Hydrogeology and Hydrogeochemistry of Government Marsh, North St. Joseph County, Michigan

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HYDROGEOLOGY AND HYDROGEOCHEMISTRY OF GOVERNMENT MARSH, NORTH ST. JOSEPH COUNTY, MICHIGAN

by

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HYDROGEOLOGY AND HYDROGEOCHEMISTRY
OF GOVERNMENT MARSH, NORTH
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Michael C. Kasenow, Ph.D.

Western Michigan University, 1994

A hydrogeologic and hydrogeochemical investigation was conducted at Government Marsh located in St. Joseph County, Michigan from May, 1988, to November, 1993. Information on glacial geology, topography, drainage patterns, hydraulic conductivity, vegetation, water chemistry, and static water table elevations has been collected and analyzed. Data were collected in order to determine directions of ground water flow and areas of recharge and discharge. Bail-down tests, grain-size analysis, and permeameters were used to determine hydraulic conductivity adjacent to and within the wetland. Water table elevations and chemistry were analyzed from wells adjacent to the wetland perimeter and within the boundaries of the wetland. The chemistry of rain water and wetland surface water was also analyzed. Results show that ground water is generally flowing north, south and west from Government Marsh and that most of the wetland is an area of ground water recharge. Government Marsh can be described as a northern bog according to vegetation and water chemistry. The surface water chemistry of the bog is acidic (mean pH = 3.99) and very low in dissolved solids (mean conductivity = 45.3 µS). Much of the vegetation in Government Marsh is of a type that thrives in low nutrient environments. The natural bog waters at Government Marsh contribute significantly to the geochemical nature of the ombrotrophic system. Low surface pH levels increase with sample depth, but remain less than 7. Organic decomposition is the major control on the system,

contributing organic acids to the bog. These organic acids contribute to alkalinity or are involved in chemical reactions that contribute to alkalinity, which raise the concentrations of calcium and magnesium with sample depth. Organic acid complexation helps to maintain saturation and supersaturation levels of sulfide, carbonate and silica species. Production of ammonium and reduction of iron at sample depth consume H+, which raises pH. Cation exchange involving ammonium also contributes to elevated concentrations of calcium and magnesium with sample depth.

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Michael C. Kasenow

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CHAPTER I

INTRODUCTION

Why Study Wetlands?

Wetlands have been misunderstood for centuries. They are associated with superstitions and disease, fog and mosquitoes, howls in the night, and the rattle of bad dreams. It is no wonder that thousands of acres of these mysterious, but beautiful and natural environments have been drained of water or filled in with sediment throughout the world. Prior to the mid-1970s, wetland drainage was accepted practice in the United States (Mitsch & Gosselink, 1986). This was believed to solve two problems: (1) the eradication of diseases such as malaria and yellow fever by eliminating the habitat of the mosquito and other pests, and (2) increasing the acreage of dry land for developmental and agricultural purposes. Nontidal or inland wetlands in the United States were lost at an average rate of 440,000 acres per year from the mid-1950s to the mid-1970s. Agricultural development was responsible for 87% of the wetland losses (Burke, Meyers, Tiner, & Groman, 1988). Michigan has lost 71% of its original 11,200,000 acres of wetlands for the same reasons (Michigan Department of Natural Resources, 1982) at a rate of about 6,500 acres per year (Tiner, 1984). California, Ohio, Iowa, Indiana and Missouri, have at best, only 13% of their colonial wetlands remaining (Mitchell, 1992). The lower Mississippi valley is losing wetlands at a rate of about 165,000 acres per year (Tiner, 1984), and Louisiana is losing forested wetlands at about 87,200 acres per year (Tiner, 1984). The United States, from the time of its settlement, has lost 54% of its original 215 million acres of wetlands (Burke et al., 1988). The major anthropogenic causes of wetland loss and

degradation are filling or drainage for navigation channels, crop and timber production, mosquito control, construction of roads, highways, dikes, dams, levees, seawalls, flood control and commercial property. Mining of wetlands for peat, coal, sand, gravel and phosphate; and nutrient loading from domestic sewage and agricultural pesticides, has added to the problem. In addition, natural threats include droughts, hurricanes, erosion, accretion, and biotic effects from muskrat, nutria and other animals (Tiner, 1984).

In recent years the value of wetlands has become apparent. The most important benefits derived from wetlands include flood and erosion control, water supply, ground water recharge, harvest of natural products, livestock grazing and recreation. According to Kusler (1989), one-acre of wetland holds about 330,000 gallons of water when flooded to a depth of about one foot; therefore, the importance of wetlands for flood control is obvious. Timber, fish, shellfish, peat, cranberries, blueberries and wild rice are harvested from wetlands. Eighty-two million acres of commercial forested wetlands are still in existence. The standing value of wetland forests in the south is about $8 billion (Frederickson, 1979). About 60% of all fish and shellfish caught commercially depend upon wetlands for their existence. Nearly all freshwater fishing is dependent on wetlands (Burke et al., 1988). Over 52 million-acres of peat deposits exist in this country and the States of Michigan, Florida, Illinois, Indiana and New York account for more than 75% of peat production from mining (Carpenter & Farmer, 1981). Research has showed that one acre of wetland can produce up to 35 tons of cattail flour and is necessary to produce 2,000 pounds of oyster meats (Kusler, 1989). Billions of dollars are spent each year by sport fishermen, hunters, bird watchers, photographers, hikers, swimmers, boaters and other wildlife enthusiasts attracted to wetlands or environments and habitats that are dependent upon them. In recent years as

much as 17% of the United States population has visited wetlands and about 47% showed an active interest relative to wildlife around their homes (Department of the Interior, 1980). In addition to their socioeconomic values, wetlands are important in maintaining the quality of the natural, and especially aquatic environments. Wetlands are located between dry land and water; therefore, they intercept runoff and help to filter sediment and nutrients from flood waters. Novitzki (1979-A) concluded that Wisconsin wetlands reduce flood flows up to 80% and sediment yields up to 90% relative to areas without lakes and wetlands. Research has showed that wetlands are important in reducing biochemical oxygen demand (BOD), phosphorous and nitrogen from polluted waters (Grant & Patrick, 1970; Jonata & Loucks, 1975). Tilton, Kadlee, and Richardson (1976) have studied the use of both constructed and natural wetlands as tertiary treatment facilities for domestic, industrial and storm water wastes. The Max Planck Institute of Germany has a patent to create such systems using the bulrush as the primary remover of waste (Burke et al., 1988). The Brillion Marsh in Wisconsin, a cattail marsh, has been significantly reducing BOD, chemical oxygen demand (COD), coliform bacteria, nitrates, turbidity, suspended solids, and phosphorous since 1923 (Boto & Patrick, 1979). The economic, aesthetic and environmental values of wetlands, coupled with the rapid loss of this ecotone, places a premium on data collected from wetland research, because most segments of modern society will benefit.

All wetlands cannot be investigated, but a sample of each type of wetland needs to be investigated in order to understand representative characteristics. According to Hollands (1988), Carter and Novitzki (1988), Novitski (1979c), and Verry and Boelter (1979), the most urgent need regarding wetland research concerns wetland hydrology, because hydrology is the dominant influence on all wetland functions. According to Siegel (1988a) current classifications of wetlands are inadequate to address recharge-

discharge functions. Classifications based upon vegetation communities are inadequate unless the vegetation is extremely sensitive to water chemistry. Classifications based solely upon hydrology are inadequate, because they do not consider the wetlands position relative to the larger hydrogeologic system. It is imperative that instrumentation be used to evaluate the recharge-discharge function of wetlands, because the recharge-discharge function of wetlands is site specific. The data are expensive and can take more than a year to collect (Hollands, 1988), but in order to understand, predict and model wetland types relative to their functions, an accurate definition of hydrogeologic characteristics must be ascertained.

Pertinent Investigations

According to Hollands (1988), wetlands are generally considered to be areas of ground-water discharge, but may vary seasonally from areas of recharge to areas of discharge, and some wetlands may have both recharge and discharge occurring at the same time. Vecchioli, Gill, and Lang (1962), concluded that the swamps in the Upper Passaic River basin in New Jersey acted as discharge areas for the adjacent uplands. O'Brien (1977) found that two wetlands in Massachusetts acted as areas for ground-water discharge and that ground-water recharge was insignificant even during periods of below normal precipitation. Shedlock, Wilcox, and Thompson (1986) and Wilcox, Shedlock, and Hendrickson (1986) studied the hydrology and hydrogeochemistry of the southern shore of Lake Michigan in order to understand the recharge-discharge function of a large interdunal wetland known as the Great Marsh. The authors concluded that the hydrogeologic setting is related to changes in water table elevations as a function of topography. They also concluded that the recharge-discharge function of the Great Marsh is not uniform over the entire wetland area. Both recharge and

discharge zones can be identified in the Great Marsh. Overbank storage on floodplain wetlands may recharge water-table aquifers after flooding has occurred (Mundorff, 1950). Wetlands may have regional discharge and recharge functions (Winter, 1976). The North Dakota prairie potholes may function as both discharge and recharge systems with recharge increasing after collecting overland flow (LaBaugh, Winter, Adomaitis, & Swanson, 1986; Sloan, 1970; Stewart & Kantrud, 1972; Winter & Carr, 1980). Evidence also indicates that the recharge-discharge function of the prairie potholes is not necessarily related to topography, and that reversal of ground water flow occurred between two of the wetlands. Greeson, Clark, and Clark (1989) have suggested that recharge from prairie potholes may be less than from depressions in which wetlands have not occurred. Brown, Stark, and Patterson (1988) studied and classified two wetlands. They classified a wetland near St. Joseph, Minnesota as a ground water-slope wetland, because they found substantial ground-water inflow and surface-water outflow. They classified a wetland near Phelps, Wisconsin as a surface-water-depression wetland, because gound-water seepage is small and surface-water outflow is restricted. Although they concluded that there is little interaction between ground water and the Phelps wetland, Novitzki (1979-B) suggested that Wisconsin wetlands are usually in contact with ground water. The classification used by Brown et al. (1988) is original to Novitski (1979b). He recognized four wetland types, surface-water-depression wetlands, which receive water from precipitation and overland flow; surface-water-slope wetlands, which are generally connected to a surface-water body; ground-water-depression wetlands; and ground-water-slope wetlands. He concluded that surface-water-depression and surface-water-slope wetlands generally recharge ground-water systems; whereas, ground-water-slope wetlands obtain discharge water from ground-water systems. Ground-water-depression wetlands can act as zones of

recharge, discharge or both recharge and discharge depending upon seasonal variations.

Ombrotrophic Peatlands

Ombrotrophic peatlands or bogs are wetlands with relatively immobile waters, are isolated from the influence of the local water table, and receive nutrient inputs from precipitation. They are characterized by thick accumulations of peat, low ionic concentrations, and low pH values (Gore, 1983; Moore & Bellamy, 1974; Radforth & Brawner, 1977). Boelter (1965) and Ivanov (1981) investigated the permeability of peats in bog areas. In their investigations they found that the hydraulic conductivity (K) was greatest in the upper surface of bogs often called the active layer, because it is where most physical and biological processes take place, and where the live *sphagnum* moss dominates ($K \geq 0.0381$ cm/sec). They found that the slowest movement of water through peat occurred in the sapric zone, well below the active layer, where the peat is highly decomposed and dense (K as low as 0.75×10^{-5} cm/sec). The K value of sapric peat is often 1000 times less than that of fibric peats, which are at or near the active zone (Verry & Boelter, 1979). This will affect ground-water velocity, which will decrease with depth in bogs. Ground-water velocity near the sapric peat is similar to many clays; whereas, ground-water velocity near the active layer can be as high as 91.4 cm/sec or 3 feet per minute (Hofstetter, 1969, cited in Siegel, 1981). Chason and Siegel (1986) calculated results similar to Boelter (1965) and Ivanov (1981), but found K values 2 to 6 times greater in partially decomposed peats deeper than 1 meter (as high as 5.0×10^{-3} cm/sec 3 meters below the active zone). Rycroft, Williams, and Ingram (1975) identified and compared a wide array of laboratory and field studies, which appear to confirm peat bog K values as offered by Boelter and Ivanov (1977).

Bogs have often been considered regulators for ground-water recharge (Boelter & Verry, 1977). Gorham (1953, 1956) collected results for pH, conductivity, calcium, sodium, potassium and bicarbonate on twenty-five samples from bogs and fens in the southern part of the English Lake district. The more chemically dilute waters relative to Ca^{+2} and HCO_3^- with pH values below 4.5 appeared to be ombrotrophic systems. The fens and transition wetlands were relatively rich in Ca^{+2} and HCO_3^- which indicated influence from the local mineral soils. The diversity of plant species appeared to increase with increasing pH, specific conductivity, Ca^{+2} and HCO_3^-. The pH and nutrient levels reported in his later study helped to support the results in his earlier study which concentrated on the chemistry of the wetland soils and plants. Plants harvested from ombrotrophic soils were found to be lowest in nutrient constituents.

In one of the first studies of its kind, Bay (1969b) investigated the water chemistry and vegetation of two bogs in northern Minnesota in relation to the local ground-water system. He was able to correlate pH and conductivity relative to ground water recharge and discharge. The lower pH and conductivities ($\leq$ 4.2 and 46.5 μS) were associated with a perched bog, while the more alkaline waters ($\geq$ 6.0 pH and 44.5 μS) were identified in a depression bog. Plant species diversity was also greater on the depression bog. Bay (1969b) concluded that the surrounding mineral-enriched ground water served to recharge the depression bog. Bay (1969a) measured runoff from four forested bog watersheds over a five-year period in northern Minnesota. He found that the bogs were effective for short-term storage, but were not effective for long-term storage or regulators of stream flow. Glaser, Wheeler, Gorham, and Wright (1969) used water chemistry and vegetation to help distinguish bogs from fens in the Red Lake Peatland area in northern Minnesota. The more chemically dilute wetlands were classified as bogs and the more ionically rich wetlands were classified as either poor

fens or fens. Bog water pH was measured as low as 3.8 and fen water pH as high as 7.0. The poor fens had pH that ranged from 4.0 to 5.1. As already discussed, wetland soils (such as bog soils) that are relatively dense, highly decomposed, and predominantly organic, generally have decreasing vertical hydraulic conductivities with depth, which can reduce ground-water discharge rates and create perched wetlands and artesian conditions (Motts & O'Brien, 1980). Verry and Boelter (1979) concluded that recharge was minor on two of three Minnesota watersheds where peatlands occurred due to the low hydraulic conductivity of the deeper peat or artesian conditions produced by the low K values. Siegel (1981, 1983) measured ground-water levels and chemistry in observation wells, studied thicknesses of bog and fen soils, and simulated ground-water flow through the use of a computer model to conclude that ground-water circulates along flow paths several kilometers long in the Glacial Lake Agassiz Peatlands in Minnesota. According to Siegel (1983), the recharge zones in the Lake Agassiz Peatlands are the raised bogs and the discharge zones are the adjacent fens. Clausen and Brooks (1983a) analyzed the chemistry of runoff waters to help classify 45 undisturbed Minnesota peatlands. Runoff pH, conductivity, alkalinity, calcium and magnesium were used to help classify the peatlands as bog, transition or fen. The lower pH and ionically dilute wetlands were considered to be bogs, while the higher pH and chemically robust wetlands were classified as fens. Clausen and Brooks (1983b) used many of the same chemical parameters to show the impact occurring from the mining of peat from the same wetlands. Although drinking water standards were not affected, peat mining increased water temperature, acidity, suspended sediment, conductivity, iron, sodium and nitrogen species. Conversely, Moore (1987) concluded that drainage and harvesting of four bogs near Sept-Iles, Quebec had little effect on bog water chemistry, due to its very acid nature (pH 3.0 to 4.5) and isolation from mineral

water. Keough and Pippen (1984) found that alkalinity, pH and Ca^{+2} concentrations decreased down gradient, in the direction of ground-water flow, through two kettle-like bogs in southwest Michigan. This is evidence that the two bogs may be recharging the local flow system, which has a water chemistry often higher in the above three parameters. In addition, they found that the two bogs dampen or stabilize the rise and fall of the local water table. Almendinger, Almendinger, and Glaser (1986) conducted a topographic survey across the Lost River Peatland in northern Minnesota. They used both laser and electronic levels to measure elevations across bogs and fens. A majority of the benchmarks rose at the center of the bogs and fens, causing the investigators to surmise that the altitudinal change is due to the swelling of peat in the subsurface in response to artesian fluid pressure generated by regional hydraulic gradients. Investigating the same peatland, Siegel and Glaser (1987) confirmed that the raised bog and spring fen are zones of ground-water discharge for at least parts of the year. Using observation wells to measure ground-water levels and chemistry, they found that the acidic waters of the bog are being neutralized below 0.5 meters in the peat profile. The bog appeared to act as an area of discharge late in the year and appeared to recharge the ground-water system during the summer months. Both alkalinity and pH appeared to increase with depth beneath the bog and fen surface areas. Ca^{+2} also appeared to increase with depth from the wetland surfaces. Siegel (1988b, 1988c) again used piezometers to measure hydraulic conductivity, water chemistry and ground water levels at a bog-fen complex near Mendenhall Valley, Juneau, Alaska. The results showed that the chemically dilute bogs were probable areas of ground-water recharge, and that the other wetland types generally acted as areas for ground-water discharge. Hydraulic conductivity was relatively consistent and not related to depth beneath the wetland.

Bog Water Chemistry

Clymo (1964) and Gorham, Eisenreich, Ford, and Santelmann (1985) contend that acidity in bog water is due to atmospheric fallout (carbonic acid), the accumulations of fulvic and humic organic acids from decomposition of plant material, the activity of sulfur-metabolizing bacteria during dry periods, the secretion of whole organic acid molecules by the live *sphagnum* plants, and cation exchange in the walls of *sphagnum* plants (H^+ for a nutrient deposited by precipitation). In bog waters unpolluted from acid rain, the H^+ contributed from rain probably does not exceed 30%. Shotyk (1988) contends that acidity in bog waters due to cation exchange on the surfaces of *sphagnum* mosses is relatively unimportant.

The major ions found in bog surface-waters are generally contributed from sea spray, soil dustfall, and air pollution (Gorham et al., 1985). Chloride, sodium and magnesium often exceed 400, 300, and 150 mg/L respectively in bog surface-waters near coastal areas. Rarely do any of the these parameters exceed 20 mg/L in unpolluted, midcontinental areas (Gorham, 1956; Munger & Eisenreich, 1983). Where dustfall is a factor, calcium and magnesium are relatively enriched in bog surface-waters (as high as 40 and 88 mg/L respectively). The low concentrations of sodium and potassium in midcontinental bog surface-waters are also contributed by soil dustfall (Gorham, Dean, & Sanger, 1983; Munger & Eisenreich, 1983; Verry, 1983). It is difficult to ascertain the amount of sulfate and nitrate contributed to surface bog waters from atmospheric pollution. Plant uptake and microbial transformations almost immediately reduce these parameters when compared to the chemistry of local rain water. As a general rule, western midcontinental bogs have lower concentrations of sulfate when compared to eastern bogs, especially eastern bogs located near urban and industrial sites (Munger & Eisenreich, 1983). Bog waters are acidic, anaerobic and

contain abundant dissolved organic matter; therefore, they are enriched with aluminum, manganese and iron relative to "normal" alkaline freshwaters. The solubility of aluminum is dependent upon pH, which is why bog waters often have more aluminum than fens. Silica is generally in low concentrations in bog waters, because of the absence of ground-water influence. Bog waters often have high concentrations of H_2 and CO_2, which are indicators of strong reducing conditions; therefore, it is not surprising that bogs are relatively enriched in hydrogen sulfide and methane (Shotyk, 1988).

Statement of the Problem

The influence of ground water on acidic peatlands (bogs) is incompletely understood. Acidic peatlands may act as reservoirs, slowly releasing ombrotrophic water in response to fluctuations of the flow system(s) in the enclosing environment. Peatlands are currently used for sewage disposal in Canada and elsewhere, and are being drained in many of the more temperate areas of the north for economic reasons. Yet only a limited amount of research on peatland hydrology has been completed; therefore, information about the environmental consequences of anthropogenic alteration is sparse. Government Marsh appears to be unique, because the plants that thrive within this wetland indicate that it may actually be a bog. Bogs of this size (approximately 640 acres) are generally limited to Canada, Minnesota, and in the upper peninsula of Michigan. Bogs of any size are relatively rare when compared to the inventory of most other wetland types; therefore, plant and animal species that live within or visit Government Marsh should also be unique and relatively rare. Previous investigations have concluded that bogs can act as recharge areas for ground-water systems; therefore, Government Marsh may recharge the local ground-water system,

which may help to supply lakes, rivers and other wetlands with ground water that eventually discharges to the surface. The physical and ecological environment of any wetland is a function of its hydrology. The purpose of this study is to investigate the interaction between the ombrotrophic (rainwater) water of Government Marsh and the minerotrophic (water in contact with rock and mineral substrate) ground water. The hydrogeology of Government Marsh will be explored and analyzed in order to ascertain how the wetland's substrate affects ground-water flow into and out of the bog. The hydrogeochemistry of Government Marsh will also be analyzed in order to substantiate the influence of ground water within the wetland's system.

CHAPTER II

DESCRIPTION OF THE STUDY AREA

Location

Government Marsh is located in St. Joseph County, Michigan (Figures 1 & 2), in sections 3 and 4, Park Township (Township 5S, Range 11W). Goose Lake, which has become part of the study area is located in Kalamazoo County, in section 34, Schoolcraft Township (Township 4S, Range 11W). Government Marsh and Goose Lake are bounded by Howard Lake to the north, Spring Creek to the west, wetlands to the northeast and farmlands to the south and east.

Topography

Government Marsh is located in an area that is the product of glacial and post-glacial erosion (Straw, Schmaltz, & Passero, 1978). The dominant landforms in this part of St. Joseph County are level to undulating outwash plains (United States Department of Agriculture [USDA], 1983). Government Marsh is one of many wetlands and lakes that appear to trend in a NE-SW direction near the terminus of the Prairie Ronde alluvial fan. The regional topographic gradient is about 11 feet per mile on a land surface sloping in a southeast direction. The regional maximum elevation occurs northwest of the bog on the Kalamazoo moraine at about 970 feet Above Sea Level (ASL), and minimum elevation is about 820 feet ASL at the banks of the Portage River, southeast of the bog. The upland perimeter bog boundary is approximately 850 feet ASL. The bog surface is approximately 835 feet ASL, and the surface of Goose Lake is approximately 834 ASL (Barrese, 1991).

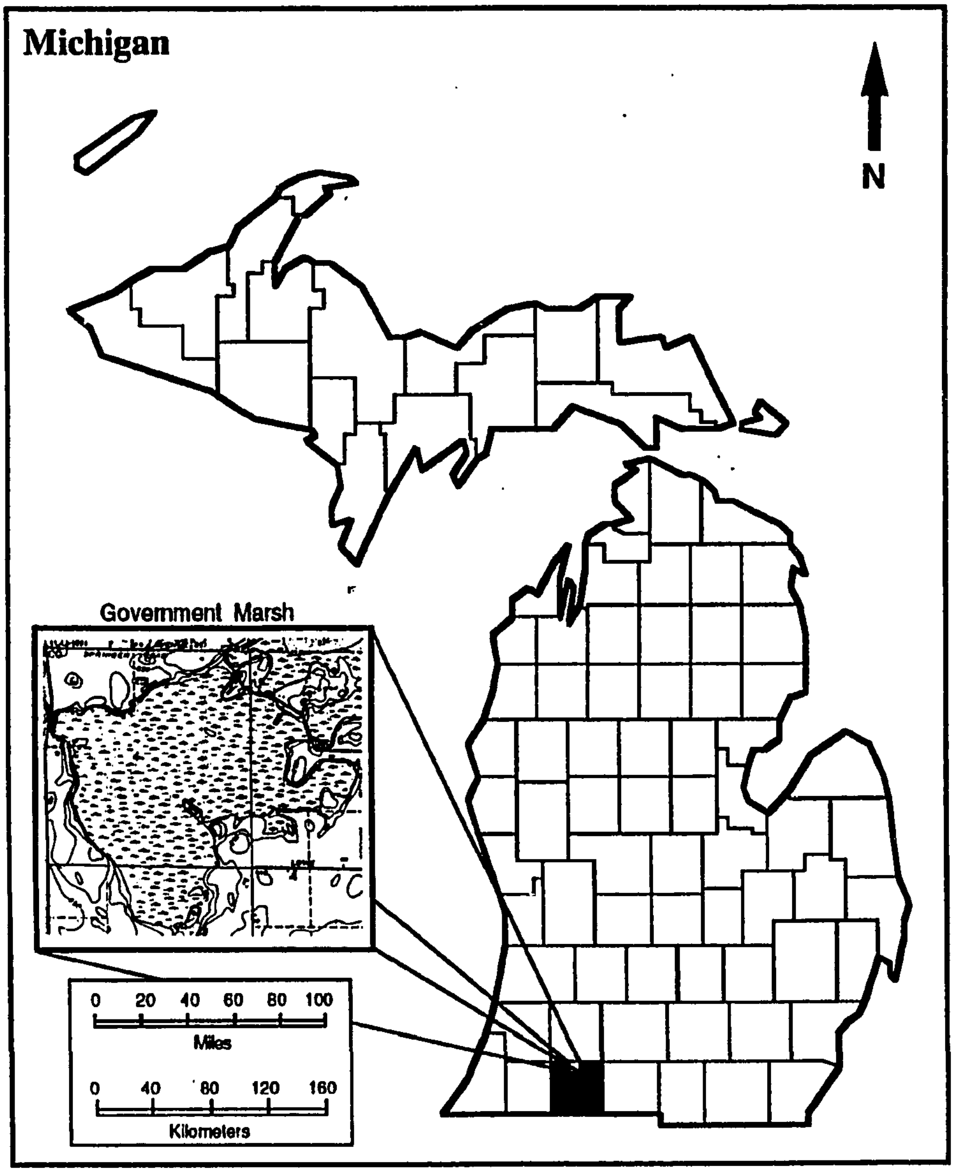


Figure 1. Location of Study Area in St. Joseph County, Michigan.

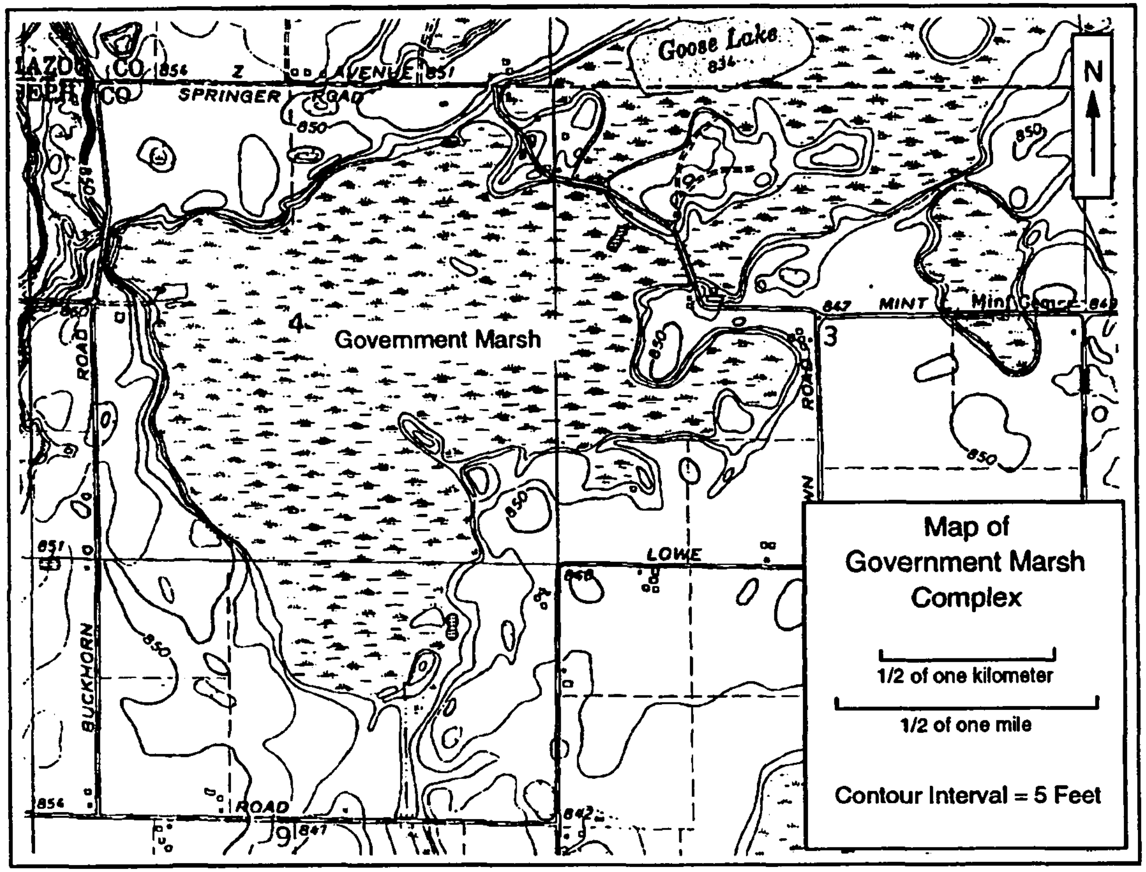


Figure 2. Government Marsh Complex in St. Joseph County.

