government /Consultants	Verbal	Phase II Remedial Investigation
3. General Coatings	Dakota	CERCLIS	9/26/86	Hotline Complaint	MPCA HW Enforcement/ Industry	Verbal	Placed on CERCLIS
4. Interplastics	Hennepin	CERCLIS	9/24/86	City of Minneapolis MPCA HW Enforcement	MPCA HW Enforcement/ Local/Industry	Verbal	EPA Site Investigation
5. Medallion Kitchens	Otter Tail	CERCLIS	12/22/87	Hotline Complaint	Industry/Private Citizen	Verbal	Placed on CERCLIS
6. Rosemount Research Ctr. (Jenson Airstrip)	Dakota	PLP, NPL & CERCLIS	8/29/86 9/2/86	PCA Site Response	University of MN	Verbal	Pending
7. Todd Jones Residence	Isanti	NPL	5/27/87	PCA Site Response	MPCA Site Resp./ Private Citizen	Verbal	Pending

(Table 1)

LCMR Study - Electromagnetic Geophysical Investigations

CATEGORY: UNDERGROUND STORAGE TANKS SITES - geophysical work performed

Site Name	County	MPCA Classification	Date of Survey	Site Discovery Origin	Cooperator	Access Method	Action Taken
1. 1400 Marshall Ave	Ramsey	CERCLIS	12/19/86 1/13/87	MPCA Property Transfer Files	Private Citizens	Verbal	Work Plan Being Developed
2. BN Waite Park	Stearns	PLP, NPL, & CERCLIS	3/5-6/87	MPCA Site Response	Industry/ Local Government	Verbal	Phase II Remedial Inv.
3. Super America HC03	Ramsey	MPCA Spills	2/13/87	MPCA Spills	Industry	Verbal	Pending
3. Super America HCO 18	Ramsey	MPCA Spills	2/17/87	MPCA Spills	Industry	Verbal	Pending
3. Super America HCO 19	Ramsey	MPCA Spills	2/11/87	MPCA Spills	Industry	Verbal	Pending
3. Super America HCO 20	Ramsey	MPCA Spills	2/19/87	MPCA Spills	Industry	Verbal	Pending
3. Super America HCO 21	Ramsey	MPCA Spills	2/12/87	MPCA Spills	Industry	Verbal	Pending
3. Super America HCO 22	Ramsey	MPCA Spills	2/19/87	MPCA Spills	Industry	Verbal	Pending
3. Super America HCO 24	Ramsey	MPCA Spills	2/17/87	MPCA Spills	Industry	Verbal	Pending

(Table 1)

LCMR Study - Electromagnetic Geophysical Investigations

CATEGORY: DUMP/LANDFILL SITES - geophysical work performed

Site Name	County	MPCA Classification	Date of Survey	Site Discovery Origin	Cooperator	Access Method	Action Taken
1. Clinton Dump	Big Stone	Solid Waste Facility	4/17/86	MPCA Program Dvlp.	MPCA Solid Waste	Verbal	Pending
2. Cropmate Trench	Freeborn	CERCLIS	4/14/87	PA Files	Industry	Verbal	Pending
3. Dilworth Dump	Clay	Solid Waste Facility	4/18/86	MPCA Program Dvlp.	MPCA Solid Waste	Verbal	Pending
4. Duluth IAP Trench	St. Louis	PLP, CERCLIS	8/5-6/86	PA Files	Military	Verbal	Pending
5. Krammer Quarry	Dakota	None	8/13/85	MPCA Solid Waste	Private Citizen	Verbal	None
6. Lake Bronson St Park Dump	Kittson	CERCLIS	6/23/86	PA Files	MDNR Division of Parks	Verbal	Monitor Wells Installed
7. Little Falls Closed Dump	Morrison	CERCLIS	4/23/86	PA Files		Verbal	Pending
8. Louisville Landfill	Scott	PLP, Permitted SLF's	4/24/86	MPCA Solid Waste	Private Industry	Access Agreement	Pending
9. Minnesota Correctional Facility Dump	Washington	CERCLIS	5/21/86	PA Files	Local Government	DNR Fish & Wildlife	Pending
10. Rosemount Research Ctr.		PLP, NPL, CERCLIS Permitted SLF's					
a. (Burn Pit)	Dakota		10/28/86	MPCA Site Response	University of MN	Verbal	Pending
b. (Demolition Pit)	Dakota		11/5/86	MPCA Site Response	University of MN	Verbal	Pending
c. (WWII Dump Area)	Dakota		9/5/86	MPCA Site Response	University of MN	Verbal	Pending

(Table 1)

LCMR Study - Electromagnetic Geophysical Investigations

CATEGORY:DUMP/LANDFILLS site visits - no geophysical work performed

Site Name	County	MPCA Classification	Date of Site Visit	Site Discovery Origin	Cooperator	Access Method	Action Taken
Greater Morrison SLF	Morrison	PLP, CERCLIS & Permitted SLF's	4/7/86	MPCA Solid Waste	Private Industry	Access Agreement	None
Hanna/Butler Taconite Project	Itasca	CERCLIS	4/24/86	PA Files	Hanna Butler Mining	Access Agreement	None
Larson Boat Dump	Morrison	CERCLIS	4/7/86	PA Files	Local Government	Verbal	None
Orten Heldt Trench	McLeod	CERCLIS	4/30/86	PA Files	Private Citizen	Access Agreement	None
Rackliffe Howard	Wright	CERCLIS	5/14/86	Hotline Complaint and PA Files	Private Citizen	Access Agreement	None
Round Lake Dump	Morrison	CERCLIS	4/9/86	PA Files	Private Citizen	Access Agreement	None
U.S. Steel Research	Itasca	CERCLIS	4/24/86	PA Files	U.S. Steel	Access Agreement	None

LCMR Study - Electromagnetic Geophysical Investigations

CATEGORY:SURFACE SPILLS/WASTE PITS - geophysical work performed

Site Name	County	MPCA Classification	Date of Survey	Site Discovery Origin	Cooperator	Access Method	Action Taken
1. 1400 Marshall	Ramsey	None	5/19/86	Property Transfer	Private Citizen	Verbal	Work Plan Being Developed
2. Ashland Oil	Washington	PLP, NPL, & CERCLIS	5/22/86	MPCA Site Response	Ashland Oil	Verbal	Pending
3. BN Waite Park	Stearns	PLP, NPL & CERCLIS	3/12-13/87	MPCA Site Response	Local Government/ Consultants	Verbal	Phase II Remedial Investigation
4. Medallian Kitchens	Otter Tail	CERCLIS	12/22/86	Hotline Complaint	Industry	Verbal	Placed on CERCLIS
5. Palm Industry	Meeker	CERCLIS	11/25/86	PA Files	Industry	Verbal	Pending
6. Ritary Post & Pole	Wadena	PLP, NPL & CERCLIS	6/3/86	MPCA Site Response	Owner	Verbal	Phase I Remedial
7a. Rosemount Research Ctr. (Georges Equip)	Dakota	PLP, NPL & CERCLIS	11/17/86	MPCA Site Response and PA Files	University of MN	Verbal	Pending
7b. Rosemount Research Ctr. (Porter Elec)	Dakota	PLP, NPL & CERCLIS	11/26/86	MPCA Site Response	University of MN	Verbal	Pending
8. Super America HCO #21	Ramsey	MPCA Spills	3/16/87	MPCA Spills	Industry	Verbal	Pending

(Table 1)

LCMR Study - Electromagnetic Geophysical Investigations

CATEGORY: SURFACE SPILLS/WASTE PITS site visit - no geophysical work performed

Site Name	County	MPCA Classification	Date of Survey	Site Discovery Origin	Cooperator	Access Method	Action Taken
Amoco Pipeline	Wright	MPCA Spills	2/4/87	MPCA Spills	Amoco	Verbal	None
Blaine Office Park	Anoka	CERCLIS	7/29/87	PA Files	Private Citizens	Verbal	EPA Site Investigation
B.J. Carney Pole Yard	Hennepin	CERCLIS	8/11/86	PA Files	Industry	Verbal	None
BN Brainerd Car Shop	Crow Wing	NPL, PLP & CERCLIS	5/9/86	PA Files	Burlington Northern	Verbal	None
BN Darling Siding	Morrison	CERCLIS	4/23/86	PA Files	MPCA Site Response	Verbal	None
Ford Assembly	Ramsey	PLP, CERCLIS	7/29/86	PA Files	Ford Motor Co.	Verbal	None
Joyners	Hennepin	CERCLIS	8/12/86	PA Files	Local Government Industry	Access Agreement	None
Midwest Brass & Aluminum	Ramsey	CERCLIS	3/27/88	PA Files	Industry	Verbal	None
Republic Creosoting	Hennepin	CERCLIS	9/11/86	PA Files	Industry	Verbal	None

(Table 1)

LCMR Study - Electromagnetic Geophysical Investigations

CATEGORY: ARSENIC SITES - geophysical work performed

Site Name	County	MPCA Classification	Date of Survey	Site Discovery Origin	Cooperator	Access Method	Action Taken
1. Burlington Northern Ramsey Blvd.	Anoka	None	10/30/86	Hotline Complaint MPCA Files	Industry	Access Agreement	EPA Site Investigation Planned
2. Esala Farm	St. Louis	Arsenic Files	6/19/86	Underground Arsenic Files	Private Citizens	Verbal	None
3. Julik Farm	Chisago	None	8/25/86	Underground Arsenic Files	Private Citizen	Verbal	None
4. Langhorst Farm	Carlton	Arsenic Files	6/18/86	Underground Arsenic Files	Private Citizen	Verbal	None
5. Linkert Farm	Kanabec	Arsenic Files	6/13/86	Underground Arsenic Files	Private Citizen	Verbal	Site Invest./ Soil Borings
6. Murry Farm	Kittson	Arsenic Files	9/10/86	Underground Arsenic Files	Private Citizen	Verbal	None
7. Ryhakowski Farm	Marshall	Arsenic Files	9/10/86	Underground Arsenic Files	Private Citizen	Verbal	Pending
8. Stephen Mixing Station	Marshall	Arsenic Files	9/9/86	Underground Arsenic Files	Private Citizen	Verbal	Pending
9. Thompson Farm	Cook	Arsenic Files	6/19/86	Underground Arsenic Files	Private Citizen	Verbal	None
10. Vanderford Farm	St. Louis	Arsenic Files	6/18/86	Underground Arsenic Files	Private Citizen	Verbal	None

(Table 1)

LCMR Study - Electromagnetic Geophysical Investigations

CATEGORY: ARSENIC SITES - no geophysical work performed

Site Name	County	MPCA Classification	Date of Site Visit	Site Discovery Origin	Cooperator	Access Method	Action Taken
Engelstad Farm	Marshall	Arsenic Files	10/24/86	Underground Arsenic Files	Private Citizen	Verbal	None

Due to a high level of magnetic susceptibility, metal targets are easily detected with the EM equipment. Drums are very good targets - especially when buried in groups (such as in trenches, pits, etc.). Inphase surveys can be affected by cultural noise - metallic fences, buildings, overhead lines; however, in most cases, these effects can be minimized.

Results at the drum sites were very good. Despite the presence of extensive cultural noise at several of the sites, anomalies were detected at all sites. In most cases, the targets exhibit a characteristic anomaly (Figure 1.6): as the metallic object is approached, the detected values increase; directly over the target the values decrease drastically; and as the survey moves away from the object, the values peak and gradually fall off. Brief descriptions of the buried drum sites investigations are presented in Attachment A.

Our experience shows the EM equipment is very effective for detecting buried metal objects (such as drums). One must, however, remember that not all metallic anomalies detected by the EM are necessarily a hazardous waste repository. When used properly, the EM technique can be rapid, cost-effective reconnaissance tool for locating buried metal.

Underground Storage Tank Investigations

There are approximately 1.4 million Underground Storage Tanks (USTs) in the United States that store petroleum products and are subject to regulation by the EPA. These tanks are primarily located near gasoline stations and other petroleum product retailers. In 1986, Congress amended the Resource Conservation Recovery Act (RCRA) to provide trust funds for the cleanup of petroleum releases from USTs. States are expected to play the key role in the trust fund cleanups since State officials know more about the tanks in their state, the local site conditions, and have more personnel to conduct an adequate program than the Federal Government. The MPCA has obtained funding from the State Legislature and is presently applying for federal monies to establish a UST program for Minnesota.

In response to the growing concern for potential problems with USTs, 17 geophysical surveys were performed at 9 UST sites. The purpose of the geophysical studies was to determine the applicability of EM equipment in UST investigations. Three different types of sites were investigated: seven active gasoline service stations, a property transfer site at which a gasoline service station was abandoned in 1966 with unknown UST locations, and an area of a Burlington Northern Railroad Site where a tank car utilized for waste oil storage was allegedly buried. Brief descriptions of each site investigation are presented in Attachment B.

The objectives of the geophysical investigations were twofold: 1) to locate and confirm the number and orientations of USTs at sites where their locations were both known and unknown and 2) to determine the limitations of the EM equipment in an urban setting with varying sources of cultural interference (powerlines, canopies, pump islands, etc.). The EM equipment proved to be a useful tool in determining underground storage tank locations at currently operating and abandoned service stations where tank locations were both known and unknown. Interference from concrete with structural reinforcement appears to have a greater distorting effect on EM equipment than asphalt. Data was the most difficult to interpret at sites where the survey area was set up over a

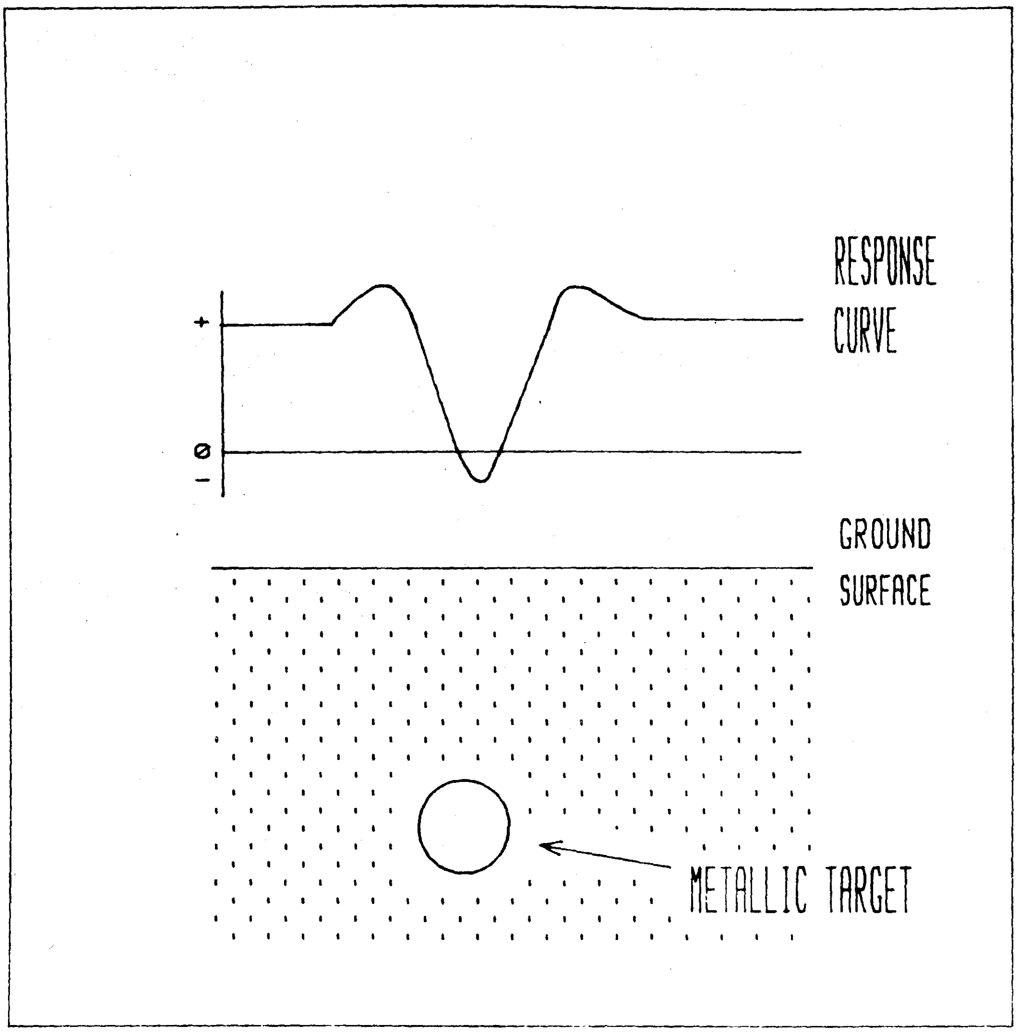


FIGURE 1.6 TYPICAL RESPONSE OVER METAL TARGET. FROM GEONICS, 1984.

combination of concrete, asphalt, and soil. Generally, interference sources such as powerlines, canopies, ice chests, etc. did not effect the survey in a manner that totally masked the tank signatures.

Landfill/Dump Site Investigation

Previous disposal methods of solid waste material in Minnesota and most other states was to discard wastes in town dumps which were burned periodically as a volume reduction technique. In 1967, the State Legislature created the MPCA to regulate pollution but did not specify a solid waste planning function. The MPCA was authorized planning activities in 1969 and published solid waste rules in 1970. Once the solid waste rules were published, the MPCA started closing dumps and began issuing permits for sanitary landfills.

There are an estimated 1,500 closed dumps in rural Minnesota and 125 dumps in the metro area. Many of these sites were selected without regard to potential contamination problems and were often located in wetlands, lakes, or river banks.

As of 1986, there are 262 permitted sanitary landfills in Minnesota of which 90 are actively operating. Minnesota presently has 8 dump sites on the National Priorities List (NPL), 54 dump sites on the Permanent List of Priorities (PLP) and 62 dump sites on the CERCLIS inventory.

Ground water becomes contaminated at dump/landfill sites as leachate percalates through the refuse and enters the ground water system. Contaminated ground water often contains a higher amount of total dissolved solids (TDS) than uncontaminated local waters. The conductivity of contaminated soil/water should increase as TDS levels increase. Geophysical investigations were performed at 12 dump sites to determine if the EM equipment could detect contamination plumes emanating from dump sites. Brief descriptions of each investigation are presented in Attachment C. A second objective of the study was to locate buried burn pits that were often used for disposing of various hazardous wastes. Results of the study indicate that at sites where cultural interference is minimal, contamination plumes and waste burn pits can be detected by the EM technique. This information could be very useful in determining the placement of ground water monitor wells during future investigations of these sites.

Surface Spills/Waste Pits

The fourth type of geophysics target is a generic group of surface spills (accidental or intentional) and waste pits where material was disposed by either burning or burial. Human activities have resulted in the burning, burying or spilling of solid or liquid wastes onto/into the ground. These practices often lead to contamination of the surrounding soil or ground water.

These sites are often aerially small. However, since they frequently are near drinking water sources, the environmental impact can be immense. Immediately upon release/disposal these sites may exhibit a surface expression. Too often however, before the threat posed to the environment is known, the site has been overgrown and is not visible. This study examined the applicability of the EM induction technique in locating and defining spills, pits, and leachate plumes eminating from these sources of contamination.

Quadrature phase surveys were conducted at nine sites. Most were industrial sites where materials were disposed in pits or released on the surface as a spill. At all sites, prior knowledge of the site allowed the surveys to be conducted in one day.

Pit detection is accomplished in two fashions. First, a pit may have a different conductivity than the surrounding soil matrix simply because excavation and refilling of the pit will in itself change the factors which control conductivity. Second, the material placed in the pit may exhibit a conductivity (either positive or negative) that would be detectable. Spills are detectable when they fill empty void space between soil grains or by displacing the pore fluids already in place. Unlike metal targets which exhibit large conductivity changes, pits or spills often exhibit small conductivity changes and thus may be more susceptible to masking by cultural noise.

Targets were detected at several of the sites. At others, results were inconclusive. In most of the negative cases, it was due to site-specific manmade or natural interference.

Past experience with this type of site indicates the equipment may be effective for detecting buried pits. Further, given a better understanding of how to deal with cultural interference, more targets of this nature could be attempted to refine the technique.

Below Ground Arsenic Burial Sites

In the 1930's, the Department of Agriculture distributed arsenic-laced grasshopper bait to farmers whose farms were plagued with grasshoppers. The bait typically consisted of 97-98 percent bran or sawdust and molasses, and 2-3 percent lead or calcium arsenate. After a time, "safer" pesticides were developed to combat grasshopper plagues and farmers buried the bait to prevent livestock from eating the arsenic-poisoned molasses.

Within the last 10 to 15 years, concern that these areas of buried arsenic may pose a threat to drinking water supplies has arisen. In 1972, several citizens from Perham, Minnesota, befell victim to arsenic poisoning from a drinking water well that was mistakenly drilled through an old arsenic burial site.

In response to this incident and potential threats to drinking water supplies, the MPCA advertised in rural areas for information on the location of old grasshopper bait burial sites. Through interviews with farmers and landowners, sixty (60) underground arsenic grasshopper bait sites were identified. In spite of the fact that considerable time has passed, the farmer or landowner generally knew something about where the burial pit was and when it was dug.

Due to the great length of time since the actual burials and the second or third hand source of information used to identify these locations, it was determined an additional screening method would be helpful in verifying site locations. The only method planned to locate buried bait was the use of a drill rig to obtain soil samples and test soil for arsenic. This method would potentially be a problem on some sites for reasons of access and impacts to a landowner's property. Based on this situation, it was felt the use of an EM geophysical method may aid in the location or verification of buried arsenic bait.

The purpose in studying these sites was twofold: 1) locate the burial sites to facilitate further site investigation work (i.e., boreholes, soil tests, excavation and removal) by the arsenic burial site project leader (Mark Oppen, MPCA) and 2) attempt to determine the application of EM surveys in locating small targets of this nature and potential contaminant plumes emanating from these burials.

After a review of available information on the 60 identified underground arsenic sites, 16 sites were chosen as potential candidates for geophysics surveys. Of the 16 sites, 8 sites had geophysical investigations performed and completed (see LCMR site list, Arsenic Category).

Of primary concern in the site selection process was the accuracy with which the burial sites had been located and secondly, the quantity of bait reported to have been buried. Preference was given to sites with larger reported quantities of buried bait and to the detail and accuracy with which burial locations had been identified. It was determined larger targets may be less difficult to detect and could pose more of a potential hazard to the public or environment and therefore should be given priority.

A majority of sites fell within two main geographic regions in northern Minnesota: 1) the northwest corner of the state centered around Thief River Falls and 2) areas north and east of Duluth.

On almost every site surveyed, farmers were very open and provided information and access to the sites. It turned out that discussions with farmers and landowners were valuable in determining the general location of burial areas.

Geophysical surveys were conducted with an electromagnetometer and most often run in the quadrature phase operation mode. Once the general location of a burial area had been determined, a survey grid was centered over the area of concern. Typical survey areas on these sites ranged from one to three acres in size. A typical arsenic burial site is 30 to 50 years old and consists of a three to five foot deep hole, perhaps 16 feet square and contains 100 to 1,000 pounds of arsenic bait in burlap sacks. On most sites, surveys took no longer than a full day to complete but often required using a detailed grid with multiple readings to obtain adequate detail to detect the small burial targets.

Most sites had few cultural interferences that prevented obtainment of representative soil conductivity readings. However, difficulties did arise due to the high conductivity of finer textured clay soil. This moist clay soil had the effect of masking subtle differences in soil terrain conductivities making interpretations of readings more difficult. Additional difficulties arose due to the small size of the burial sites and the uncertainties involved with locating pits dug 40 to 50 years ago.

In theory, the location of buried mass of either lead or calcium arsenate grasshopper bait would be expected to produce a conductivity reading different from that of the natural soil condition. These differences were expected to be a result of several possible scenarios:

1. a soil solution conductivity high would occur due to the increased ion activity from the bait,

2. a soil solution conductivity low would occur due to the sawdust/molasses media the arsenic compound was mixed with and,

3. a relatively different conductivity from the disturbed soil as compared to natural soil conditions would occur.

Overall, geophysical surveys at these sites have proven to be inconclusive in detecting either the location of burial pits or contaminant plumes eminating from these arsenic bait burials. This is primarily due to the fact that verification of the presence of buried arsenic baits has not taken place. At present, the "Below Ground Arsenic" program, that investigates these sites, is in the initial stages of site investigation work and only one site where geophysics has been performed has had soil sampling and analysis completed. On this site (Linkert Farm) geophysics work identified an area of possible arsenic burial that was sampled extensively and found not to be contaminated. However, additional soil sampling outside the geophysics anomaly was performed and high levels of arsenic were detected.

Due to the fact that only one site has had soil sampling performed where geophysics has been completed, it would be premature to totally exclude EM as a viable tool in searching for buried arsenic sites. However, until more soil testing work has been completed on these sites, it is recommended that additional geophysical investigations at these sites be curtailed. If upon further site investigation work testing of soil shows areas of arsenic bait that correlate with geophysical anomalies, it may be helpful to continue EM investigations on these sites.

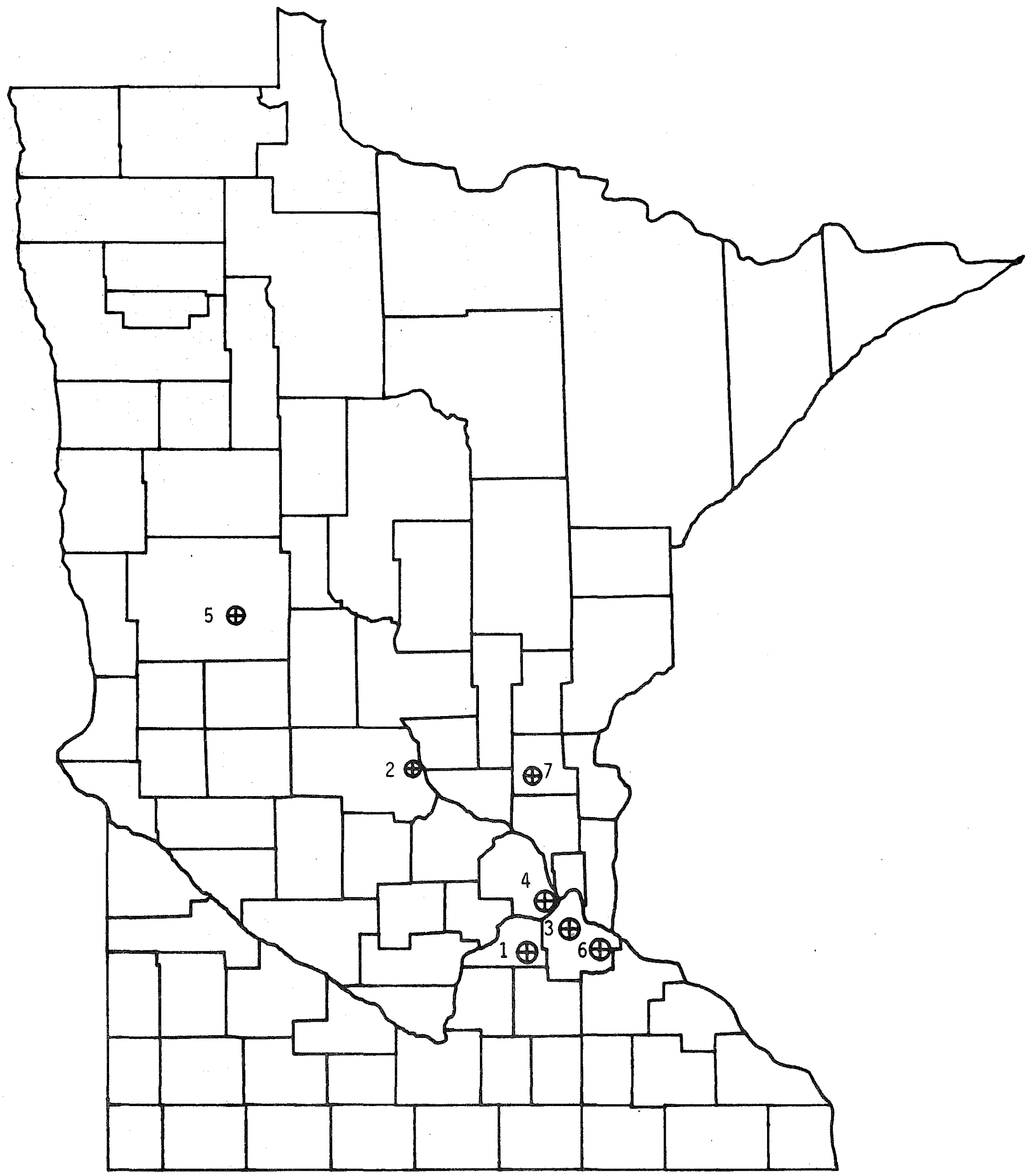


FIGURE 1.7 BURIED DRUM SITES

Case Studies: Buried Drum Sites:

1. Buried Drum Criminal Investigation — Scott County — Lakeville

On May 26, 1987, an EM survey was conducted on a farm site in Scott County to obtain legally permissible evidence of illegal hazardous waste burial. The survey was conducted at the request of the MPCA Hazardous Waste Enforcement Unit in cooperation with Scott County's Environmental Health and Sheriff's departments.

The purpose of using geophysics in this investigation was to provide a more precise location of buried drums of alleged hazardous wastes so as to minimize excavation efforts required to unearth the barrels.

A search warrant was served to the property owner at 6:30 a.m. May 26, 1987 and the investigation team followed the Scott County Sheriff's officers onto the site. An EM-31 inphase (metal detection) survey was performed over an approximate three-quarter (3/4) acre area where about 20 barrels of alleged hazardous waste were reportedly buried to depths as great as 20 feet. Two small areas of significantly higher and lower readings were detected and marked with wooden stakes. The excavation began shortly after the two anomalies were staked.

A trench was initially dug south of the anomalies in an area the property owner had indicated the barrels were buried. No barrels were found in this area, and a secondary trench was dug perpendicular to the first in the direction of the wood stake marking the positive anomaly.

At 3:30 p.m. the first barrel was unearthed at about a 10 foot depth directly beneath the wooden stake. Upon deepening of the trench, eighteen (18) additional barrels were uncovered at a depth range of 15 to 20 feet directly beneath the detected anomaly high. Further trenching was performed in the direction of the other staked anomaly where metal and plastic debris were unearthed.

In summary, a walkover survey with the EM-31 successfully located areas of buried drums at depths of ten (10) feet and greater in a fine-textured soil. The utility of this geophysical technique was directly demonstrated for this investigation in the savings of time to the on-site investigation team in their efforts to unearth the buried drums.

2. Burlington Northern - Waite Park — Stearns County — Waite Park

On March 12, 1987, an EM survey was conducted at the Burlington Northern Railroad (BN) Waite Park site located on land now owned by the City of Waite Park. Access was arranged by the MPCA project hydrologist Jan Faltisek (Site Response Section).

Between 1884 and 1985, the BN Waite Park railroad yard was used for constructing, repairing, and maintaining BN railcars and freight equipment. In January 1985, volatile organic compounds (VOC's) were detected in two municipal wells located on the site. The survey was conducted in the municipal well area to locate any buried metals that may be there.

Three anomalies were observed in the vicinity of Municipal Well 3. One anomaly could be traced to an existing water line. The remaining anomalies could not be traced laterally to the water lines and are believed to represent metallic sources. A test pit is warranted to identify the nature of the anomaly. This geophysical data is currently being incorporated into Phase 2, Remedial Investigation work at the BN Waite Park site under the MPCA's Site Response Section Enforcement efforts.

3. General Coatings — Dakota County — Eagan

On September 26, 1986, an EM survey was conducted at the General Coatings (GC) site located on property owned by GC in Eagan, Minnesota. The investigation was a supplement to the work of Ron Swenson (MPCA - Hazardous Waste). Mr. Swenson also arranged site access.

Several former GC employees allege that paints, thinners, and epoxies used by GC were collected in one to five gallon paint cans or 55 gallon drums and were disposed of in a 16-18 foot deep pit behind the main building. Some of the smaller waste volumes were poured directly into the pit. One employee estimated that about 300-400 gallons of liquid wastes were disposed in this fashion between 1973 and 1975. Sometime since the dumping occurred, the pit was covered with sand; however, its location is evident on aerial photos taken during the time of dumping. The survey objective was to locate and define the trench.

An inphase survey was conducted over the area highlighted by the aerial photos. Despite numerous cultural noise sources, several anomalies corresponding to the burial site location were detected. Borings or a test pit based on the geophysical data were recommended. The site is currently under investigation by the MPCA Hazardous Waste Section.

4. Interplastic Corporation — Hennepin County — Minneapolis

On September 24, 1986, an EM survey was performed at the Interplastic Corporation (IC) site located in northeast Minneapolis, Minnesota. The investigation was done as a supplement to the work of George Johnson and Darryl Weakley (MPCA - Hazardous Waste Enforcement). A verbal access agreement was arranged by George Johnson.

It is alleged that, IC disposed of approximately 50-60 drums of hazardous waste in a pit (about 50 feet by 50 feet, ten feet deep) that is now covered by a portion of the parking lot. This area was the target of the survey.

Quadrature phase and inphase surveys were conducted over the alleged burial site. A large conductivity peak and linear conductivity high (a possible trench) were detected by the inphase survey. The quadrature phase survey defined a peak and adjacent zone of decreasing conductivity (which could be a contaminant plume). The inphase and quadrature phase anomalies agree with the reported burial location. Soil borings or a test pit, as well as extension of the survey lines were recommended. The case is currently under investigation by the EPA.

5. Medallion Kitchens — Ottertail County — Vining

On December 22, 1986, an EM survey was conducted on the Medallion Kitchens drum burial site located on the Roy Mickelson farm near Vining, Minnesota. Verbal permission from the property owner provided access to the site.

At some time between 1969 and 1983, drums of "laquer dust" were shipped to and buried on the Mickelson farm. Laquer dust was also transported to the farm and dumped onto the ground from drums where it accumulated for several months and was burned. Surveys were conducted over the area the property owner reported as the drum burial location and the dumping area.

The inphase survey over the drum burial zone defined two strong anomalies. The anomalies are within several meters of the reported burial location. An excavation based on the geophysical plots was recommended.

6. RRC Jensen Field Airstrip — Dakota County — Rosemount

On August 29 and September 2, 1986, and April 9, 1987, EM surveys were conducted on the Rosemount Research Center Jensen Field Airstrip site located on land owned by the University of Minnesota. Verbal permission from the University of Minnesota representative Dr. Fay Thompson provided access to the site.

It is alleged that barrels had been buried beneath the runway while the airstrip was constructed. An inphase survey was conducted to investigate this allegation. The survey defined three anomalies. One anomaly is believed to be due to a buried utility line. A small test pit was recommended for each of the other anomalies.

7. Todd Jones' Backyard — Isanti County — Isanti

On Wednesday May 27, 1987, an EM-31 inphase (metal sensitive) survey was conducted at the Todd Jones' residence in Isanti County. The survey was to corroborate results of a previous proton magnetometer survey that indicated metal objects were buried in the backyard of the Jones' residence. Initial concerns on this site revolved around a complaint that alleged 100 barrels of potentially hazardous wastes were disposed of on Mr. Jones' property prior to his ownership.

The geophysical investigation was located in Mr. Jones' backyard and covered an area of 26 by 22 meters. Results indicated a small anomaly was present that may represent buried metal. These results were somewhat contrary to the previously performed magnetic survey in that fewer significant positive readings were detected. Based on this survey, there appears to be little evidence to support the allegation that 100 barrels of hazardous waste were buried in the area surveyed.

Recent testing (May, 1987) of the Jones' drinking water well has shown that no detectable VOC's are present. Recommendations for further action include:

1. the taking of at least one soil boring in the vicinity of the detected anomaly; and,

2. an extension of the survey into the garden area where access was not obtainable at the time of the survey.

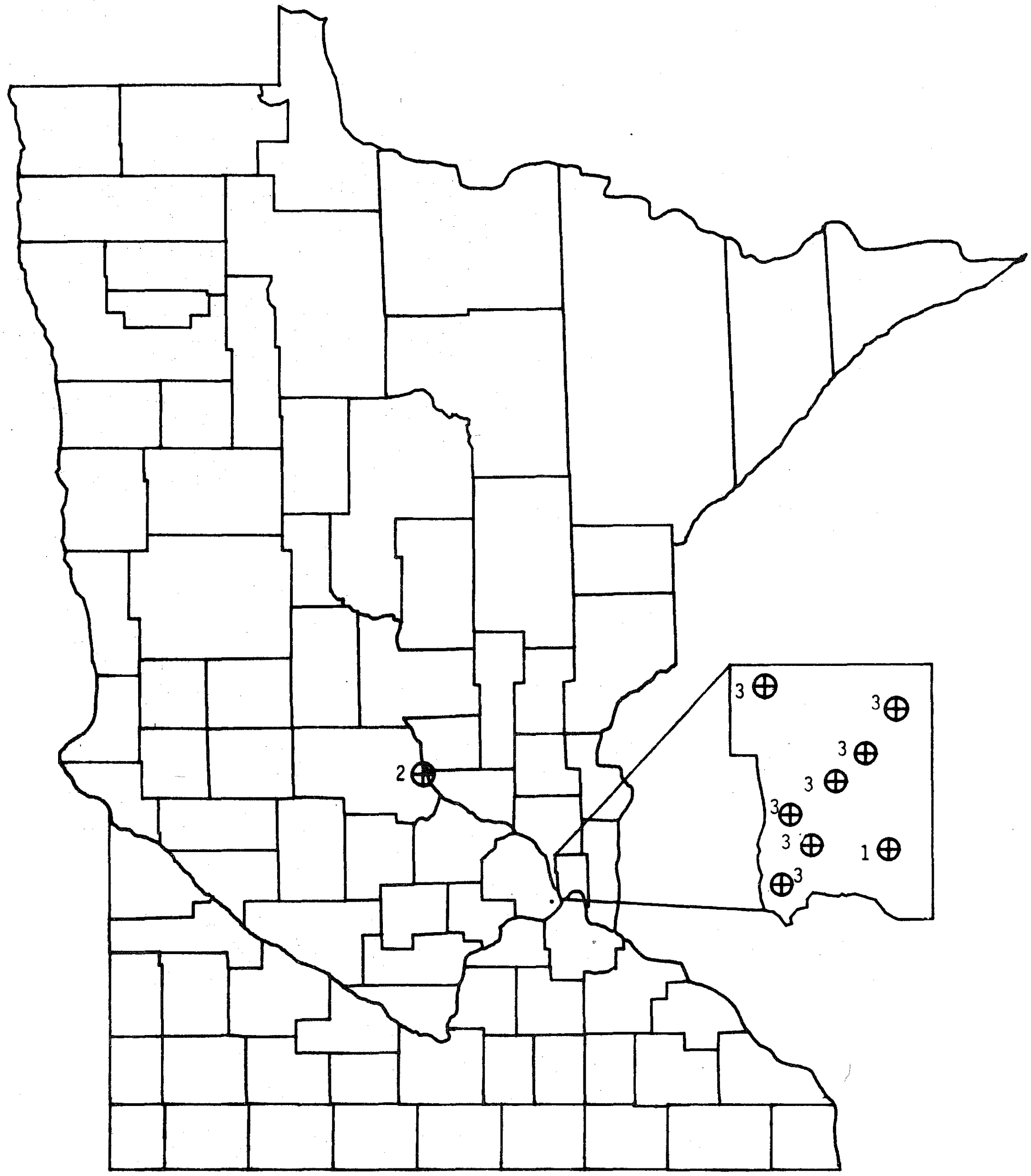


FIGURE 1.8 UNDERGROUND STORAGE TANKS

Case Study: Underground Storage Tank Investigations

1. 1400 Marshall Avenue | Ramsey County | St. Paul

On December 19, 1986 and January 13, 1987, three EM surveys were conducted at 1400 Marshall Avenue as part of a combined investigative effort between the owner of the property and the MDNR and MPCA staff. The site was used as a gasoline service station and for bulk storage of fuel and motor oil from 1931 to 1966. A petroleum spill occurred on-site some time in the past. A local consulting engineering firm is presently conducting a pre-purchase investigation of the property. Soil and ground water contamination have been detected in an area of the site once occupied by above-ground bulk storage tanks.

The objective of the geophysical surveys were twofold: 1) to determine the location of any underground storage tanks in the area previously used as a service station, and 2) define the area where petroleum products were spilled in the past.

Anomalies from the geophysical study have been interpreted as one underground storage tank and a plume of hydrocarbon contaminants. The orientation of the geophysical anomaly representing contaminated soil is very similar to geotechnical interpretations based on lab analysis of subsurface soil.

Recommendations were made that the excavation of one storage tank and the removal of contaminated soil be performed prior to site development. The owner is currently negotiating for a contractor to do the required work.

2. Burlington Northern Waite Park | Stearns County | Waite Park

At the request of Jan Faltisek (MPCA), EM surveys were conducted at the Burlington Northern (BN) Waite Park Site between March 5-13, 1987. The surveys were conducted as part of the Phase I Remedial Investigation presently being reviewed by MPCA staff.

Since 1884, the BN railroad yard in Waite Park had been used for constructing, repairing, and maintaining BN rail cars. Former BN employees have alleged that at some time in the past, BN had cut a rail tank car in half and had buried it on site with waste materials. The survey objective was to confirm or disapprove this allegation.

Inphase surveys were conducted over the suspected burial locations. Nine anomalous areas were detected in the alleged burial tank car area. Several of the anomalies have dimensions and magnitudes large enough to possibly represent a tank car. However, without knowing the size and/or contents of the tank car, it is not possible to predict which, if any, of the anomalies represent it. Test pits were recommended at each anomaly to determine the nature of the sources. The geophysical data is currently being incorporated into the Phase 2 Remedial Investigation of the site.

3. Super America Midwest Ramsey County St. Paul

Between February 11-19, 1987, 11 EM surveys were performed at seven future Super America service station locations as a supplement to the work of Richard Kable (MPCA-Spills). Each of the seven locations is an actively operating convenience store/service station at which hydrocarbon contamination had been identified. Preliminary subsurface investigations were performed at each site prior to the geophysical investigations. This study was conducted as part of a combined investigative effort between Super America Midwest, DELTA Environmental Consultants, Inc. and the MDNR and MPCA staff. The objectives of the geophysical surveys were twofold: 1) to locate and confirm the number and orientations of underground storage tanks on site and 2) to determine the limitations of the EM equipment in an urban setting with varying sources of cultural interference.

It was estimated that 26 tanks existed at the 7 locations. In most cases, the locations of the tanks were known. Of the 26 tanks, 14 were located under reinforced concrete, 6 under asphalt and 6 under soil. Results of the surveys are as follows: 14 tanks were located with good resolution; 11 tanks could be infered from the data; and 1 tank was not detected. At service stations where 1 or 2 tanks were located, generally good tank definitions were seen in the data. At stations where several tanks (up to 5) were confined to a small area, individual tank definitions could not be interpreted from the data; however, the general outline of the tank grouping was observed.