Source: U.S.G.S. Topographic Quadrangle Map of Vicksburg, Michigan, 7.5 Minute Series (1967, photo revised 1973).

Climate

The climate in northern St. Joseph County is similar to the climate in Kalamazoo County, which is humid continental (Straw et al., 1978). Lake Michigan to the west of St. Joseph County modifies the local climate due to prevailing westerly and southwesterly winds. Lower summer and higher winter temperatures result from this "lake effect," as well as higher snowfalls. Precipitation ranges from 30 to 35 inches per year (DeWiest, 1965). The mean annual precipitation is about 34 inches per year and about 60% of this falls between the months of April and September. The average seasonal snowfall is about 46 inches per year. The winter mean temperature is 26.2 degrees F and the summer mean temperature is 70.2 degrees F. The mean relative humidity in St. Joseph County in midafternoon is about 63% (USDA, 1983).

Soil

The soils in areas adjacent to the bog are generally Oshtemo sandy loam or Spinks loamy sand. The Oshtemo-Spinks association is characteristic of level to gently rolling terrain, and is typical of outwash plains. This association covers about 65% of St. Joseph County. Both soils are generally well drained with a moderately rapid permeability (2.0 to 6.0 inches/hour). The available water capacity of the soils is low to moderate. Runoff is slow due to the 0 to 6% slopes on which these soils develop and the high permeability. Both soils are used mainly for agricultural purposes (USDA, 1983).

Geology

Government Marsh is located in an area of Wisconsinian glacial deposition. Thickness of the glacial drift is between 100-200 feet, and it overlies the Coldwater

Shale of Lower Mississippian Age (Passero & Straw, 1981). The drift is mainly comprised of glacial outwash dominated by pale to reddish brown, well to poorly sorted, fine to coarse-grained sand, alternating with layers of small gravel to cobbles, and in places crossbedded (Farrand & Bell, 1982). Government Marsh is situated near the terminus of a humid type, glacially generated alluvial fan (Prairie Ronde fan). The deposition of the fan was one of the last glacial events to occur in this area (Straw et al., 1990). The Prairie Ronde fan is well defined topographically and sedimentologically, descending 143 feet in altitude in a southeast direction (Leverett & Taylor, 1915). Grain size also decreases in a southeast, down-fan direction. The fan deposits are generally well stratified, well-to moderately-sorted with discontinuous lenticular units of clayey/silty fines interbedded within the coarser sediment. The Prairie Ronde fan is a product of a braided meltwater stream emanating from a point on the Kalamazoo recessional moraine (Barrese, 1991). The Kalamazoo Moraine trends in a NE-SW direction, northwest of Government Marsh (Figure 3). The Kalamazoo moraine is a product of the Lake Michigan Lobe of the Laurentide Ice Sheet. Northeast of Government Marsh is the Tekonsha recessional moraine. The Tekonsha moraine may trend in a NW-SE direction and is also a product of the Lake Michigan Lobe of the same ice sheet. A buried arm of the Tekonsha Moraine trends NE-SW in the vicinity of the Barton-Howard Lake chain. South of Government Marsh is the Sturgis moraine, a moraine deposited by the Saginaw Lobe (Leverett & Taylor, 1915).

Surface-Water

Numerous lakes, rivers and wetlands occur within the region (Figure 4), which is located within the St. Joseph River Basin; therefore, almost all of the water within this region drains into the St. Joseph River. The majority of lakes and wetlands are

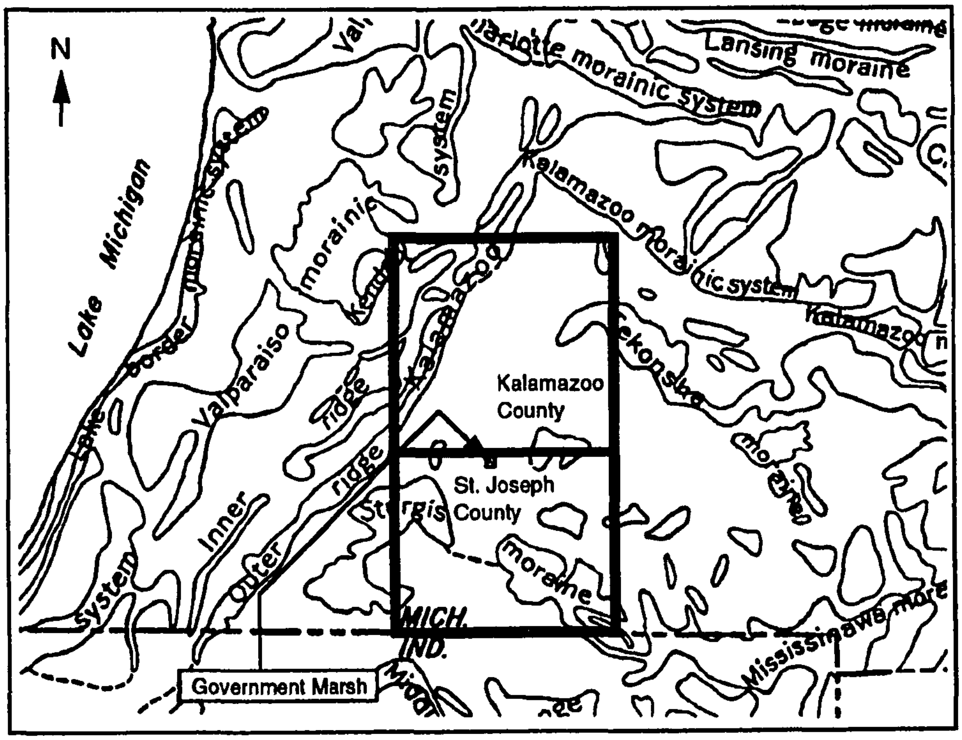


Figure 3. Map Showing Moraines in Southwest Michigan (Leverett & Taylor, 1915).

Source: Monographs of the United States Geological Survey Volume LIII, Washington, DC: Government Printing Office.

located around the perimeter of the Prairie Ronde fan. These lakes and wetlands are the result of buried ice blocks that melted more slowly than the other uninsulated portions of the ice sheets. Sugarloaf, Gourdneck, and Austin Lakes drain to the south where waters from Howard and Barton Lakes, northeast of Government Marsh, join the system and eventually drain into Portage Creek. Spring Creek, west of Government Marsh, connects with Flowerfield Creek, north of Rocky River, into which they drain. Portage and Rocky Rivers meet the St. Joseph River at Three Rivers, Michigan (Figure 4). A considerable amount, if not all of the water supplied to

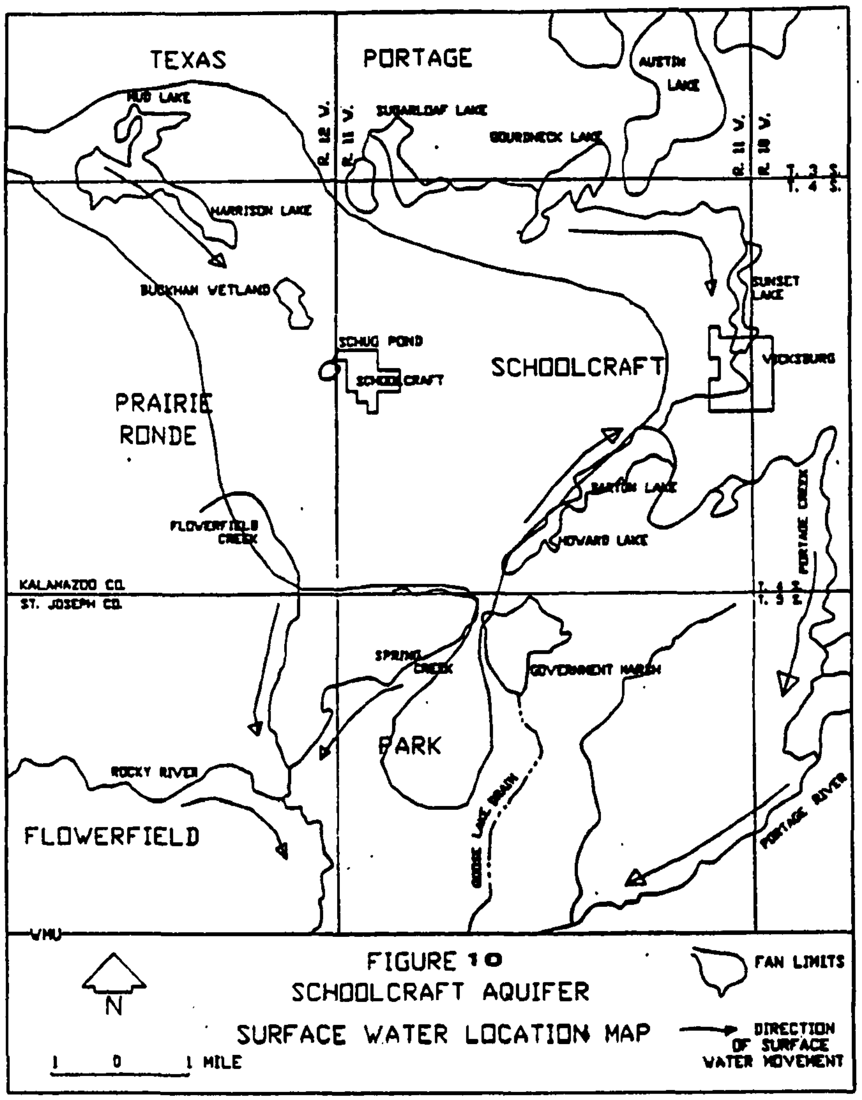


Figure 4. Surface-Water Features and Flow Map Near Government Marsh (Straw et al., 1990).

Source: Straw, W.T., Kehew, A.E., Barrese, P.G., Kasenow, M.C., & Steinmann, W. (1990). The hydrogeological and hydrogeochemical characterization and implications for consumptive groundwater use of a large glacial drift aquifer system in southwest Michigan: Final report. Kalamazoo, MI: Western Michigan University, Water Sciences Center, p. 17.

these features, results from the Schoolcraft aquifer (Straw et al., 1978). Government Marsh drains west into Spring Creek, south via the Goose Lake Drain, and probably north into the Barton-Howard Lake system via Goose Lake. The Goose Lake Drain eventually breaks into Portage River about a mile northeast of Three Rivers.

Ground-Water Flow

Government Marsh overlies the Schoolcraft aquifer, the principal aquifer within the region. The saturated thickness of the aquifer ranges from about 230 feet near Harrison Lake to about 200 feet near Howard Lake (Barrese, 1991). Two ground-water divides are present in the area. One near the apex of the Prairie Ronde fan (extreme northwest), adjacent to the Kalamazoo Moraine, just east of Paw Paw Lake; and a second near the Barton-Howard Lake chain (Figure 5). The ground-water divide near Barton and Howard Lakes corresponds to the buried arm of the Tekonsha moraine. Ground water generally flows southeast, in the down-fan direction. The average hydraulic gradient ranges from 0.005 to about 0.002 (Barrese, 1991). Flow net analysis shows ground water flow to be stratified with horizontal flow predominating. Vertical flow is associated with areas of recharge and discharge. A single regional flow system is present near the base of the aquifer and local flow systems can be found at the upper levels (Straw et al., 1990). Beyond the Barton-Howard Lake ground-water divide, near the terminus of the Prairie Ronde fan, in the area underlain by the buried Tekonsha moraine, ground-water flow is generally to the southwest and southeast toward the Rocky and Portage Rivers, and to the northeast, from Government Marsh, toward the Barton-Howard Lake chain. This indicates that Government Marsh is isolated from the regional ground-water flow system associated with the Prairie Ronde fan.

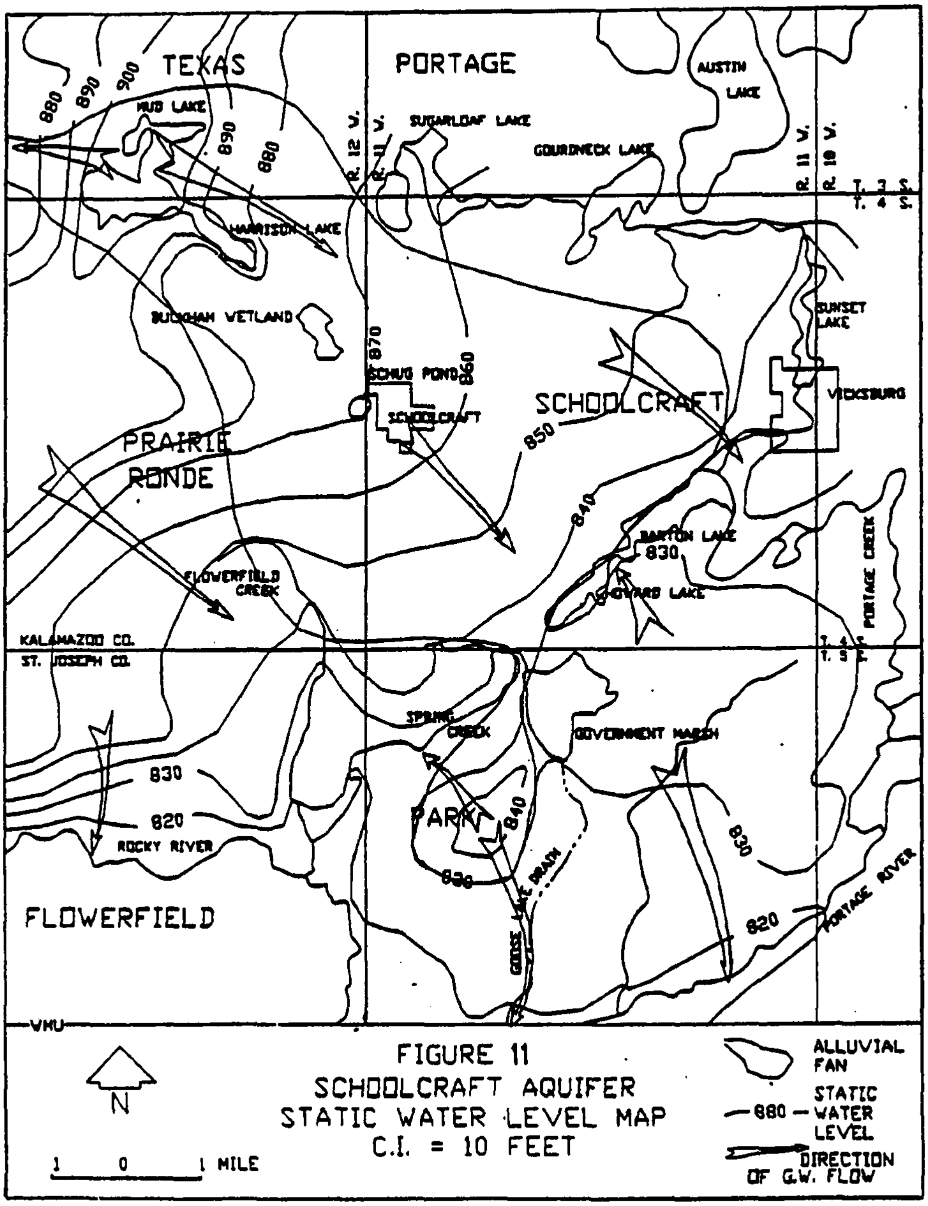


Figure 5. Static Water Level Map for the Schoolcraft Aquifer (Barrese, 1991).

Source: Barrese, P.G. (1991). A hydrogeological characterization of a glacial-drift aquifer system in southwest Michigan. Unpublished master's thesis, Department of Geology, Western Michigan University, Kalamazoo, MI., p. 19.

Aquifer Parameters

Three full aquifer tests have been conducted on the Prairie Ronde fan. Two were completed by Western Michigan University's Hydrogeology Field Course: one near the Village of Schoolcraft, and a second to the northwest of Government Marsh near the fan's terminus. A third test was completed by Peerless, Midwest, Inc., near the Village of Schoolcraft. Results of the tests range as follows (Straw et al., 1978): transmissivity from 118,000 to 168,000 gpd/ft; hydraulic conductivity from 784 to 1102 gpd/ft^2 (105 to 148 ft/day); and specific yield from .021 to .353. Well production within the unconfined aquifer is estimated between 100 to more than 500 gpm (Great Lakes Basin Commission, 1975).

Ground-Water Chemistry

Barrese (1991) used statistical analysis and hydrogeochemical facies comparison to separate the outwash region into two distinct and separate ground-water zones: Northern and Southern Flow Systems (NFS, SFS). The NFS is north of the Barton-Howard Lake system and includes the Prairie Ronde fan. The SFS is south of the same lake system and includes Government Marsh. Barrese did not collect samples from Government Marsh, but he did analyze ground water from residences living near the wetland. His conclusions are based upon the percentage distribution of total cations and total anions and results from two-sample *t* tests. Seven chemical parameters: pH, TDS, hardness, alkalinity, conductivity, calcium and magnesium, showed significant differences between the two flow systems. Barrese also concluded that calcite and dolomite are the principal carbonate minerals contributing to the geochemical character of the schoolcraft aquifer system, and that degradation of the Schoolcraft aquifer by nitrate and chloride contamination is extensive.

Land Use

Agricultural activity is the primary land use in St. Joseph County, which is probably the principal source for the nitrate contamination. Corn and soybeans are the major crop; wheat, oats and rye are also grown. The current farming practice in the area is center-pivot irrigation. In 1969 only 3,000 acres of farmland were irrigated. Ten years later, in 1979, 52,000 acres were irrigated in the southwestern Michigan, St. Joseph County. Reliance upon ground water for irrigation is expected to increase (USDA, 1983). Light and heavy industry is primarily located within the vicinity of the Village of Schoolcraft, north of Government Marsh. The industrial activity includes tooling, rubber/plastics manufacturing, and lumber treatment (Barrese, 1991).

The Millburn Peat Company is farming peat moss from Government Marsh. Forty employees help to harvest 30,000 cubic yards each year. Four million cubic yards will eventually be harvested over a 25-to 30-year period. All of the harvesting is located in the west and northwest areas of the bog. Millburn Peat has a permit to drain and pump 487,000 gallons of water per day from 230-acres of the wetland. The wetland's water is drained through a series of constructed canals, and pumped into holding ponds where sediment is allowed to settle. The water is eventually discharged into Spring Creek or the Goose Lake Drain (Michigan Department of Natural Resources, 1989). Harvesting of the peat is expected to continue past the year 2000 (Figure 6).

Government Marsh Vegetation

Identification of vegetation at Government Marsh was completed with the assistance of Dr. Eugene Jaworski and members of J and J Consulting, Inc. Dr. Jaworski and the J and J Consulting team specialize in wetland delineation through the

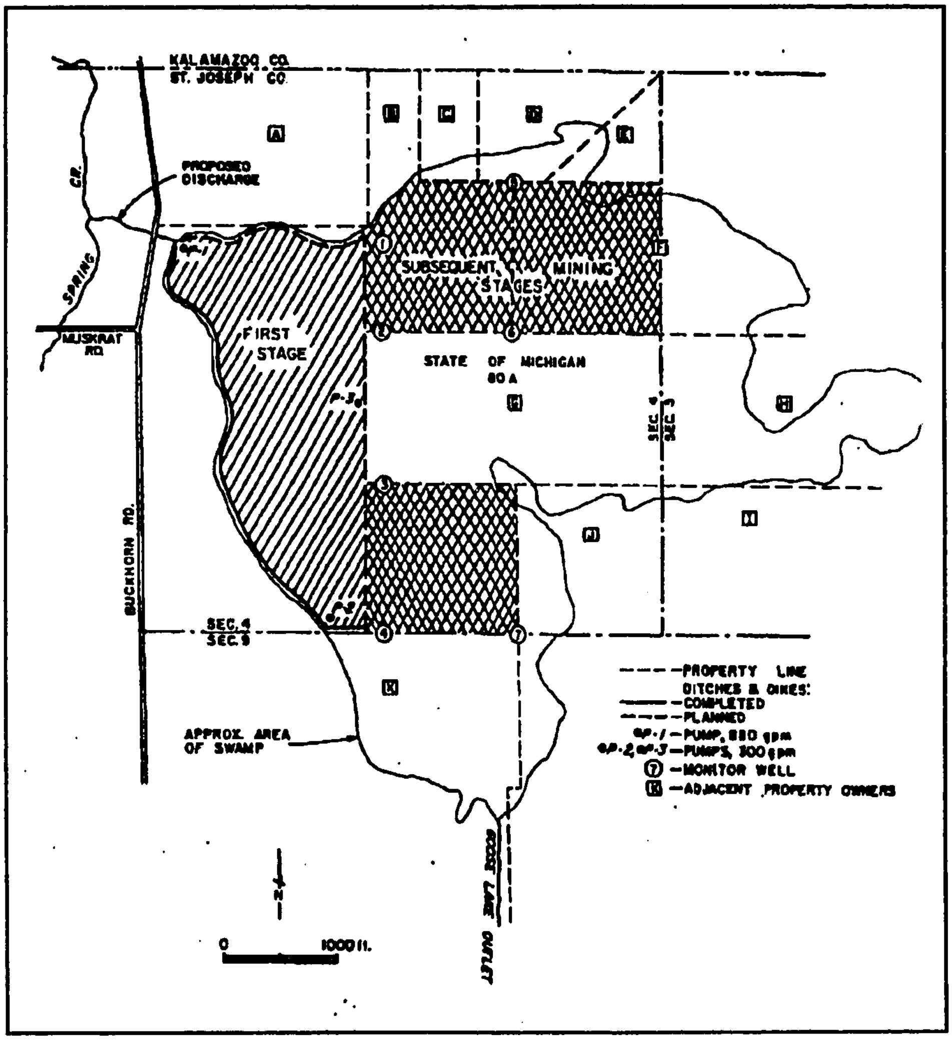


Figure 6. **Map of Government Marsh Showing Areas That Will be Farmed by the Millburn Peat Company. First Stage Production is Currently Underway.**

Source: **Michigan Department of Natural Resources, 1989.**

use of wetland plant identification. Dr. Jaworski is a Professor in the Department of Geography and Geology at Eastern Michigan University. He has seventeen years of experience relative to wetland delineation.

The vegetation at Government Marsh is diverse in some areas and dominated by only a few plants in other areas. Low plant species diversity is typical of low nutrient, ombrotrophic bog environments; whereas, high plant species diversity is more typical of minerotrophic environments. The Government Marsh Vegetation Map (Figure 7) shows eight identifiable areas described by predominating vegetation (Table 1). Area 1 is the western portion of the wetland that is being drained and farmed for its peat. Areas 2, 3, 7, and 8 contain plants that adapt more readily to minerotrophic or nutrient rich environments. Areas 4, 5, and 6 contain plants adapted to low nutrient environments (bogs).

Area 2 in the southern portion of the wetland, and south of the road constructed by the Millburn Peat Company, can probably be classified as a pond (south pond). Minerotrophic water from drainage canals is pumped into this area. The floating vegetation in the pond is dominated by *Nuphar variegatum* (yellow pond lily), and emergent vegetation is dominated by *Pontederia cordata* (pickerelweed) and *Decodcon vertilcillatus* (swamp loosestrife). Area 3, north and adjacent to the road constructed by the Millburn Peat Company, contains typical bog plants and plants adapted to high nutrient environments that have encroached on the bog environment. This is probably the result of alkaline water being discharged by the Millburn Peat Company into the south pond and back-flowing into the once-ombrotrophic environment. Area 4 is a section of Government Marsh that contains typical, low nutrient, ombrotrophic plants. Area 4 is probably fertilized by low pH rainwater that contains few dissolved solids. *Sphagnum* spp. moss, *Chamaedaphne calyulata* (leatherleaf), and *Decodcon vertilcillatus* (swamp loosestrife) predominate. Areas 5 and 6 also contain plants commonly found in bogs. Area 5 is dominated by *Larix laricina* (tamarack) and *Vaccinium corymbosum* (highbush blueberry). Area 6 is dominated by *Vaccinium*

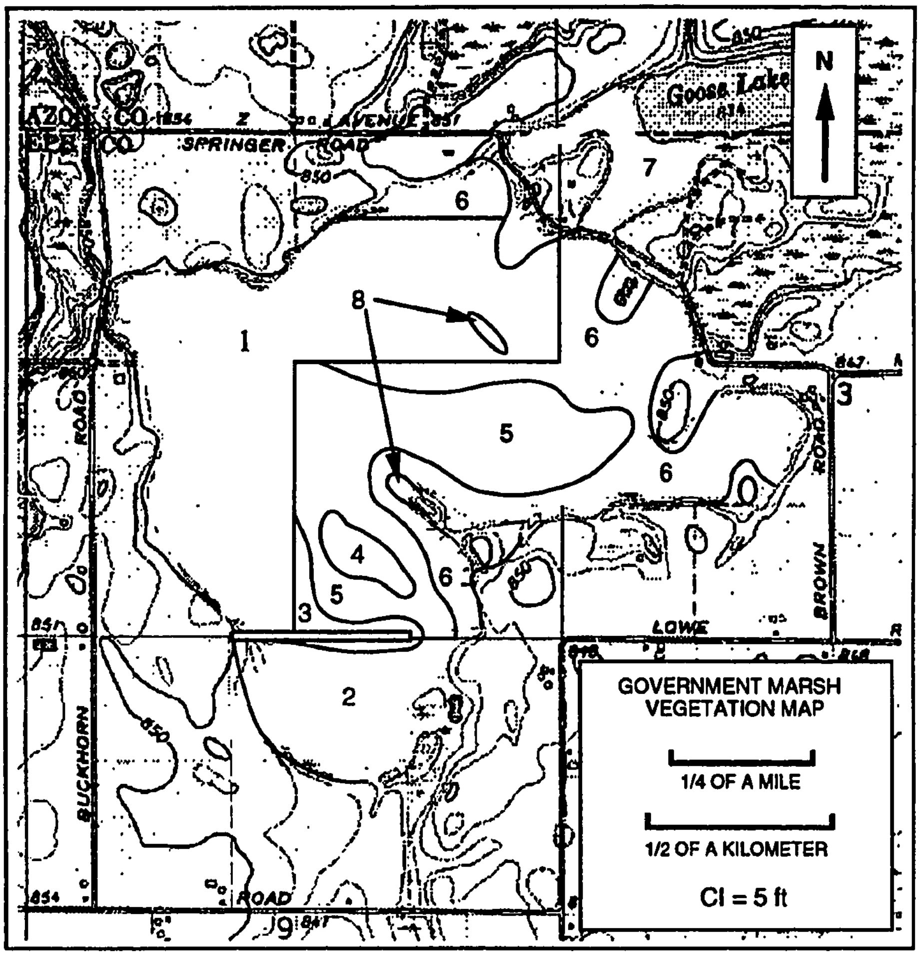


Figure 7. **Vegetation Map of Government Marsh.**

Source: **U.S.G.S. Topographic Quadrangle Map of Vicksburg, Michigan, 7.5 Minute Series (1967, photo revised 1973).**

corymbosum **(highbush blueberry),** ***Chamaedaphne calyulata*** **(leatherleaf),** ***Sphagnum*** **spp. moss, and** ***Decodcon vertilcillatuss*** **(swamp loosestrife).**

Area 7, a swamp located southwest of Goose Lake, generally contains plants adaptable to minerotrophic environments. Nutrients are probably derived from upland runoff waters that mix with the acidic surface-waters of the bog. Area 7 is

Table 1

Government Marsh Vegetation

Map Location	Scientific Name	Common Name
1	Area is being farmed for fibrous peat in the upper layers.	
2	*Nuphar variegatum*	Yellow Pond Lily
	Pontederia cordata	Pickerelweed
	Phalaris arundinacea	Reed Canary Grass
	Decodcon vertilcillatus	Swamp Loosestrife
	Polygonum amphibium	Water Smartweed
	Cephalanthus occidentalis	Button Bush
	Impatiens capensis	Spotted Jewel Weed
	Eupatorium perfoliatum	White Boneset
	Sambucus canadensis	Elderberry
3	*Vaccinium corymbosm*	Highbush Blueberry
	Rhus vernix	Poison Sumac
	Thelypteris palustris	Marsh Fern
	Ilex verticillata	Winterberry
	Chamaedaphne calyulata	Leatherleaf
	Sphagnum spp.	Sphagnum Moss
	Typha glauca	Hybrid Cattail
	Atrovirens	Scirpus
	Verbena hastata	Blue Vervain
	Juncus effusus	Soft Rush
	Larix laricina	Tamarack
	Impatiens capensis	Spotted Jewelweed
	Spirea japonica	Pink Meadow Sweet
	Utricularia vulgaris	Bladderwort
4	*Sphagnum* spp.	Sphagnum Moss
	Chamaedaphne calyulata	Leatherleaf
	Decodcon vertilcillatus	Swamp Loosestrife
	Eriophorum spp.	Cotton Grass
	Drosera rotundiflora	Sundew
	Sarracenia purpurrea	Northern Pitcher Plant
	Vaccinium uliginosum	Bog Cranberry
	Calla palustris	Water Arum
	Xyris montana	Yellow-Eyed Grass
5	*Larix laricina*	Tamarack
	Vaccinium corymbosum	Highbush Blueberry
	Chamaedaphne calyulata	Leatherleaf
	Sphagnum spp.	Sphagnum Moss
	Decodcon vertilcillatus	Swamp Loosestrife

Table 1--Continued

Government Marsh Vegetation		
Map Location	**Scientific Name**	**Common Name**
6	*Vaccinium corymbosum*	Highbush Blueberry
	Chamaedaphne calyulata	Leatherleaf
	Sphagnum spp.	Sphagnum Moss
	Decodcon vertilcillatus	Swamp Loosestrife
7	*Acer rubrum*	Red Maple
	Acer saccharinum	Silver Maple
	Ilex verticillata	Winterberry
	Alnus rugosa	Speckled Alder
	Betula alleghamiensis	Gray Birch
	Vaccinium corymbosum	High-Bush Blueberry
	Sphagnum spp.	Sphagnum Moss
	Osmuda regalis	Royal Fern
	Thelypteris palustris	Marsh Fern
	Osmunda cinnamonea	Cinnamon Fern
8	*Quercus velutina*	Black Oak
	Quercus alba	White Oak
	Quercus rubra	Red Oak
	Hamamelis virginiana	Witch Hazel
	Acer rubrum	Red maple
	Vaccinium corymbosum	High Bush Blueberry
	Spiraea latifolia	Meadow Sweet

predominated by *Acer rubrum* (red maple); and has therefore has been identified as a "Red Maple Swamp" by the landowner. Area 8 includes a sandy island in the northwest section of Government Marsh and a peninsula to the southeast. Both the island and peninsula are relatively homogeneous, upland, sandy environments, that are probably glaciofluvial landforms. Hardwood trees with deep root systems that can reach the water table predominate on these landforms.

CHAPTER III

DESIGN AND METHODOLOGY

Design

Five essential factors were investigated: (1) the flow directions of ground water within the area containing and surrounding Government Marsh, (2) fluctuation of hydraulic head in the ground water within Government Marsh, (3) the permeability of the geologic material adjacent to and upon which Government Marsh is embedded, (4) the permeability of the inactive layer of peat within Government Marsh, and (5) the chemistry of rain water, surface water and ground water within the area containing and surrounding Government Marsh.

1. The establishment of ground-water flow directions will help to determine the relationship between Government Marsh and the local ground-water flow system. The static water table was carefully measured in wells at selected locations and depths. The data was then plotted and interpolated in order to construct static water table maps. Static water table maps resemble topographic maps, except that contours represent elevation of the static water table instead of land surface elevation. The flow direction of ground water was established by constructing arrows perpendicular to the static water table contours in a down-gradient fashion.

2. Head fluctuations in the ground water within Government Marsh was established by determining the static water table at carefully selected locations and depths within a nest of wells. A well nest is more than one well constructed adjacent to each other (usually not more than 2-feet apart), but screened at different depths. Each

screen set at a selected depth will measure the hydraulic head of the screened interval. Equipotential lines, lines along which the static water level is the same for all points will be constructed using these data (Figure 8). Assuming three wells screened at three successive depths: when the static water table in the deepest well is situated below the static water table in the shallow well it is concluded that ground water is recharging the flow field (ground water is flowing into the system); conversely, when the static water table in the deepest well is situated above the static water table in the shallow well it is concluded that ground water is discharging from the flow field (ground water is flowing up to the surface) (Figure 9).

3. & 4. Information regarding the permeability of geologic material within and surrounding Government Marsh will help to establish the rate of ground-water movement between Government Marsh and the local ground-water flow field. This information will also help to establish the relationship between the systems. Permeability is the rate at which a porous medium will transmit a liquid. Different types of geologic material will transmit water at different rates. This is analogous to electrons being transmitted through a copper wire compared to electrons being transmitted through an aluminum wire: each wire type will transmit electrons at a particular rate along a distance. Different types of geologic material will transmit ground water at different rates along a distance. Clays, for example, will transmit ground water at much slower rates relative to coarse-grained material. Geologic material collected from bore holes will be examined and logged in order to make comparisons throughout the study area. Core samples from the bog are needed to (a) help determine the permeability of the inactive peat as a function of depth, (b) to understand the nature of the contact between the minerotrophic system and the water of Government Marsh, and (c) to determine the thickness or depth of the peat.

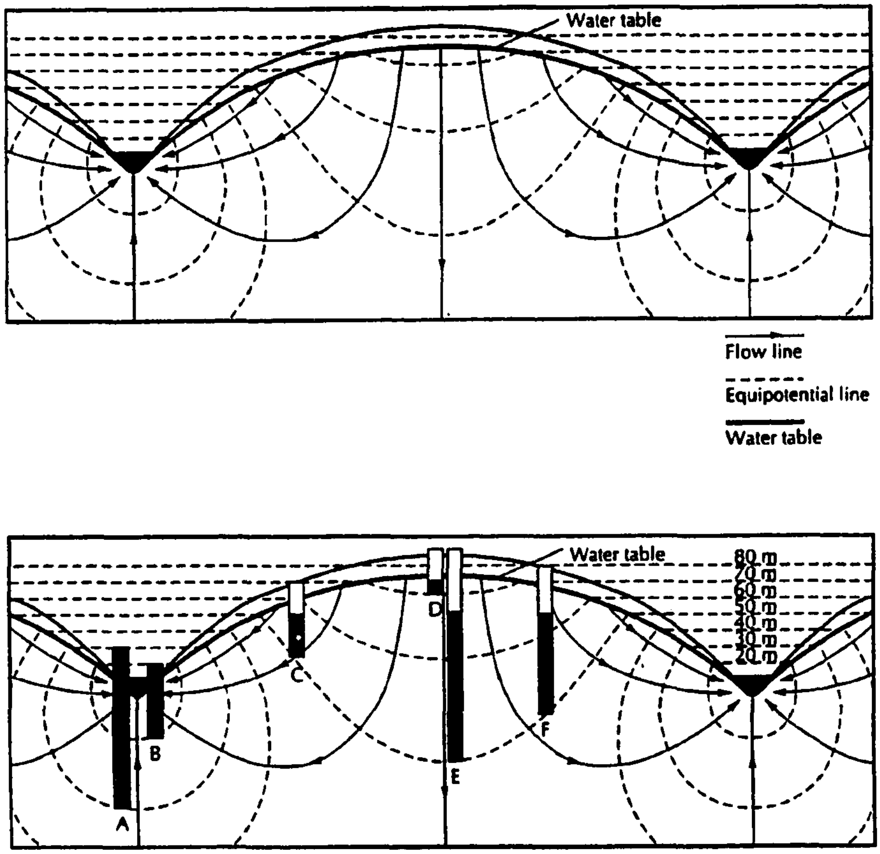


Figure 8. **Top, Equipotential Lines in a Flow Field. Bottom, Static Water Table Relative to Equipotential Lines (Fetter, 1994).**

Source: **Fetter, C.W. (1994). Applied hydrogeology (3rd ed.). New York: Merrill Publishing Company, p. 277.**

5. Minerotrophic ground water may seep into wetlands under some conditions and wetland water may enter the mineral water in the aquifer under other conditions. The amount of dissolved constituents in ground water is a function of the length of the

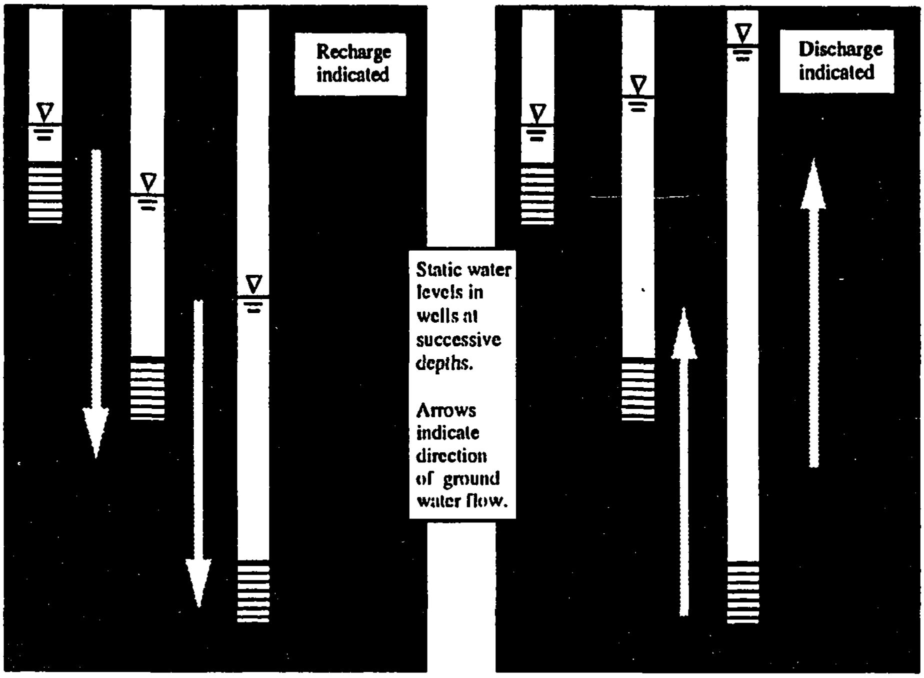


Figure 9. Well Nests as Indicators for Direction of Ground Water Flow.

flow path, which roughly correlates to the length of time water has been in the flow system. High dissolved solids contents is due to long flow paths through relatively whole soluble materials When chemical gradients increase with ground water depth it is often concluded that ground water is entering the flow system (recharge is is occurring); conversely, when chemical gradients decrease with depth it is often concluded that ground water is discharging from the system (Figure 10). Data from monitoring pH, specific conductivity, and major ions in the vertical column of water, should permit determination of the degree to which minerotophic ground water mixes with the water of Government Marsh. In order to do this ground water was collected and analyzed from specific locations and depths using monitoring wells adjacent to the

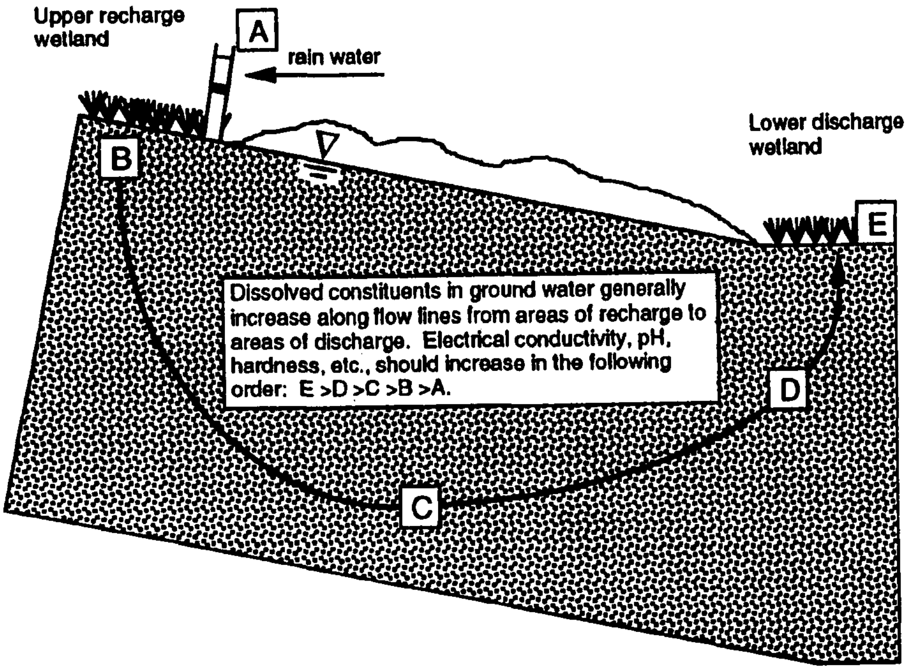


Figure 10. Dissolved Solids Content as a Function of Flow Path Length.

wetland perimeter (deep wells) and well nests. Rain water and bog surface water was also collected and analyzed and compared to ground water sampled from the wells. The parameters analyzed are: total hardness, temperature, electrical conductivity, pH, Cl^-, HCO_3^-, NO_3^-, SiO_2, SO_4^{-2}, Ba^{+2}, Ca^{+2}, Fe^{+2}, K^+, Mg^{+2}, Mn^{+2}, Na^+, and NH_4^+. [The Millburn Peat Company is draining Government Marsh to "farm" peat, and it is the west side of the bog that is most severely affected by this drainage. Because of this situation, chemical analysis of water to be extracted from the bog was generally limited to the eastern half of the bog or where the bog is least affected by drainage.]

Methodology

Ground-Water Flow Maps

Deep wells, water table piezometers and well nests, designed to monitor water pressure relative to the elevation of the static water table, were installed throughout the site. The eight deep wells generally consisted of 2-inch diameter metal casing and screens that were installed using the Western Michigan University Geology Department's hollow-stem auger rig. The depth of the wells range from about 30 feet to about 55 feet. Six of the deep wells were installed at several locations adjacent to the perimeter of Government Marsh. Two of the deep wells were installed within the boundaries of the wetland. The deep wells were used to measure depth to the static water table and to extract ground-water samples for chemical analysis. Water table piezometers consisted of 3/4-inch diameter pvc pipe and screen installed with the aid of a hand auger that utilized 2-3/4-inch diameter steel buckets. The piezometers were also installed adjacent to the perimeter of Government Marsh to gather additional data relative to the fluctuation of the water table. The nine well nests consisted of 2-inch pvc casings and screens. The nests generally contained three wells (when possible) installed at different depths within the boundaries of Government Marsh. The screens of the wells in the nests were generally set at depths of 5, 12 and 20 feet below the wetland surface. The nests of wells were used to collect ground water for chemical analysis and to measure the static water table in each well. All of the wells were surveyed from a known point of elevation using an automatic level and datum set at sea level. Water table or head measurements for the deep wells and piezometers were measured and recorded from January 1989 to December 1989. Water table measurements for the well nests and deep wells were measured and recorded from

January 1992 to December 1992. Measurements were not recorded during the month of November (deer hunting season). A Solinst Water Level Meter, which can be obtained from Forestry Suppliers, Inc., was used to determine depth to the static water table. Preliminary static water table maps were produced with the C-Map Computer Mapping Program developed by the Geography Department at Michigan State University. The maps were then checked for accuracy and final maps were produced by members of G.R. Kunkle and Associates, Inc., a hydrogeological firm located in Brighton, Michigan.

Equipotential Comparisons

Fluctuation comparisons between the wells in each nest were completed by using the measured data described above. The water table in the shallow well was compared to the water level in the deeper wells. The difference between the values was identified and then defined as follows: a negative (-) fluctuation = ground water recharge; a positive (+) fluctuation = ground water discharge.

Well Logs

Geologic logs for the eight deep wells and for the wells in the nine well nests have been constructed using the Logger for the MacIntosh Log Plotting computer Program, developed by RockWare Scientific Software, Inc. Cross-sections showing the results of many of these logs in profile have been constructed using the MacSection II Cross Section Plotting Program for the MacIntosh, also developed by RockWare Scientific Software, Inc.

Core samples for three of the well nests (peat deposits) were extracted using a hand auger. Samples were recovered from depths between 20 to 30 feet. Peat deposits

were also cored near the sandy island located in the wetland to the northeast. Depths of extraction near the sandy island were from depths less than about 5 feet. Data relative to sediment size and distribution (sorting) for the deep wells were obtained from field observation (well drilling) and then checked when possible using grain-size analysis and classified according to Wentworth system for sediment size classification. Grain-size analysis utilizes a series of sieves with decreasing mesh size at the bottom of each succeeding pan. The largest mesh size is at the bottom of the first pan and the smallest in the last sieve. All of the sieves are bolted together in a machine aptly called a "shaker." A premeasured sample of sediment from a specific cored depth is set in the first sieve, the shaker is operated, and sediment falls through the meshes until each grain lands on the sieve corresponding to its size and through which it cannot fall further--that is--sediment is segregated by size (Figure 11). After a predetermined time has passed, the shaker is shut-off, and the amount of sediment in each sieve is again carefully weighed. The weight by percent of sediment from each sieve is then plotted on a cumulative frequency curve. A curve is then constructed through each point and the effective grain (d_n) size is determined. The effective grain size represents the diameter of sediment at which n% of the sediment is smaller than the particular size (d). The degree of sorting and type of sediment by size can be determined by selecting predetermined, empirical, effective grain-size values from the cumulative frequency curve. A Gilson Sieve Shaker Model SS-15 and 8-inch brass sieves meeting American Standards and Testing Material (ASTM) E11 standards ranging up to No. 200 sieve were employed. The resulting grain-size data was analyzed using the Geosystem Grain-size Distribution Computer Program, developed by Von Gunten Engineering Software, Inc. Sediment type and distribution was determined using Figure 12 and the following equations (Folk, 1974):

sediment type = gm = $[ø_{16} + ø_{50} + ø_{84}] / 3$ (1)

sorting = gsd = $[(ø_{84} - ø_{16}) / 4] + [(ø_{95} - ø_5)] / 6.6]$ (2)

where

$ø_n$ = the effective grain-size converted from millimeters using

$(-3.3219281)\log d_n = ø_n$ (Kasenow, 1993). (3)

d_n = the effective grain size in mm

gm = the graphic mean, and

gsd = the graphic standard deviation.

Gamma ray geophysical logs, using the Western Michigan University Department of Geology's Gamma Ray Logger, were completed to help verify and rectify geologic logs for the eight deep wells. [The location of well nests within the boundaries of Government Marsh prohibits the use of gamma ray logging equipment for those wells.] A gamma-ray log measures the natural radioactivity of the formation. For shales and clays the radioactive isotope measured is probably Potassium-40. Most gamma ray logging devices can record emanation from about one foot into the formation through which the well has been constructed. The curve of the log responds to the presence of K_{40} by "actively" trending horizontally from the vertical profile. The greater the horizontal displacement the greater the amount of postassium-40 which is taken as a measure of the amount of clay or shale present in a layer. The thickness of clay in the formation can be measured from the depth where the horizontal trend originates to the depth where the reaction recovers. When the curve of the log remains "inactive" in the vertical profile, it is concluded that coarse sand or larger with minimal amounts of clay is present (Figure 13).

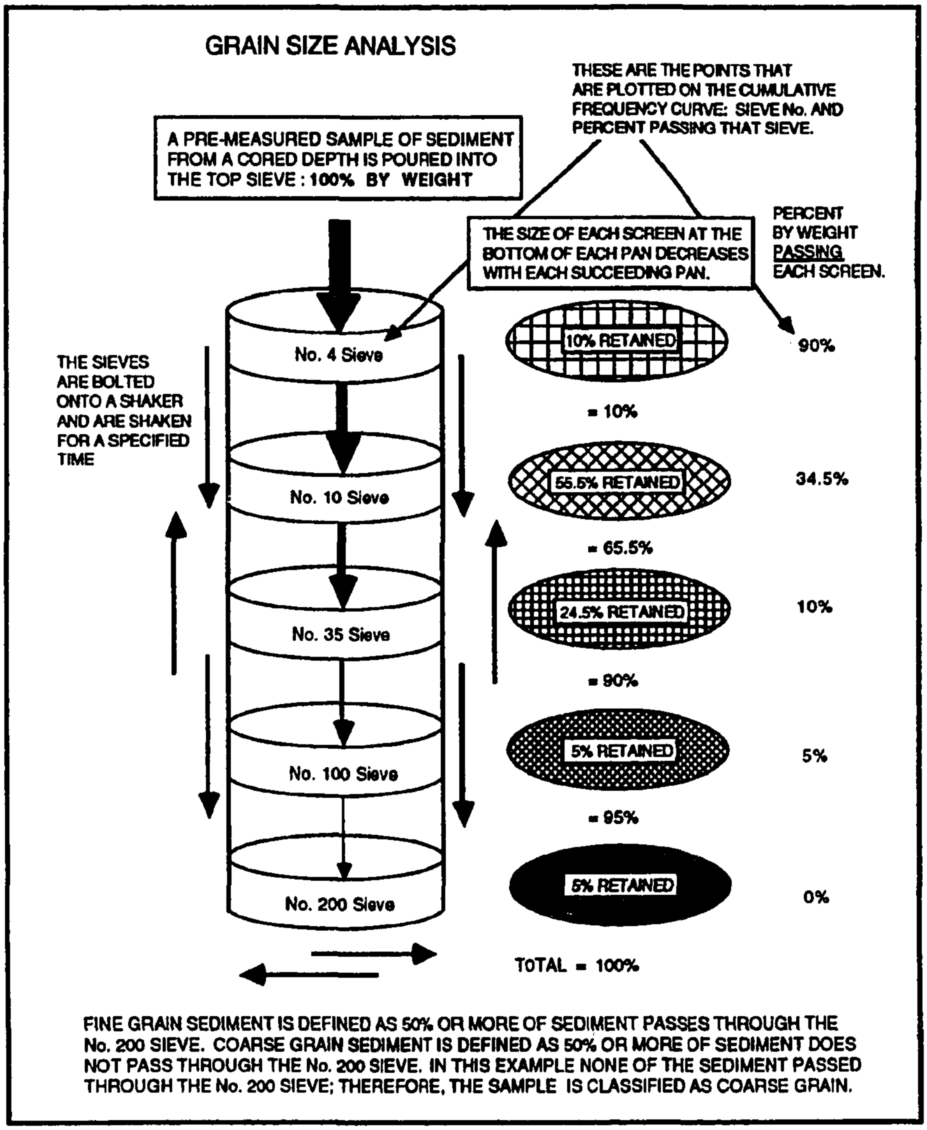


Figure 11. **Example of Grain Size Analysis Data Collection (Kasenow, 1993).**

Source: **Kasenow, M.C. (1993). Introduction to aquifer analysis, Dubuque, IA: Wm. C. Brown Publishing Company, p. 225.**

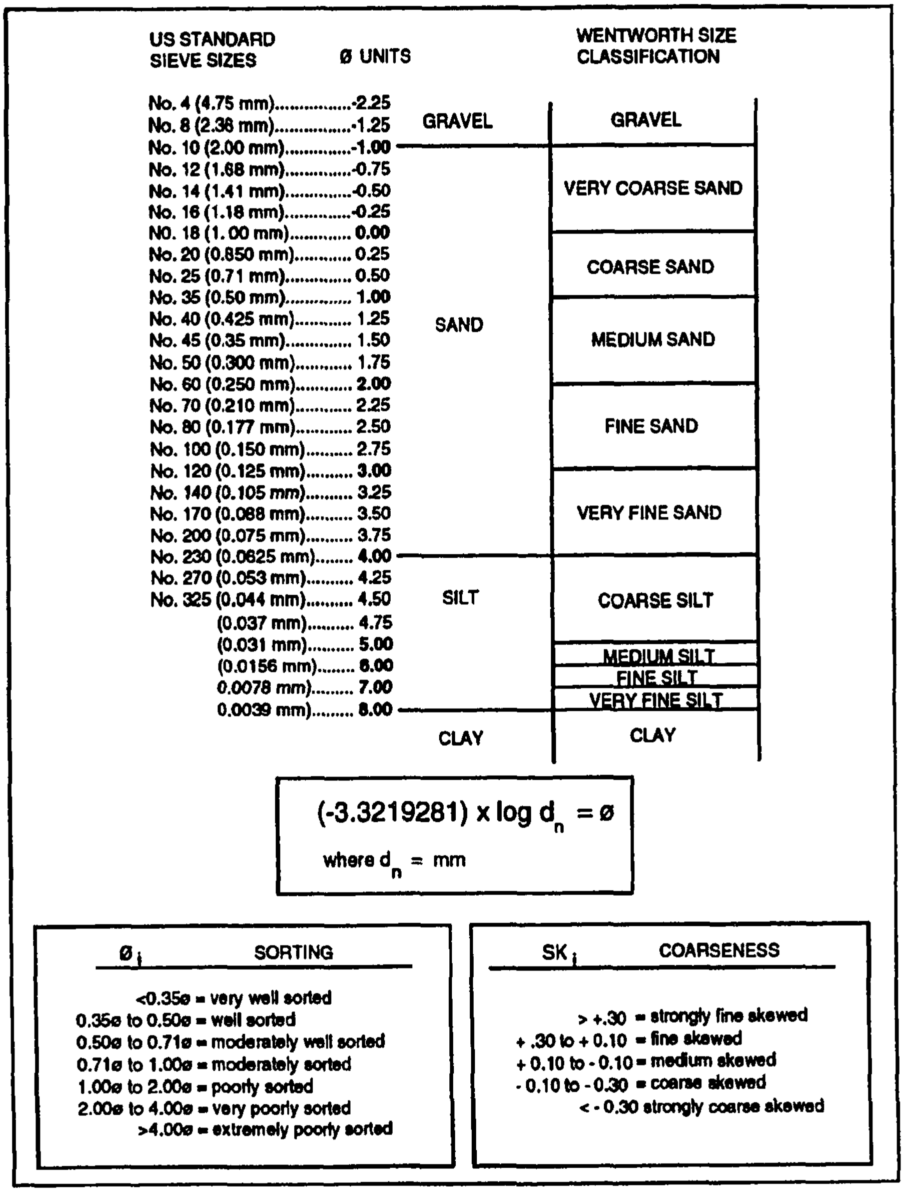


Figure 12. Wentworth Sediment Size and ø Scale (Kasenow, 1993).

Source: Kasenow, M.C. (1993). Introduction to aquifer analysis, Dubuque, IA: Wm. C. Brown Publishing Company, p. 230.