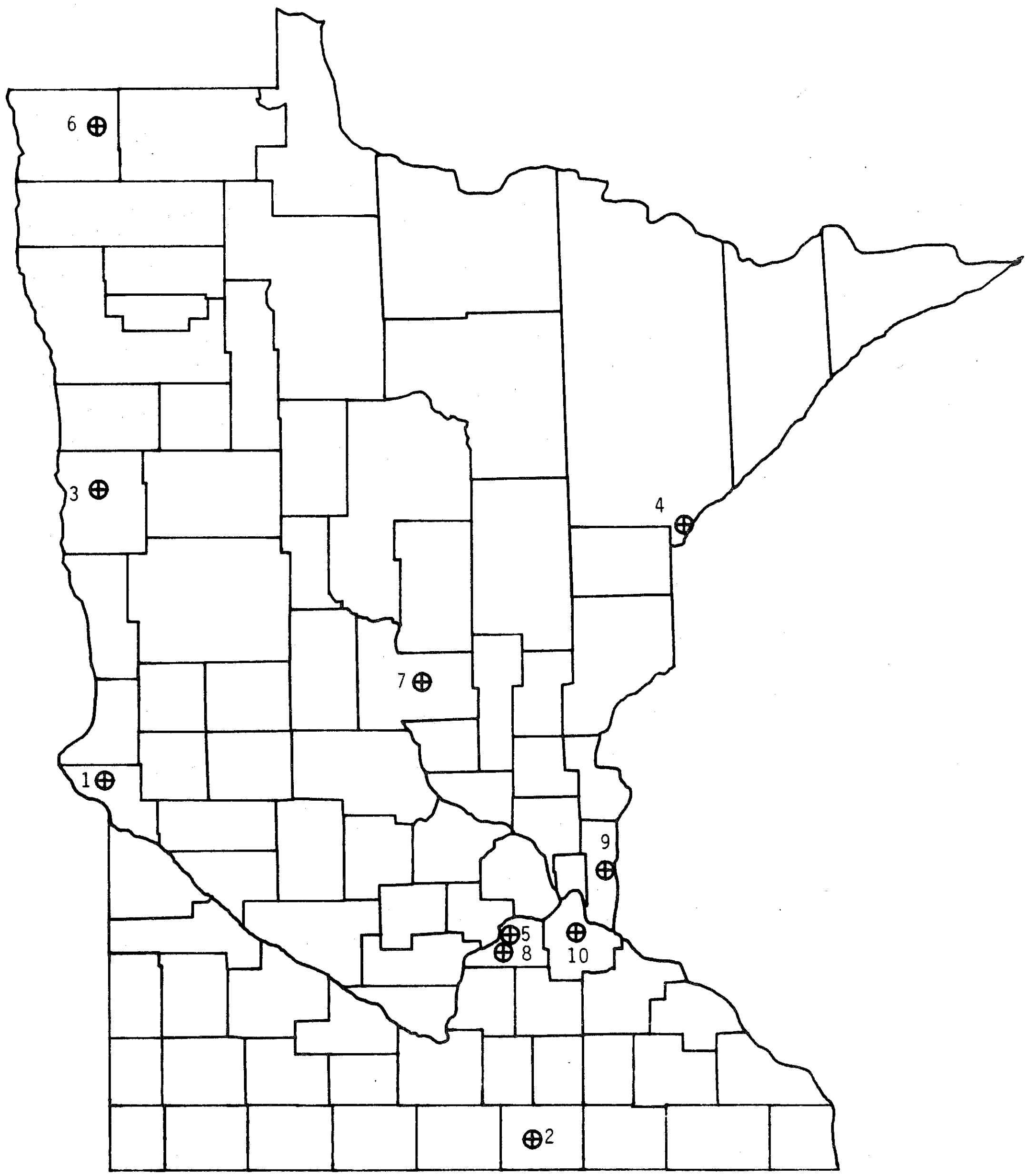


FIGURE 1.9 LANDFILL/DUMP SITES

Case Study: Landfill/Dump Site Investigation

1. Clinton Dump — Big Stone County — Clinton

On April 17, 1986, an EM survey was conducted at the now closed Clinton Dump (CD) located north of Clinton, Minnesota. The investigation was undertaken as supplementary work to an ongoing remedial investigation by Brad Sielaff (MPCA-Program Development Section). Access was arranged by Mr. Sielaff.

The CD operated from 1950-1982 and accepted mixed solid waste, demolition material, and sewage sludge for disposal. Existing borings and monitoring wells indicate the presence of high levels of TDS, high sulfates, and low heavy metal concentrations. The survey objective was to determine the lateral extent of the dump.

The quadrature phase survey defined multiple anomalies over the entire gridded area. The data indicates that the dump extends at least as far northwest as the gridded survey boundary. Additional EM survey lines to the northwest may determine the limit of dumping in that direction.

2. Cropmate — Freeborn County — Albert Lea

On April 14, 1987 an EM survey was conducted at the Cropmate Company (CC) trench site located on CC property near Albert Lea, Minnesota. Verbal permission from the CC Manager provided access to the site.

Between 1969 and 1975 fiber drums containing Aldron and various metal drums were placed in and then burned in a trench located on the site. Until 1974, Amoco owned and operated the facility. On October 7, 1974, it was sold to Imperial, Incorporated, and part of the land was sold to CC. The survey objective was to locate and define the trench.

Quadrature phase and inphase surveys were conducted over an area reported as the trench site. Unfortunately, a large metal tank used for burning trash was situated on the land surface over the trench area. Despite the cultural interference, three anomalies thought to be the trench were detected. Borings or a test pit based on the geophysical work was recommended.

3. Dilworth Dump — Clay County — Dilworth

On April 17, 1986, an ER survey was conducted at the Dilworth Dump (DD) site located south of Dilworth, Minnesota. The survey was conducted as part of an ongoing remedial investigation being conducted by Brad Sielaff (MPCA-Program Development Section). Mr. Sielaff arranged access to the site.

For over seventy years, the dump accepted solid waste for disposal. Dump management was unique in that the same small area was repeatedly retrenched, resulting in a concentration of waste materials. The concentrated wastes and a high water table combine to make the ground water highly susceptible to contamination. Existing site borings and monitoring wells show slightly lower levels of TDS and sulfates and high concentrations of sodium and chlorides. The ER survey objective was twofold: 1) determine the dump's vertical and lateral extent and 2) define subsurface conditions around the dump. The ER survey results at DD successfully determined the depth and extent of buried waste and subsurface conditions beneath the dump. An EM induction survey conducted around the dump site may help define a contaminant plume. At present, no further EM work is planned for this site.

4. <u>Duluth IAP</u> <u>St. Louis County</u> <u>Duluth</u>

On August 5-6, 1986, an EM survey was conducted on the Minnesota Air National Guard RD-1 Site (Site) at the Duluth International Airport (IAP) as a supplement to the work of Enrique Gentzsch (MPCA-Site Response).

Throughout the 1950's and 1960's, several on-base locations were used for the disposal of hazardous materials. Low level radioactive wastes were reported buried in a trench at the Site. The low level radioactive wastes include cathode ray tubes, radar scopes, watch dials, etc. The waste trench was approximately 5 meters deep and 13 meters long. Garbage and general refuse was placed over the radioactive materials and a soil cap was used as final cover. The exact location of the trench is presently unknown. The geophysical survey objective was to determine the location of the trench. A 60 by 100 meter survey was conducted over an area allegedly containing the trench.

Four anomalous areas were detected. Two of the anomalies could be attributed to cultural interference. The other anomalous areas do not appear to be caused by surface or cultural sources and are dimensionally large enough to represent the trench. Recommendations were made that further investigation be centered on these anomalies.

5. <u>Krammer Quarry</u> <u>Dakota County</u> <u>Burnsville</u>

On August 13-14, 1985, two EM surveys were conducted at the Krammer Quarry which is in the vicinity of the Burnsville and Freeway landfills. The investigation was performed as a supplement to the work of Paul Book (MPCA-Solid Waste). Mr. Book was reviewing proposed additional monitor well locations at the referenced landfills.

Fracture patterns in the bedrock were observed in the quarry walls. Mr. Book's hope was that if the EM equipment could detect fracture patterns in the bedrock, he could use that information to locate suitable sites for monitoring well placement. A fairly large river channel was also crosscut by quarry operations. The objective of the geophysical study were twofold: 1) to determine if the EM equipment could detect the fracture orientations in the bedrock, and 2) to determine if changes in the slope of the bedrock caused by the river channel were detectable. The geophysical surveys were performed on top of the quarry adjacent to the quarry face.

Fracture orientations and the buried river channel could be located in the survey areas from interpolating their locations from the quarry face onto the survey area. Results of the surveys indicated that the resolution of the fractures in the data was not clear enough at this particular site to warrant additional investigation at the Burnsville or Freeway landfills. The change in slope of the bedrock caused by the buried river channel was very apparent in the data.

6. Lake Bronson State Park — Kittson County — Lake Bronson

During the week of June 23, 1986, an EM survey was conducted at the "old dump" site located within the Lake Bronson State Park. The project was undertaken in cooperation with MDNR Division of Parks.

The facility was operated as a municipal dump from 1927-1970 and may have received pesticides including lead-arsenate, DDT as well as chlorinated hydrocarbons. In August, 1983, concern was raised over the possibility of leachate from the dump contaminating the North Kittson Rural Water District's (NKRWD) wells located approximately 0.5 miles away and the public Water Wells in the park. The wells were sampled, and analysis revealed no contamination of the wells by landfill leachates. The issue became one of international importance since the NKRWD is empowered to sell water to Canadian towns. The survey objectives were twofold: 1) determine the extent of on-site buried metal debris and 2) investigate the possibility of a contaminant plume downgradient of the dump site.

Inphase (metal detection) measurements found that except for a small "household trash" area and a few scattered can parts, all metal debris was located within the fenced in dump area. The quadrature phase survey defined a downgradient conductivity high which may represent a contaminant plume.

Between September 11 and 13, 1986, six monitoring wells were installed and sampled in areas defined by the surface geophysics. Comparison of the surface conductivity data and the monitoring well water conductivities shows an excellent correlation. Where EM predicted the highest relative conductivities the water well conductivities were highest. Where EM was lowest, the water well conductivity was lowest. Analysis of the ground water samples revealed no significant contamination except for elevated chloride concentrations which account for the higher conductivities.

7. Little Falls Closed Dump — Morrison County — Little Falls

On April 22-23, 1986 an EM survey of the Little Falls Closed Dump was conducted to locate a series of alleged trenches where alleged hazardous materials were dumped and burned. Wastes were reportedly received from manufacturers, plastic molding companies and other local businesses. Types of wastes disposed of include: solvents, paint sludges, polyester resins and acids. The dump operated for approximately 20 years and was closed in 1970. Several residents in the vicinity of the site are dependent on local ground water for their water supply. Eleven wells tested in 1986 by the U.S. EPA's Field Investigation Team, Ecology and Environment, indicate no contaminants are present above the Recommended Allowable Limits for drinking water. The objective of the surveys was to determine the location of the trenches and to locate a suspected contaminant plume migrating from the trenches. East-west trending trenches were observed in the data. A contamination plume may also be represented in the data and appears to be migrating in a northeast direction. A copy of our findings have been forwarded to the City of Little Falls and Ecology and Environment who will be conducting additional investigations of the site.

8. Louisville Sanitary Landfill — Scott County — Shakopee

On April 9, 1986 and April 24, 1986, EM and ER surveys were conducted at the Louisville Sanitary Landfill located south of Shakopee, Minnesota. The investigations were supplement to work done by Sheila Grow (MPCA-Solid Waste). Verbal permission from the owner allowed access to the site.

Louisville Sanitary Landfill began operation in 1968; a permit for construction and operation of the landfill was issued by MPCA staff in 1971. In 1980 and 1984, the permit was amended to allow the disposal of household, commercial, demolition, and approved industrial wastes. In 1985, the site was placed on the PLP. The estimated remaining useful life of the landfill is about eight years. Analysis of water taken from on-site monitoring wells indicate the presence of several VOC's; however, no known hazardous wastes were accepted at the landfill. The survey objectives were twofold: 1) define bedrock fracture orientations down gradient of the dump and 2) locate and define a contaminant plume thought to be eminating from the landfill.

The ER survey defined two fracture orientations - both correlate with fracture orientations measured in a nearby quarry. The EM survey defined an area of higher conductivity apparently down gradient of the landfill. Subsequent soil borings based on the EM data indicated the presence of more conductive clay soils but did not detect any leachate.

9. Minnesota Correctional Facility — Washington County — Bayport

On May 20 and 21, 1986, EM surveys were conducted at the Minnesota Correction Facility (MCF) Old Dump site. Access was coordinated with MDNR Division of Fish and Wildlife.

The dump site was established about 1962 for the disposal of sisal (rope fiber) dust and garbage from MCF. A rat problem soon developed from food and garbage so it was then halted. By 1977, the dump was receiving foundry slag, T-1 paint thinner, wood waste, cinders and ash, used paint filters, hemp, and sisal dust. In 1976, the dump and surrounding area was acquired by the DNR and is currently a wildlife refuge area. An Order from the MPCA required MCF to close and cover the dump by August, 1977. The survey objectives were twofold: 1) detect the lateral boundaries of buried metallic material and 2) delineate the presence and boundaries of a suspected contaminant plume migrating off-site.

The inphase (metal detection) survey defined the lateral boundary of the buried metal. The quadrature phase survey appears to have detected what is interpreted to be a contaminant plume emanating from the metallic rich area. Soil borings to substantiate the presence of a plume were recommended.

10a. RRC-Burn Pit — Dakota County — Rosemount

On October 28 and November 5, 1986, EM surveys were conducted on the Rosemount Research Center Burn Pit (BP) site located on land owned by the University of Minnesota. University of Minnesota representative Fay Thompson provided verbal permission to access the site.

From 1960 to 1977, the University of Minnesota disposed of liquid hazardous materials in this waste dump/burn pit. During the summer of 1971, the burn pit was covered with lime, filled with soil, and capped with clay. Dr. Thompson thought there were two primary burn areas within the pit. In addition, a second small trash pit was reported to be located east of the burn pit.

The objectives of the survey were twofold: 1) to locate the two burn areas within the pit, and 2) to locate/define the trash pit located to the east of the now clay capped burn pit.

A quadrature phase survey conducted over the burn pit identified one anomaly along the southern edge of the clay cap. An inphase and quadrature phase survey conducted east of the burn pit defined two anomalies in the area reported to be the trash pit area. A test pit was recommended in the trash pit anomaly.

10b. RRC-Demolition Pit — Dakota County — Rosemount

On November 5, 1986, an EM survey was conducted at the Rosemount Research Center Demolition Pit (DP) site located on land owned by the University of Minnesota. Verbal permission from the University of Minnesota representative Dr. Fay Thompson allowed access to the site.

The University of Minnesota, Minneapolis, and St. Paul police departments have occasionally used the DP for detonating unstable chemicals and materials. The survey objective was to define the trenches in which the detonations occurred. The quadrature phase survey defined a large anomalous area that may represent the trenched zones. Soil boring locations were recommended.

10c. RRC-World War II Construction Dump — Dakota County — Rosemount

On September 5, 1986, an EM survey was conducted at the Rosemount Research Center World War II Construction Dump site located on land owned by the University of Minnesota.

While conducting the Jensen Field Airstrip Survey, MDNR staff were approached by a man who informed them about a site that had received construction materials and tools from construction of the Gopher Ordinance Works during World War II. The material was mostly copper and lead tools as well as construction scrap. Concrete with metal rebar could be seen protruding from the ground at the site. An inphase survey was conducted to define the extent of burial. The survey revealed a large area of elevated conductivities that correspond to the location of burial. Test pit locations were recommended.

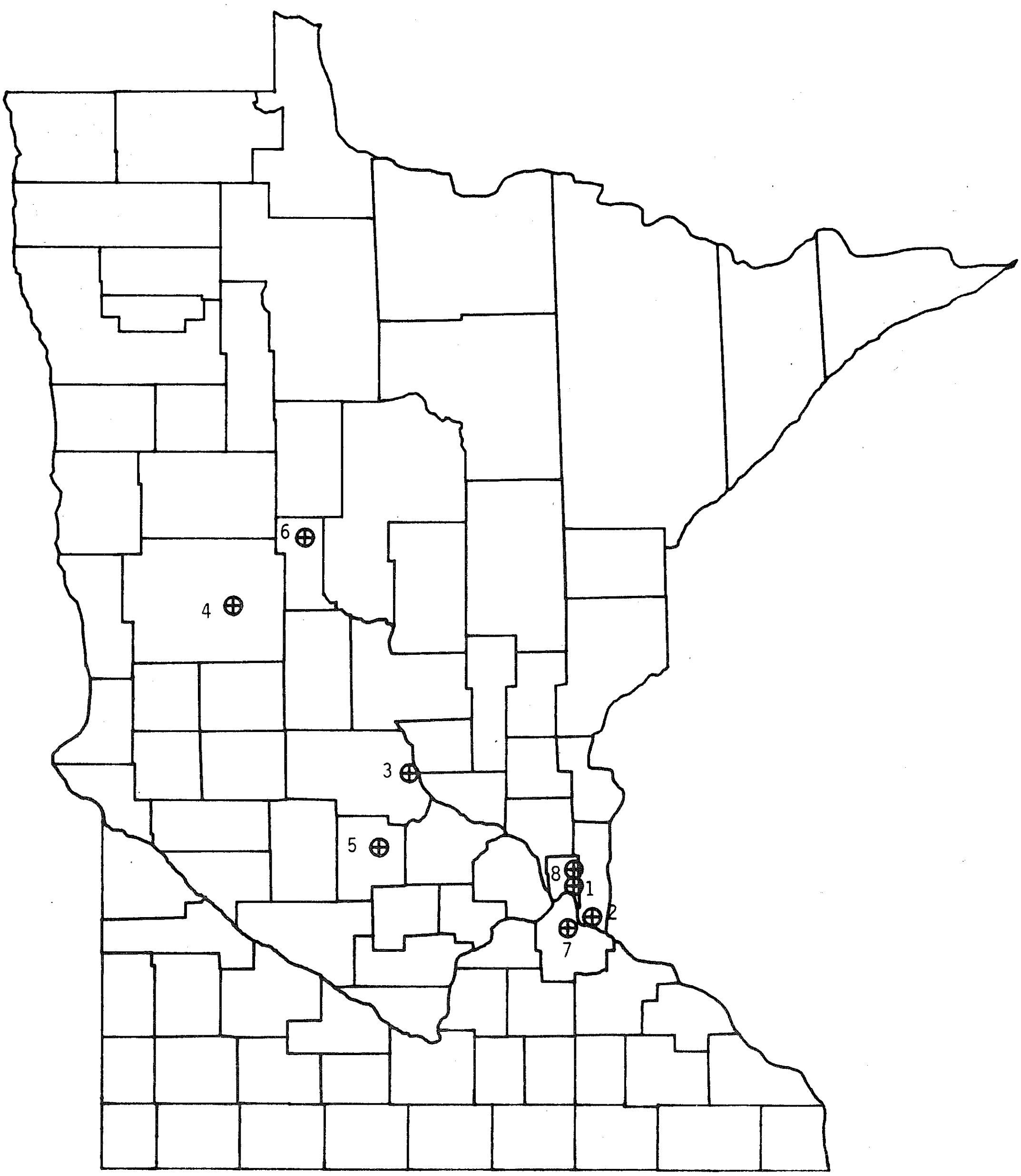


FIGURE 1.10 SURFACE SPILLS/WASTE PIT SITES

Case Study: Surface Spills/Waste Pits

1. 1400 Marshall Avenue — Ramsey County — St. Paul

See Underground Storage Tank Investigations, Site 1.

2. Ashland Oil Company — Washington County — Cottage Grove

On May 22, 1986, an EM survey was conducted on property owned by Ashland Oil Company (AOC) in Cottage Grove, Minnesota. The investigation was undertaken as a supplement to an ongoing remedial investigation. Access to the site was arranged through Gary Schroeder (MPCA, Site Response Section)

The AOC acquired the Cottage Grove property in 1956 for the disposal of refinery wastes in lagoons and trenches. MPCA records indicate that from 1965 to 1969, the lagoons received asphalt, oily emulsions, and calcium carbonate wastes. No known contamination exists in the underlying aquifers or the off-site ground water or surface water; however, lead contamination has been found in the site soil. The survey objectives were to define the boundaries of the lagoons and possibly detect any ground water contaminant plumes.

The survey successfully located the buried lagoons by means of detecting high conductivities of the soil contaminated by lead. An apparent contaminant plume was also detected moving off-site in the downgradient direction. Soil boring locations were recommended.

3. Burlington Northern Waite Park — Stearns County — Waite Park

On March 13, 1987, an EM survey was conducted at the Burlington Northern (BN) Railroad Waite Park site located on land now owned by the City of Waite Park. Site access was arranged by MPCA project hydrologist Jan Faltisek (MPCA Site Response Section).

Between 1884 and 1985, the BN Waite Park railroad yard was used for constructing, repairing, and maintaining BN railcars and freight equipment. As part of an ongoing remedial investigation, a geophysical survey was performed in a calcium hydroxide (CaOH) disposal area where CaOH was allegedly disposed in a trench and on the ground. The objective of the survey was to determine the lateral extent of the disposal area.

The EM survey conducted in the CaOH disposal area can be divided roughly in half between an anomalous and a featureless area. Two distinct anomalies exist within an area of generally elevated conductivities. Soil borings taken previously in this area indicate variable concentrations of CaOH deposits, oil saturated soil, and soil containing high pH values and elevated metal concentrations. The anomalous area may represent any one or any combination of these contaminants. An existing soil boring located in the featureless area of the survey indicates lower levels of metals but no oils or CaOH. Test pit and soil boring locations were suggested. This geophysical data is currently being incorporated in the Phase 2 Remedial Investigation of the site.

4. Medallion Kitchens — Ottertail County — Vining

On December 22, 1986 an EM survey was conducted on the Medallion Kitchens drum burial site located on the Roy Mickelson farm near Vining, Minnesota. The property owner's verbal permission allowed access to the site.

At some point between 1969 and 1983, drums of "laquer dust" were shipped to and buried on the Mickelson farm. Laquer dust was also transported to the farm and dumped onto the ground from drums, where it accumulated for several months and was then burned. Surveys were conducted over the area the property owner reported as the drum burial location (see buried drum section) and the dumping/burning area. The quadrature phase survey over the dumping/burning area defined a zone of anomalously high conductivity values. The high conductivity region agrees with the location the property owner reported for the dumping. A larger, gridded EM survey was recommended as well as soil borings to provide further evidence of the location of the alleged burning sites.

5. Palm Industries — Meeker County — Litchfield

On October 10 and November 25, 1986, EM surveys were conducted on property owned by Palm Industries (PI) of Litchfield, Minnesota. A verbal access agreement with the PI Manager provided site access.

From 1970 to 1983, solvents, heavy metals, and oily wastes generated on site were deposited in trenches behind the company's main building and burned. Unfortunately, the area over the trenches is now a storage area for the metal cabs that PI manufacturers; thus, it was not possible to survey the trench area. However, two surveys were conducted downgradient of the trench area in an attempt to define a potential contaminant plume.

Both surveys were conducted in the quadrature phase over the same grid. The first survey was run without regard to topographic influences, the second survey was conducted in a fashion to compensate for the topographic effects caused by a four meter deep ravine which traverses the survey area. Several anomalies were defined by the survey and soil borings were recommended to determine the contaminant charactertistics of these anomalies. An extension of the survey to include the trench areas (once the surface metal were removed) was also suggested.

6. Ritari Post and Pole — Wadena County — Sebeka

On June 3 and 4, 1986, an EM survey was conducted on the Ritari Post and Pole site located near Sebeka, Minnesota. Site access was arranged by MPCA employee Amy Loiselle.

Ritari is a site where wood posts and poles are treated with pentachlorophenol (PCP). The survey objective was to define a leachate plume over and around the wood treatment facility.

Although the conductivities over the area were slighly elevated, the results in general were inconclusive. This conclusion may, however, be expected since water well conductivity measurements taken at the site's monitoring wells were not noticeably elevated over those of "background" offsite samples.

7a. RRC - George's Used Equipment — Dakota County — Rosemount

On November 17, 1986, an EM survey was conducted on the Rosemount Research Center George's Used Equipment (GUE) site located on land owned by the University of Minnesota. Verbal permission from the University of Minnesota representative Dr. Fay Thompson provided access to the site.

The GUE site formerly was used as a transformer reprocessing and salvaging facility. The practice of dumping polychlorinated biphenyl (PCB) - laden oil on the ground while dismantling the transformers allegedly occurred at the property between 1968 and 1983. The survey objective was to define the contaminated soil and to define an area where an incinerator allegedly operated.

The survey was conducted over the area reported to have the the highest PCB contamination. The survey also included the area thought to contain the incinerator. The survey defined two anomalies. The first anonaly is an area of low conductivity that may correlate with the soils contaminated by PCB-laden oils. The second anomaly correlates with the reported location of the incinerator. No recommendations were made for this site.

7b. RRC-Porter Electric — Dakota County — Rosemount

On November 26, 1986, an EM survey was conducted on the Rosemount Research Center Porter Electric (PE) site. Verbal permission to survey the property was obtained from University of Minnesota representative Dr. Fay Thompson.

The PE site was also used by a transformer salvage business. PCB-laden oils were allegedly poured on to the ground. The survey objective was to locate and define the contaminated soil. The survey covered an area where PCB laden oil is visible on the ground and over an area downgradient of the visible oil. The survey may have detected the visible oil area but failed to detect any other anomalies. Therefore, the survey was inconclusive. The survey was probably inconclusive due to the low concentration of contaminant in the soil. No recommendations were made for this site.

8. Super American HCO #21 — Ramsey County — White Bear Lake

On March 21, 1987, an EM survey was conducted at the Super America HCO #21 site near White Bear Lake, Minnesota. This work was supplemental to a geophysical survey conducted February 21, 1987 (see underground storage tank section).

Monitoring wells installed by a local consulting engineering firm as part of a pre-purchase investigation indicated the presence of petroleum on top of the shallow water table. The survey objective was to locate and define the extent of the petroleum plume.

The survey appeared to define a region of low conductivity that could be indicative of a petroleum plume. The low values could, however, also be due to cultural interference found in the area. The results were therefore considered inconclusive and no actions were recommended.

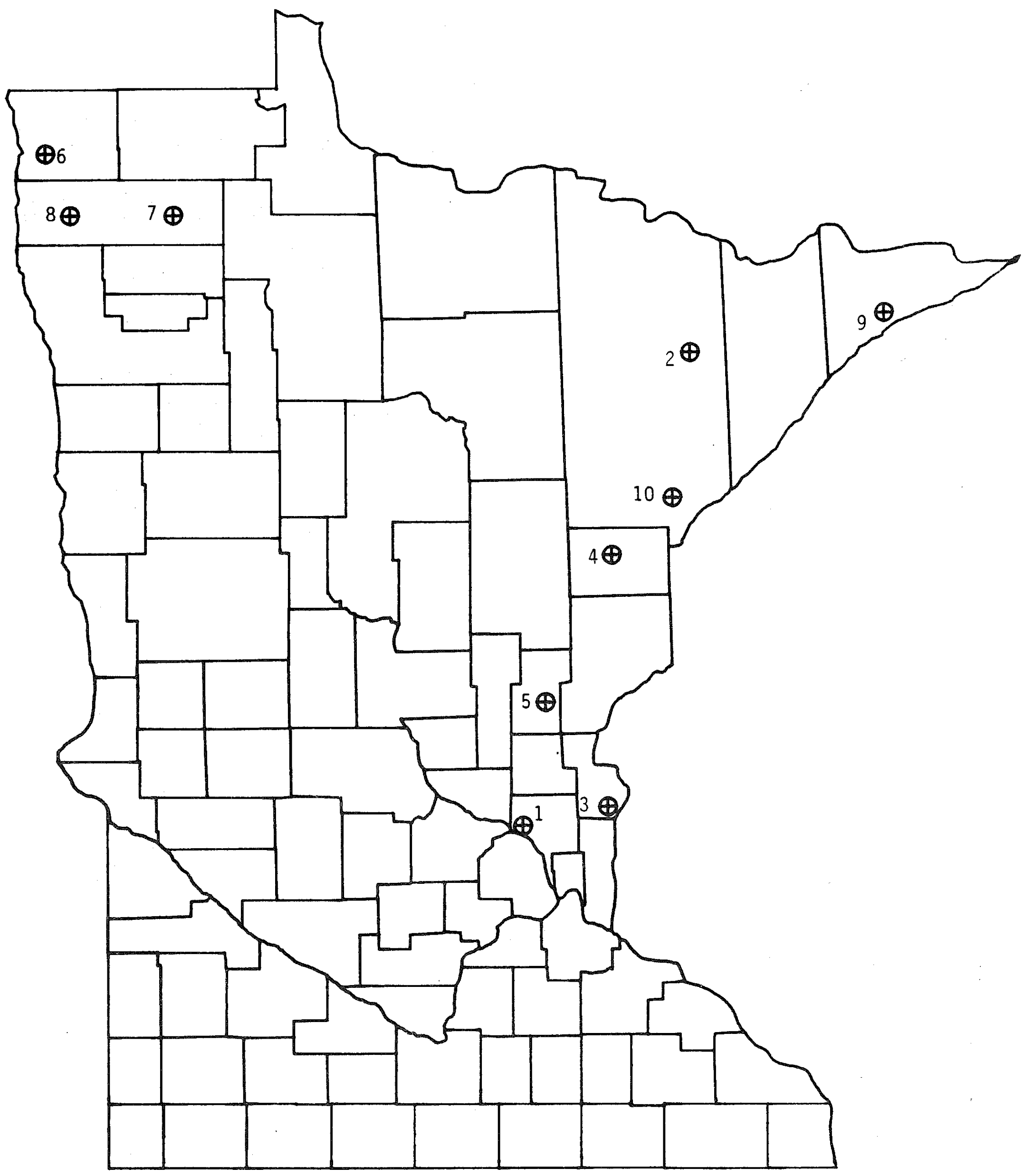


FIGURE 1.11 BELOW GROUND ARSENIC BURIAL SITES

Case Study: Below Ground Arsenic Burial Sites

1. Burlington Northern - Ramsey Boulevard   Anoka County   Anoka

On October 30, 1986, an EM survey was conducted at the Burlington Northern Ramsey Boulevard train derailment site located on Anoka County Road 56. An Access Agreement between the MPCA and BN provided access to the train wreck site.

A hotline complaint alleged that drummed lead arsenate was buried on site following a train wreck in 1963. BN claims that the material, originally in wooden crates, was repackaged and returned to the manufacturer. The hotline complaint alleges the material may have been in drums and was initially buried on site, then removed after about a year to a different site. The survey objective was to locate the reported landfilling and/or drums, if present.

An inphase survey was conducted over an area where aerial photos showed the derailment had occurred. The survey defined three zones of resistive material. Borings or test pits based on the geophysics were recommended.

2. Esala Farm   St. Louis County   Embarrass

On June 19, 1986 an EM survey was conducted on the Julo Esala farm located near Embarrass, Minnesota. Verbal permission from the property owner allowed site access. The survey was conducted as a supplement to the work done by Mark Oppen (MPCA - Site Response).

In 1934, the property owner and his brother buried six burlap sacks of arsenic laced grasshopper bait in a shallow pit and covered the pit with muskeg. They did not want to bury it on their own property, so they took it over to state land (now Superior National Forest) to bury it. The survey objective was to locate the buried sacks.

The presence of powerlines directly over the alleged burial site resulted in an inconclusive survey. The powerline anomaly dominated the survey data. No recommendations were made at this site.

3. Julik Farm (Buried Gunny Sack Experiment)   Chisago County   Taylors Falls

On July 16 and September 25, 1986, EM surveys were conducted over an experimental target on the Julik farm located near Taylors Falls, Minnesota. Access was arranged by MPCA Hydrologist Joe Julik.

On the morning of July 16, an EM survey was conducted over a pre-selected site in the field. Following this initial survey, six 100-pound sacks of grain were buried in two small pits. The grain was meant to simulate the grasshopper bran bait found at the lead-arsenic sites. Following burial, two EM surveys were conducted over the burial site to locate the grain sacks.

The quadrature phase survey conducted immediately after burial nor a survey conducted two months later detected the buried grain sacks. It appears the pits small size and the grain sacks' lack of conductivity difference (compared to the surrounding soil) resulted in the inconclusive data.

4. Langhorst Farm — Carlton County — Barnum

On June 18, 1986, an EM survey was conducted at the Langhorst Farm near Barnum, Minnesota . Verbal permission to access the site was granted by the property owner. The investigation was conducted as a supplement to the work of Mark Oppen (MPCA-Site Response).

The father of the landowner knew the approximate burial location of four 100 pound burlap sacks containing the lead-arsenic mixture. The sacks were buried in a shallow pit next to several old buildings no longer standing. The property owner directed the survey to an area where the buildings once stood. The survey objective was to locate the burlap sacks near the foundations.

The quadrature phase survey defined a pair of anomalies. The first anomaly corresponded with the suspected foundation location. The second anomaly, next to the foundation, may correlate with the burial site. Proposed soil boring locations were recommended.

5. Linkert Farm — Kanabec County — Mora

On June 13, 1986, an EM survey was conducted on the Linkert Farm near Mora, Minnesota to locate buried arsenic-laced grasshopper bait. The investigation was conducted as a supplement to investigations being performed under the Below Ground Arsenic program. Permission to gain access to the farm and perform the survey was given by the property owner.

The geophysical investigation was located in the area where four to six 100-pound sacks of grasshopper bait were reported to have been buried adjacent to an old barn foundation. The burial pit was reported to be four feet deep by 16 feet square and capped by fill.

The survey was restricted to a rectangular area adjacent to a barn where the former owner remembered the sacks were buried. A conductivity high (anomaly) was selected and mapped in this area using the quadrature phase mode. There was some uncertainty as to what this high reading represented because an old silo apparently stood in this area a number of years back. Recommendations were made to take soil borings in the vicinity of this anomaly.

As a follow up to this recommendation, the Below Ground Arsenic program took soil borings in the vicinity of the anomaly and outside this area. Results from the soil sampling showed no arsenic in samples taken from within the anomaly but a high level of arsenic in a soil boring sample taken outside the anomaly. It is believed the anomaly high more than likely represented the old silo foundation and not sacks of buried arsenic.

6. Murray Farm — Kittson County — Donaldson

On September 10, 1986, an EM survey was conducted on the Murray farm near Donaldson, Minnesota. The property owner's verbal permission allowed site access. The survey was conducted as a supplement to the work done by Mark Oppen (MPCA-Site Response).

One 55-gallon steel drum filled with liquid technical grade calcium arsenic was buried on the farm in a small pit. The barrel had been placed above ground for 20-25 years before burial, and the barrel was in a poor, rusty condition at the time of burial. The survey objective was to locate the buried drum.

Site specific conditions (very clayey soil, single barrel, poor burial location knowledge) resulted in an inconclusive survey. No recommendations were made for this site.

7. Ryhakowski Farm — Marshall County — Middle River

On September 10, 1986, an EM survey was conducted at the Daniel Beito Farm formerly owned by Ray Ryhakowski near Middle River, Minnesota. The survey objective was to locate a burial pit where nine to fourteen 100-pound burlap sacks of grasshopper bait were reportedly disposed of in a collapsed root cellar. Access to the site and permission to conduct the survey were granted by the landowner.

The survey was executed over a 60 by 85 meter grid to ensure the burial area was included in the survey grid. Two small anomalies were found over the grid and were thought to correlate well with the reported location of the root cellar where the bait had been disposed.

Recommendations for further action included soil borings in the area of the reported anomaly. At this time, no follow up soil samples have been taken.

8. Stephen Mixing Station — Marshall County — Stephen

On September 9, 1986, an EM survey was performed at the former Stephen Mixing Station Site on the farm of Tom Peterson. The survey was undertaken as a supplement to investigatory work being performed under the Below Ground Arsenic program. The property owner's verbal permission allowed site access.

The objective of this survey was to locate a trench where a pick-up load of arsenic-laced bait had reportedly been disposed. The trench was within the foundation of the old mixing station. In addition, a rectangular area the general shape of the mixing station foundation was targeted for the survey. This was done because a "burn area" of about 50 to 60 feet was present in the form of stressed vegetation in the past year's crop.

A study area of 150x150 feet was surveyed to encompass the mixing station foundation (17x17 feet) and accompanying burn area. Several subtle differences in conductivity were detected in the survey area which may be representative of arsenic contaminant. Further, it appears the trench was identified. However, the differences in conductivities could also be due to variable soil moisture or texture properties. The clayey soil on this site do exhibit high soil conductivities so subtle differences in soil physical properties may create the observed conductivity differences.

For this particular site, the stressed vegetation may be the best indicator of the extent of arsenic contamination and should be used as a guide for further soil sampling work.

9. Thompson Farm — Cook County — Grand Marais

On June 19, 1986, an EM survey was conducted at the Thompson Farm in an attempt to locate two to three 100-pound sacks of lead arsenate laced grasshopper bait that were buried on the property approximately 50 years ago. Metallic waste was also observed in the area of burial. The survey indicated several anomalous areas that may represent the exposed surface metal, buried building foundations, the buried lead arsenic bait or disturbed soil. The results do not appear to confirm the burial location. No recommendations were made at this site.

10. Vanderford Farm — St. Louis County — Hermantown

On June 18, 1986, an EM survey was conducted on the Vanderford Farm in an attempt to locate 100-500 pounds of lead arsenate buried on the property 40 years ago. The survey was performed in the alleged burial area. Location of the burial area could not be inferred from the data. No recommendations were made for further action at this site.

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Appendix A

"Electromagnetic Exploration of Hazardous Waste Sites in Various Minnesota Settings"

By:

Jay R. Frischman

and

James R. Lundy

ELECTROMAGNETIC EXPLORATION OF HAZARDOUS WASTE SITES IN VARIOUS MINNESOTA SETTINGS

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Electromagnetic (EM) surveys, also called terrain conductivity surveys, have been used experimentally at approximately 30 hazardous waste sites in Minnesota. This Legislative Commission on Minnesota Resources funded project was designed to determine the usefulness of the EM technique in defining the extent and location of contaminated soils, ground waters and buried metal objects in a variety of settings.

The first setting is in an industrialized area where drums of hazardous waste may have been buried beneath an asphalt parking lot. Despite severe "cultural noise" (fencelines, powerlines, etc.), the method successfully detected a conductivity anomaly, which may represent the buried drums of wastes. The second setting is a former rural dumpsite (household wastes) which may have also received pesticides. EM surveys detected a conductivity plume downgradient from the dumpsite. Analysis of ground water in the plume revealed no significant contamination except for elevated chloride concentrations, which may account for the higher conductivity. Thirdly, burial sites containing small volumes of lead-arsenate and sawdust-bran mixture were surveyed. EM results were inconclusive; the lead-arsenate was not detected but at several locations, EM surveys successfully located the burial pits. Therefore, the usefulness of EM in these settings is limited.

The surveys provided a basis for the follow-up drilling and sampling programs required in hazardous waste site assessment. These case histories show that EM is a rapid, cost-effective reconnaissance tool for many potential hazardous waste sites in Minnesota.

Chapter 2

Geophysical Applications

Seismic Exploration

By Andrew Streitz

Department of Natural Resources

Introduction

The successful application of geophysical methods depends upon contrasts in physical properties of the rocks or deposits being studied. The seismic methods rely on contrasts in the velocities of propagation of an energy wave; electrical resistivity (ER) and electromagnetic induction (EM) both rely on contrasts in the ability to pass an electrical current or detect a phase change in a transmitted electromagnetic field. Each tool provides a different 'view' of the subsurface: seismic is suited to define structure, the boundaries separating consolidated or unconsolidated, geologic units; EM provides a fast survey for near surface anomalies (e.g. barrels, disturbed ground, foundations) or trace ground water contamination plumes; while ER measures the same physical parameters (though as the inverse of EM) and can be used to both a greater depth of investigation and provide finer resolution.

Seismic Methods

Sites discussed in this report are divided by application (i.e. water supply, bedrock, etc.). A short description of the types of seismic tools used, government agencies cooperating with the Division of Waters (DOW) on this project, targets of interest and work sites follows.

Seismic Refraction

This technique has been used for over 50 years to measure depth to bedrock and track lateral variations in near surface geologic structure. Though the equipment purchased for this project was configured with the more sophisticated shallow seismic reflection research in mind, it is also well suited for the simpler refraction investigation.

Seismic Reflection

Seismic reflection is a new tool that is more flexible than refraction exploration, capable of defining depths to geologic unit boundaries as shallow as 40 feet and to depths greater than 1,000 feet. It has now become the most important seismic tool for investigation of the Minnesota geologic environment.

Cooperators

Division of Minerals (DOM)

The current emphasis in Minnesota mining is on iron ore, yet substitutes must be found for this declining industry. One alternative is gold and associated metals. Seismic techniques were used to assist in exploration for these minerals. Seismic exploration (both refraction and reflection) complements other geophysical tools that the DOM has at its disposal. By calibrating results from these other techniques with information available from seismic work, the Division of Minerals is able to prioritize sites for expensive exploratory drilling.

Minnesota Geological Survey (MGS)

Gathering information on the bedrock geology of Minnesota is difficult due to the thick blanket of glacial material found in much of the State. Indirect exploration methods, such as geophysics, provide a cost-effective method of exploring bedrock under these conditions. County atlas work has made up the bulk of cooperative MGS/DOW effort as the MGS seeks to fill in gaps between existing drill points and make this information available to government planners and industry in county-wide reports.

United States Geological Survey (USGS)

The USGS has been a partner in the development of shallow seismic reflection to define buried drift aquifer boundaries. This investigation of unconsolidated units has required the most research and development, though success here has improved results for all seismic targets.

Pollution Control Agency (PCA)

Siting the proper location for monitoring wells is crucial to understanding the movement and, therefore, consequence of contaminants in ground water. The Agency has been more interested to date in electromagnetic induction for the promise it holds of directly sensing contaminants in ground water. Attention is now being focused as well on seismic exploration's ability to map glacial and bedrock units that affect the movement of ground water and thus improving the understanding of the possible movement of the contaminants.

Study Sites

Water Supply Studies

Many of the areas included in this section were part of the original research effort to develop shallow seismic reflection as an exploratory tool (1983-1985). Targets range from buried drift aquifers to bedrock surfaces. For the most part, geologic control was available from nearby wells. The USGS cooperated in this effort. An abstract of a professional presentation is contained in Appendix B.

Marshall County

The Warren site was extensively drilled in the 1960's as part of a USGS investigation of buried drift aquifers. Working from this control, reflection results were very good to the upper boundary (till/sand) and good to the bottom (sand/till). It is suspected that great variation in the depth of the lower boundary degraded the reflection signal.