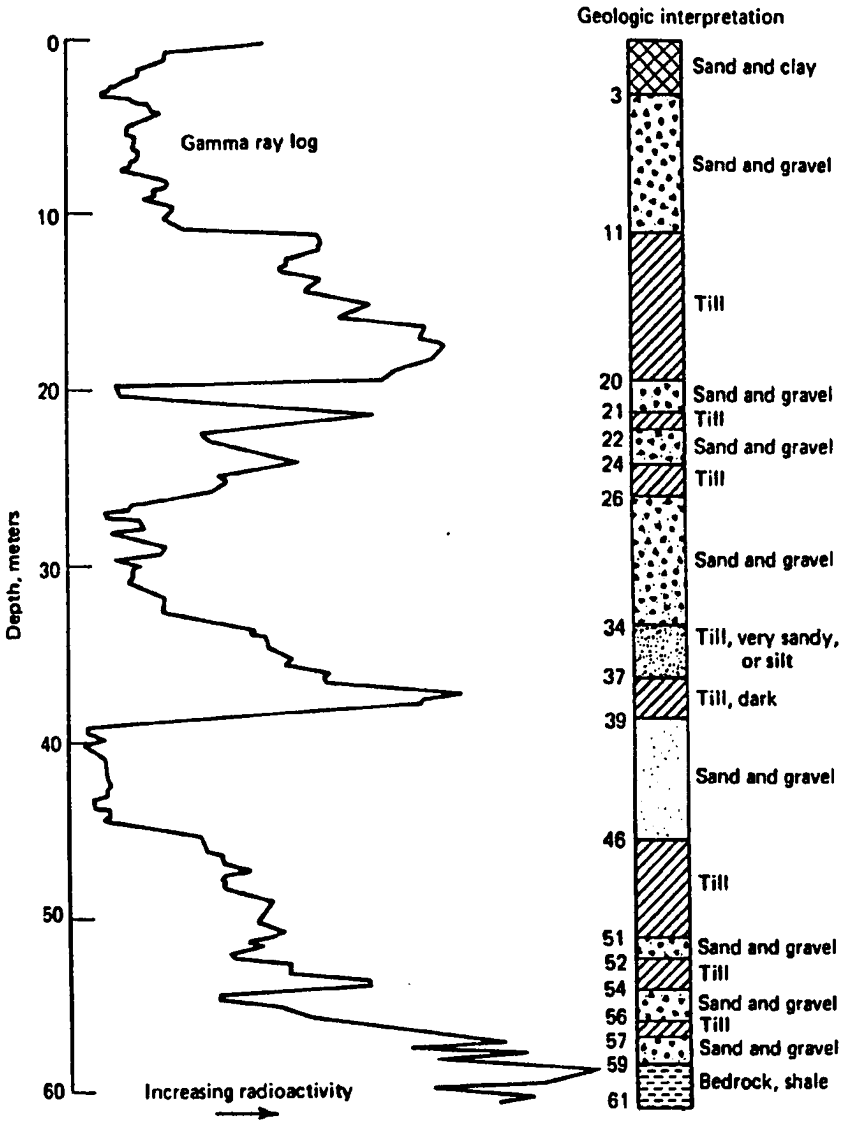


Figure 13. Example of a Gamma Ray Log (Todd, 1980).

Source: Todd, D. K. (1980). Ground water hydrology. New York: John Wiley and Sons, Inc., p. 447.

Permeability

Slug tests, permeameters and grain size analysis (bail-down tests) were

employed in all of the deep well and well nests to help determine the permeability of peat and interstitial ground-water material. A slug test is an aquifer test made by either pouring a small instantaneous charge of water into a well or by withdrawing a slug of water from the well. A synonym for this test, when a slug of water is removed from the well is a bail-down test (Fetter, 1988). The rate at which the water level rises or falls is controlled by the characteristics of the material being measured. Hydraulic conductivity can then be calculated, and then transmissivity if the aquifer thickness is known. Bail-down testing was begun in May 1991 and were completed in October 1991. Tests were conducted manually when the rise of ground water was sufficiently slow for measurements to be collected with the Solinst Water Level Meter and a stop watch. When the rise of ground water was excessively fast and difficult to measure manually, a Hermit Datalogger and Pressure Transducer, Model 1000-C was used (with cooperation from Eneco Tech, Inc., an environmental engineering firm, located in Novi, Michigan). A pressure transducer measures the rise or fall of the static water table utilizing ground water pressure. The Bouwer and Rice method (Fetter, 1994) was used to analyze bail-down test information. The Aquifer Test Solver (AQTESOLV) computer program was used to analyze slug test data relative to Bouwer and Rice. AQTESOLV utilizes correction factors to calculate $\ln(R_e/r_w)$ compiled into the program and the following equation by Bouwer and Rice:

$$K = [r^2_c \ln (R_e / r_w) / 2 L_e][1/t][s_o / s_t] \quad (4)$$

where, for consistent units,

K = hydraulic conductivity,

r_c = well pipe radius,

R_e = effective radius,

r_w = bore hole radius,

L_e = length of the well screen

t = time at which s_t is measured

s_t = measured drawdown, and

s_o = initial drawdown.

A permeameter is a laboratory device that measures the rate at which a sample of geologic material will transmit water. All permeameters have a cylindrical chamber that holds the sample and is constructed about tubing through which water enters and leaves the chamber. Hydraulic conductivity is calculated using an equation specific to the type of permeameter used: falling head permeameter for fine-grain material or constant head permeameter for coarse-grain material (Figures 14 & 15). The permeameter used to analyze geologic material extracted from the site is a Soilest K-605 Combination Permeameter. Permeameter analyses were performed in October 1972 and October to November 1993. The following equations and parameters apply to specific permeameters (Fetter, 1994).

Constant head:

$$K = VL/Ath \qquad (5)$$

where, for consistent units,

K = permeability,

V = volume of water moving through sample,

L = length of the sample,

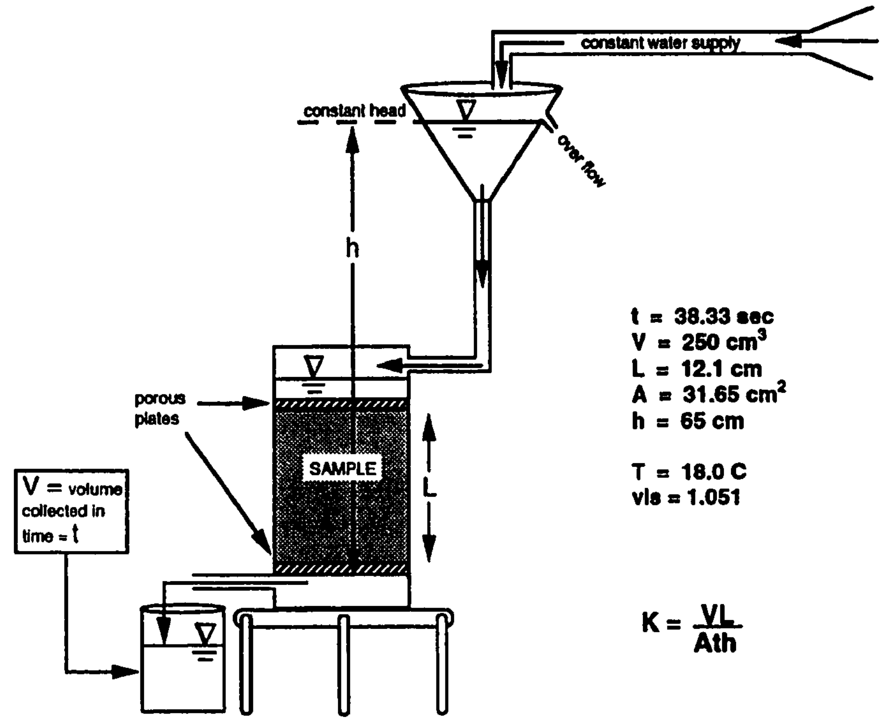
A = cross-sectional area of the sample,

t = time for the measured volume of water to pass through the sample, and

h = difference in water level between the sample chamber and overflow;

Falling head:

$$K = [Ld^2/D^2t][\ln (h_i/h_f) \qquad (6)$$



$$K = \frac{(250\ cm^3)(12.1\ cm)}{(31.65\ cm^2)(38.33\ sec)(65.0\ cm)} = (0.0384\ cm / s)$$

$$K_{calculated} = (0.0384\ cm / s)(1.051\ vis) = K_{corrected} = 0.0404\ cm / s$$

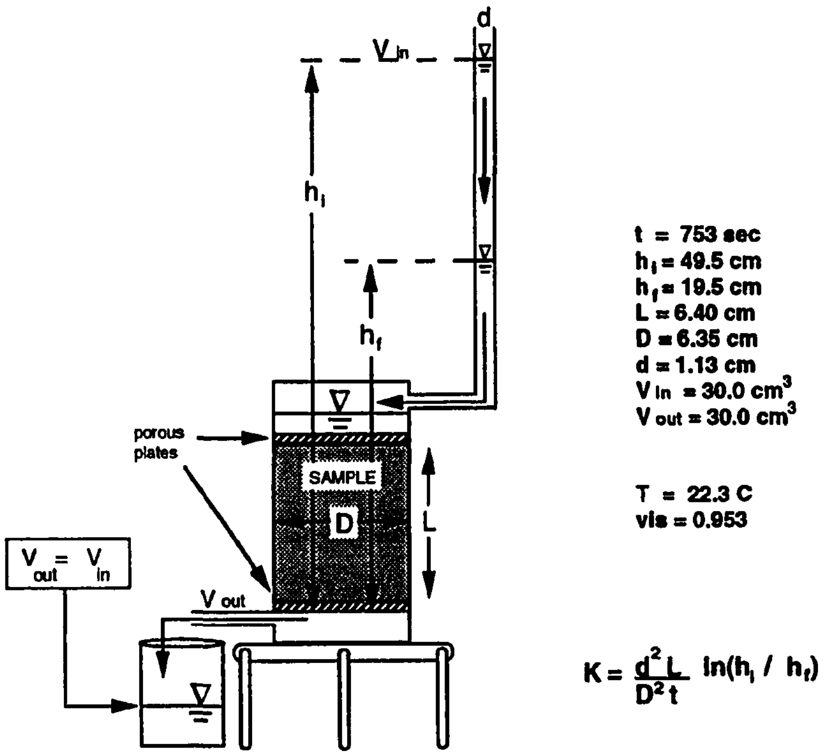
Figure 14. Example of a Constant Head Permeameter (Kasenow, 1993).

Source: Kasenow, M.C. (1993). Introduction to aquifer analysis, Dubuque, IA: Wm. C. Brown Publishing Company, p. 256.

where, for consistent units,

K = permeability,

L = length of the sample,



$$K = \frac{(1.13\ \text{cm})^2\ (6.40\ \text{cm})}{(6.35\ \text{cm})^2\ (753\ \text{sec})} \ln(49.5\ \text{cm} / 19.5\ \text{cm}) = (0.000250\ \text{cm / s})$$

$$K_{calculated} = (0.000250\ \text{cm / s})(0.947\ \text{vis}) = K_{corrected} = 0.000237\ \text{cm / s}$$

Figure 15. Example of a Falling Head Permeameter (Kasenow, 1993).

Source: Kasenow, M.C. (1993). Introduction to aquifer analysis, Dubuque, IA: Wm. C. Brown Publishing Company, p. 257.

d = diameter of the falling head tube,

t = time for the measured volume of water to pass through the sample,

D = diameter of the sample chamber,

h_i = initial height of water in falling head tube, and

h_f = final height of water in falling head tube.

The K values calculated from equations 5 or 6 were corrected for temperature relative to viscosity using Table 2.

Permeability was also determined using grain-size analysis and a predetermined effective grain-size (d_n) relative to the following equations:

$K = Cd^2_{10}$	(Hazen, 1901)	(7)
$K = 0.36(d^{2.3}_{10})$	(Vukovic & Soro, 1992)	(8)
$K = (-223.445)(X^2) + (647.248)(X - 86.112)$	(Wilson, 1993)	(9)

where

K = cm / s (2830) = ft / day	(equations 7 & 8)
K = ft / day	(equation 9)

d_n = mm,

X = gm / gsd or equation 1 / equation 2 = mm

C is a dimensionless coefficient = 60 for fine sand, = 100 for medium sand, and = 135 for coarse sand (Fetter, 1994).

The grain-size solution employed was based upon Table 3, which is based upon the work of Wilson (1993), Masch and Denny (1966), Hazen (1901), and Rose and Smith (1957).

Chemical Analysis of Ground and Surface Water

Over a two-year period, sixty-five water samples were collected from monitoring wells and surface water either adjacent to or within Government Marsh. This includes samples collected near and from Goose Lake, and a sample extracted from the canal network constructed by the Millburn Peat Company. Eight samples

Table 2

Viscosity-Temperature Correction Factors

°C	0	0.1	0.2	0.3	0.4	0.5	0.6	0.7	0.8	0.9
10	1.301	1.298	1.294	1.290	1.287	1.283	1.280	1.276	1.272	1.269
11	1.265	1.262	1.258	1.255	1.251	1.248	1.244	1.241	1.237	1.234
12	1.230	1.227	1.223	1.220	1.217	1.214	1.210	1.207	1.204	1.200
13	1.197	1.194	1.191	1.187	1.184	1.181	1.178	1.175	1.171	1.168
14	1.165	1.162	1.159	1.156	1.153	1.150	1.147	1.144	1.141	1.138
15	1.135	1.132	1.129	1.126	1.123	1.120	1.117	1.114	1.111	1.109
16	1.106	1.103	1.100	1.097	1.094	1.092	1.089	1.086	1.080	1.080
17	1.077	1.075	1.072	1.069	1.067	1.064	1.061	1.059	1.056	1.053
18	1.051	1.048	1.045	1.043	1.040	1.038	1.035	1.033	1.030	1.027
19	1.025	1.022	1.020	1.017	1.015	1.012	1.010	1.007	1.005	1.003
20	1.000	0.998	0.995	0.993	0.990	0.988	0.986	0.983	0.981	0.979
21	0.976	0.974	0.972	0.969	0.967	0.965	0.962	0.960	0.958	0.955
22	0.953	0.951	0.949	0.947	0.944	0.942	0.940	0.938	0.936	0.933
23	0.931	0.929	0.927	0.925	0.923	0.920	0.918	0.916	0.914	0.912
24	0.910	0.908	0.906	0.904	0.902	0.900	0.898	0.895	0.893	0.881
25	0.889	0.887	0.885	0.883	0.881	0.879	0.877	0.875	0.873	0.871
26	0.869	0.868	0.866	0.864	0.862	0.860	0.858	0.856	0.854	0.852
27	0.850	0.848	0.847	0.845	0.843	0.841	0.839	0.837	0.836	0.834
28	0.832	0.830	0.828	0.826	0.825	0.823	0.821	0.819	0.818	0.816
29	0.814	0.812	0.811	0.809	0.807	0.805	0.804	0.802	0.800	0.798
30	0.797	0.795	0.793	0.792	0.790	0.788	0.787	0.785	0.783	0.782
31	0.780	0.779	0.777	0.775	0.774	0.772	0.771	0.769	0.767	0.766
32	0.764	0.763	0.761	0.760	0.758	0.756	0.755	0.753	0.752	0.750
33	0.749	0.747	0.746	0.744	0.743	0.741	0.740	0.738	0.736	0.735
34	0.733	0.732	0.731	0.729	0.728	0.726	0.725	0.723	0.722	0.720
35	0.719	0.718	0.716	0.715	0.713	0.712	0.711	0.709	0.708	0.706

In order to report the value of K in cm / s for the standard temperature of 20° C, the computed values need to be corrected by multiplying the ratio of viscosity of water at the test temperature to the viscosity of water at 20° C.

Example: 24.6 degrees Celcius = 0.898 correction factor = vis.

Source: Kasenow, M.C. (1993). Introduction to aquifer analysis, Dubuque, IA: Wm. C. Brown Publishing Company, p. 258.

were collected for each season in one year from the eight deep wells (DW) adjacent to Government Marsh. Three rain samples were collect within the boundaries of Government Marsh from containers situated above the wetland floor. The rain water

samples were collected over a 3-month period, from August to October 1989. Four samples of surface bog water were collected beginning in June 1989 and ending in April 1990. Samples were also collected from well nests in August 1991. The nest samples were collected over a three-week period. One set of nest samples was collected near Goose Lake. Three sets of nest samples were collected from areas described as "northern bogs" according to vegetation criteria (Keough & Pippen, 1981). An attempt was made to collect the nest samples from wells not influenced by the current drainage operations imposed by the Millburn Peat Company. Four other sets of nest samples were collected from wells which are probably influenced by bog drainage. Another set of nest samples was collected from the Mattheis residence, on the northern perimeter of the wetland. Sampling began in Spring of 1989 and ended in August of 1991. Well water was pumped using a 1 and 1/2 horse power Homelite, Charlotte, North Carolina, centrifugal pump when depth to water was less than 30 feet. A Keck SP-80 downhole submersible pump was used when depth to water was greater than 30 feet. A Brainard-Kilman hand pump was used to collect samples from nests within the wetland boundary. Each pump was lowered to the midpoint of the well screen where purging was considered to have occurred and samples collected. Optimum purging occurred when the water was clear of turbidity and temperature, conductivity, and pH were consistent. Two one-liter samples were extracted from each well or specified location. One liter was collected for metal analysis and one liter was used for non-metal analysis. Samples were generally filtered in the field through a .45 micron filter fitted on a Geofilter tripod filter stand and forced through the filter using a Masterflex peristalic pump. The filtered metal sample was acidified with 5 ml of a 1M nitiric acid solution. All samples were refrigerated for transport to the Western Michigan University Water Quality Lab. Temperature, pH and conductivity were

Table 3

Applicability of Grain Size Analysis Solutions to Estimate Permeability

Method	Limits of Applicability	Best Use
Masch & Denny	$0.01 \text{ mm} \le d_{10} \le 0.7 \text{ mm}$ or $0.01 \text{ mm} \le d_{20} \le 0.7 \text{ mm}$	when $d_{10} \le 0.6$ mm when $d_{20} \le 0.6$ mm
The Masch and Denny method generally offers the best results over the entire range of most aquifer material; this is especially true for medium to medium-coarse sand.		
Wilson	$d_{10} \ge 0.3$ mm	when $d_{10} \ge 0.6$ mm when $d_{20} \ge 0.6$ mm
The Wilson equation generally offers better results for coarse to very coarse aquifer material. Wilson should not be used when $X < 0.14$ or when $X > 1.5$. Wilson is generally superior to Masch and Denny for coarse to very coarse aquifer material; where as, Masch and Denny is generally superior to Wilson for fine to medium-coarse material.		
Hazen	$0.1 \text{ mm} \le d_{10} \le 0.3$ mm or $0.1 \text{ mm} \le d_{20} \le 0.3$ mm	when $d_{10} \le 0.2$ mm when $d_{20} \le 0.2$ mm
Hazen should only be used for fine to medium-fine aquifer material.		
USBR	$0.1 \text{ mm} \le d_{10} \le 0.3$ mm or $0.1 \text{ mm} \le d_{20} \le 0.3$ mm	when $d_{10} \le 0.25$ mm when $d_{20} \le 0.25$ mm
USBR should only be used for fine to medium-fine aquifer material.		
Rose & Smith	$0.15 \text{ mm} \le d_{10} \le 1.0$ mm and $C_u \le 6$	$0.2 \text{ mm} \le d_{10} \le 0.6$ mm
The Rose and Smith method offers reasonable results for medium-fine to medium aquifer material when $C_u \le 6$.		

measured in the field. Temperature and conductivity were measured using a Yellow Springs Industries (YSI) Model 3000 TLC meter set at a range of 0 to 2 mmhos/cm. Accuracy range for temperature and conductivity is +/- .2°C and +/- 3% at 25 °C,

respectively. pH was measured using a Orion 230 digital pH meter. The pH meter automatically compensates for temperature and was calibrated with buffers 10 or 4, depending upon the expected pH of the sample environment, and 7. Accuracy range for pH measurements is +/- .1 pH unit for ground water at 10 to 15 °C. All other concentrations of chemical species were determined at the Water Quality Laboratory, Institute for Water Sciences, at Western Michigan University, Kalamazoo, Michigan.

Seasonal concentrations of deep well chemical parameters have been listed and are compared using descriptive tables and graphs. Tabular comparisons are also made between surface water sampled from the constructed canals and mean seasonal parameter concentrations of the deep wells. The WATEQ4F software package, version 2.0 (Ball & Nordstrom, 1992), which uses thermodynamic data to calculate and suggest which processes control water composition, was utilized to ascertain mineral solubility relative to the flow field external to Government Marsh. Both deep well and canal chemical data were analyzed using WATEQ4F. WATEQ4F calculations assume formation of complexes described by mass action equations and stability constants, and that activity coefficients are only a function of temperature and ionic strength (Barrese, 1991). Mean chemical parameters for the four Michigan seasons relative to the deep wells were entered into WATEQ4F and an assumed Eh value of 9.9. The summer 1991 chemical data for the constructed canal were also entered into WATEQ4F along with the same assumed Eh value.

Chemical parameter concentrations relative to rain gauges, the bog surface, and well nests are also displayed in tables and graphs showing the relationship between chemical concentration relative to ground water depth. Tabular comparisons between chemical parameters sampled from Goose Lake and those sampled from the bog surface have also been completed.

Statistical Analysis

The Instat Mac Statistical Software Program, Version 2, Rock Ware Scientific Software, was used to further analyze chemical parameters. Statistical analysis between seasonal chemical concentrations sampled from the eight deep wells have been completed using one-way analysis of variance (ANOVA) and a significance level of 0.05. The null hypothesis is as follows: There is no statistical significant difference between ground water parameter concentrations sampled from the eight deep wells for each of the four Michigan climatic seasons. The Kruskal-Wallis nonparametric ANOVA test was also employed using the same data, null hypothesis, and level of significance, because statistical results show that differences between some of the seasonal parameter standard deviations are significant (Bartlett statistic). This is not a critical assumption violation relative to ANOVA in this study, because samples tested are of equal size, but the addition of nonparametric Kruskal-Wallis results helps to confirm parametric statistical decision(s)--without assumption violation.

Linear parametric regression analysis was also employed using the Instat program in order to ascertain if a relationship exists between chemical parameter concentrations and ground-water depth within Government Marsh. Parameter concentrations sampled from each well in nests B, C, D, and F were tested. Following is the null hypothesis for each test: The Pearson Product Moment Correlation Coefficient for X parameter and ground water depth is equal to zero (where X = a chemical parameter). The level of significance was again set at 0.05.

Ground water was sampled from nests A, E, G, H, I, and J, and analyzed for the same chemical parameters, but no statistical testing was employed, because parameter concentration at each location has been influenced either by the input and

distribution of "fill" material or a surface water back-flow caused by the enormous discharge of water by the Millburn Peat Company.

CHAPTER IV

RESULTS AND DISCUSSION FOR HYDROGEOLOGY

Hydrogeology

Well Construction

Six wells were constructed around the perimeter of Government Marsh and two wells were constructed within the wetland from July 7 to August 16, 1988 (Figure 16). These wells were identified as "deep wells" (DW), because they are significantly deeper than other well types used in this study. DWs 3 through 8 are constructed around the wetland; DWs 1 and 2 were constructed in the wetland. DW 9 was donated by a resident who had abandoned the well on his property (data collected as piezometer 8). The wells were constructed using a drill rig supplied by the Department of Geology at Western Michigan University. The construction of DWs 1 and 2 was possible because a local road was constructed by the Millburn Peat Company into Government Marsh. The DWs range in depth from 32 to 55 feet and are 2-inches in diameter. The well screens are 3-feet in length and were emplaced near the bottom of the bore hole. All of the wells are steel, except for DW 2, which is constructed of pvc (Table 4).

Thirty-nine water-table piezometers were constructed around the perimeter of Government Marsh from June 29 to August 22, 1988 (Figure 17). All of the piezometers are made of pvc pipe and are 3/4-inches in diameter. Most of the piezometers were constructed using a hand auger. The depths of the piezometers that were constructed using a hand auger generally range from 7 to 12 feet (Table 5). Piezometers 8, 25 and 35 were constructed using a drill rig. Their depths are 29, 18

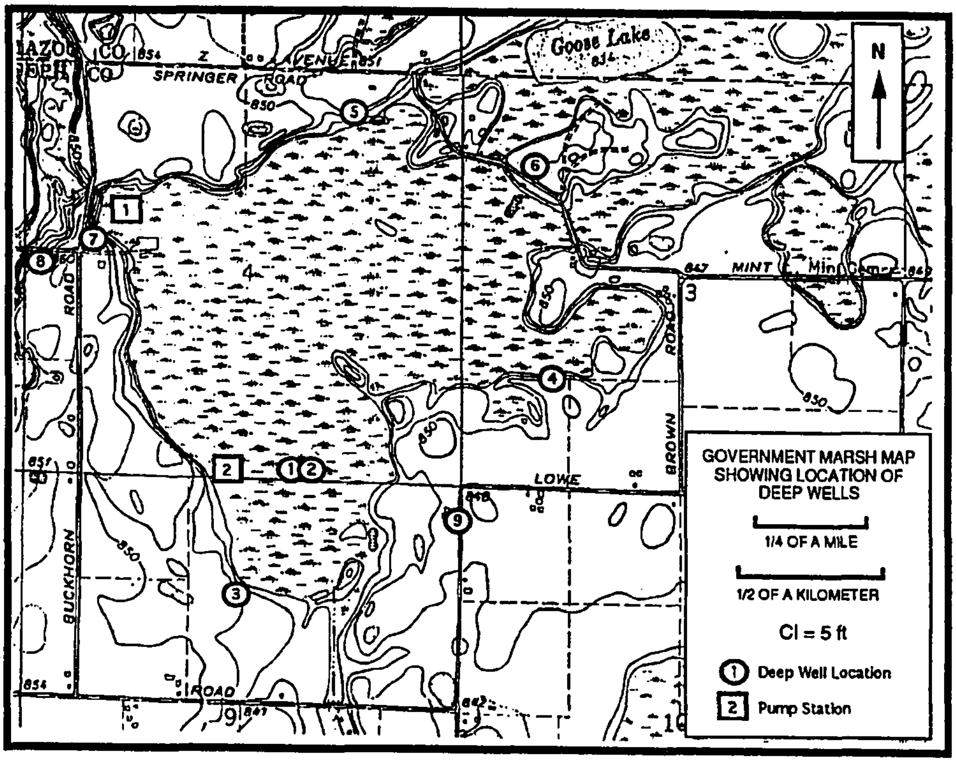


Figure 16. Map Showing Location of Deep Wells and Millburn Peat Pump Stations.

Source: U.S.G.S. Topographic Quadrangle Map of Vicksburg, Michigan, 7.5 Minute Series (1967, photo revised 1973).

and 16 feet, respectively. Piezometers 25 and 35 were constructed next to DWs 4 and 6, respectively. Information from piezometers 11, 12, 14, 16, 19, 30, 31, 32, 33 and 36 was not collected due to vandalism or access disagreement with the residents.

Ten well nests were constructed from July 11, 1990 to June 6, 1991. Eight well nests were constructed within the boundaries of Government Marsh. One nest was constructed west of Goose Lake Drain and one nest was constructed near Goose Lake (Figure 18). Most of the nests contain 3 wells except for nest E and G, which contain 2 wells each. The nests were constructed using a hand auger, where possible, until collapse of subsurface sediment occurred, then a weighted driver was used to

Table 4

Deep Well Construction Data

Well	TD (ft)	*Screened Interval (ft)	Slot Size (in.)	Material, Diameter (in)	Elev. TOC (ft)	Elev. Surface (ft)
DW-1	32	29-32	10	steel-2	837.46	834.30
DW-2	55	52-55	10	pvc-2	837.32	835.15
DW-3	35	32-35	10	steel-2	841.31	838.84
DW-4	35	32-35	10	steel-2	849.38	847.21
DW-5	33	30-33	10	steel-2	839.48	837.08
DW-6	33	30-33	10	steel-2	846.80	844.25
DW-7	43	40-43	10	steel-2	860.54	858.12
DW-8	45	42-45	10	steel-2	858.28	856.33

TD = Total Depth
*Depth from TOC = Top of Casing

complete the construction to the desired depth. The wells are 2-inches in diameter and are made of pvc. All are completed with 5-foot well screens installed at the bottom of the bore hole. The well screens are set at depths that are about 5, 12, and 20 feet below the surface. The shallowest well screen is identified by the lowest number and each succeeding well number identifies a well screened at a greater depth (Table 6).

Well Logs

Deep Wells

Grain-size analysis and gamma ray logs were used to substantiate field observations of sedimentary material collected from the DW bore holes. Gamma ray

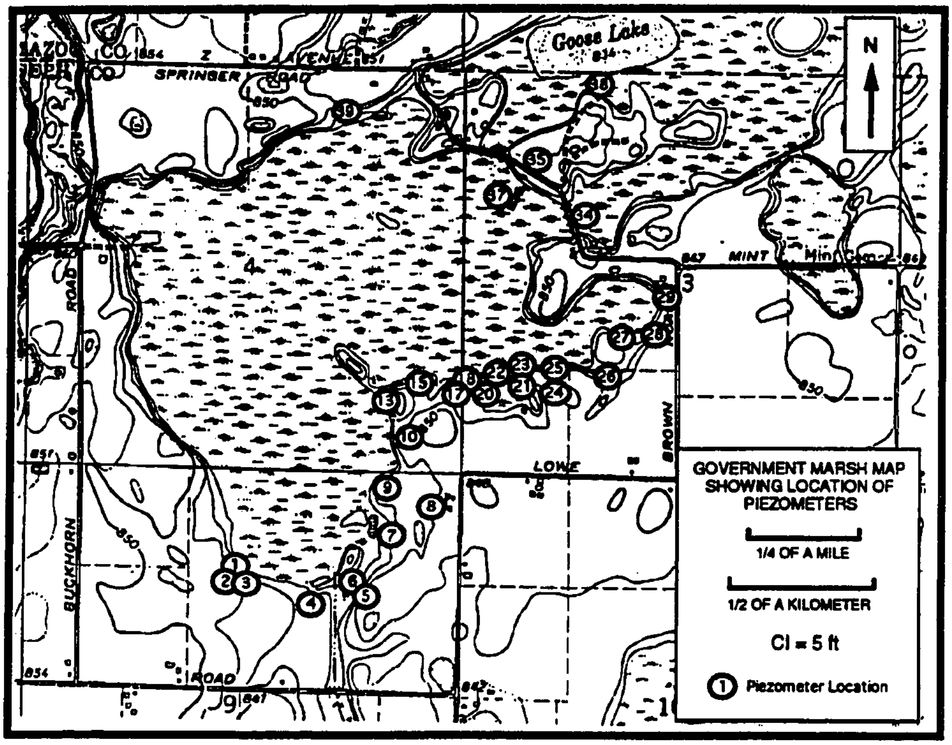


Figure 17. Location of Water-Table Wells.

Source: U.S.G.S. Topographic Quadrangle Map of Vicksburg, Michigan, 7.5 Minute Series (1967, photo revised 1973).

logging was completed in late August 1988. Grain-size analysis was completed in November 1993 and the data utilized in equations 1 and 2 along with Figure 12 to help determine sediment type and the degree of sorting (Table 7). Grain-size analysis curves and gamma ray logs are in Appendix A and B, respectively. Much of the deep well sediment is relatively homogeneous, moderately sorted and ranges from medium sand to coarse-grained sand, but significant variations do occur. DWs 1 and 2, which were constructed within the boundaries of Government Marsh, contain a layer of sapric peat about 4-feet thick, overlying 5 feet of clayey marl (Figure 19). This is substantiated by the gamma ray log depicted in Figure 20. At about 20 feet, beneath the clayey marl,

Table 5

Piezometer Construction Data

Well	Total Depth of 6-inch screen (ft)	Material, Diameter (in.)	Elev. TOC (ft)	Elev. Surface (ft)
1	7	pvc-3/4	841.19	837.39
2	12	pvc-3/4	844.03	840.13
3	12	pvc-3/4	844.28	840.13
4	10	pvc-3/4	840.71	836.76
5	12	pvc-3/4	844.36	840.21
6	10	pvc-3/4	842.13	838.03
7	10	pvc-3/4	841.94	838.14
8	29	steel-3/4	852.97	N/A
9	10	pvc-3/4	842.43	838.93
10	12	pvc-3/4	845.16	841.86
13	8	pvc-3/4	841.06	837.01
15	8	pvc-3/4	842.70	838.55
17	14	pvc-3/4	846.21	841.51
18	10	pvc-3/4	842.81	838.31
20	8	pvc-3/4	841.78	838.73
21	8	pvc-3/4	842.14	838.84
22	10	pvc-3/4	844.32	841.52
23	8	pvc-3/4	841.44	839.34
24	12	pvc-3/4	846.08	842.43
25	18	pvc-3/4	850.99	847.49
26	10	pvc-3/4	843.67	840.52

Table 5--continued

Well	Total Depth of 6-inch screen (ft)	Material, Diameter (in.)	Elev. TOC (ft)	Elev. Surface (ft)
27	12	pvc-3/4	845.09	843.49
28	10	pvc-3/4	843.15	839.80
29	8	pvc-3/4	842.30	839.43
34	7	pvc-3/4	836.46	832.86
35	16	pvc-3/4	847.22	844.17
37	7	pvc-3/4	839.28	835.18
38	7	pvc-3/4	839.95	835.85
39	8	pvc-3/4	839.64	837.19

TOC = Top of Casing

*Depth from TOC

medium sand is present and extends to a depth of about 30 feet at which point a layer of clay is present. The amount of clay appears to increase with depth and is substantial after about 30-feet in DW 2. The materials penetrated in DWs 3 and 4 generally consist of sand with coarseness increasing with depth (Figure 21). DWs 5 and 6 also contain medium to coarse-grained sand, but each well log shows a layer of clayey sand (Figure 21). The clay is about 5 feet thick in DW 5 and is located near the surface; whereas, the clay in DW 6 is about 10-feet thick and is situated between layers of sand beginning at a depth of about 10 feet. The materials penetrated by DW 7 are mostly sand. DW 8 penetrated medium sand capped off by about 25 feet of silty clay and clayey sand (Figure 22). Gravel or gravelly sand were identified at various depths in DWs 5, 6, 7,

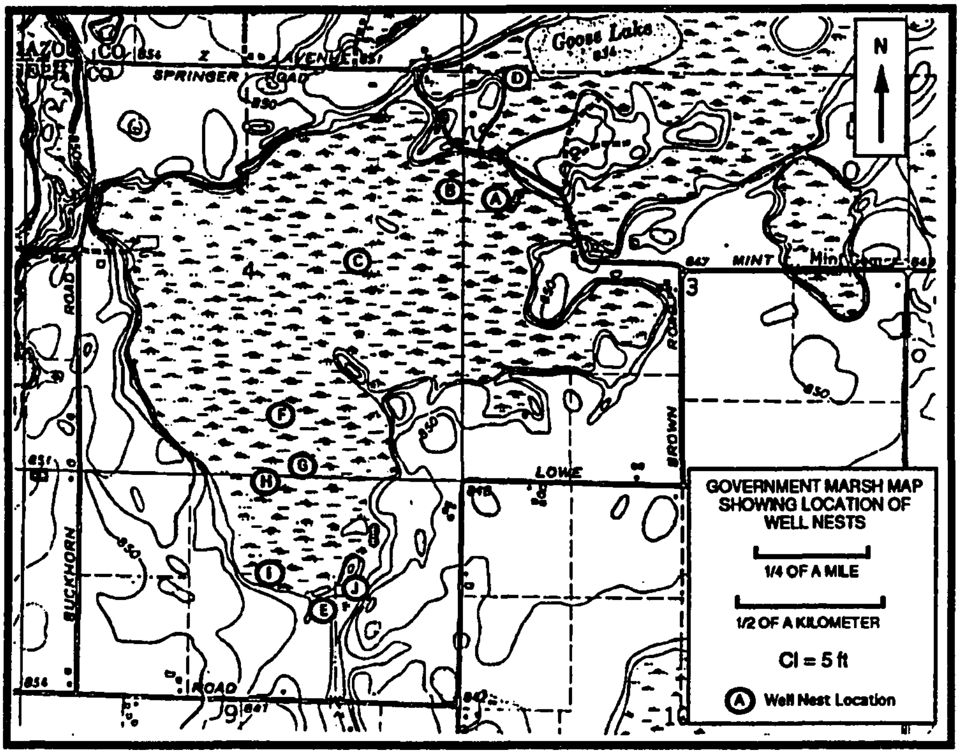


Figure 18. Location of Well Nests.

Source: U.S.G.S. Topographic Quadrangle Map of Vicksburg, Michigan, 7.5 Minute Series (1967, photo revised 1973).

and 8.

Field observation was used to log material collected from well nest bore holes. Hydraulic conductivity was used to infer sediment type when the material could not be collected (when the wells had to be pounded into the subsurface). Nests A, B, C, D and F, which are located within the "bog" section of Government Marsh, generally show the same pattern relative to depth: an active layer of vegetation, then successive layers of fibric, hemic and sapric peat, each with decreasing fiber content respectively (Figures 23 & 24). The fiber content in peat is important for hydraulic conductivity,

Table 6

Well Nest Construction Data

Well	TD (ft)	*Screened Interval (ft)	Slot Size (in.)	Material, Diameter (in)	Elev. TOC (ft)	Elev. Surface (ft)
A-1	7.5	2.5-7.5	10	pvc-2	836.28	834.88
A-2	15	10-15	10	pvc-2	837.68	835.18
A-3	25	20-25	10	pvc-2	837.65	835.25
B-1	7.5	2.5-7.5	10	pvc-2	835.82	834.57
B-2	22.5	17.5-22.5	10	pvc-2	836.83	834.33
B-3	30	27.5-32.5	10	pvc-2	836.97	834.46
C-1	10	5-10	10	pvc-2	837.98	834.98
C-2	15	10-15	10	pvc-2	837.59	835.09
C-3	20	15-20	10	pvc-2	838.17	835.07
D-1	7.5	2.5-7.5	10	pvc-2	838.33	835.93
D-2	15	10-15	10	pvc-2	838.42	835.92
D-3	22.5	17.5-22.5	10	pvc-2	838.07	835.87
E-1	7.5	2.5-7.5	10	pvc-2	838.71	836.21
E-2	15.0	10-15	10	pvc-2	838.77	836.27
F-1	7.5	2.5-7.5	10	pvc-2	838.31	835.81
F-2	15	10-15	10	pvc-2	838.27	835.77
F-3	24	19-24	10	pvc-2	838.43	835.93
G-1	7.5	2.5-7.5	10	pvc-2	837.78	835.28
G-2	17.5	12.5-17.5	10	pvc-2	835.73	834.73

Table 6--Continued

Well	TD (ft)	*Screened Interval (ft)	Slot Size (in.)	Material, Diameter (in)	Elev. TOC (ft)	Elev. Surface (ft)
H-1	4.0	3.0-4.0	N/A	pvc-2	838.41	836.61
H-2	10	5-10	10	pvc-2	838.35	837.05
H-3	17.5	12.5-17.5	10	pvc-2	837.65	836.65
I-1	7.5	2.5-7.5	10	pvc-2	837.46	N/A
I-2	12.5	10-15	10	pvc-2	838.42	N/A
I-3	22.5	17.5-22.5	10	pvc-2	838.11	N/A
J-1	7.5	2.5-7.5	10	pvc-2	837.08	N/A
J-2	12.5	6-11	10	pvc-2	839.15	N/A
J-3	17.5	12.5-17.5	10	pvc-2	837.06	N/A

TD = Total Depth

*From TOC = Top of Casing

because the hydraulic conductivity of peats generally decreases with decreases in fiber content (Verry & Boelter, 1978). According to Verry and Boelter, "The rate of saturated water movement through fibric peat is a thousand times faster than the rate of saturated water movement through sapric peats" (p. 391). A layer of marly clay was also found at the interface between granular material and the base of peat in well nests C, D, F and G. The clay collected from Nest C was mixed with sand. The base of peat was not penetrated in nests A and B; therefore, it is possible that layers of marly clay could be present at these sites. The depth of total peat accumulation in Nest B was determined to be 30 feet.

Nests E, H, I and J were constructed just south of Government Marsh. Much

Table 7

Results Using Grain Size Analysis and Equations 1 & 2

Well	Depth (ft)	G_m (ø)	$Ø_i$	Decision
DWs 1&2	0-3	0.92	0.39	Well sorted, coarse sand
	3-8	1.86	0.68	Moderately well sorted, medium sand
	13-23	0.34	1.04	Moderately sorted, coarse sand
	23-28	1.90	0.61	Moderately well sorted, medium sand
	28-23	1.56	0.83	Moderately sorted medium sand
	33-38	1.24	1.07	Poorly sorted medium sand
	38-43	1.02	0.98	Moderately sorted, medium sand
DW 3	0-5	1.86	0.54	Moderately well sorted medium sand
	5-15	1.50	0.90	Moderately sorted medium sand
	15-34	0.48	1.38	Poorly sorted coarse sand
DW 4	0-3	2.40	0.97	Moderately sorted fine sand
	3-15	1.33	0.85	Moderately sorted medium sand
	15-36	1.03	0.72	Moderately sorted medium sand
DW 5	0-5	1.61	0.73	Moderately sorted medium sand
	5-15	0.33	1.30	Poorly sorted coarse sand
	15-20	0.36	1.33	Poorly sorted coarse sand
	20-30	1.32	0.77	Moderately sorted medium sand
	30-40	0.79	1.08	Poorly sorted coarse sand
DW 6	0-10	0.26	1.18	Poorly sorted coarse sand
	10-20	1.20	0.82	Moderately sorted medium sand
	20-30	1.48	0.74	Moderately sorted medium sand
DW 7	0-15	1.94	0.86	Moderately sorted medium sand
	15-20	1.14	1.06	Poorly sorted medium sand
	20-30	0.93	1.12	Poorly sorted coarse sand
	30-40	1.26	0.88	Moderately sorted medium sand
DW 8	25-35	1.57	0.96	Moderately sorted medium sand
	35-40	1.19	1.07	Poorly sorted medium sand
	40-45	1.00	1.13	Poorly sorted medium sand

G_m = Graphic Mean

$Ø_i$ = graphic standard deviation

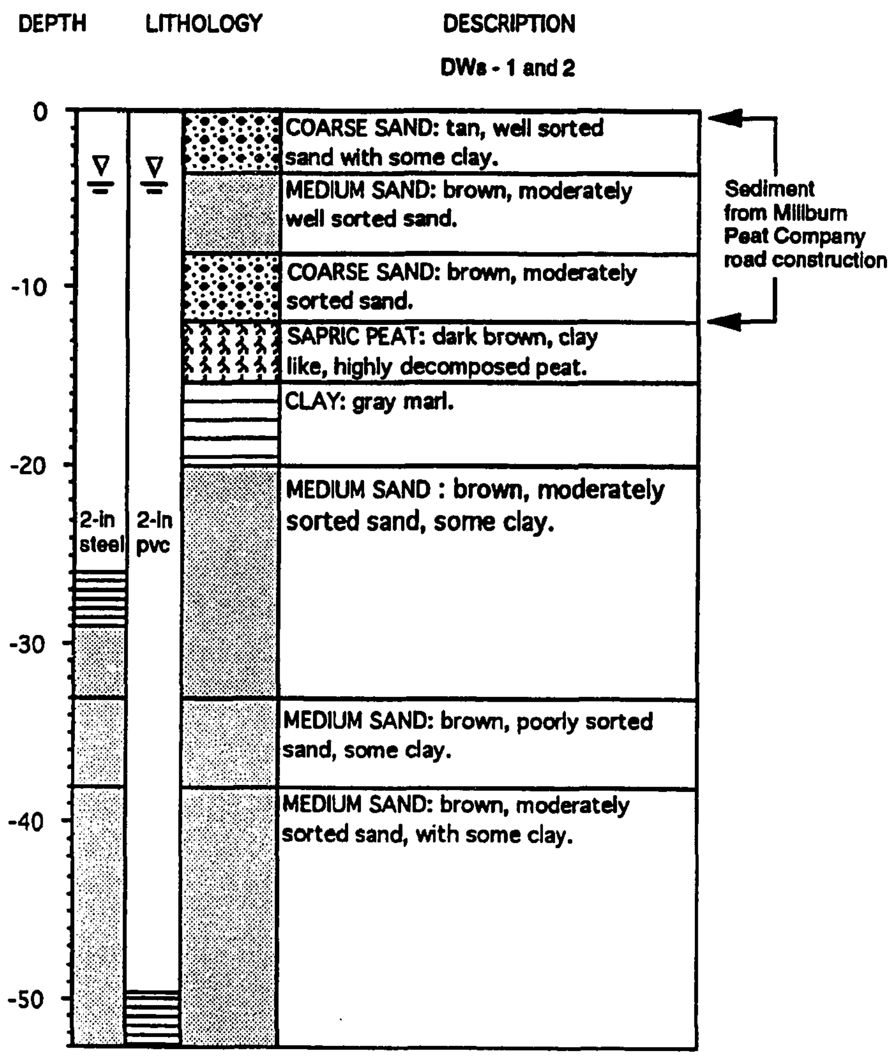


Figure 19. Well Log for DWs 1 & 2. Static Water Table, July 1989.

of the material in these nests is a medium to coarse-grained sand (Figures 25 & 26). Layers of a marly clay with sand occur near the surface in Nests I, E and J. A brown inorganic clay was found above the marly clay in Nest J, and is probably the result of agricultural run-off. No clay was found in Nest H.

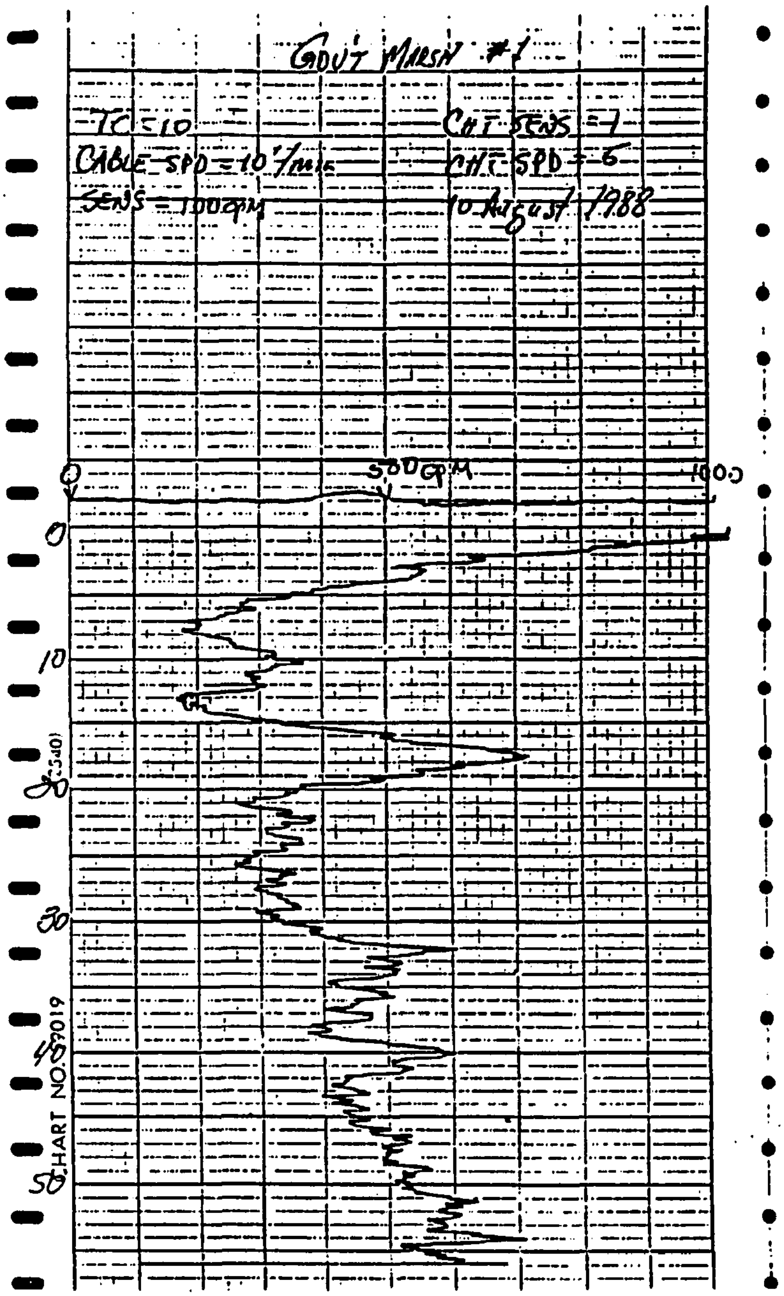


Figure 20. Gamma Ray Log for DWs 1 & 2.

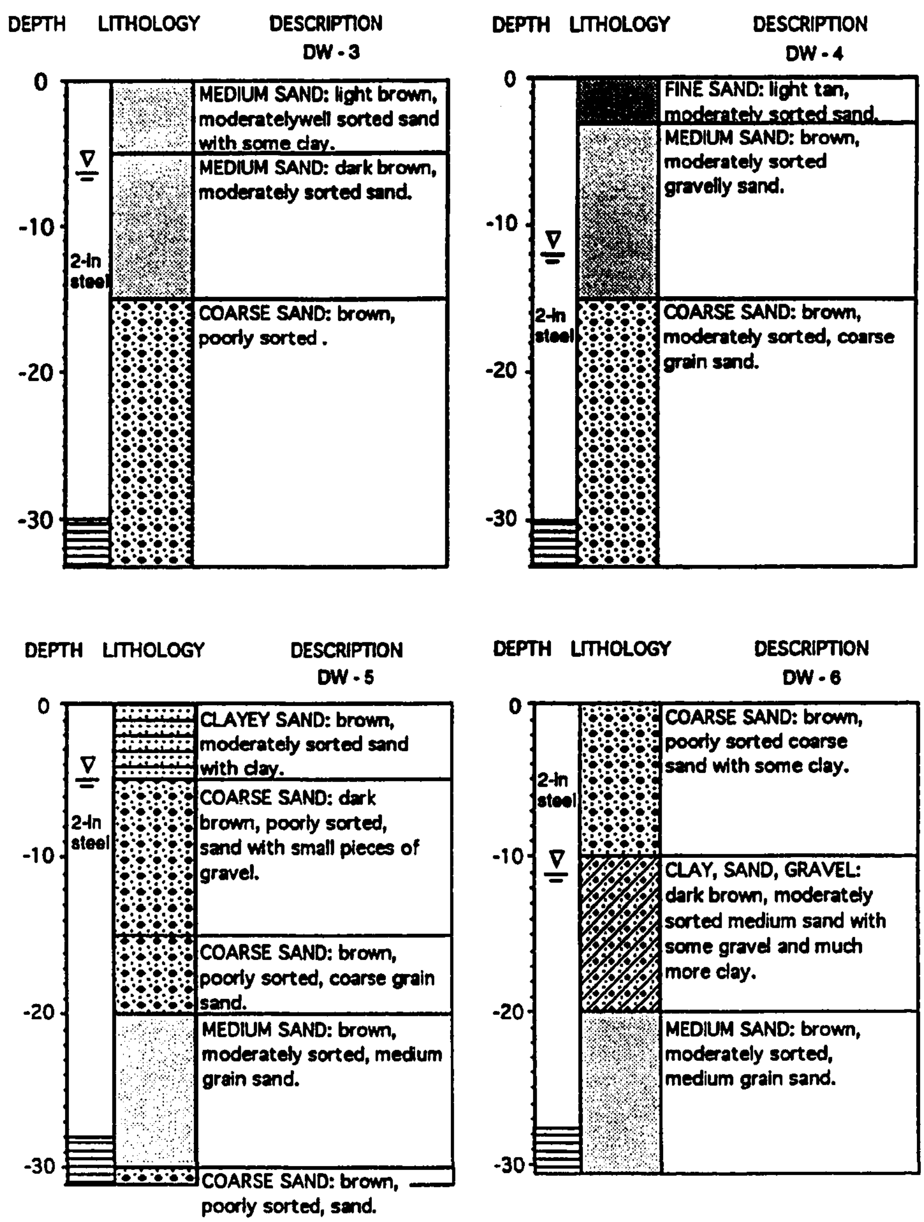


Figure 21. Well Logs for DWs 3, 4, 5, 6. Static Water Table, July 1989.

The presence of clay in most of the well nests is important, because the clay, along with sapric peat, may act as a barrier preventing the quick release of surface and shallow ground water into the local flow system below the layers of clay.

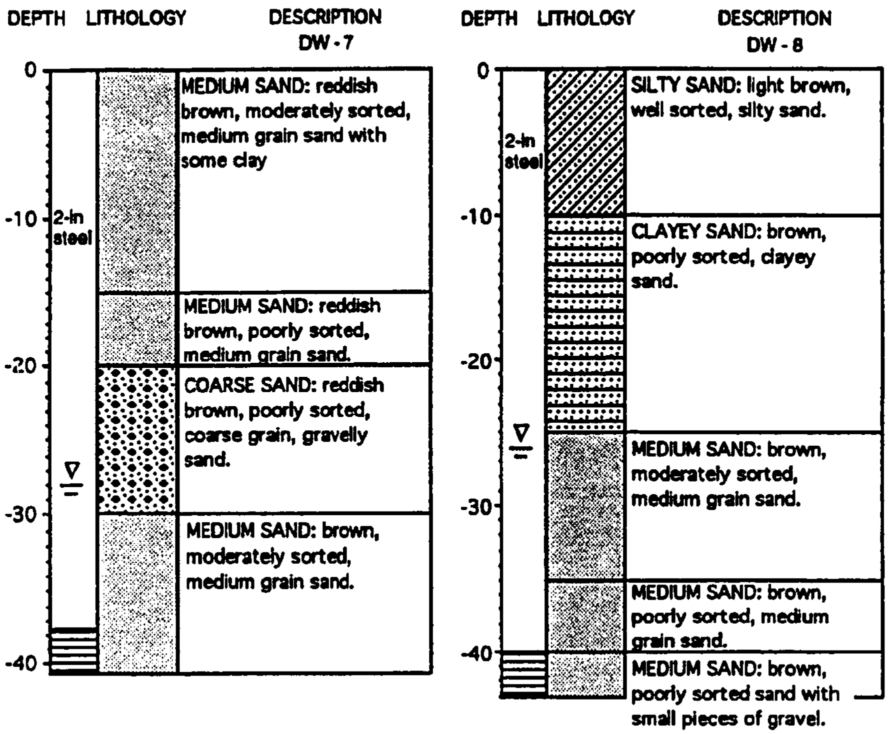


Figure 22. Well Logs for DWs 7 & 8. Static Water Table, July 1989.

Stratigraphic cross sections were constructed in order to show the relationship between geologic material and depth within and between well nests in Government Marsh (Figure 27). A cross section from Nest I to Nest D shows good correlations between the nests relative to peat and clay material (Figures 27 & 28). The relationship between the type of peat, regarding decomposition, is the same in Nests F, C, B and D (Figure 29). Clay also correlates at the base of the peat layers in these nests. The clay at the base of the peat layers in Nest D is a marl clayey sand. Sapric peat and marly clay also correlate in DW 2. Fibric peat is present in Nests I and H, but the degree of decomposition never reaches the sapric state. The thickness of peat in Government

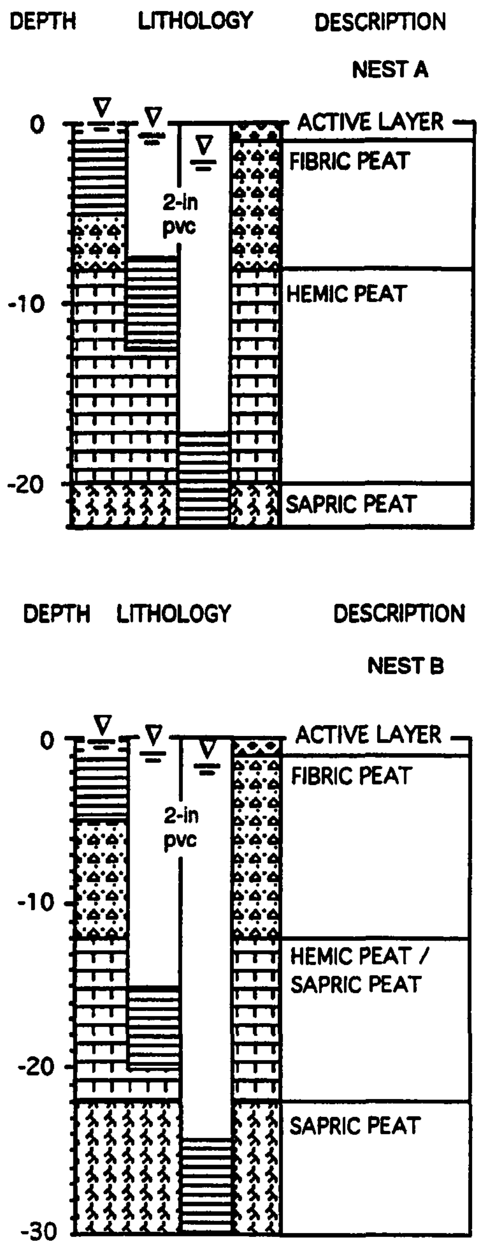


Figure 23. Well Logs for Well Nests A & B. Static Water Tables, July 1992.