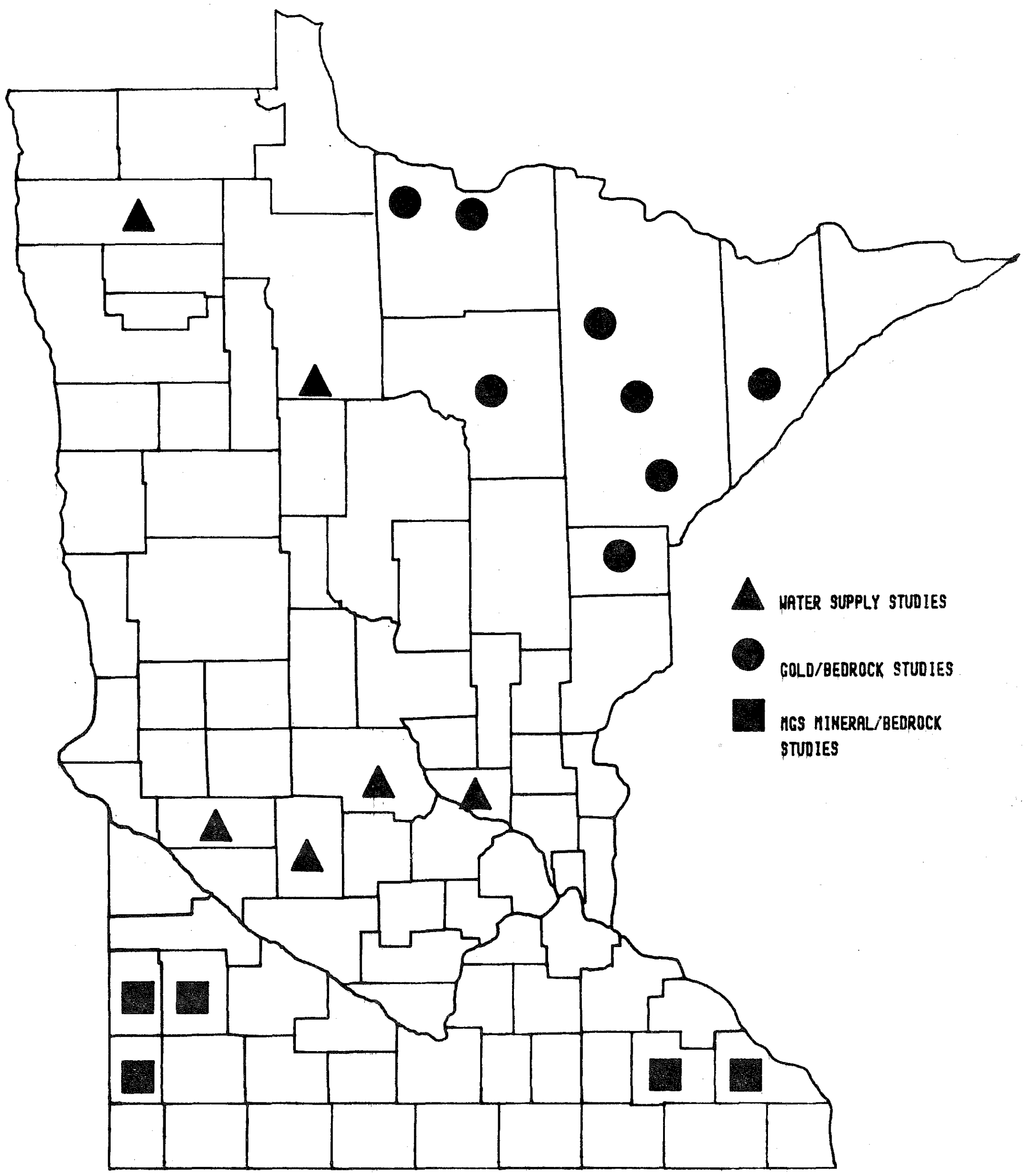
Beltrami County

The reflection tools was successful in tracing a boundary later identified by drilling as a sand/till interface throughout the Bemidji area. A shallower boundary was not identified in drill logs.

Swift County

This area was intensively studied in the previous biennium. Improvements in the equipment (analog filters) and in the energy source (pipe green) provided opportunity to do more referred work and to compare results. Improvements did greatly improve results; in one instance, aquifer boundaries were traced in detail over 1,000 feet from an observation well.

FIGURE 2.1 LOCATION OF SEISMIC INVESTIGATION SITES



Stearns, Kandiyohi and Sherburne Counties

This study area provided the opportunity to concurrently collect and analyze both surface and bore-hole geophysical data. The borehole data was collected by the USGS on part of the USGS-DNR cooperative study of Bonanza Valley aquifers. This effort enabled direct comparison of data sets with borehole stratigraphy.

Pioneering work was also carried out with Vertical Seismic Profiling (See Appendix B) which provided a new seismic technique to augment surface work and for calibration of the velocity model for surface work. This region and the work described here makes up the bulk of the upcoming USGS professional paper slated for publication in 1988.

MGS Mineral/Bedrock Studies

Winona, Olmsted Counties

When this work first started, seismic refraction was the only tool used. By the later stages of data collection for the Olmsted County Atlas, shallow reflection was being used 50% of the time. (Current atlas work in Hennepin County is 100% reflection-based). This area provided ideal geophysical study conditions as bedrock is near surface. This study also benefitted from the introduction of a new seismic source, the elastic wave generator (EWG or Whammer), a powerful non-destructive source for greater depth of penetration.

Pipestone, Lincoln and Lyons Counties

The techniques used to gather shallow reflection information may also be used to collect information from a greater depth. In southwest Minnesota, the MGS was eager to trace the Precambrian Sioux Quartzite in order to identify bedrock valleys that may contain manganese deposits. With the use of the EWG source, very good results were obtained to depths greater than 1,000 feet, results that had close correlation to exploratory wells that had been put in by industry. The prospect of gathering information to that depth has suggested other projects to the MGS, some of which will be carried out this fall.

Gold/Bedrock Studies

The mineral exploration work with the Division of Minerals (DOM) started out as just refraction investigations and is now mostly reflection-based. The one exception is the tracing of fracture zones, which is still done best with the refraction tool. Over 200 sites have been investigated in the counties of St. Louis, Koochiching, Itasca, Carlton and Lake; results have been very good. Correlation between reflection calculations and true depths (when drilled) have consistently very good. DOM has also incorporated reflection surveys so completely into their strategy of exploration that they consider surface geophysics a logical first step at any new site. This is in large part due to the leadership of their staff geophysicist and his working relationship to his understanding of the cost-effectiveness of reconnaissance tools.

Interest in mineral potential is widespread and considerable work is being done by the Canadian Geological Survey (CGS). Informal communication with staff of CGS has been maintained so that we are sharing the results of our developmental work. A technique called broad till sampling, which the Candians have developed, is of great use to us in Minnesota. It involves the application of seismic reflection to determine the boundaries between till lobes and the depth of the base of the till (the till-bedrock interface). These zones are then sampled and analyzed for mineral content. It is hoped that the integration of geological interpretation, geophysical exploration and geochemical sampling will identify new mining opportunities for the State.

Appendix B

"Locating Confined Aquifers in Glacial Drift with Seismic - Reflection Methods" (Abstract) by Jeffrey D. Stoner and Andrew R. Streitz

"Off-End Surface Seismic Sounding with Vertical Seismic Profiling in Glacial Terrain" by Andrew R. Streitz

LOCATING CONFINED AQUIFERS IN GLACIAL DRIFT
WITH SEISMIC REFLECTION METHODS, WESTERN MINNESOTA

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Seismic-reflection methods were used to locate confined sand and gravel aquifers at depths from 20 to 84 meters below land surface at selected sites in Stearns and Marshall Counties, Western Minnesota. Reference to logs of test holes drilled near the Stearns County site showed that depths to seismic reflectors generally correlated within 4 meters of either (1) the bottom or center of two aquifers, each less than 5 meters thick, and (2) both the top and bottom of another aquifer that is 7 meters thick. Three other reflectors at the site correlated to minor textural changes in the clay-rich till that represent non-aquifer boundaries. Differences between non-aquifer and aquifer boundaries could not be identified from the seismic record. However, borehole sonic, gamma, and resistivity logs showed that the highest-quality reflection patterns matched interfaces having sharp contrasts in acoustic velocity and grain size. Sonic-log analyses quanlitatively verified that a two-layer velocity model based on average velocities of sound propagation through unsaturated and saturated glacial drift is valid for estimating reflector depths from seismic arrival times, even for conditions where velocity in the aquifer is 20 percent slower than in the surrounding till. At the Marshall County site, reflection methods successfully delineated the top of a 15-meter-thick aquifer that ranged from 23 to 26 meters below land surface. The method was unsuccessful in delineating the bottom of the aquifer, however, because of the oversimplified velocity model used. Hydrogeologic conditions common to successful use of seismic reflection at the study sites included (1) a depth to the water table of less than 2.5 meters, (2) moist, sandy clayey soil, (3) a relatively flat-lying reflecting strata, and (4) a relatively sharp lithologic contrast between aquifer and confining unit.

"OFF-END SURFACE SEISMIC REFLECTION SOUNDING WITH VERTICAL SEISMIC PROFILING IN GLACIAL TERRAIN"

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Abstract

The successful collection and interpretation of surface shallow seismic reflection information is dependent upon the proper mix of field technique, equipment configuration and processing strategies. Surface seismic geophysical results were compared against geologic and geophysical logs at a site near Belgrade, Minnesota. Targets of interest included aquifer boundaries within glacial deposits. Vertical seismic profiling (VSP) information also was gathered to clarify the reflection velocity analysis and judge the validity of the processing routines. Depths calculated for reflection arrivals from the surface seismic records correlated to within 4% of a 27 meter reflector and within 6% of a 73 meter reflector identified from well logs . The agreement of VSP-calculated velocities and the root-mean-squared velocities developed from the surface refraction-based velocity model was also of a high order, with a correlation of 97% between the two velocities for the 27 meter interface. Moreover, analysis of the entire waveform from several of the VSP records revealed reflections from two unit boundaries that correspond with the dominant reflectors isolated from the surface seismic records. This study provides a reference point for further surface shallow seismic reflection work in glacial terrain and reinforces the interpretation of our previous investigations in other parts of Minnesota. The conclusions both strongly support the rationale behind the provisional, exploratory surveys that dominate our work and highlight the value of VSP to future projects.

Introduction

Shallow seismic reflection exploration has evolved rapidly in the past five years due to advances in hardware and field technique. In Minnesota, we have worked to modify this new tool into an instrument capable of fast and reliable surveys in the service of resource development, ground water management, and contamination investigations. The direction of the modifications was influenced by the geophysical properties of the near ubiquitous, thick layer of glacial material of the state and the need to keep costs down for potential users within the geoscience community. For targets of low intrinsic value, this last requirement is a necessity.

The field procedure chosen is the off-end spread. It is a powerful reflection seismic exploration tool because arrival patterns are easily recognized, data are simple to interpret and because it is flexible enough for use in different subsurface environments.

This paper presents the progress to date of a four year joint project of the Minnesota Department of Natural Resources, Division of Waters and the United States Geological Survey. This project has been funded by the Legislative Commission on Minnesota Resources. An overview of the approach of one site is presented to illustrate the project's goals and successes. Because of space constraints the data collection and processing procedure will be presented in an abbreviated form. The surface seismic data is part of a larger comprhensive study of shallow seismic reflection investigations (Stoner, 1987).

Off-end method

The off-end spread geometry consists of a common line of geophones and source position lying with the source off either end (forward or reverse shot point). The off-end seismic record provides a systematic study of the expanding wavefront and its passage through the subsurface. This approach confers several benefits, the most important of which is the interpretation of the seismic record. It is from this basic geometry (Figure 1) that identification of the various arrival patterns has been accomplished in refraction-based engineering investigations. A substantial amount of work has been done with off-end spreads, and although the majority of these surveys concentrated upon first breaks, the unique wave path of the reflected energy is readily identified on the seismic record produced by this method. The selective generation and filtering of high frequency energy allowed by improvements in hardware has strengthened this field strategy through the increased efficiency of shallow seismic reflection exploration, yet the method is still dependent upon the off-end geometry for signal identification. The fact that both reflection and refraction information can be collected with one spread geometry speeds data collection.

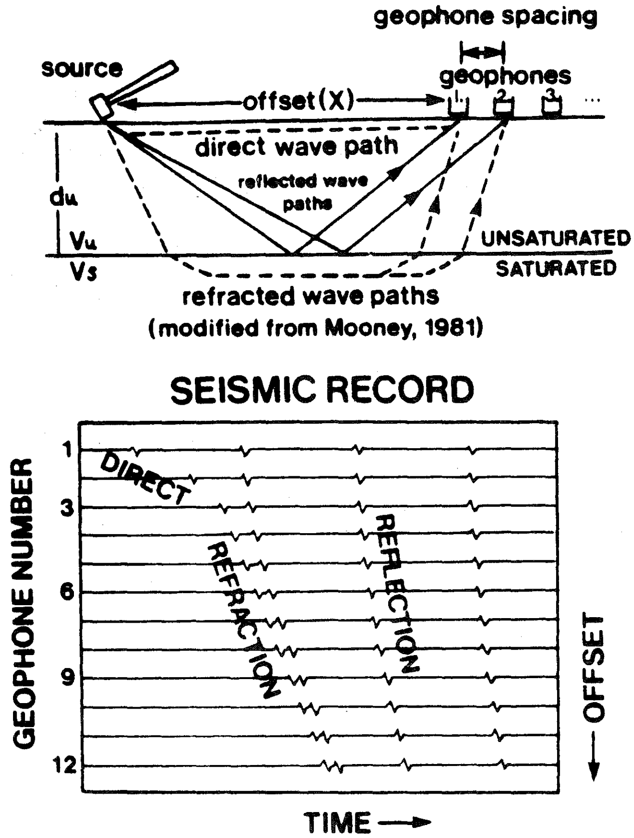

Figure 1. Idealized cross section of direct, refracted, and reflected wave paths from seismic source to geophones and idealized seismic record.

The refraction analysis that results from the off-end spread is the basis of the two-layer velocity model. The assumption of this approach is that the geologic column (quaternary deposits) may be divided into two distinct acoustic regimes: unsaturated and saturated unconsolidated sediments. This division therefore requires only the acoustic velocity of both the saturated and unsaturated material and the depth of the unsaturated zone for the calculation of a root-mean-squared velocity. One strength of this method is that the zone with the greatest variation in velocities between offsets and spreads is also the zone from which we receive the most information, that being the near-surface unsaturated material. Close monitoring of the unsaturated velocity in conjunction with the more consistent saturated velocity allows the calculation of an accurate velocity model.

Because of the geometry of the off-end spread, it is biased toward soundings. This stems from the small lateral extension of the sampled interface (roughly half the length of the surface seismic spread) that is required for the identification of the tell-tale reflection arrival pattern (the hyperbola formed by the reflection arrivals in Figure 1) across the seismic record. The depths provided by these soundings are all the information that is required for the majority of targets in our work.

Where continuous profiling is required, the off-end method may be repeated at set intervals to provide a series of depth measurements along a reflector. In effect this resembles a profile of sounding surveys. The interval required to adequately define a reflector must be determined in the field due to the unpredictability of the lateral extension of a glacial interface.

Data

The off-end method was tested at Belgrade, Minnesota. This included surface seismic work, geologic and geophysical logs from a test well and vertical seismic profiling (VSP) data. The Belgrade site (Figure 2) lies in Stearns County in the central part of the state. Four spreads of 12 phones each were collected, all with three meter takeouts (Figure 3). Off-sets ranged from 3 to 50 meters for both forward and reverse shots. Equipment included the Bison Geopro 8012A, a 12 channel signal processing seismograph, 40 Hz natural frequency, marsh case geophones and a 12 gauge pipe-gun source.

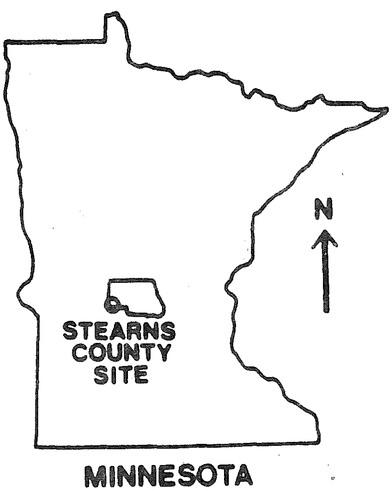

Figure 2. Location of Belgrade Study Site.

A sample seismic record from spread 2 is displayed in Figure 4, where the source offset is 33 meters south. The record was collected with an analog filter bandpass of 75-1000 Hz and processed with a digital filter bandpass of 150-350 Hz. The arrival patterns identified are first breaks (unlabeled) and three reflections labeled 2, 3, and 5. For this site, five reflectors were isolated (numbered consecutively from shallowest to deepest).

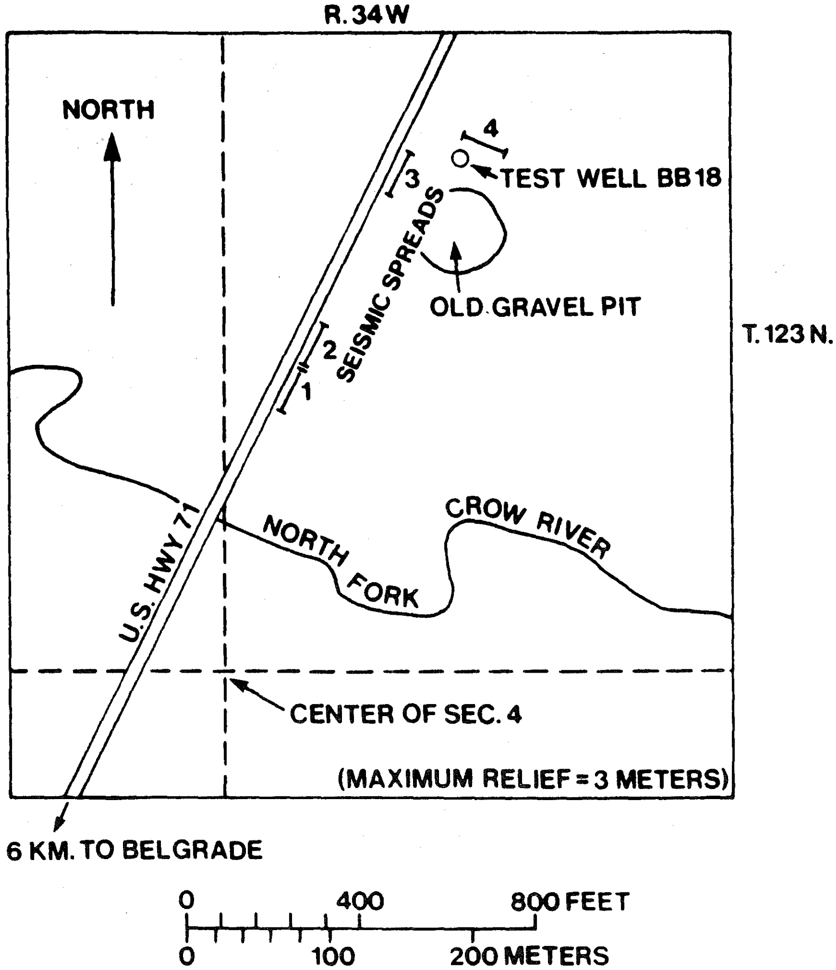

Figure 3. Location of seismic spreads at the Belgrade site in Stearns County.

The velocity model is developed as described above; acoustic velocities are 380 m/s in the unsaturated material and 2220 m/s in the saturated material. The thickness of the unsaturated zone is 0.9 meters. These numbers result from data taken from all four spreads and lead to the calculation of a Vrms for each reflector which in turn leads to the calculation of five depths: 27.3, 34.1, 54.3, 68.0 and 74.1 meters.

The calculated depths may be compared to the geologic and downhole geophysical logs collected at the test well (Figure 5). The geologic log has been generalized into till, sand and gravel aquifer, and bedrock. Superimposed across the logs are dashed lines which represent the calculated depths from the reflection analysis. The calculations, depths and the logged aquifer boundaries are very close. Confined aquifer boundaries from the geologic log are 27.4 - 32.3, 42.1 - 45.1, 49.7 - 53.0 and 67.7 - 70.1 meters. The base of the unconfined aquifer was too shallow for this method. Bedrock is at a depth of 74.1 meters.

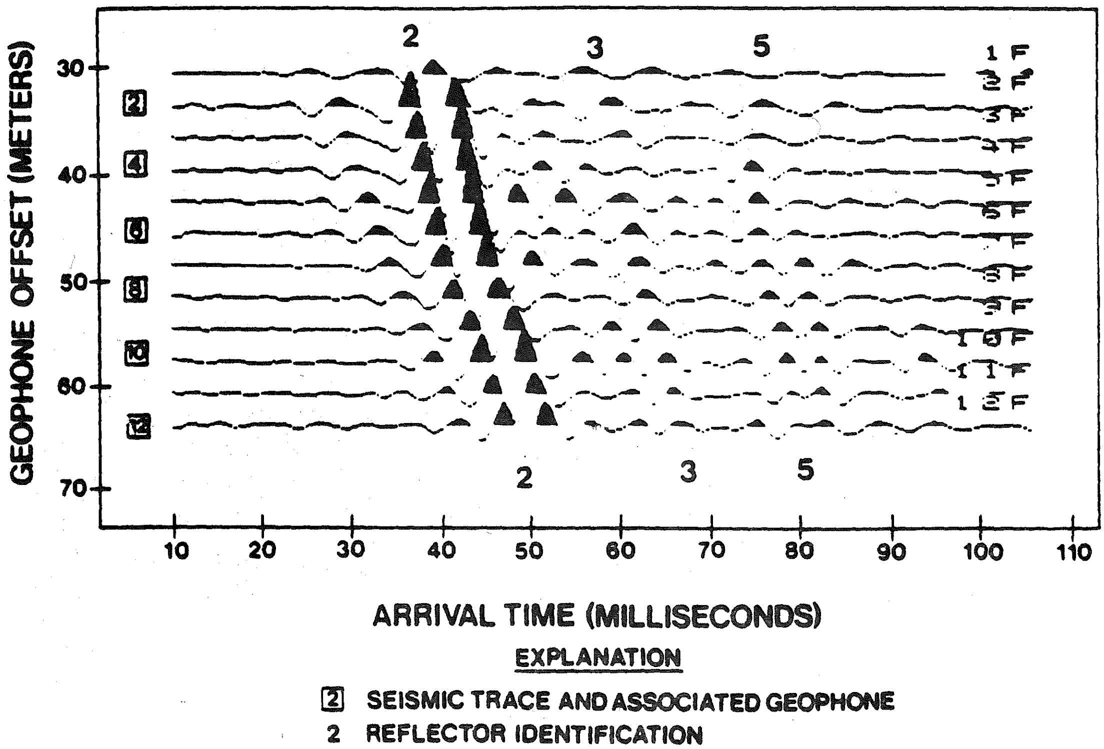

Figure 4. Seismic record with reflection identification, Belgrade site.

The sonic log is useful for evaluating the physical properties of the subsurface boundaries that surface seismic work is dependent upon. Using the hole diameter (as measured by a caliper prior to the running of the other logs) to modify the interpretation of the sonic log, it is apparent that the major velocity contrasts within the geologic column were visible to surface reflection seismic investigations. However, sonic log anomalies do not correlate to surface seismic results. Some velocity anomalies relate to textural changes within the till as was observed at other sites in the same county.

To provide a different view on the accuracy of the two-layer velocity model, three methods of determining the subsurface velocity distribution are displayed in Figure 6. Far left is the geologic log for reference. Next to this is a plot of the change of velocity with depth of the sonic log-derived interval velocities and the simpler case (2 velocities, no change below 1 meter depth) provided by the two layer velocity model. On the far right, a comparison of the calculated Vrms values from the two interval velocity plots on the left. The dashed line is the Vrms produced by the two layer model. The small circles represent calculated Vrms values developed from the sonic log at aquifer boundaries. The two are in agreement, though there are built-in errors from the use of interval velocities in this way (Mooney 1980). The most accurate method to determine subsurface velocities is through the use of a downhole geophone. This follows from the nature of the Vrms, which is an estimate of the composite velocity of the signal from the surface to the reflector. The X's are the velocities determined from VSP data. The velocities as measured by the downhole geophones provide a very close correlation with the calculated velocities of the two-layer velocity model.

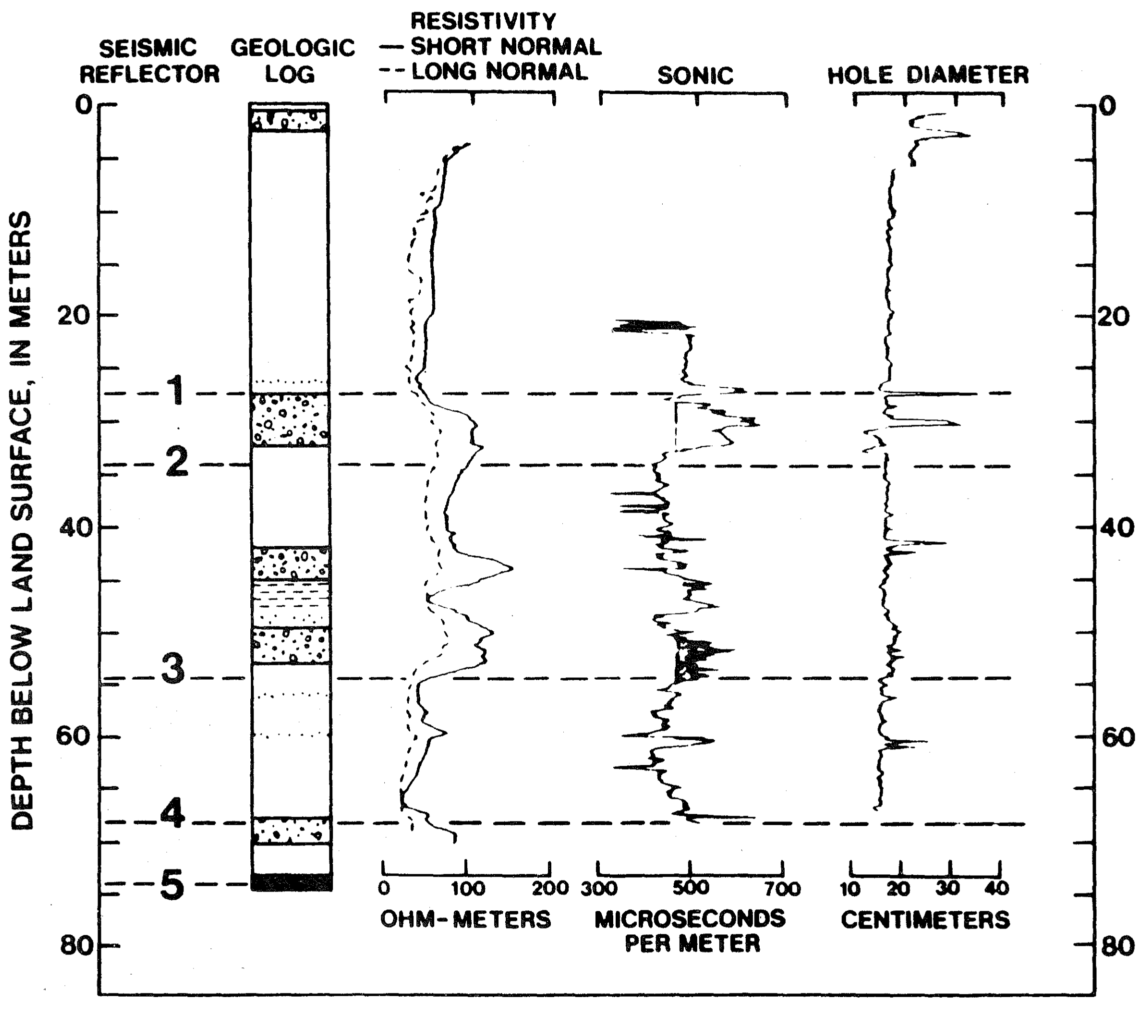

Figure 5. Correlation of reflection depth calculations with geologic and geophysical logs.

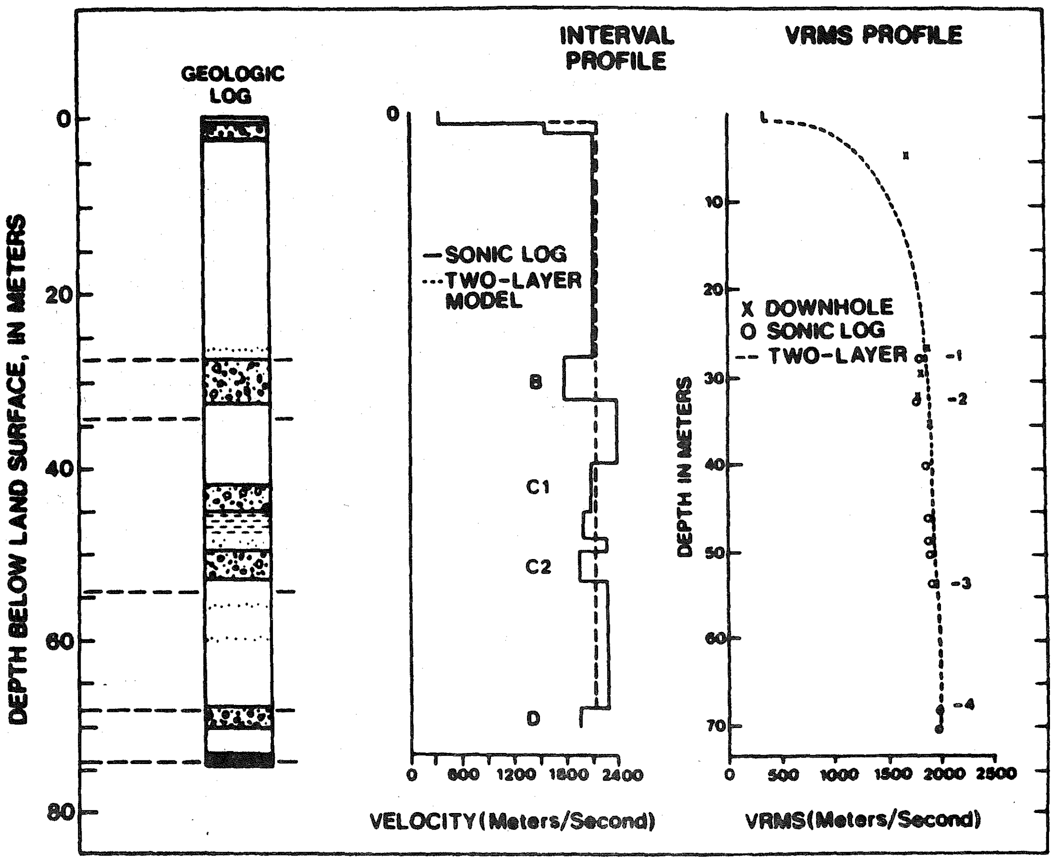

Figure 6. Comparison of two-layer velocity model vs. geologic and sonic logs and downhole geophone velocity data.

Vertical Seismic Profiling

Vertical seismic profiling is seismic exploration with the geophones strung vertically down a test hole. In the case of engineering geophysics, except for the use of a modified geophone, all of the equipment and most of the data collection routine remains the same. The 8 Hz, surface geophone sensor is encased in a molded plastic 'bottle' with an attached air bladder. Coupled with the electronic cable transmitting the geophones output to the seismograph is tubing for the inflation of the bladder from a compressed air source. At each station, the bladder is filled and the geophone sensor is thus coupled to the well casing. The signal source for the two records displayed here is a 16 pound sledge.

The cross-section in Figure 7 illustrates a few of the possible ray-paths of acoustic energy from source to geophone. The source position and geophones are no longer placed in a single line, though they do share a common plane. This leads to a change in the appearance of the seismic record. The first arrivals probably follow a more complicated path because of the glacial terrain, yet the geometry is not much more complex than a surface seismic example. An important point to concentrate upon is the reflection path. The closer the geophone is to the surface, the longer the ray-path between source and geophone. The consequence is that the reflection arrival pattern of the VSP record has a positive slope. For the special case of a multiple reflection, the pattern formed by both the upgoing and downgoing energy will be an inverted 'V'.

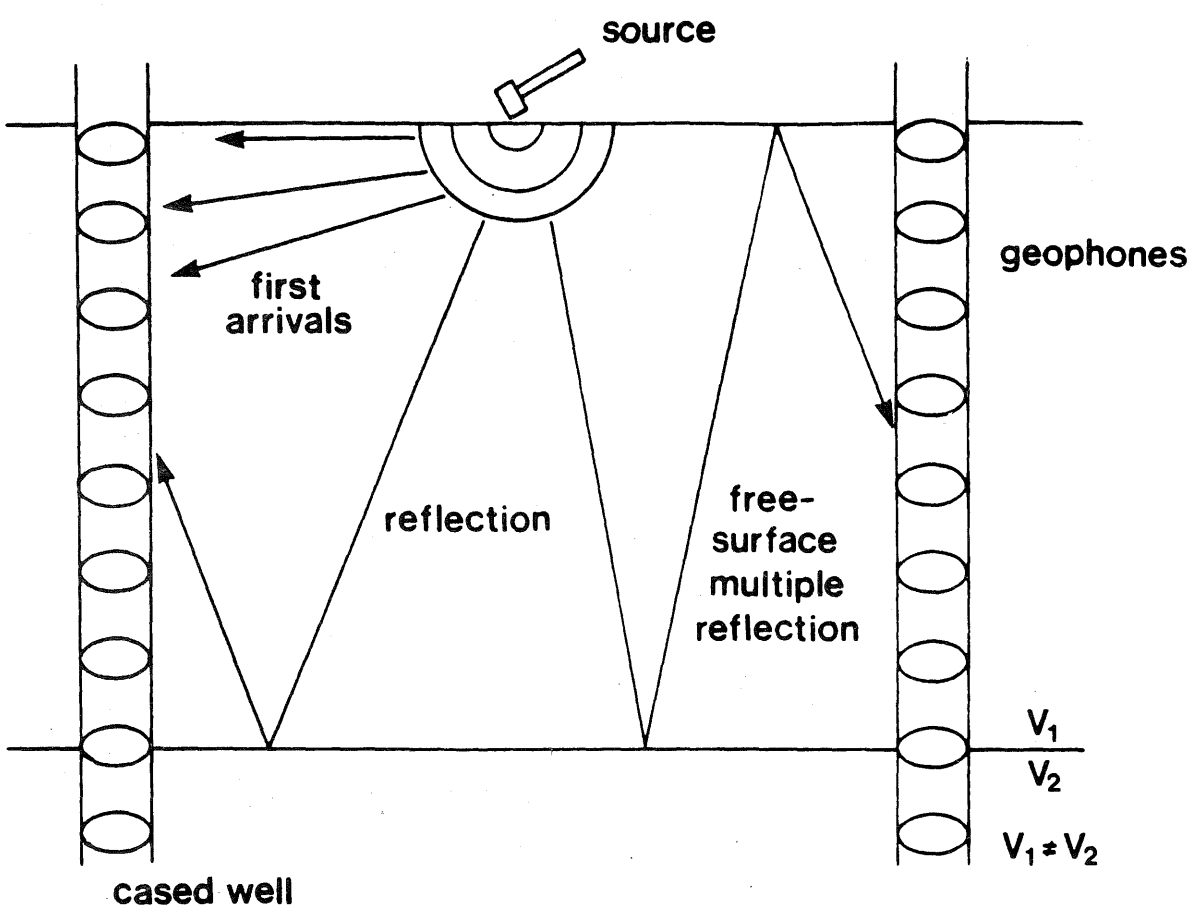

Figure 7. Cross-section of acoustic wave-paths to downhole geophones in test wells.

A VSP record (Figure 8) was collected at the Belgrade site test well; the first geophone was at land surface, the separation between geophone depths is 4.5 meters and the source offset is 45 meters. The change in slope for first breaks is not a measure of the increasing velocity with depth but rather an artifact of the geometric relationship between depth and source offset (in fact, the change in the first break slope is opposite that of what may be expected due to an increasing material velocity). The arrival pattern marked 'A' is a reflection event that emerges from a reflector at approximately 28 meters. The arrival pattern marked 'B' appears to arise from a reflector just below geophone 12. Extrapolating down 4.5 meters gives a depth of about 55 meters.

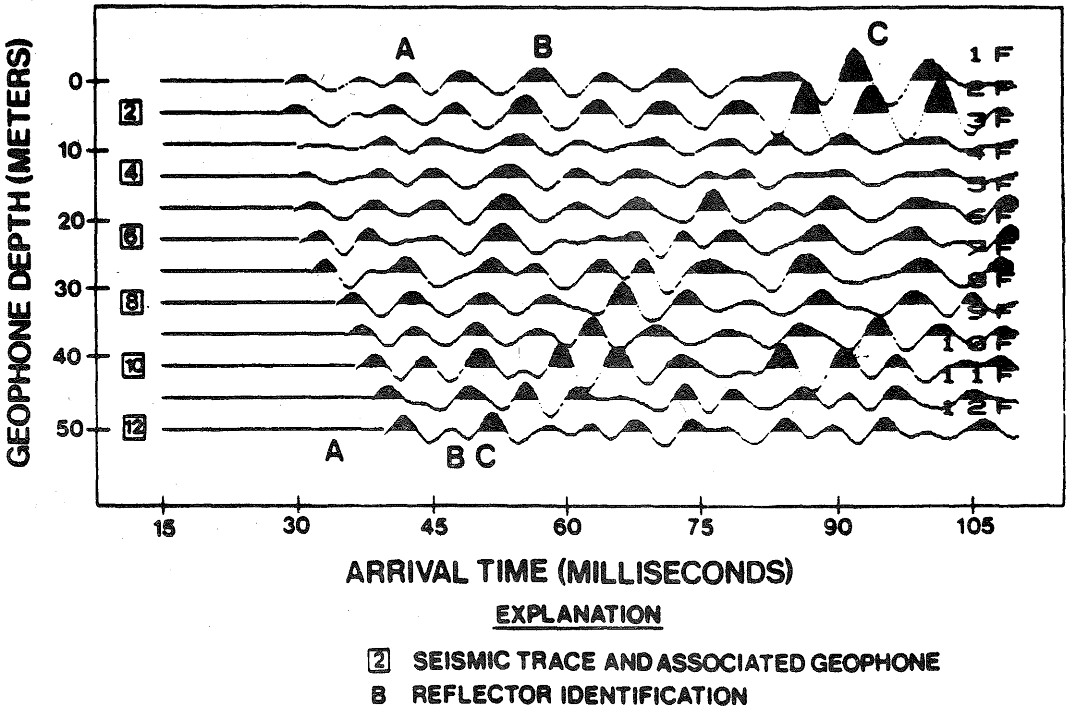

Figure 8. Downhole geophone seismic record with reflection identification, Belgrade site; 45 meter offset.

A third reflection event merges with arrival 'B', here labeled arrival 'C'. Because of the different character of this pattern (higher energy, higher frequency and lower apparent velocity across the geophones) it would seem to have a different origin. The simplest explanation would be that this is a tube wave, energy traveling up through the water-filled casing. Such a pattern is ubiquitous in VSP work. A defense of this identification is the correlation of the extrapolated origin of the energy pattern and the bottom of the casing (53 meters). There are several arguments against such an interpretation, however, the first being that a tube wave usually is first spotted as a downgoing event that forms from the coupling of ground roll from the source wave (travelling along the surface) with the well casing (Wyatt, 1981). No such downgoing pattern is recognized in this body of work.

A more sophisticated discussion is taken from a paper on VSP theoretical seismograms (Suprajitno, 1986). Here the authors state that a primary transmitted wave reaching a unit boundary can give rise to both a primary-wave reflection and a shear-wave reflection and exhibit the patterns seen in Figure 8. Further, they contend that such a shear conversion is off-set dependent and high amplitude relative to primary-wave reflections, both of which conditions are met by this VSP work. Off-set dependent refers to the importance of the proper geometry for an arrival pattern to appear in the seismic record. Tube wave is not off-set dependent, whereas the pattern discussed here is only recognized on two records. The second point, relating to relative amplitude, is less visible in Figure 8 due to processing (a wide bandpass filter). The unprocessed record revealed arrivals with higher amplitudes for the pattern labeled 'C' than the other two sets of reflection arrivals.

One last conclusion that may be gained from this shear-wave generation is the comparison of the apparent velocities of the two reflection patterns that emerge from the reflector. The ratio of the velocity of 'C' to 'B' is approximately .2. This is well within the expected ratio of shear to primary wave in glacial terrain (Mooney, 1980).

A second VSP record (Figure 9) was collected with the first geophone 4.5 meters below the surface, a geophone separation of 3 meters and a source offset of 15 meters. This record is similar to Figure 8, where reflection arrival patterns 'A' and 'B' coincide with the same reflectors as the previous record (or in the case of arrival 'B' where it is estimated to coincide). The one difference lies in the behavior of the upgoing pattern 'B' when it reaches the surface. The reflection itself is reflected off of the land surface and is recorded by the geophones a second time on the same traces as a downgoing arrival pattern labeled 'D'. This 'free-surface' reflection appears to have a large amplitude, low frequency wavetrain that dominates the latter portion of the seismic record.

The two reflections labeled 'A' and 'B' correlate closely with the downhole logs and surface geophysics. Further analyses may reveal the physical properties of the units adjacent to the reflector that were responsible for the successful VSP reflection interpretation and the physical properties of units adjacent to interfaces that were not visible to seismic exploration techniques. Further analyses may also reveal a correlation between physical properties of glacial units and the success of both VSP and surface reflection investigations.

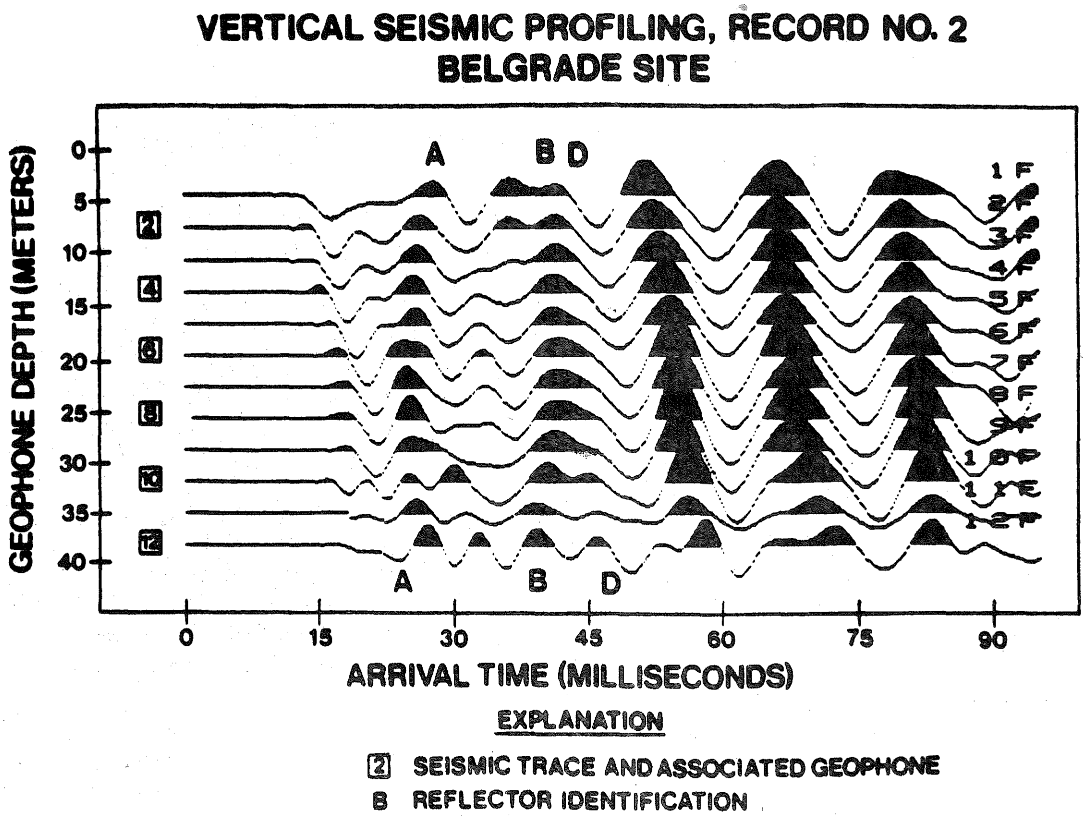

Figure 9. Downhole geophone seismic record with reflection identification, including multiple reflection, Belgrade site.