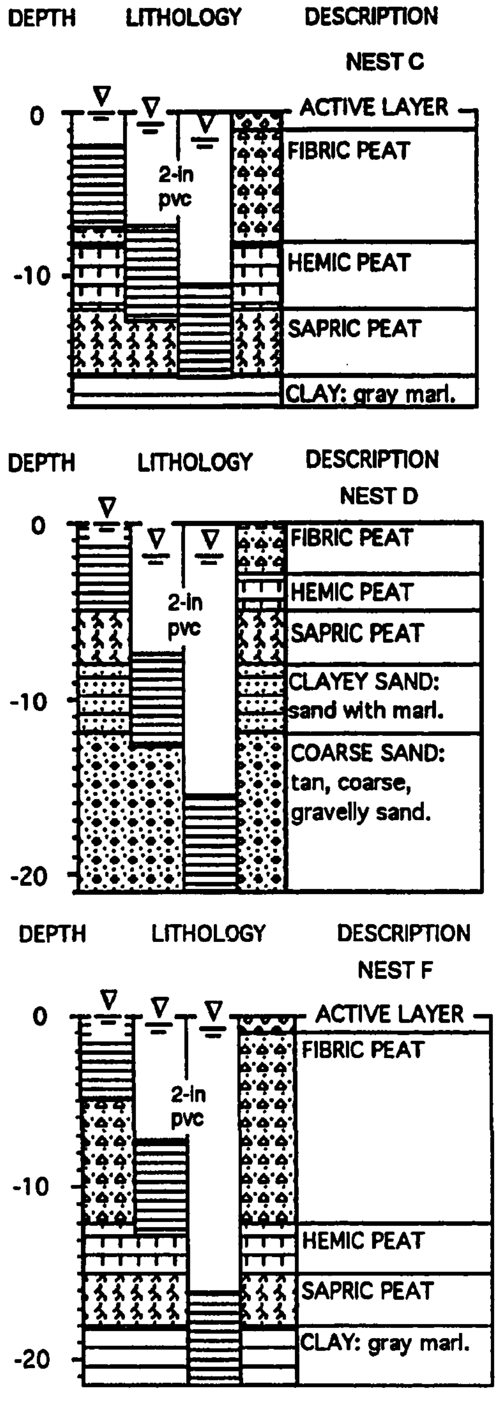


Figure 24. Well Logs for Well Nests C, D, & F. Static Water Table, July 1992.

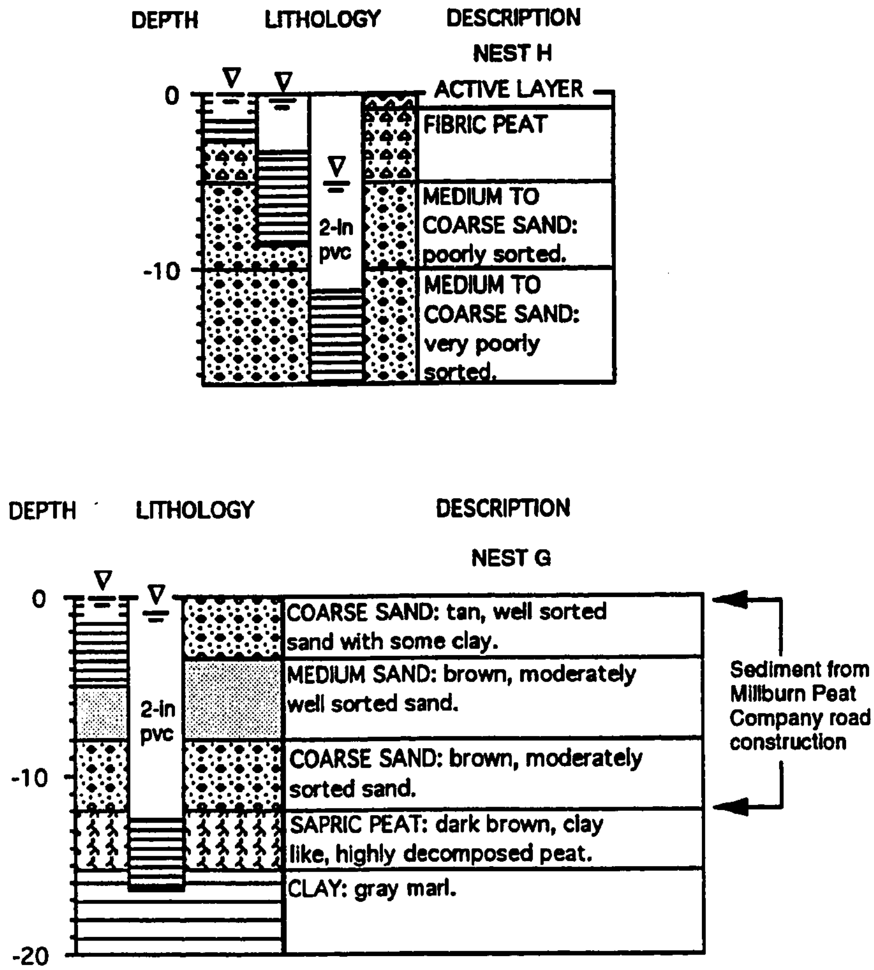


Figure 25. Well Logs for Well Nests H & G. Static Water Tables, July 1992.

Marsh increases substantially from Nest H in a northward direction. The thickness is greatest in Nest B at 30 feet, and it is shallowest in Nest D, near Goose Lake, at about 9 feet. Ground water generally flows from east to west (Figure 30).

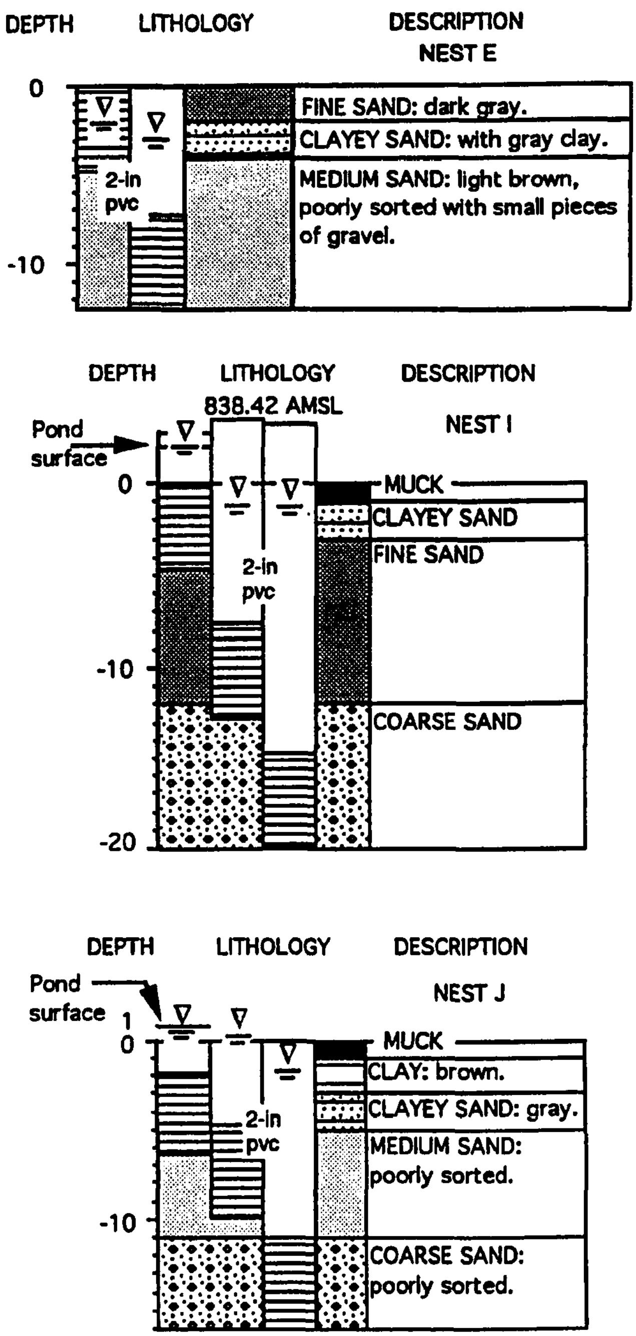


Figure 26. Well Logs for Well Nests E, I, & J. Static Water Tables, July 1992.

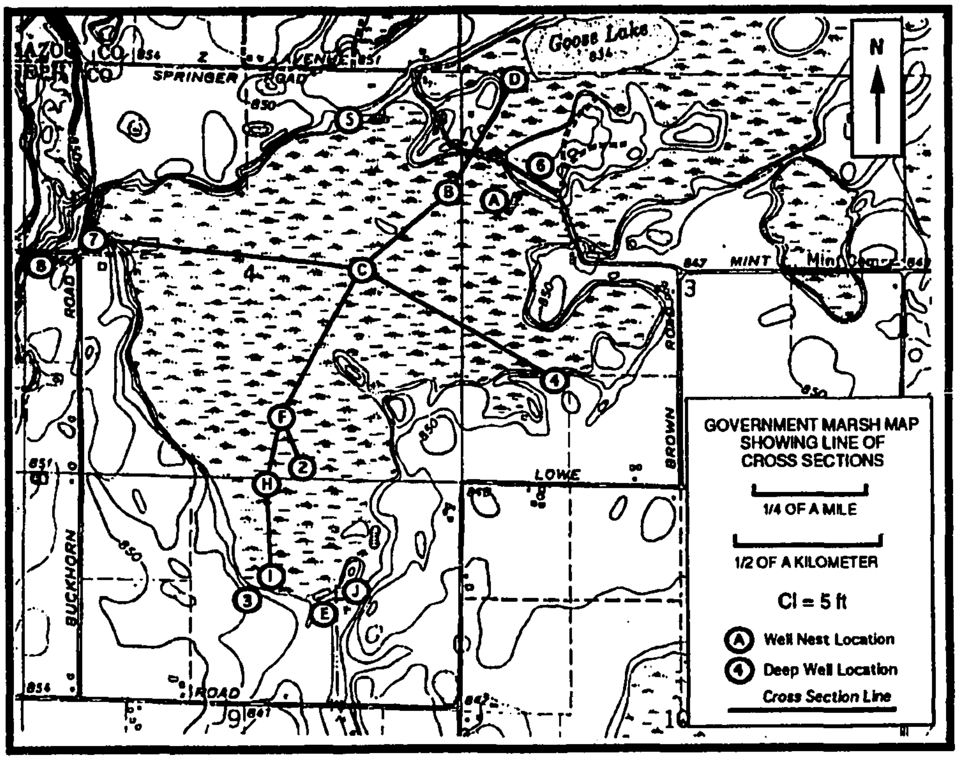


Figure 27. Map Showing Lines of Cross Sections.

Source: Base Map Taken from U.S.G.S. Topographic Quadrangle Map of Vicksburg, Michigan, 7.5 Minute Series (1967, photo revised 1973).

Ground-Water Flow Maps

Ground-water flow maps have been constructed for the 1989 deep wells and the 1992 well-nest data.

The deep well flow maps generally show a consistent east to west hydraulic gradient throughout a complete season. The deep well flow maps also show a consistent northern flow through the Goose Lake area beginning in the month of June. It is possible that ground water flows south from the bog in this system, but there are not sufficient deep well data to substantiate this opinion (Figure 31).

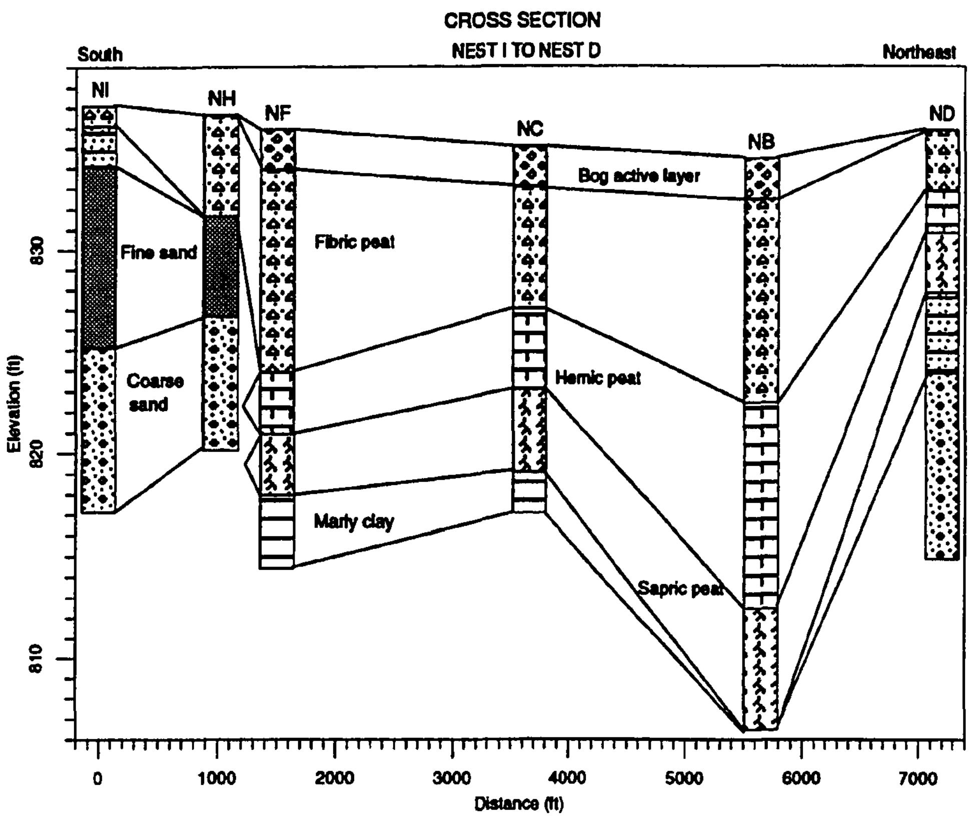


Figure 28. Cross Section From Nest I to Nest D.

Flow maps for the shallow and intermediate wells in the well nests show a flow field that is somewhat subradial. A consistent flow field to the north through Goose Lake, south through the Goose Lake Drain and westward is generally consistent throughout the season. The Millburn Peat Company is pumping water into the south pond using pump station 2. The enormous amount of water discharged by pump station 2 is causing a back-flow to occur from the south pond into the bog. It is also apparent that water discharged at pump station 2 is at a volume that distorts the natural

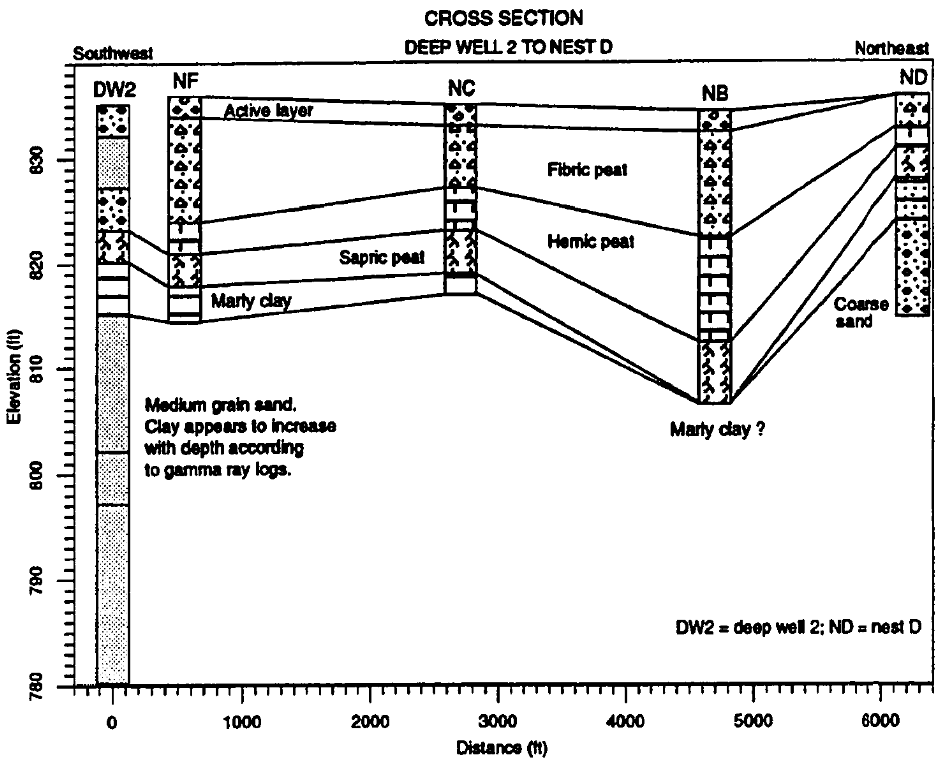


Figure 29. Cross Section From Deep Well 2 to Nest D.

flow of water through the shallow peat system in that area of the wetland (Figures 32 & 33).

Flow maps for the deep wells in the well nests appear to resemble the flow field of the deep well system. They also appear to be less influenced by the great volume of water discharged at pump station 2. Again, a northern flow pattern appears to begin at mid-season, but the southern portion of the wetland shows an east-to-west gradient (Figure 34).

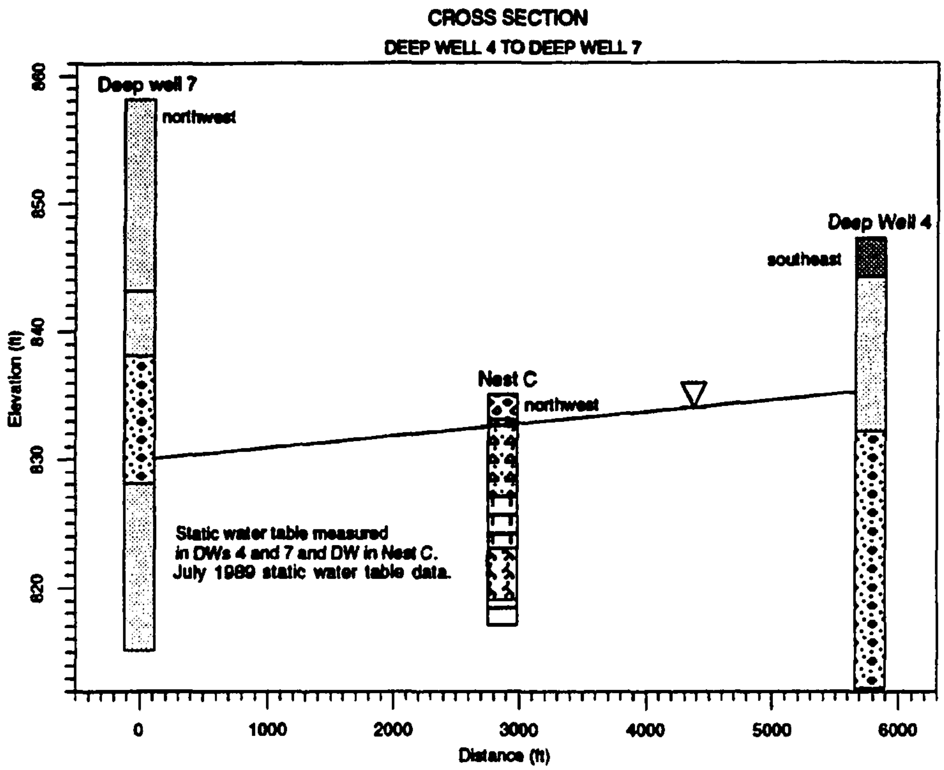


Figure 30. Cross Section From Deep Well 4 to Deep Well 7.

To summarize, according to the static water-table maps, ground-water flow north through Goose Lake is generally dependent upon the shallow flow field during the early part of the season and is joined by the deep flow system beginning at about mid-season. Ground water flow south through the Goose Lake drain area is also dependent upon the shallow flow fields. All of the flow fields show an east to west trend throughout most of the Government Marsh area, which indicates that the wetland is recharging the local ground water flow field, and that the local ground water flow

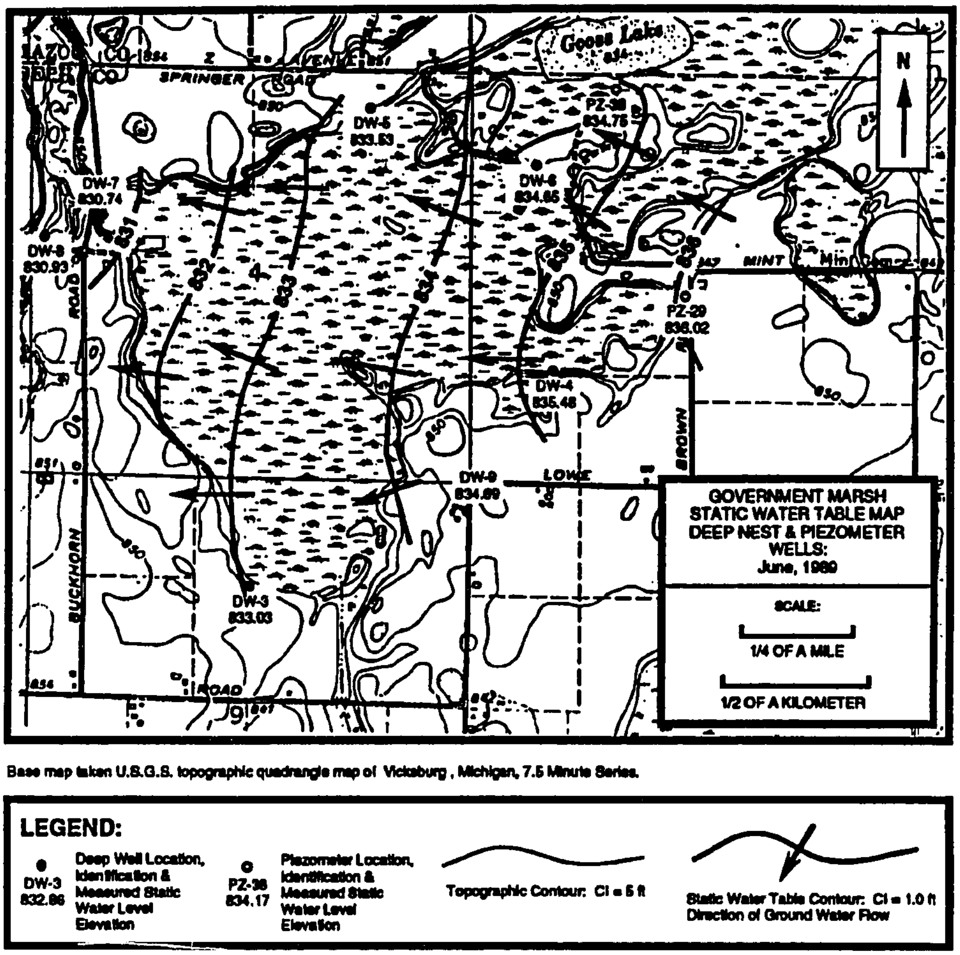


Figure 31. Deep Well Static Water Table Map for June 1989.

Source: U.S.G.S. Topographic Quadrangle Map of Vicksburg, Michigan, 7.5 Minute Series (1967, photo revised 1973).

field is recharging the Spring Creek Wetland. The deep well flow field may have a component of flow southward from the wetland, but evidence to substantiate this opinion is not available. Deep well and piezometer static water table data for 1989 are located in Appendix C. Well nests and deep well static water table data for 1992 are located in Appendix D. A compilation of deep well static water table maps is located in

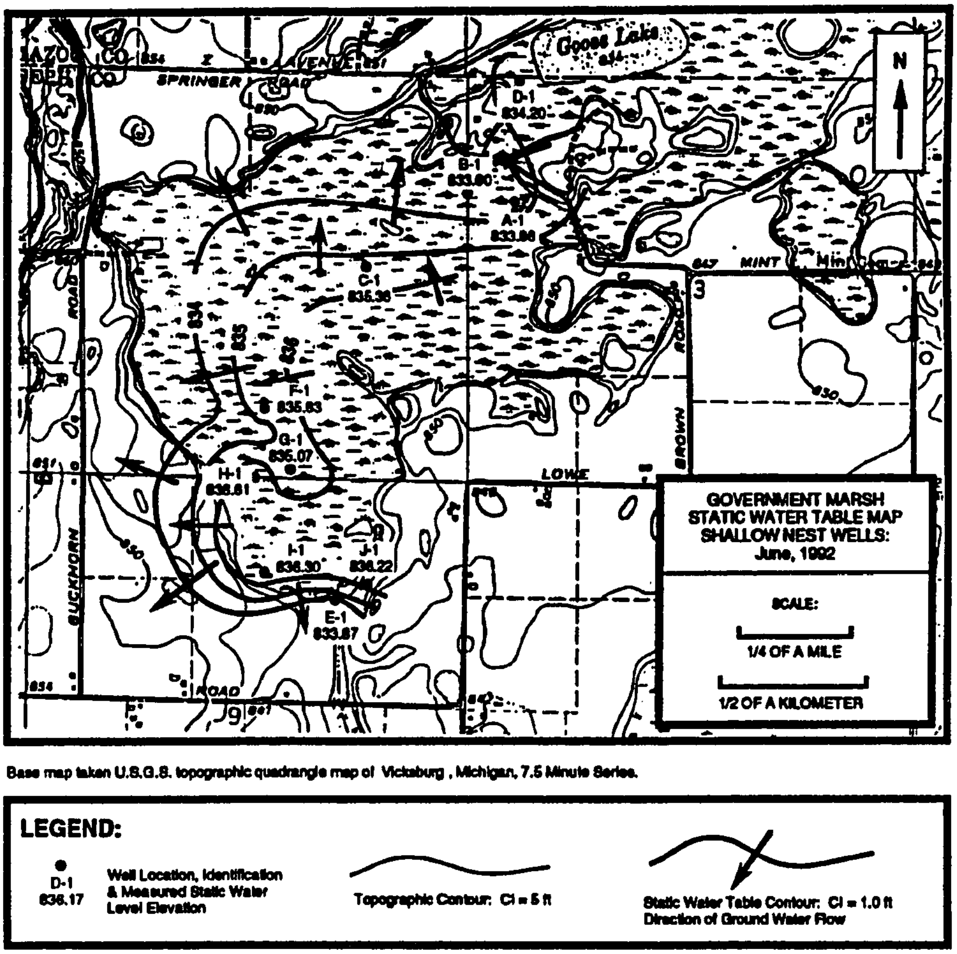


Figure 32. Static Water Table Map for Shallow Wells in Well Nests; June 1992.

Source: U.S.G.S. Topographic Quadrangle Map of Vicksburg, Michigan, 7.5 Minute Series (1967, photo revised 1973).

Appendix E. A compilation of static water table maps for the three generalized well depths in the well nests are located in Appendix F.