Conclusion

The off-end method of shallow seismic reflection sounding is a powerful tool for the investigation of the glacial environment. When used in conjunction with geologic control, it is a cost-effective means of tracing glacial unit boundaries between test wells. In areas without adequate control, surveys may be collected and interpreted from a geophysical point of view and then 'calibrated' with selected test wells in selected locations. The addition of VSP as an investigative technique opens the possibility of more detailed analyses of the nature reflectors and the units that define these reflectors.

Acknowledgments

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Author's Biography

Streitz, Andrew R. Mr. Streitz graduated from St. Olaf College with a B.A. in History and received an M.S. in Geophysics from the University of Minnesota. Employed by the Minnesota Department of Natural Resources, Division of Waters he has for four years worked to develop shallow seismic reflection as an exploratory tool.

Chapter 3

"Isotope Analyses for Identification of Nitrogen Sources in Ground Water, Central Minnesota".

by

Henry W. Anderson, Jr.
U.S. Geological Survey

ISOTOPE ANALYSES FOR IDENTIFICATION OF NITROGEN SOURCES IN GROUND WATER, CENTRAL MINNESOTA

by Henry W. Anderson, Jr.
June 1987

Nitrate concentrations have increased in water from surficial-sand aquifers in Minnesota in recent years, causing concern about the source and significance of nitrate. Several studies were conducted in Minnesota that identify land-use settings where nitrates are a concern. Intensively cultivated areas, especially irrigated areas, are related to nitrate concentrations that are significantly above natural backgound levels. Ground-water contamination by nitrates from residential areas where septic systems are used was investigated also. However, debate continues regarding the source of nitrate in some areas. Sources that were suggested include rainwater, natural decomposition of organic material in fields, commercial fertilizers, and animal wastes from feedlots and septic systems.

In hope of resolving the debate over the source or sources of high nitrate concentrations in surficial sand aquifers, the Minnesota Department of Natural Resources (MDNR) requested the U.S. Geological Survey to conduct a study of nitrate sources based on the results of previous studies. The purpose of the study was to determine, at least qualitatively, the relation between various land uses and high nitrate concentrations in the surficial aquifers. Results of the study will be used by water-resources planning and management agencies to encourage changes in land-use practices that would reduce further degradation of ground-water quality and possibly reverse the present trend of increasing nitrate concentrations.

Background

Variations in naturally occurring nitrogen-isotope ratios ($^{15}N/^{14}N$) have been used by Kohl and others (1971) to identify sources of nitrate in surface water. Kreitler and others (1978), Gormly and Spalding (1979), and Flipse and Bonner (1985) have used isotope ratios in studies of ground water. Nitrogen-isotope ratios are used to define delta^{15}N, which quantifies the relative abundance of ^{15}N isotope in various compounds where:

$$\text{delta}^{15}N = \frac{^{15}N/^{14}N \text{ Sample} - {}^{15}N/^{14}N \text{ Standard}}{^{15}N/^{14}N \text{ Standard}} \times 1000 \qquad (1)$$

The $^{15}N/^{14}N$ isotope ratio used as a standard is that of nitrogen in air. The delta^{15}N values are calculated based on equation (1) and expressed in permil or parts per thousand.

Edwards (1973), working in an area of Webster clay-loam soils, indicated dissatisfaction with a "natural labeling" approach and recommends fertilizer tracing using fertilizer artificially enriched or depleated in ^{15}N. Areas with heavy soils, such as where he worked, are considered unsatisfactory for use of natural-isotope ratios to identify sources of high nitrate concentrations. Rapid infiltration through sandy soils is a prerequisite for use of natural-isotope ratios. Hauck and others (1972) question Kohl and others (1971) in their use of stable isotopes to identify sources of nitrate in surface water. Questions regarding the effect of soil were raised, and isotope fractionation was identified as a complicating factor. Kohl's response to Hauck and others (1972) was that "All the fractionations (of nitrogen isotopes) tend to understate the contribution of fertilizer nitrogen to the nitrate nitrogen appearing in surface waters." These comments emphasize the importance of careful consideration of various factors affecting delta^{15}N values, including soil types and fractionation of nitrogen isotopes.

Flipse and Bonner (1985) indicate delta^{15}N values for fertilizers used on Long Island, New York, ranged from below 2.4 to above 5.0, and that ground water below heavily fertilized fields can have delta^{15}N values that average between 6.2 and 6.5. This indicates the importance of determining representative reference delta^{15}N values for nitrate sources as well as for nitrate in ground water in each study area. These problems were discussed also by Hauck (1973) and Bremner and Tabatabai (1973). However, successful use of this stable-isotope technique in identifying nitrate sources in ground water was reported by Kreitler and Jones (1975) in Texas; Kreitler, Ragone, and Katz (1978) in Long Island, New York; Gormly and Spalding (1979) in Nebraska; and Flipse and Bonner (1985) in New York.

Verification of laboratory and sampling procedures

Results of analyses of replicate samples within 0.3 permil indicate good results from the laboratory as is shown in the following table. Even feed-lot

Land-use setting	Well depth below the water table	Date sampled	Delta^{15}N replicate samples	Date and delta^{15}N resampled for sampling verification
Undeveloped	< 10 ft	6/06/86	2.0, 2.1, 2.3	7/9=2.0; 8/2=2.4
Residential	< 10 ft	6/18/86	3.9, 3.8, 4.0	7/9=2.3; 8/19=7.2
Cultivated	< 10 ft	7/01/86	3.2, 3.3, 3.1	8/21=3.0; 8/21=3.2
Irrigated	< 10 ft	7/16/86	4.3, 4.2, 4.4	7/29=4.4
Feed lot	10-20 ft	7/02/86	30.9,34.0,29.9	7/9=32.5; 7/10=33.2

values vary only 6.5 percent above and below the average value. The resampling resulted in verification of the reliability of field-sampling procedures by duplicating the replicate-sampling values within a reasonable range. The resampling values from the residential land-use setting indicate a substantial difference from replicate values; however, the interaction of commercial lawn fertilizer and the influence of septic systems may reasonably explain the difference over a two-month time period.

Nitrate sampling in Minnesota

Samples were collected from 53 wells representing four land-use settings (fig. 31): 12 wells from nonirrigated cultivated areas, 13 from irrigated areas, 14 downgradient from residential areas with septic systems, 10 downgradient from feed lots or cattle yards, and 4 samples from wells in undeveloped areas with minimum effect from man's activities. Sampling sites were selected to represent maximum influence of the various land-use settings; however, samples from seven wells were too dilute in nitrate to analyze for nitrate nitrogen-isotope ratios. Two of these seven samples had high ammonium concentrations and the ammonium nitrogen-isotope ratios were determined.

The mean nitrate concentration (NO_2+NO_3,N) was 14.4 mg/L (milligrams per liter) in nonirrigated and irrigated cultivated areas, 9.0 mg/L downgradient from feed lots, 8.5 mg/L downgradient from residential areas with septic systems, and 2.2 mg/L in undeveloped areas. Two wells screened in septic-system drain fields had nitrate nitrogen concentrations of <0.1 and 0.68 mg/L. The concentrations of ammonium ion as nitrogen in samples from these two drain-field wells were 0.07 and 10 mg/L. Four water samples from feed-lot or cattle-yard areas had relatively high ammonium-ion concentrations: 1.2, 2.9, 3.0, and 120 mg/L. In cattle yards, nitrogen is added to the ground water in the form of ammonia and is oxidized to nitrate through nitrification as the water moves even a few hundred feet away from the cattle yard.

Significance of delta^{15}N values

Other nitrogen-isotope studies have reported that delta^{15}N values less than +4.0 permil indicate commercial fertilizer as the nitrogen source, while values greater than +9.0 permil indicate human or animal waste as the source. Delta^{15}N values between 4.0 and 9.0 may represent a mixing of effects from the two main sources. Data from this study generally support the previously reported results. In irrigated and nonirrigated cultivated areas, delta^{15}N values ranged from -2.2 to +22.6, but the values generally were less than 5.0 (fig. 32). Downgradient from feed lots, delta^{15}N values ranged from 6.5 to 43.1 just as was expected. Downgradient from residential areas with septic systems, delta^{15}N values ranged from 2.3 to 9.6 in wells less than 10 feet below the water table and from 2.9 to 11.7 in wells screened more than 10 feet below the water table. The larger number of low values in shallow wells indicates lawn fertilizer as the main source of nitrogen at the water table. The larger number of higher delta^{15}N values in water from deeper wells indicates that septic-system discharge is an important nitrogen source in wells screened 10 to 20 feet below the water table.

The very large range in fluctuation in delta^{15}N values in cultivated areas either with or without irrigation indicates the presence of a complicating factor that was not taken into account. The cultivated sites were reevaluated regarding the type of fertilizer used. Delta^{15}N values were determined for 23 wells at 16 sites. At 11 wells commercial fertilizer was the main fertilizer used. At 10 wells, both commercial fertilizer and manure was used on the fields. At one site with two wells, manure was the main fertilizer used. Figure 33 shows the distribution of delta^{15}N values by type of fertilizer used and by well depth, either less than 10 feet below the water table or 10 to 20 feet below the water table. Areas in which mainly commercial fertilizer was used had delta^{15}N values clustered around four permil. Areas in which both commercial fertilizer and manure were used had a wide distribution of values. The one site where manure was reported as the main fertilizer had high values in both the shallow and the deeper well.

Conclusions

Nitrogen isotope ratios can be used successfully to identify the source of high nitrate concentrations, but sampling, analysis, and interpretation of data must be done with considerable care. The proceedure works in the sand-plain areas of Minnesota to identify the source of nitrate where there is one clear source. Where there is more than one source of nitrate, some indication of the source can be obtained, but the conclusions will be less certain.

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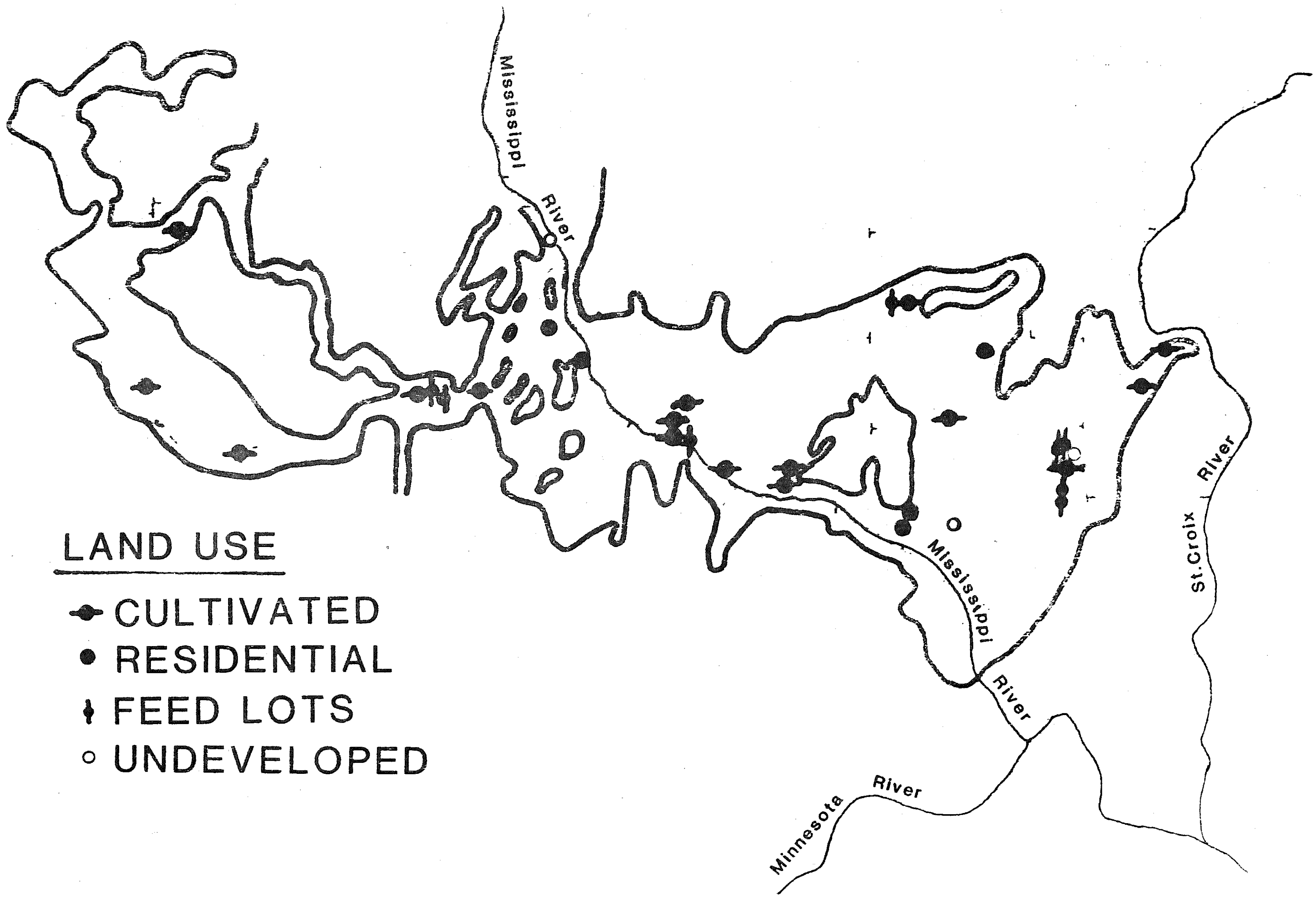

Figure 3.1.-- Nitrogen-isotope sampling locations and land use.

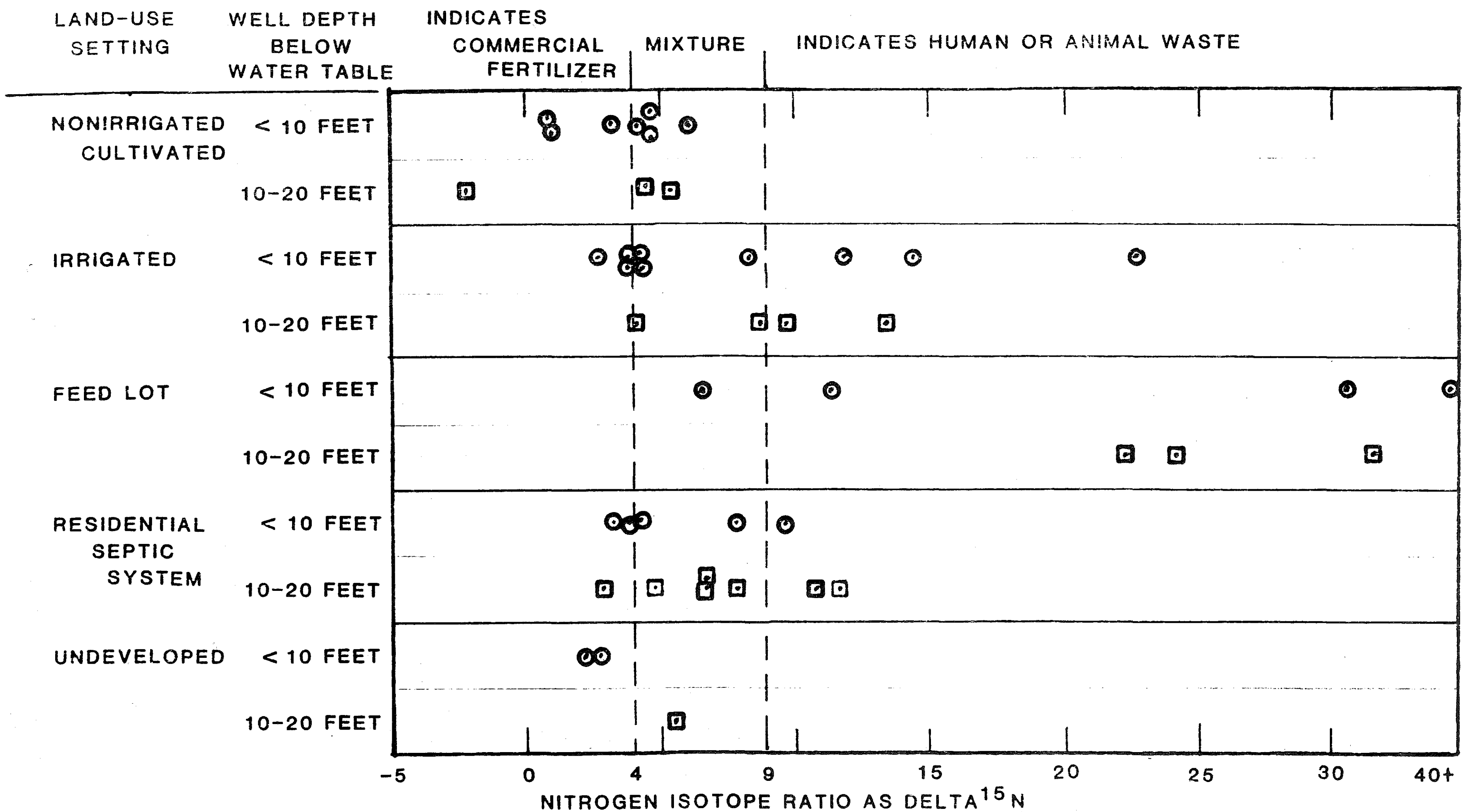

Figure 32.-- Distribution of delta ^{15}N values related to land use and well depth.

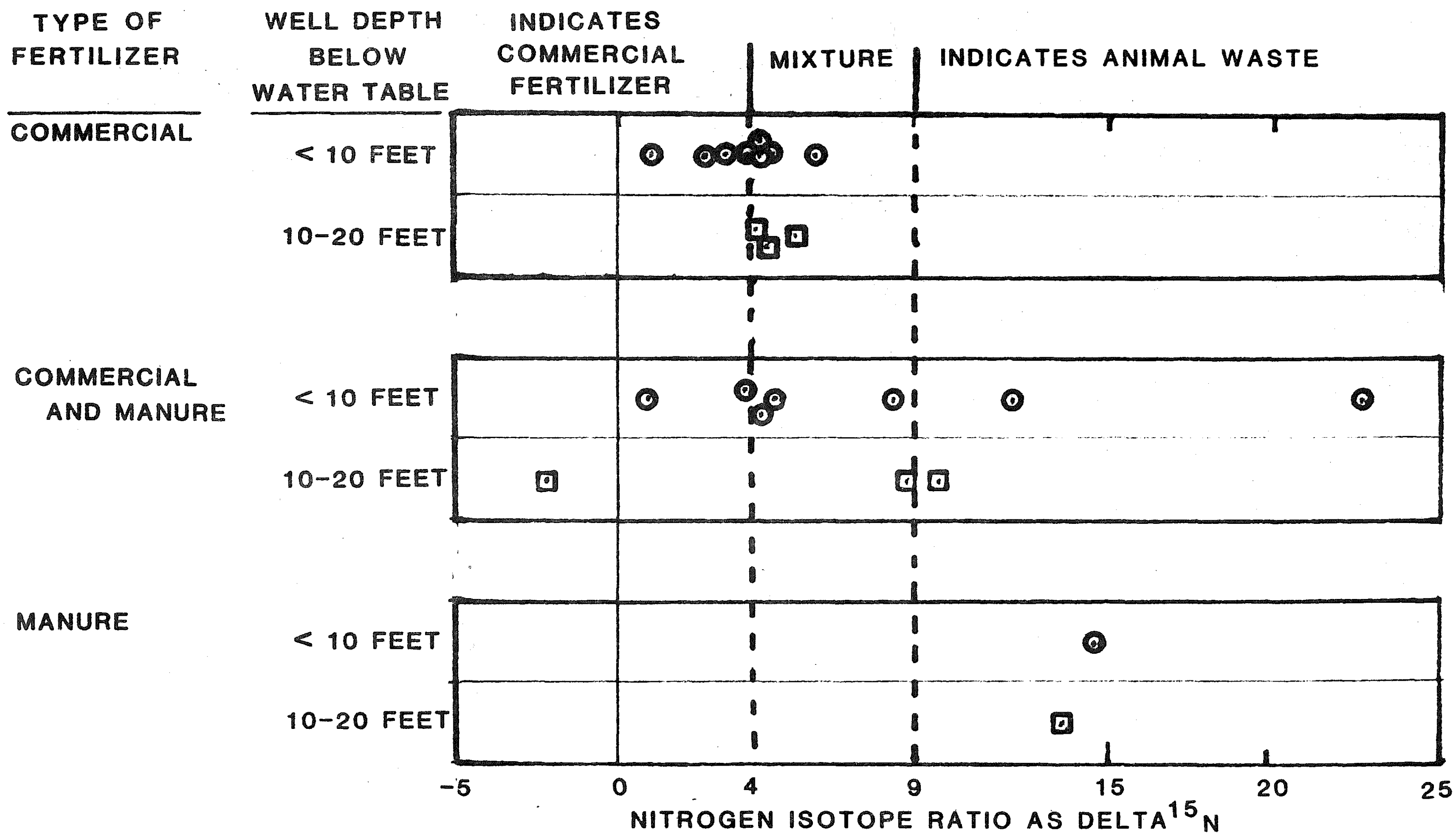

Figure 33– Distibution of delta^{15}N related to type of fertilizer and well depth.