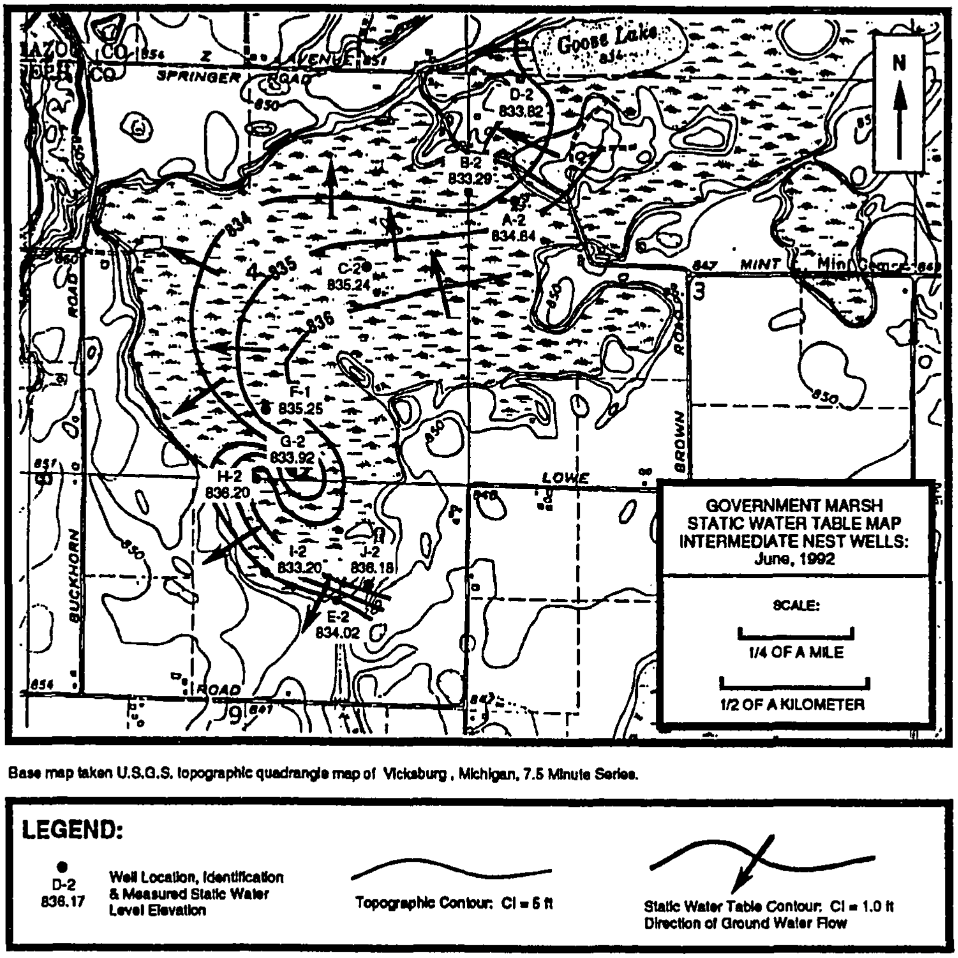


Figure 33. Static Water Table Map for Intermediate Wells in Well Nests; June 1992.

Source: U.S.G.S. Topographic Quadrangle Map of Vicksburg, Michigan, 7.5 Minute Series (1967, photo revised 1973).

Hydraulic Conductivity

Deep Wells

Cost effective methods were selected to analyze the hydraulic conductivity (K) of sediment at screened intervals in the deep wells. Bail-down testing began in May

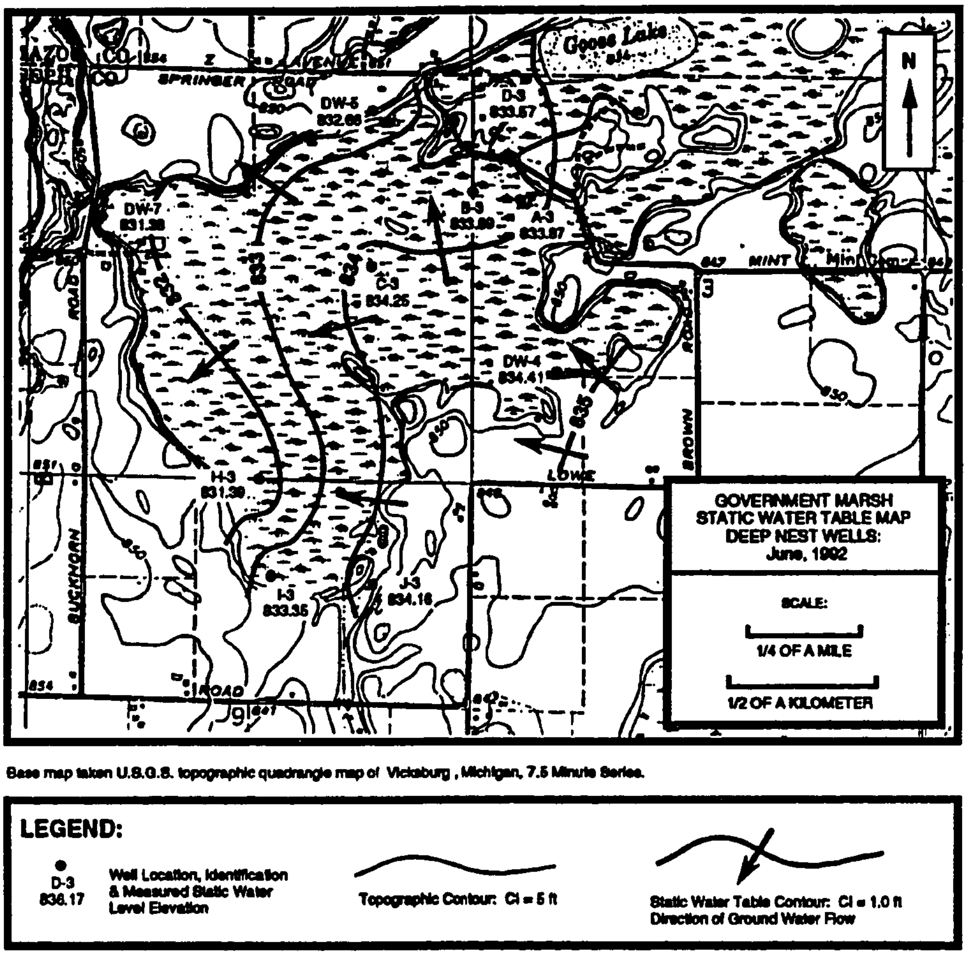


Figure 34. Static Water Table Map for Deep Wells in Well Nests; June 1992.

Source: U.S.G.S. Topographic Quadrangle Map of Vicksburg, Michigan, 7.5 Minute Series (1967, photo revised 1973).

1991 and was completed in October 1991. Permeameter and grain-size analysis were performed from October 1992 to November 1993. Results show that the hydraulic conductivity of sediment at screened intervals in the deep wells is rapid (Table 8). Values measured by different methods are consistent. The mean K value for all of the

Table 8

Deep Well K Values at Screened Interval

Well	Bail Test (B& R)[1] (ft/day)	Permeameter (ch)[2] (ft/day)	Grain Size Analysis (ft/day)		Mean (ft/day)
DW-1	N/A	95.60	60_{Hazen}		77.8
DW-2	110.17	101.43	97_{Hazen}		102.9
DW-3	119.62	82.5	97_{USBR}	108_{Wilson}	101.8
DW-4	81.19	111.40	110_{USBR}	89_{Wilson}	97.9
DW-5	116.63	111.00	91_{USBR}	91_{Wilson}	102.4
DW-6	70.42	86.00	64_{USBR}	61_{Wilson}	70.4
DW-7	124.23	103.00	80_{USBR}	75^{Wilson}	95.6
DW-8	86.27	78.00	59_{USBR}	61_{Wilson}	71.1

[1]Bouwer and Rice Method

[2]Constant head

N/A = Not Available

wells is about 90 ft/day. The K values range from a low of 71.1 ft / day in DW 8 to a high of 102.9 ft / day in DW 2. DWs 2, 3, 4, 5, and 7 have K values approximating 100 ft /day. DWs 1, 6, and 8 have K values around 70 ft / day. Bail down and permeameter data are located in Appendix G.

Well Nests

Cost effective methods were also used to analyze hydraulic conductivity (K) at various screened intervals for wells in the well nests. Bail-down testing was conducted

from May 1991 to October 1991 and permeameter analysis was completed in January 1994. Results show that K values generally decrease with depth for nests located within Government Marsh, and K values generally increase with depth for wells located at the south perimeter of the wetland (Table 9). Nests E, I and J show K values at screened depths that are greater than those measured in the deep wells. The exception is nest H. The relatively slow K values in the shallow wells in nests E, I and J is probably due to the presence of clayey sand and organic matter (muck). K values for wells located within Government Marsh range from slow for wells completed in hemic or sapric peat to very rapid at the upper fibric peat layers, where decomposition of peat is relatively minimal. For the same nests (B, C, F and G), but in the deepest wells, K values are extremely slow. This is due to the presence of sapric peat, which is highly decomposed, and where present, marly clay (Table 10). The slow transmissive property of sapric peat and clayey marl at the interface between interstitial material and the base of the bog prevents the rapid movement of ground water from one system into another.

Seasonal Well Nest Equipotential Measurements

Mean seasonal equipotential comparisons between wells in each nest have been made using the well nest static water-table measurements (Tables 11, 12, 13, & 14). The mean hydraulic head is generally less at depth relative to the surface in every nest during the four seasons. Well A-2 shows a very slight seasonal increase for spring (Table 12) and is probably due to an increase in spring melt water from localized recharge hills to the northeast. For the same season well A-3 generally shows a decrease in the static water table relative to well A-1. The change in hydraulic head with depth is commonly pronounced. The greatest change occurs in nest H for all four

Table 9

Well Nests K Values at Screened Intervals

Nest/ Well	Hydraulic Conductivity Bail Test (Bouwer & Ruce) (ft/day)	Hydraulic Conductivity Permeter (falling head) (ft/day)
A-1	0.323	
A-2	0.063	
A-3	N/A	
B-1	0.095	
B-2	1.388×10^{-4}	
B-3	2.350×10^{-4}	4.81×10^{-3}
C-1	Rapid	
C-2	0.023	
C-3	3.008×10^{-4}	1.58×10^{-3}
D-1	0.228	
D-2	0.010	
D-3	Rapid	
E-1	0.044	
E-2	157.0	
F-1	Rapid	
F-2	1.192	
F-3		0.020
G-2	3.334×10^{-4}	
H-1		.566
H-2	2.50	
H-3	0.908	
I-1	3.90	
I-2	9.87	
I-3	82.84	
J-1	1.95	
J-2	59.37	
J-3	129.83	

Rapid = The rise of ground water was too fast to measure manually in an area where a pressure transducer could not be used.

N/A = Not Available.

Table10

K Values for Sapric Peat and Marly Clay

Nest/ Well	Material	Hydraulic Conductivity: Bail Test (Bouwer & Rice) (ft/day)	Hydraulic Conductivity: Permeameter (Falling Head) (ft/day)
B-2	Sapric/hemic peat	0.00014	
B-3	Sapric peat	0.00026	0.00481
C-3	Sapric peat	0.00031	0.00158
	Marly		0.00764
D-2	Clayey sand	0.01000	
E-1	Clayey sand	0.04400	
F-3	Sapric peat		0.01019
	Marly		0.00481
G-2	Sapric peat	0.00033	
	Marly		0.01962

seasons, ranging from a 4 to greater than a 5-foot drop in the static water table! This is probably due in part to the change in the local flow field caused by the Millburn Peat Company as canal water is released from pump station 2. Nests C, D, G, I, and J also show dramatic changes in the static water table with depth--ranging from about a 1 to 2.0-foot drop in spring to about a 1.3 to over a 3-foot drop in autumn. The seasonal mean is often greater for summer and autumn compared to winter and spring for all of the wells. The seasonally consistent measured drop in the static water table with depth offers very good evidence that most of Government Marsh is an area of ground-water recharge.

Table 11

Mean Winter 1992 Static Water Table Elevation Change for Wells in Well Nests

Nest Well	ΔWT(ft) January 1992	ΔWT(ft) February 1992	ΔWT(ft) March 1992	Mean ΔWT(ft) Winter 1992
A-1	N/A	N/A	N/A	N/A
A-2	N/A	-.022	-0.18	-0.2
A-3	-0.88	-1.17	-1.26	-1.10
B-1	N/A	N/A	N/A	N/A
B-2	-0.6	-0.57	-0.69	-0.62
B-3	-0.06	-0.21	-0.13	-0.13
C-1	N/A	N/A	N/A	N/A
C-2	N/A	-0.01	-0.03	-0.02
C-3	-0.97	-1.16	-0.95	-1.06
D-1	N/A	N/A	N/A	N/A
D-2	-1.24	-1.31	-1.55	-1.37
D-3	-1.39	-1.51	-1.54	-1.48
E-1	N/A	N/A	N/A	N/A
E-2	-0.63	-0.63	-0.75	-0.67
F-1	N/A	N/A	N/A	N/A
F-2	N/A	-0.07	-0.03	-0.05
F-3	N/A	-0.16	-0.12	-0.14
G-1	N/A	N/A	N/A	N/A
G-2	N/A	-1.06	-1.07	-1.065

Table 11--Continued

Nest Well	ΔWT(ft) January 1992	ΔWT(ft) February 1992	ΔWT(ft) March 1992	Mean ΔWT(ft) Winter 1992
H-1	N/A	N/A	N/A	N/A
H-2	N/A	-0.47	-0.33	-0.40
H-3	-3.56	-4.08	-4.78	-4.14
I-1	N/A	N/A	N/A	N/A
I-2	N/A	-2.43	-2.16	-2.30
I-3	N/A	-2.45	-2.73	-2.59
J-1	N/A	N/A	N/A	N/A
J-2	N/A	+0.19	+0.21	+0.21
J-3	-2.02	-1.81	-1.86	-1.90

Negative sign (-) indicates head loss (a decrease in the static water table)

Positive sign (+) indicates head gain (an increase in the static water table)

TOC = Top of casing

WT = Water table

N/A = Not available

Change in static water table elevation is relative to the shallowest unfrozen well in each well nest.

Table 12

Mean Spring 1992 Static Water Table Elevation
Change for Wells in Well Nests

Nest Well	ΔWT(ft) April 1992	ΔWT(ft) May 1992	ΔWT(ft) June 1992	Mean ΔWT(ft) Spring1992
A-1	N/A	N/A	N/A	N/A
A-2	-0.13	+0.31	+0.98	+0.38
A-3	-1.12	-0.68	+0.01	-0.60
B-1	N/A	N/A	N/A	N/A
B-2	-0.7	-.042	-0.31	-0.48
B-3	-0.18	-0.16	-0.29	-0.21
C-1	N/A	N/A	N/A	N/A
C-2	+0.05	-0.1	-0.12	-0.06
C-3	-0.97	-0.84	-1.11	-0.97
D-1	N/A	N/A	N/A	N/A
D-2	-1.36	-0.97	-0.38	-0.90
D-3	-1.6	-1.66	-0.63	-1.30
E-1	N/A	N/A	N/A	N/A
E-2	-0.51	-0.28	+0.15	-0.21
F-1	N/A	N/A	N/A	N/A
F-2	-0.09	-0.17	-0.38	-0.21
F-3	-0.21	-0.19	-0.6	-0.33
G-1	N/A	N/A	N/A	N/A
G-2	-1.1	-0.77	-1.15	-1.01

Table 12--Continued

Nest Well	ΔWT(ft) April 1992	ΔWT(ft) May 1992	ΔWT(ft) June 1992	Mean ΔWT(ft) Spring1992
H-1	N/A	N/A	N/A	N/A
H-2	-0.29	-0.37	-0.41	-0.36
H-3	-4.77	-5	-5.22	-5.0
I-1	N/A	N/A	N/A	N/A
I-2	-2.47	-2.61	-3.1	-2.73
I-3	-2.39	-2.65	-2.95	-2.66
J-1	N/A	N/A	N/A	N/A
J-2	+0.17	0	-0.04	+0.04
J-3	-1.84	-2.01	-2.06	-1.97

Negative sign (-) indicates head loss (a decrease in the static water table)

Positive sign (+) indicates head gain (an increase in the static water table)

TOC = Top of casing

WT = Water table

N/A = Not available

Change in static water table elevation is relative to the shallowest unfrozen well in each well nest.

Table 13

Mean Summer 1992 Static Water Table Elevation
Change for Wells in Well Nests

Nest Well	ΔWT(ft) July 1992	ΔWT(ft) August 1992	ΔWT(ft) September 1992	Mean ΔWT(ft) Summer 1992
A-1	N/A	N/A	N/A	N/A
A-2	-0.17	-0.23	-0.25	-0.22
A-3	-1.22	-1.44	-1.48	-1.38
B-1	N/A	N/A	N/A	N/A
B-2	-0.65	-0.73	-0.85	-0.74
B-3	-0.14	-0.32	-0.29	-0.25
C-1	N/A	N/A	N/A	N/A
C-2	-0.07	-0.02	+0.01	-0.03
C-3	-1.29	-1.07	-1.06	-1.14
D-1	N/A	N/A	N/A	N/A
D-2	-1.71	-2.11	-1.94	-1.92
D-3	-1.94	-2	-2.17	-2.04
E-1	N/A	N/A	N/A	N/A
E-2	-0.52	-0.42	-0.6	-0.51
F-1	N/A	N/A	N/A	N/A
F-2	-0.26	-0.19	-0.36	-0.27
F-3	-0.37	-0.26	-0.56	-0.40
G-1	N/A	N/A	N/A	N/A
G-2	-1.27	-1.51	-1.4	-1.39

Table 13--Continued

Nest Well	ΔWT(ft) July 1992	ΔWT(ft) August 1992	ΔWT(ft) September 1992	Mean ΔWT(ft) Summer 1992
H-1	N/A	N/A	N/A	N/A
H-2	-0.27	-0.35	-0.34	-0.32
H-3	-5.17	-4.95	-5.07	-5.06
I-1	N/A	N/A	N/A	N/A
I-2	-2.94	-2.78	-3.09	-2.94
I-3	-2.99	-2.82	-3.09	-2.97
J-1	N/A	N/A	N/A	N/A
J-2	-0.35	-0.09	-0.42	-0.29
J-3	-2.36	-2.11	-2.43	-2.30

Negative sign (-) indicates head loss (a decrease in the static water table)

Positive sign (+) indicates head gain (an increase in the static water table)

TOC = Top of casing

WT = Water table

N/A = Not available

Change in static water table elevation is relative to the shallowest unfrozen well in each well nest.

Table 14

Mean Autumn 1992 Static Water Table Elevation Change for Wells in Well Nests

Nest Well	ΔWT(ft) October 1992	ΔWT(ft) November 1992	ΔWT(ft) December 1992	Mean ΔWT(ft) Autumn 1992
A-1	N/A		N/A	N/A
A-2	-0.3	No data was	-0.14	-0.22
A-3	-1.59	collected in the	-0.93	-1.26
		month of		
B-1	N/A	November	N/A	N/A
B-2	-0.73	due to	-0.68	-0.71
B-3	-0.25	deer hunting	-0.23	-0.24
		season.		
C-1	N/A		N/A	N/A
C-2	-0.04		N/A	-0.04
C-3	-1.34		-1.29	-1.32
D-1	N/A		N/A	N/A
D-2	-2.05		-1.41	-1.73
D-3	-2.26		-1.25	-1.76
E-1	N/A		N/A	N/A
E-2	-0.72		-0.66	-0.69
F-1	N/A		N/A	N/A
F-2	-0.33		0	-0.33
F-3	-0.44		+0.06	-0.19
G-1	N/A		N/A	N/A
G-2	-1.33		N/A	N/A

Table 14--Continued

Nest Well	ΔWT(ft) October 1992	ΔWT(ft) November 1992	ΔWT(ft) December 1992	Mean ΔWT(ft) Autumn 1992
H-1	N/A		N/A	N/A
H-2	+0.01		-0.28	-0.14
H-3	-5.03		-3.68	-4.36
I-1	N/A		N/A	N/A
I-2	-3.19		-2.03	-2.61
I-3	-3.08		-2.11	-2.60
J-1	N/A		N/A	N/A
J-2	-0.47		+0.85	+0.19
J-3	-2.49		-1.17	-1.83

Negative sign (-) indicates head loss (a decrease in the static water table)

Positive sign (+) indicates head gain (an increase in the static water table)

TOC = Top of casing

WT = Water table

N/A = Not available

Change in static water table elevation is relative to the shallowest unfrozen well in each well nest.

CHAPTER V

RESULTS AND DISCUSSION FOR HYDROGEOCHEMISTRY

Hydrogeochemistry

Deep Well Ground-Water Chemistry

Eight deep-well ground-water samples were collected for each of the four seasons: for a total of thirty-two samples. Sampling occurred during the spring, summer and autumn months in 1989 and in the winter months in 1990. The analysis of ground-water temperature, pH and conductivity was completed in the field. The analysis of all other chemical parameters was completed by the Water Quality Laboratory, Institute for Water Sciences, Western Michigan University, Kalamazoo, Michigan (Table 15).

The water chemistry revealed by these analyses for this part of St. Joseph County is generally consistent with that reported by Barrese (1991). Median concentrations of calcium, total hardness, total dissolved solids (TDS), alkalinity, and electrical conductivity are slightly higher compared to values reported by Barrese, but the values from both studies are interpreted as being in reasonable agreement (Tables 16 & 17). Median concentrations of silica reported by Barrese are about twice the concentration analyzed from samples taken from wells near Government Marsh, but both values fall within the common range of natural waters (1-30 mg/L) as reported by Hem (1985). Dominant cations are calcium and magnesium with total quarterly mean concentrations of 60.71 and 14.56 mg/L, respectively. Dominant anions are sulfate and bicarbonate (as alkalinity) with total quarterly mean concentrations of 24.54 and 179

Table 15

Mean Ground-Water Quality Data for Deep Wells: 1989-1990

Well	Temp[1]	pH	TDS	Total[2] Hard.	HCO_3^-	Conduct. (μS)
DW1	11.03	7.31	265	213	207	393
DW2	10.83	7.58	235	235	161	397
DW3	11.90	7.34	209	206	174	373
DW4	11.35	7.76	207	194	158	360
DW5	11.98	7.56	246	243	186	433
DW6	10.45	7.6	229	185	163	363
DW7	11.00	7.46	254	229	208	453
DW8	11.43	7.47	233	215	175	425

Well	Cl^-	SO_4^{-2}	NO_3^-	NH_4^+	K^+	Na^+	Ca^{+2}
DW1	3.23	4.23	0.30	0.89	0.34	2.90	70.1
DW2	11.06	36.6	0.30	0.13	0.64	3.14	56.9
DW3	3.81	19.0	0.64	0.79	1.34	1.96	61.0
DW4	2.69	23.0	0.27	0.29	0.64	2.94	53.4
DW5	5.73	35.8	0.51	0.11	0.74	2.46	67.5
DW6	2.05	22.2	0.29	2.71	0.24	1.55	49.5
DW7	6.62	22.8	0.27	2.80	0.62	3.24	65.6
DW8	8.90	32.7	0.27	5.80	0.45	2.46	62.4

Table 15--Continued

Well	Mg^{+2}	Mn^{+2}	Fe^{+2}	Ba^{+2}	SiO_2
DW1	9.2	0.18	1.98	0.03	4.69
DW2	16.4	0.14	1.98	0.03	4.69
DW3	13.1	0.13	0.37	0.04	5.20
DW4	14.7	0.21	0.85	0.04	4.19
DW5	18.2	0.27	0.44	0.06	3.38
DW6	14.7	0.08	3.34	0.05	4.60
DW7	15.9	0.09	2.27	0.07	6.63
DW8	14.4	0.10	2.08	0.06	5.50

[1] Degrees Celsius

[2] as $CaCO_3$ (mg/L)

mg/L, respectively. The total quarterly mean for conductivity was about 400 μS; the mean pH about 7.5. Mean ferrous iron (Fe^{+2}) concentrations in DWs 1, 3, 6, 7, and 8 suggest that these wells may be influenced by reducing conditions and organic acids in ground water produced by infiltration of bog water. The low concentration of sulfate analyzed from a sample collected from DW 1 can also be interpreted as an effect of bog water chemistry. Deep well 1 is screened at a depth of 6-9 feet below the contact between the wetland and local ground-water flow system. Deep well 2, adjacent to deep well 1, is screened at a depth of 50-53 feet beneath the same contact, but the mean sulfate concentration analyzed from a sample collected from DW 2 is 36.6 mg/L. The large difference in sulfate concentration between the two analyzed samples indicates that H_2S may be the dominant sulfur species near the base of the wetland, where a reducing environment has developed. The mean potassium concentration for DW 3 (1.34 mg/L)

Table 16

Deep Well Chemical Data (mg/L)

Season	n	Temp[1] C	pH	TDS	Conduct (µS)	Total Hard.[2]	HCO_3^-
Spring-1989	8	11.29	7.61	222	398	213	171
Summer-1989	8	11.64	7.58	218	400	206	179
Fall-1989	8	11.33	7.49	259	391	229	180
Winter-1990	8	10.70	7.35	239	409	210	185
Mean	32	11.24	7.51	235	399	215	179

Season	n	Ca^{+2}	Mg^{+2}	K^+	Na^+	Ba^{+2}	Mn^{+2}	Fe^{+2}
Spring-1989	8	57.89	13.75	0.57	2.97	0.05	0.17	1.49
Summer-1989	8	58.33	14.78	0.51	2.41	0.05	0.15	1.46
Fall-1989	8	67.83	14.35	0.48	2.26	0.02	0.15	1.46
Winter-1990	8	59.05	15.35	0.94	2.69	0.06	0.14	1.30
Mean	32	60.77	14.56	0.63	2.58	0.05	0.15	1.43

Season	n	Cl^-	SiO_2	SO_4^{-2}	NO_3^-
Spring-1989	8	5.09	3.71	26.42	0.26
Summer-1989	8	5.23	5.86	25.08	0.50
Fall-1989	8	5.17	5.26	24.55	0.37
Winter-1990	8	6.55	5.21	22.09	0.29
Mean	32	5.51	5.01	24.54	0.35

n = Number of samples (wells)

[1] Degrees Celsius

[2] as $CaCO_3$ (mg/L)

Table 17

Comparing Deep-Well Chemical Parameters Reported in This Study to Background Southern Flow System Chemistry Reported by Barrese (1991)

	Barrese (1991)	This Study
Parameter	Median	Median
Temp	12	11.3
pH	7.84	7.52
TDS (mg/L $CaCO_3$)	172	230
Total Hardness (mg/L $CaCO_3$)	165	209
Alkalinity (mg/L $CaCO_3$)	155	174
Conductivity (µS)	355	402
Cl^- (mg/L)	3.29	4.81
SO_4^{-2} (mg/L)	22.7	24.2
NO_3^-/N (mg/L)	0.38	0.34
NH_4^+/N (mg/L)	0.02	0.58
K^+ (mg/L)	0.65	0.53
Na^+ (mg/L)	3.17	2.58
Ca^{+2} (mg/L)	48.6	59.0
Mg^{+2} (mg/L)	12.9	14.9
Mn^{+2} (mg/L)	0.10	0.14
Fe^{+2} (mg/L)	0.42	1.36
Ba^{+2} (mg/L)	0.05	0.04
SiO_2 (mg/L)	11.64	5.24

is interpreted as the result of agricultural fertilizer. Mean chloride concentration for DWs 2 and 8 were 11.06 and 8.90 mg/L, respectively. These concentrations may be the result of winter salt applications and influx from septic systems, which introduce NaCl into ground water. The total seasonal nitrate mean was 0.35 mg/L and no higher than 0.50 mg/L for any one season, but the total seasonal mean for ammonium was

1.69 mg/L. Mean ammonium concentrations for DWs 6, 7 and 8 were 2.71, 2.80 and 5.80 mg/L, respectively. Influx from septic systems, agricultural fertilizers and livestock waste may be sources of nitrogen species for these concentrations, but the breakdown of amino acids during decay of plant material into peat is also a source for nitrogen in ground water. The concentrations of ammonium in samples from wells reported in this study indicate low redox potential and can be interpreted as confirmation of a conclusion reported by Barrese (1991), that elevated concentrations of ammonium have chemically degraded the Schoolcraft aquifer system, which includes the Government Marsh study area.

WATEQ4F results suggest that the principal minerals that contribute to the geochemical character of water sampled from the deep wells are calcite and dolomite (Appendix H). This makes intuitive sense, because the mean concentrations of calcium (60.77 mg/L), magnesium (14.56 mg/L) and bicarbonate (179 mg/L) are relatively high. This is substantiated by saturation index (SI) values calculated using the WATEQ4F program (calcite = -0.99; dolomite = -.675). SI values are approximately equal to zero when a water is at equilibrium with a mineral species. SI values greater than zero indicate supersaturation; values less than zero indicate that a water is undersaturated with respect to a mineral and that the mineral would continue to be dissolved by the water. The mean Ca^{+2}/Mg^{+2} molar ratio is 2.53, suggesting that the principal carbonate species contributing to the geochemical character of the ground water are calcite and dolomite, because Ca^{+2}/Mg^{+2} molar ratios approach values greater than 5 when pure calcite is the predominant contributing species (Barrese, 1991). Results from WATEQ4F indicate that these waters are supersaturated with respect to siderite ($FeCO_3$, SI = .424). This is interpreted as an effect of bog water chemistry, where low redox potential and/or complexation by organic acids keeps iron in solution beyond the

point it would precipitate (this subject will be discussed later in greater detail).