Chapter 4

Ground Water Data Automation

by

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INTRODUCTION

This report summarizes the accomplishments of the "Ground Water Data Automation" contract between the Minnesota Geological Survey and the Division of Waters of the Minnesota Department of Natural Resources. Funding was provided by the Legislative Commission on Minnesota Resources and extended from July 1, 1985 until June 30, 1987.

The principal objective for the project was to establish an automated data base containing summary information about water wells. However, it soon became apparent that the data base had uses and applications beyond those originally envisioned. Other state and federal agencies, local units of government, and the private sector have expressed interest in using it to manage and to exchange water well information. There is great potential for this data base to serve as a major component of a coordinated ground-water information system for the state.

Design Criteria

Prior to this project, the only ongoing development of an automated file containing data from all types of water wells was the water well log data base (WELLOG) maintained by the Minnesota Geological Survey (MGS). WELLOG stores all of the information recorded on a drillers log in addition to a geological interpretation of the stratigraphic conditions penetrated by the well. MGS uses WELLOG for compiling geologic maps and for referencing subsurface geological conditions. However, data from a driller's log are entered only if the well's location has been verified. Funding to maintain WELLOG has not been provided to MGS at a level so that all water well records can be automated. MGS maintains WELLOG on a very limited basis using its general operating funds awarded by the legislature.

In June, 1985, the Division of Waters of the Minnesota Department of Natural Resources (DNR) and MGS agreed to cooperate on the development of a ground-water information system which would use water well records as a central reference. Only summary information taken from well records would be utilized in order to reduce the costs associated with WELLOG data entry and to ensure state-wide data coverage. This new data base was called the Well Log Listing System (WELLS) and formed the core of a DNR ground-water data system. Concurrently, the Minnesota Pollution Control Agency (MPCA) was developing an automated data base to store its well information, the Integrated Ground Water Information System or IGWIS. All three agencies recognized the need to coordinate their efforts so they could share common data elements and eliminate duplication of effort over data entry.

The Ground Water Subcommittee of the Systems for Water Information Management (SWIM) provided guidance for the design of WELLS and IGWIS so they are interactive and are compatible with the data storage requirements of the Land Management Information Center (LMIC). LMIC compatibility and SWIM data base design approval were confirmed for WELLS in December, 1985. A listing of the water well data elements stored in WELLS is presented in the appendix to this report.

Data Entry and Storage

The file structure used to summarize well data in WELLS is an adaptation of an internal MGS file termed the County Water Well Index or INDEX. It was developed by MGS to be an inexpensive means for storing summary geologic information about a water well and for storing water quality data. INDEX is used by MGS to plot data types needed for compiling geologic and hydrogeologic maps and to establish ground-water data bases for counties to use and to update. It is a key component in the MGS county geologic atlas program.

The additional data elements requested by the SWIM Ground Water Subcommittee expanded INDEX capabilities to describe ground-water use and well construction practices. INDEX became the working file for MGS to transfer data to the WELLS system being maintained by DNR and housed on computers at both LMIC and the U.S. Geological Survey office in St. Paul.

WELLS data are entered via personal computers using software developed by MGS. A minimal amount of training is required to learn data entry procedures. This enables anyone who is unfamilar with computers to quickly start using WELLS. "User friendly" capability was a major consideration in software design as was the low cost of storing and retrieving data afforded by the use of personal computers.

Data may be entered either on diskettes or hard disc using a data entry program with editorial capabilities. Data manipulation and updating are performed by another program. Quality control is maintained by automated editing procedures which check for format errors and by visual inspection of monitor display or printout. Generally, a very low incidence of entry error has been experienced. MGS reformats its INDEX files into an INFO data base structure prior to the transfer of data to WELLS at DNR. Data transfer may be accomplished either by the delivery of tapes generated from personal computers or by telephone linkage to USGS or LMIC computers.

Accomplishments

The most important achievement of this project is the development of an effective means to store and retrieve summary information about water wells on a state-wide basis. WELLS can provide a reference point for state and federal agencies to correlate other ground water data bases, and thus establish a coordinated ground-water data system for Minnesota. The data elements filed in WELLS can link together agency data such as water level measurements, stratigraphic information, water use data, and water quality analyses. Also, counties or other local units of government can use WELLS to access state agency water well data or to provide additional data to the state. The software developed by MGS to enter and to access WELLS data may be used on IBM compatible personal computers. This gives WELLS a cosmopolitan capability.

Summary information for about 95,000 water wells throughout Minnesota was entered into WELLS during this project. No specified number of well entries was proposed, but most of the readily useable water well records housed at MGS now can be accessed. THe WELLOG file provided summary data for approximately 34,000 wells and student workers entered the rest using personal computers. Information from about 5,000 well records remain to be entered at MGS but these have little or no information describing their geographic locations. Also, about 5,000 to 10,000 wells are drilled annually and records of these wells are forwarded to MGS by the Minnesota Department of Health. Future data entry into WELLS should be inexpensive because data entry procedures and coordination between MGS and DNR are already established. Also, the equipment to update WELLS has been purchased and should be relatively maintenance free.

Limitations

Although the development of WELLS should be viewed as a major advancement in providing data for managing Minnesota's ground-water resources, it has limitations which should be realized if it is to be used effectively. WELLS will only provide a central reference for other ground-water data bases to key in to, it cannot replace them. For example, the WELLOG data base maintained by MGS stores much more detailed geologic information than that summarized by WELLS. Detailed information stored on data bases such as WELLOG is essential for thoroughly understanding Minnesota's ground-water resurces and the impacts that land and water use have on them. The development of these other ground-water data bases such as WELLOG, OBWELL, SWUDS, IGWIS, STORET, and GWSI must be supported in order to achieve a comprehensive ground-water information system. If not, WELLS will function as little more than a directory of water wells.

Past efforts to establish ground-water data bases have worked during developmental stages but the lack of long-term funding has either severely limited or eliminated data entry. The WELLOG data base of MGS is a good example of this. Resources must be made available to maintain and update WELLS or it will lose its potential as a coordinating tool. MGS and DNR must determine how they wish to continue cooperating on WELLS as well as to exploit its usefulness to other agencies and the public.

Recommendations

It would be unfortunate if the expiration of the contract between MGS and DNR entitled "Ground Water Data Automation" marked the end of the updating and editing of WELLS data. If continuing funds can be identified, it would be highly desirable for MGS and DNR to maintain a commitment to work together on the enhancement of a coordinated ground water information system for Minnesota. In view of the successful development of WELLS, the following recommendations should be considered for continuing activities:

1. A funding source should be identified so that DNR and MGS can develop a memorandum of agreement to continue the updating and editing of WELLS data.

2. DNR and MGS should request LMIC to establish WELLS as the SWIM reference data base for the State's water-well information.

3. DNR and MGS should encourage counties and other local units of government to use WELLS for accessing and storing water well data.

4. DNR and MGS should support the development of ground-water information systems which use WELLS data elements to reference information related to a specific water well.

Supplemental Agreement

Additional funding was awarded to this contract in May, 1987 to: (1) acquire equipment necessary to transfer WELLS data to the U.S. Geological Survey PRIME computer and 2) to prepare and publish a brochure on accessing and interpreting ground-water data. The brochure is intended for distribution to local citizens and officials who will be involved in local water planning activities.

A tape drive was acquired and is being used to transfer WELLS data from MGS computer data systems to the PRIME computer used by the DNR. This equipment will provide a very effective means for MGS and DNR to transfer data in the future.

A report entitled "Using Ground Water Data for Water Planning" was prepared under MGS supervision with input from DNR, USGS, MPCA, LMIC, SPA, MDH, and LCMR. It will be published as an MGS educational series booklet and should be available by August, 1987.

Appendix C

WELLS DATABASE ITEM DEFINITIONS

DATA ITEM	ITEM TYPE	ITEM WIDTH	COLUMNS*	DESCRIPTION
UNIQUE NO.	Integer	6	1-6	The Minnesota Geological Survey six digit unique well number.
W-SERIES UNIQUE #	Character	6	7-12	A W-series unique # includes a leading W followed by a 5 digit sequential number. This alphanumeric unique # indicates no geolo gic log, but some information will be available.
COUNTY	Integer	2	13-14	Minnesota state county numbers.
TOWNSHIP	Integer	3	15-17	The individual well public land survey (PLS) township number.
RANGE	Integer	3	18-19	The individual well PLS range number.
EAST RANGE	Character	1	20	The letter "E" is assigned to this field when the public land survey shifts to east ranges. Afects wells located in the NE corner of Cook County.
SECTION	Character	1	21-22	The individual well PLS section number.
QUARTER	Character	4	23-26	The well is located to the nearest quarter-quarter-quarter-quarter section if field located. Each quarter is described by an alphabetic code A, B, C, or D representing the NE, NW, SW and SE quarters respectively, and is ordered from largest to smallest quarter.
WELL NAME	Character	30	27-56	Name of well or owner's name.
DATE COMPLETED	Integer	6	57-62	The date the well was completed taken from the driller's well log.
USE TYPE	Integer	2	63-64	Minnesota DNR use type designation.

WELLS DATABASE
ITEM DEFINITIONS

DATA ITEM	ITEM TYPE	ITEM WIDTH	DATA COLUMNS*	DESCRIPTION
			USE CODES:	

Use	DNR Groundwater file codes
domestic	10
public supply	20
air conditioning	30
industry	40
commerical	50
observation	60
monitoring	70
test well	80
irrigation	90
relief well	98
municipal	11
multiple dwelling	95
abandoned	97
other	99

DATA ITEM	ITEM TYPE	ITEM WIDTH	DATA COLUMNS*	DESCRIPTION
ELEVATION	Integer	4	65-68	Elevation in feet above mean sea level for a verified well location.
DEPTH COMPLETED	Integer	4	69-72	The depth in feet the well was completed after drilling.
MATERIAL	Integer	1	73	A numeric code assigned to the type of casing material: 1 - wrought iron 2 - tile 3 - concrete 4 - plastic 5 - steel 6 - stainless steel 7 - PVC 9 - other
CASED	Integer	4	74-77	Depth of the innermost casing expressed in feet.
AQUIFER	Character	4	78-81	MGS four-letter geological code for the water bearing formation(s) that transmit(s) water to supply a well.
OPEN HOLE STRATIGRAPHIC				

TOP	Character	4	82-85	The MGS four-letter geologic code for the top formation of the open hole portion of the well.
OPEN HOLE STRATIGRAPHIC BOTTOM	Character	4	86-89	The MGS four-letter geologic code for the bottom formation of the open hole portion of the well.

WELLS DATABASE
ITEM DEFINITIONS

DATA ITEM	ITEM TYPE	ITEM WIDTH	DATA COLUMNS*	DESCRIPTION
QUADRANGLE	Character	4	23-26	The DNR alphanumeric code which corresponds to the quadrangle map on which the well is located. A conversion table will indicate USGS and MGS quadrangle map codes. If well is not field located this item is left blank.
STATIC WATER LEVEL	Integer	3	94-96	Water level in the well when pump is off, expressed in feet below grade.
SWL DATE MEASURED	Integer	6	97-103	The date the static water level was measured.
DEPTH TO BEDROCK	Integer	4	107-110	Depth in feet to bedrock
DIAMETER	Integer	2	111-112	The diamater of the innermost casing expressed in inches.
GROUT	Character	4	113-116	Material such as cement, or bentonite used to prevent undesirable materials from entering the well. Indicates either the volume of grout (given in cubic yards), or with a Y for (yes), or a B for (bentonite), or an N for (not grouted).
FLAGS	Integer	1		Remarks flag indicates if remarks exist in remarks file.
FLAGS	Integer	1		Numeric codes which indicates if more information is available for a particular well.
FLAGS	Integer	1		Well log has been entered in MGS WELLOG data base.
LAST.DATE	Date	8		System generated each time a well log is entered or updated. Today's data is entered.

DATA

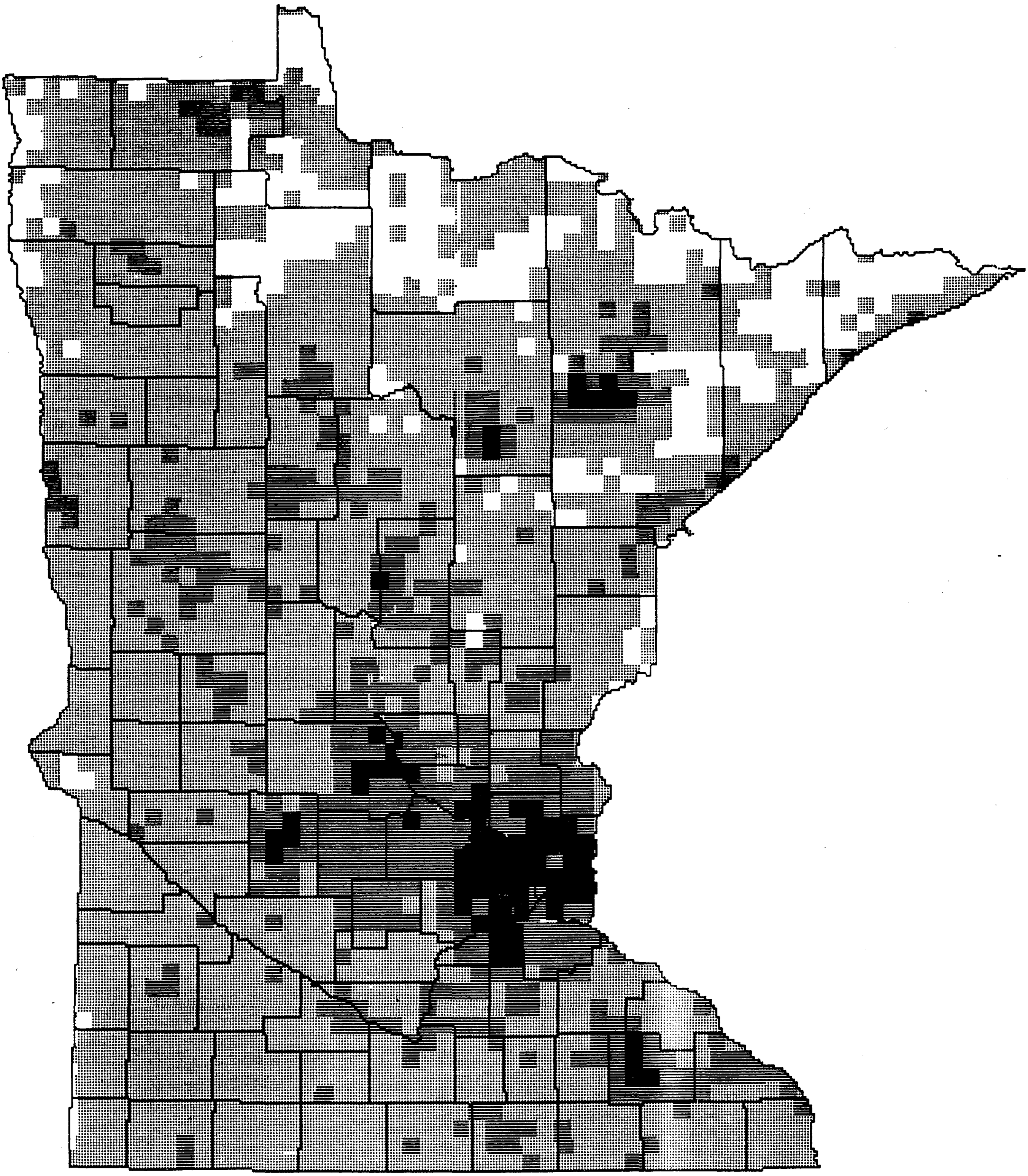
DATA ITEM	ITEM TYPE	ITEM WIDTH	COLUMNS*	DESCRIPTION

NOTE: Remarks are transferred on separate data files. The first 14 columns of each record are the same as that of the corresponding data file entry followed by the integer (1-9) and the remark itself.

DATA ITEM	ITEM TYPE	ITEM WIDTH	COLUMNS*	DESCRIPTION
REMARK1	Character	80		Remarks will be entered to indicated more specific information about the well, such as multiply casings.
REMARK2...9	Character	80		Refer to data item REMARK1. Repeating group.

*"Columns" indicate the column locations of the data item on the fixed-format text data transfer file.

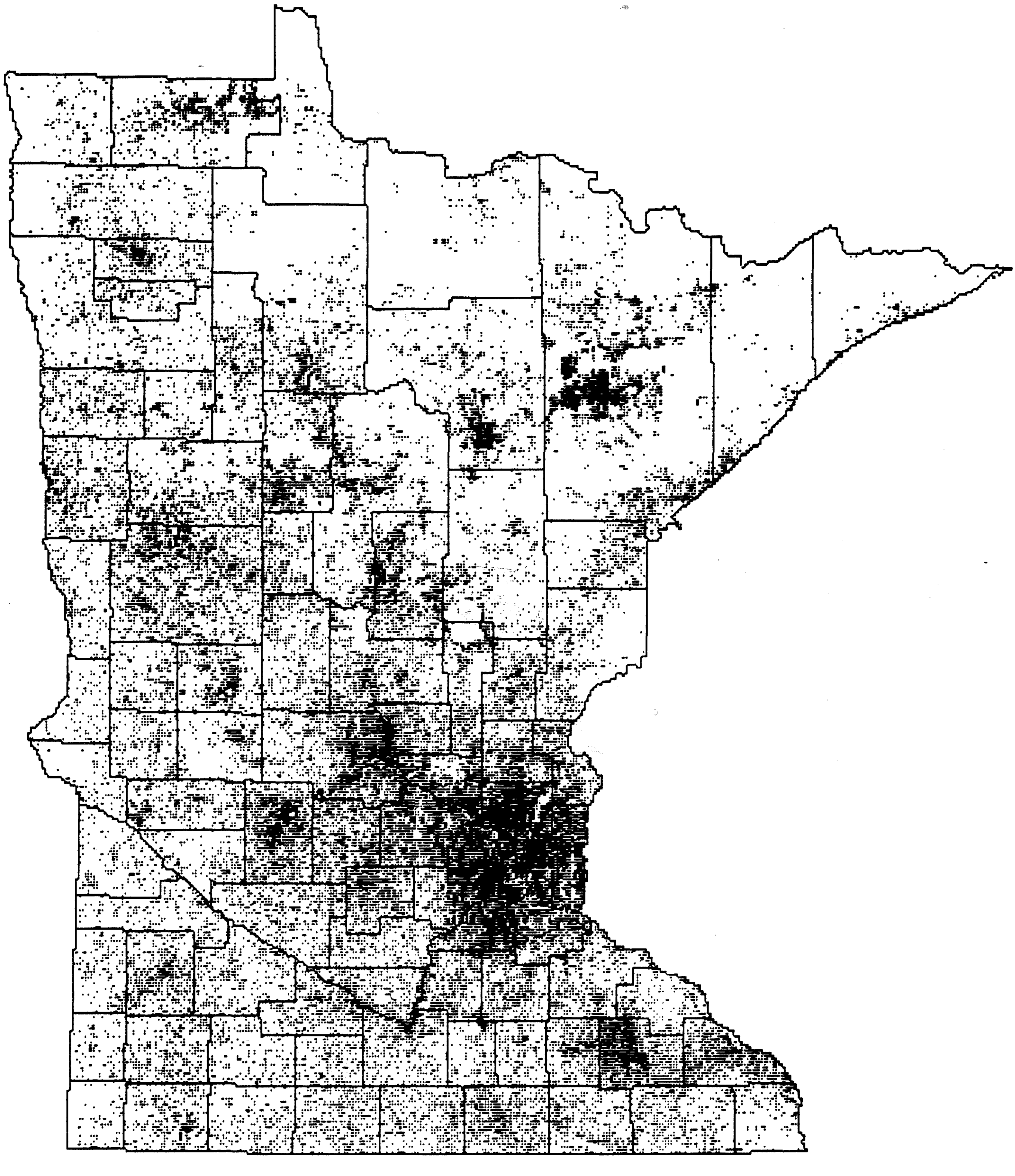
WELL LOG COUNT PER TOWNSHIP
DNR WELLS DATA BASE



WELL LOG COUNT PER TOWNSHIP DNR WELLS DATA BASE 1987

SYMBOL	COUNT	PERCENT	ACRES	LEGEND
0	9889	11.6	395560.0	NO WELL LOG DATA IN TOWNSHIP
1	56841	66.8	2273640.0	1 THRU 36 WELL LOGS IN TOWNSHIP (1 PER SQ. MILE)
2	15699	18.5	627960.0	37 THRU 180 WELL LOGS IN TOWNSHIP (2 - 5 PER SQ. MILE)
3	2660	3.1	106400.0	181 WELL LOGS OR MORE IN TOWNSHIP (MORE THAN 5 PER SQ. MILE)

WELL LOG COUNT PER SECTION
DNR WELLS DATA BASE



WELL LOG COUNT PER SECTION DNR WELLS DATA BASE 1987

SYMBOL		COUNT	PERCENT	ACRES	LEGEND
	0	56684	66.6	2267360.0	NO WELL LOG DATA IN SECTION
	1	14583	17.1	583320.0	ONE WELL LOG PER SECTION (1 PER SQ. MILE)
	2	10813	12.7	432520.0	2 THRU 5 WELL LOGS PER SECTION (2 - 5 PER SQ. MILE)
	3	3009	3.5	120360.0	MORE THAN 5 WELL LOGS PER SECTION (MORE THAN 5 PER SQ. MILE)