One-way analysis of variance (ANOVA) and the Kruskal-Wallis nonparametric ANOVA were used to determine if seasonal variations between wells relative to the chemical parameters were statistically significant. The null hypothesis was stated as: $\mu_1 = \mu_2 = \mu_3 = \mu_4$, where 1, 2, 3 and 4 are equal to each of the four seasons. Level of significance was set at 0.05 *alpha*. Results show that 15 out of 18 chemical parameters for the deep wells are not statistically significant (Table 18). The three parameters that were significant are interpreted as the result of anthropogenic variations previously mentioned. Because most of the seasonal means showed no statistical significance, no conclusion can be made regarding seasonal ground-water chemistry, but intuitively it seems reasonable to conclude that variation in ground-water chemistry was minimal throughout the four seasons.

Rain and Nests B, C, D, and F Water Chemistry

Rain water samples were collected on August 14, August 30, and September 17, 1989. Bog surface water samples were collected near nest C on August 30, 1989 and August 29, 1991. Surface water samples were collected near nest F on September 17, 1989 and April 22, 1990. Ground-water samples were collected from nests D and B on August 15 and 16, 1991, respectively. Ground-water samples were collected from nest C and F on August 21, 1991 (Figure 35) (Appendix I). A ground-water sample was collected from each well in each well nest. The analysis of ground-water temperature, pH and conductivity was completed in the field. The analysis of all other chemical parameters was completed by the Water Quality Laboratory, Institute of Water Sciences, Western Michigan University, Kalamazoo, Michigan (Tables 19, 20, & 21).

Results show that pH, conductivity, calcium and total hardness generally

Table 18

One-Way Analysis of Variance: Four Seasons
Chemical Data for Eight DWs

Variable	Cases	p_{anova}	$p_{K\text{-}W}$	Alpha	Decision
Temp	32	.0617	.1025	.05	NS
pH	32	.0469	.0795	.05	NS
TDS	32	.0736*	.1474	.05	NS
Alkalinity (HCO_3^-)	32	.6613	.8274	.05	NS
Total Hardness	32	.4909	.3880	.05	NS
Conductivity	32	.9223	.9859	.05	NS
K^+	32	.4658*	.8294	.05	NS
Na^+	32	.0001*	.0004	.05	S
Ca^{+2}	32	.1082	.2205	.05	NS
Mg^{+2}	32	.6861	.4537	.05	NS
Mn^{+2}	32	.8872	.9441	.05	NS
Fe^{+2}	32	.9872	.8618	.05	NS
Ba^{+2}	32	.1418	.1071	.05	NS
Cl^-	32	.8724*	.9978	.05	NS
SiO_2	32	.0142*	.1100	.05	NS
SO_4^{-2}	32	.9019	.8191	.05	NS
NO_3^-	32	.2636*	.0167	.05	S
NH_4^+	32	.1746*	.0493	.05	S

*Standard deviations are not equal according to the Bartlett test.

p_{anova} = One-way analysis of variance (parametric statistic)

$p_{K\text{-}W}$ = Kruskal-Wallis anova (nonparametric test)

NS = Not significant

S = Significant

increase with sample depth for well nests located within areas of Government Marsh that contain "bog" vegetation [well nests B, C, D, and F]. The mean pH and

Table 19

Chemical Data for Rain, Wetland Surface and Ground Water (mg/L)

Location	Temp[1] C	pH	Conduct (µS)	Ca^{+2} (mg/L)	Total Hard[2]
Rain Gauge - F	22.5	4.02	41.0	0.9	3.3
Rain Gauge - F	18.7	4.07	20.9	1.9	6.0
Rain Gauge - F	22.7	3.71	21.7	2.1	3.8
Mean	21.3	3.93	27.9	1.6	4.4

Location	Temp[1] C	pH	Conduct (µS)	Ca^{+2} (mg/L)	Total Hard[2]
Surface - C	22.3	4.20	40.0	2.7	7.57
Surface - C	23.2	4.26	43.1	3.7	17.2
Surface - F	7.0	3.72	56.2	3.1	10.2
Surface - F	24.4	3.77	41.7	2.5	11.6
Mean	19.0	3.99	45.3	3.0	11.6

Well	Depth of Sample(ft)	Temp[1] C	pH	Conduct (µS)	Ca^{+2} (mg/L)	Total Hard[2]
B-1	5.0	17.3	4.07	80.0	2.2	7.48
C-1	7.0	14.3	4.43	36.0	2.8	7.82
D-1	5.0	17.3	4.72	75.0	8.3	26.1
F-1	5.0	20.0	4.39	66.0	5.8	27.0
Mean	5.5	17.2	4.40	64.3	4.8	17.1

Table 19--Continued

Well	Depth of Sample(ft)	Temp[1] C	pH	Conduct (µS)	Ca^{+2} (mg/L)	Total Hard[2]
B-2	12.5	13.9	6.22	625.0	44.0	153
C-2	12.5	14.1	6.50	207.0	44.0	132
D-2	12.5	13.9	5.38	88.0	14.9	84
F-2	12.5	14.9	4.81	95.0	12.6	37
Mean	12.5	14.2	5.73	253.8	28.9	102

Well	Depth of Sample(ft)	Temp[1] C	pH	Conduct (µS)	Ca^{+2} (mg/L)	Total Hard[2]
B-3	30.0	12.8	6.46	1100.0	88.4	319
C-3	17.0	12.0	6.58	345.0	61.5	187
D-3	21.0	12.6	6.83	344.0	64.5	215
F-3	21.5	14.9	6.33	579.0	213.2	545
Mean	22.4	13.1	6.55	592.0	106.9	317

Well	Depth of Sample(ft)	Temp[1] C	pH	Conduct (µS)	Ca^{+2} (mg/L)	Total Hard[2]
Mean	Rain Gauge	21.3	3.93	27.9	1.6	4.4
Mean	Surface	19.0	3.99	45.3	3.0	11.6
Mean	Shallow	17.2	4.40	64.3	4.8	17.1
Mean	Intermediate	14.2	5.73	253.8	28.9	102
Mean	Deep	13.1	6.55	592.0	106.9	317

[1] Degrees Celsius

[2] As $CaCO_3$ (mg/L)

Table 20

Chemical Data for Rain, Wetland Surface and Ground Water (mg/L)

Location	Ba^{+2}	Fe^{+2}	K^{+}	Mg^{+2}	Mn^{+2}	Na^{+}	TDM[1] wo-Ca^{+2}
Rain Gauge - F	0.01	0.08	0.36	0.41	0.02	1.68	2.60
Rain Gauge - F	0.01	0.07	0.34	0.14	0.01	0.82	1.40
Rain Gauge - F	0.05	0.04	0.24	0.32	0.01	1.56	2.20
Mean	0.02	0.06	0.31	0.29	0.01	1.35	2.10

Location	Ba^{+2}	Fe^{+2}	K^{+}	Mg^{+2}	Mn^{+2}	Na^{+}	TDM[1] wo-Ca^{+2}
Surface - C	0.02	2.00	1.20	0.20	0.04	0.70	4.16
Surface - C	0.01	1.19	1.82	1.96	0.02	1.92	6.92
Surface - F	0.01	1.03	0.12	0.57	0.03	0.66	2.42
Surface - F	0.01	0.92	1.68	1.30	0.03	2.44	6.38
Mean	0.01	1.29	1.21	1.01	0.03	1.43	4.97

Well	Screen Depth (ft)	Ba^{+2}	Fe^{+2}	K^{+}	Mg^{+2}	Mn^{+2}	Na^{+}	TDM[1] wo-Ca^{+2}
B-1	5.0	0.02	1.10	1.80	0.30	0.002	0.60	3.82
C-1	7.0	0.008	2.80	1.00	0.20	0.03	1.10	5.14
D-1	5.0	0.07	1.80	1.40	1.30	0.10	1.10	5.77
F-1	5.0	0.02	1.00	1.40	3.00	0.03	1.30	6.75
Mean	5.5	0.03	1.68	1.40	1.20	0.04	1.03	5.37

Table 20--Continued

Well	Screen Depth (ft)	Ba^{+2}	Fe^{+2}	K^{+}	Mg^{+2}	Mn^{+2}	Na^{+}	TDM[1] wo-Ca^{+2}
B-2	12.5	0.09	7.90	2.00	10.50	0.20	1.40	22.09
C-2	12.5	0.08	7.60	1.70	5.40	0.20	0.90	15.88
D-2	12.5	0.30	35.10	4.50	11.30	0.40	2.30	22.31
F-2	12.5	0.03	1.50	1.50	1.40	0.08	1.30	5.81
Mean	12.5	0.13	5.13	2.43	7.15	0.22	1.48	16.52

Well	Screen Depth (ft)	Ba^{+2}	Fe^{+2}	K^{+}	Mg^{+2}	Mn^{+2}	Na^{+}	TDM[1] wo-Ca^{+2}
B-3	30.0	0.20	22.90	2.40	23.80	0.20	1.90	51.40
C-3	17.0	0.07	6.60	2.00	8.00	0.20	1.00	17.87
D-3	21.0	0.02	14.50	3.30	13.20	0.40	1.80	33.22
F-3	21.5	0.10	6.20	3.00	9.00	0.40	1.00	19.70
Mean	22.4	0.10	12.55	2.68	13.50	0.30	1.43	30.55

	Depth of Sample (ft)	Ba^{+2}	Fe^{+2}	K^{+}	Mg^{+2}	Mn^{+2}	Na^{+}	TDM[1] wo-Ca^{+2}
Mean	[2]Rain Gge.	0.02	0.06	0.31	0.29	0.01	1.35	2.10
Mean	Surface	0.01	1.29	1.21	1.01	0.03	1.43	4.97
Mean	Shallow	0.03	1.68	1.40	1.20	0.04	1.03	5.37
Mean	Intermediate	0.13	5.13	2.43	7.15	0.22	1.48	16.52
Mean	Deep	0.10	12.55	2.68	13.50	0.30	1.43	30.55

[1] Total dissolved metals without Ca^{+2}

[2] Rain gauge

Table 21

Chemical Data for Rain, Wetland Surface and Ground Water (mg/L)

Location	Cl^-	[1]HCO_3^-	SiO_2	SO_4^{-2}	NO_3^-/N	NH_4^+/N
Rain Gauge - F	0.76	0.00	0.10	4.75	0.24	0.08
Rain Gauge - F	0.52	0.00	0.51	5.12	0.32	0.34
Rain Gauge - F	1.19	0.00	0.31	9.61	0.96	0.19
Mean	0.82	0.00	0.31	6.49	0.51	0.20

Location	Cl^-	[1]HCO_3^-	SiO_2	SO_4^{-2}	NO_3^-/N	NH_4^+/N
Surface - C	2.00	0.00	4.40	0.00	0.08	0.06
Surface - C	4.66	7.70	3.24	1.00	0.30	0.22
Surface - F	5.42	0.00	1.98	3.80	0.28	1.25
Surface - F	5.04	0.00	3.64	2.97	0.22	0.23
Mean	4.28	1.90	3.32	1.94	0.22	0.44

Well	Screen Depth (ft)	Cl^-	[1]HCO_3^-	SiO_2	SO_4^{-2}	NO_3^-/N	NH_4^+/N
B-1	5.0	2.05	0.00	0.26	5.78	0.04	3.50
C-1	7.0	2.00	3.10	5.60	2.93	0.04	0.33
D-1	5.0	2.37	0.00	4.30	3.20	0.04	2.70
F-1	5.0	2.00	35.00	7.20	0.00	0.13	0.55
Mean	5.5	2.11	9.53	4.34	2.98	0.06	1.77

Table 21--Continued

Well	Screen Depth (ft)	Cl^-	[1]HCO_3^-	SiO_2	SO_4^{-2}	NO_3^-/N	NH_4^+/N
B-2	12.5	2.00	286.00	2.40	0.00	0.04	52.10
C-2	12.5	2.00	92.00	14.00	0.00	0.74	4.50
D-2	12.5	2.20	20.80	8.50	0.00	0.16	6.50
F-2	12.5	2.00	32.80	7.20	3.05	0.00	1.60
Mean	12.5	2.05	107.90	8.03	0.76	0.21	16.18

Well	Screen Depth (ft)	Cl^-	[1]HCO_3^-	SiO_2	SO_4^{-2}	NO_3^-/N	NH_4^+/N
B-3	30.0	2.00	535.00	34.00	0.00	0.04	90.30
C-3	17.0	2.00	166.00	3.50	2.77	0.09	6.40
D-3	21.0	2.00	163.00	6.20	0.00	0.13	4.30
F-3	21.5	2.00	302.00	12.60	0.00	0.21	6.20
Mean	22.4	2.00	292.00	14.08	0.69	0.18	26.80

	Depth of Sample (ft)	Cl^-	[1]HCO_3^-	SiO_2	SO_4^{-2}	NO_3^-/N	NH_4^+/N
Mean	[2]Rain Gge.	0.82	0.00	0.31	6.49	0.51	0.20
Mean	Surface	4.28	1.90	3.32	1.94	0.22	0.44
Mean	Shallow	2.11	9.53	4.34	2.98	0.06	1.77
Mean	Intermediate	2.05	107.90	8.03	0.76	0.21	16.18
Mean	Deep	2.00	292.00	14.08	0.69	0.18	26.80

[1]Alkalinity as $CaCO_3$

[2]Rain gauge

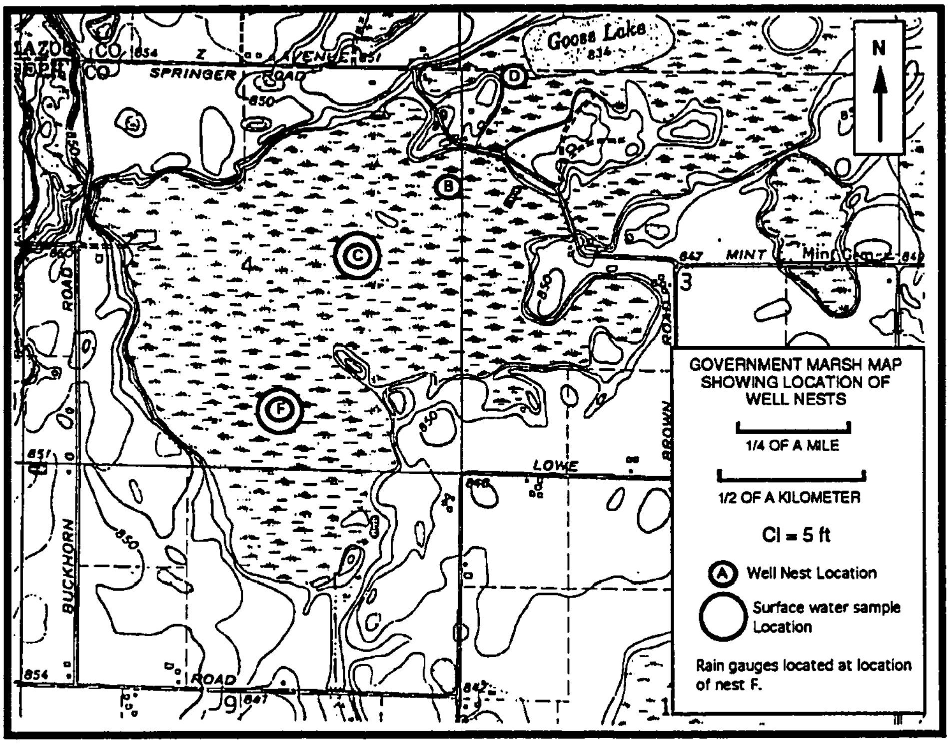


Figure 35. Map Showing Location Where Surface Water Samples, Rain Gauge Water Samples, and Ground Water Samples Were Collected From Well Nests B, C, D, and F.

Source: U.S.G.S. Topographic Quadrangle Map of Vicksburg, Michigan, 7.5 Minute Series (1967, photo revised 1973).

conductivity of rain water are 3.93 and 27.9 uS, respectively. The mean calcium and total hardness values are 1.6 and 4.4 mg/L, respectively. The mean values for the same parameters for water sampled from the surface of Government Marsh are 3.99, 45.3 uS and 3.0 and 11.6 mg/L, respectively. This is good evidence that the surface waters of Government Marsh are ombrotrophic (originate from atmospheric precipitation). The pH, conductivity and calcium values of Government Marsh surface water are within ranges established by Hawkinson and Verry (1975) and Boelter and Verry (1977), to distinguish ombrotrophic bogs from wetlands influenced by ground-water flux

Table 22

Pearson Product Moment Correlation Results
for Well Nests B, C, D, & F

	PPMCC			
Relationship	*r*	*p*	alpha	decision
Depth vs pH	.8766	.0001	.05	S
Depth vs TDS	.8531	.0001	.05	S
Depth vs TDM without Ca^{+2}	.8957	.0001	.05	S
Depth vs Alkalinity (HCO_3^-)	.8659	.0001	.05	S
Depth vs Total Hardness	.8239	.0001	.05	S
Depth vs Conductivity	.8509	.0001	.05	S
Depth vs K^+	.5830	.0178	.05	S
Depth vs Na^+	.1855	.4916	.05	NS
Depth vs Ca^{+2}	.7355	.0012	.05	S
Depth vs Mg^{+2}	.8872	.0001	.05	S
Depth vs Mn^{+2}	.7407	.0010	.05	S
Depth vs Fe^{+2}	.6024	.0135	.05	S
Depth vs Ba^{+2}	.6768	.0040	.05	S
Depth vs SiO_2	.7325	.0012	.05	S
Depth vs SO_4^{-2}	-.4024	.1223	.05	NS
Depth vs NO_3^-	-.1017	.7078	.05	NS
Depth vs NH_4^+	.6316	.0087	.05	S

r = Pearson Product Moment Correlation Coefficient (PPMCC)

p = probability relative to PPMCC

S = significant

NS = not significant

[ombrotrophic bog criteria: pH between 3-4; conductivity < 80 µS and Ca^{+2} < 5 mg/L].

The pH of the rain samples meets the criterion of acid rain (less than 4.5) according to

Drever (1982). As previously stated, all parameters increase with depth, but calcium, hardness and conductivity values are extremely high at depth in nests B and F. Increases in cation species other than calcium also occur with ground-water depth in the same nests as does total dissolved metals without calcium (TDM) (Table 20). Mean values of alkalinity (HCO_3^-) and SiO_2 increase with depth; sulfate decreases with depth, and Fe^{+2} and NH_4^+ increase with depth (Table 21). The odor of "rotten eggs" seeps from the bog indicating that sulfate is being reduced to H_2S. A reducing environment is indicated by extreme concentrations of Fe^{+2} and NH_4^+.

Linear regression analysis was used to determine if a relationship exists between the several chemical constituents and ground-water depth for nest B, C, D, and F (Table 22). The null hypothesis was stated as: the Pearson Product Moment Correlation Coefficient for X chemical parameter and ground-water depth is equal to zero. The level of significance was set at 0.05 *alpha*. Results show 3 of the parameters were found to have no significant statistical correlation; however, 14 out of 17 chemical parameters have significantly positive correlations relative to ground-water sample depth. Half of those parameters have r values greater than 0.85; six of those parameters have r values greater than 0.60, and sodium has an r value greater than 0.50. A strong significant statistical correlation exists between most of the chemical parameters sampled from well nests B, C, D, and F, and sample depth. This is consistent with other evidence indicating Government Marsh to be an area of ground-water recharge.

Bog Surface Water Chemistry

Alkalinity, pH, calcium, magnesium, conductivity, and total hardness concentrations analyzed from Government Marsh surface water samples are similar to

concentrations analyzed from rain water samples. Naturally occurring carbonic acid, and sulfuric acid provided by industrial pollution, contribute significantly to bog surface water acidity (Shotyk, 1988). Clymo (1964) suggested that the activity of sulfur-metabolizing bacteria contributes to bog water acidity, especially during dry periods, as demonstrated by reactions (1) and (2).

$$2S + 2H_2O + 3O_2 \dashrightarrow 4H^+ + 2SO_4^{-2} \quad (1)$$

$$S_2O_3^{-2} + H_2O + 2O_2 \dashrightarrow 2H^+ + 2SO_4^{-2} \quad (2)$$

Clymo (1964) also suggested that secretion of organic acids from live *sphagnum* plants, and cation exchange in the walls of *sphagnum* plants for nutritionally important cations that occur in rain water also contribute significantly to bog surface water acidity. Gorham, Eisenreich, Ford and Santelmann (1985) obtained a significant correlation ($p < 0.01$, $r = 0.76$) between absorbance, measured using a spectrophotometer, and dissolved organic carbon using 28 North American bog surface water samples. This analysis was used to substantiate their conclusion that "... clearly the acids responsible for low pH values in unpolluted bog waters are organic in nature" (p. 360). Wetzel (1983) contends that *sphagnum* acts as a cation exchanger even when dead, because of its high concentration of uronic acid (up to 30 percent of the plant's dry weight), and that cation exchange that occurs from the live plant originates from freshly produced plant growth. Increases in other chemical parameters analyzed from bog surface water samples, relative to the rain water chemistry, result from dustfall, decomposition of plant material and run-off from the watershed, which is located within an area dominated by farms. Concentrations of potassium, for example, increase significantly in the bog surface water analyses. Potassium is a common element in agricultural fertilizers; it is also an important constituent in the chemical composition of many enzymes and amino acids. Iron is an important constituent in the chemical composition

proteins that serve as electron carriers during respiration and photosynthesis. Magnesium is attached to a chelate that makes up the chlorophyll molecule (Krauskopf, 1979). A summary of the inorganic nutrients in plants is located in Table 23. Soil dustfall is known to enrich bog surface waters in respect to calcium, magnesium, potassium and sodium, especially in North American bogs located in the midcontinent area (Gorham, Eisenreich, Ford, & Santelmann, 1985).

Nests B, C, D, and F

Alkalinity, pH, Calcium, Magnesium, Conductivity, and Total Hardness

Alkalinity, pH, calcium, magnesium, conductivity, and total hardness increase with sample depth (Figures 36 - 47). The vertical increase in pH with depth is not unusual to bog water chemistry (Shotyk, 1988). Studies by Kurtz (1928), Wakman and Stevens (1928), and Bellamy and Riley (1967), measured pH at bog surfaces and then at depths similar to those in this study. The pH increased from less than 4 to pH greater than 7. According to Shotyk (1988), bogs that show a vertical pH profile approaching or exceeding neutral values with depth, such as those analyzed from samples in this study, evolved from calcareous fens, and at depth, are under the influence of calcareous terrain ground-water chemistry. The southern flow system (SFS) ground-water chemistry is characterized by carbonate dissolution (Barrese, 1991) and influences the vertical profile of pH and other chemical parameter concentrations within Government Marsh as ground water flows through the deeper sections of the bog. Extreme values that are anomalously above SFS concentrations indicate the mechanics of another process. Bogs are "natural landfills" where plant material is decomposed into peat. Bog waters are rich in carbonic acid and organic

Table 23

A Summary of the Functions of Inorganic Nutrients in Plants

	Macronutrients	
Element	Principal Form in Which Element is Absorbed	Usual Concentration In Healthy Plants (% of Dry Weight)
Carbon	CO_2	~ 44%
Oxygen	H_2O or O_2	~ 44%
Hydrogen	H_2O	~ 6%
Nitrogen	NO_3^- or NH_4^+	1-4%
Potassium	K^+	0.5-6%
Calcium	Ca^{2+}	0.2-3.5%
Phosphorus	$H_2PO_4^-$ or HPO_4^{2-}	0.1-0.8%
Magnesium	Mg^{2+}	0.1-0.8%
Sulfur	SO_4^{-2}	0.05-1%

	Micronutrients	
Element	Principal Form in Which Element is Absorbed	Usual Concentration In Healthy Plants (ppm of Dry Weight)
Iron	Fe^{2+} or Fe^{3+}	25-300 ppm
Chlorine	Cl^-	100-10,000 ppm
Copper	Cu^{+2}	4-30 ppm
Manganese	Mn^{2+}	15-800 ppm
Zinc	Zn^{+2}	15-100 ppm
Molybdenum	MoO_4^{2-}	0.1-5.0 ppm
Boron	BO^{-3} or $B_4O_7^{2-}$	5-75 ppm

Table 23--Continued

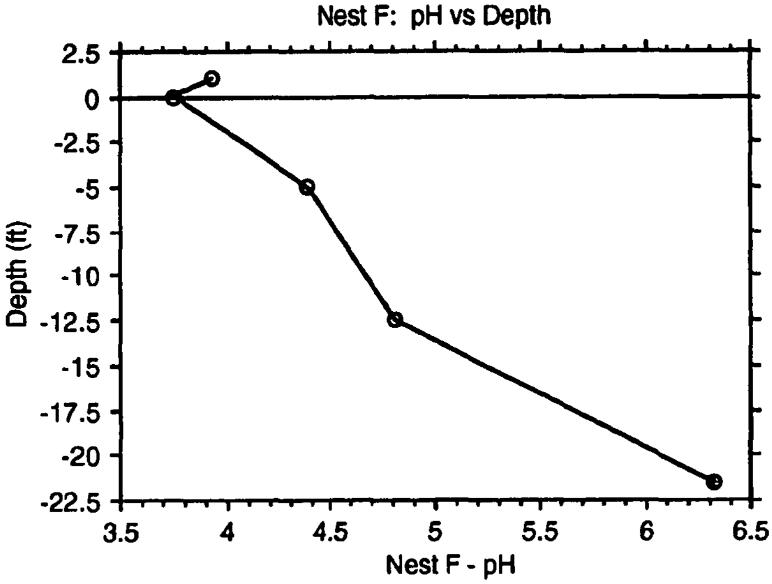
Element	Elements Essential to Some Plants or Organisms: Principal Form in Which Element is Absorbed	Usual Concentration In Healthy Plants (ppm of Dry Weight)
Cobalt	Co^{2+}	Trace
Sodium	Na^{+}	Trace

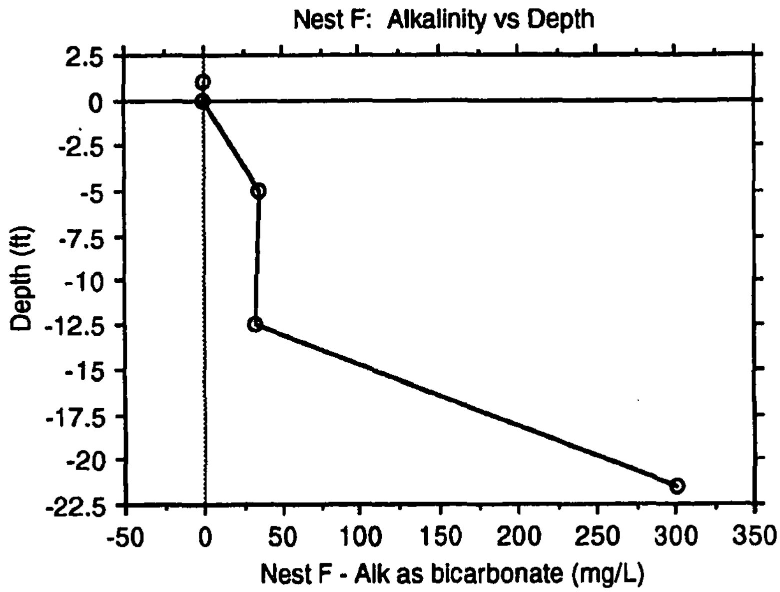
Source: Raven, P., Evert, R., & Eichhorn, S. (1986). Biology of plants. New York: Worth Publishers.

acids from this decomposition, especially humic and fulvic acids (Wetzel, 1983). Fulvic acids are low molecular-weight organic acids that stain a water yellow. They are generally found in surface and near-surface bog waters. Humic acids are high molecular-weight organic acids that stain a water brown or a "tea color". They are generally associated with subsurface bog waters. Acetic, gallic, oxalic, tartaric, tannic and citric acids (from cranberries) have been identified in bog water samples (Shotyk, 1988). Some of these same organic acids have been identified in anthropogenic landfill leachate (Rudder, 1988). Kehew and Passero (1990) have proposed that organic acids and carbonic acid generated during the decomposition of organic wastes in anthropogenic landfill leachate, result in open system dissolution of carbonate minerals in carbonate soils between the refuse and the water table in a landfill environment. Reactions (3) and (4) demonstrate the dissolution of calcite and dolomite by reaction with acid.

$$CaCO_3 + H^+ \rightarrow Ca^{+2} + HCO_3^- \quad (3)$$

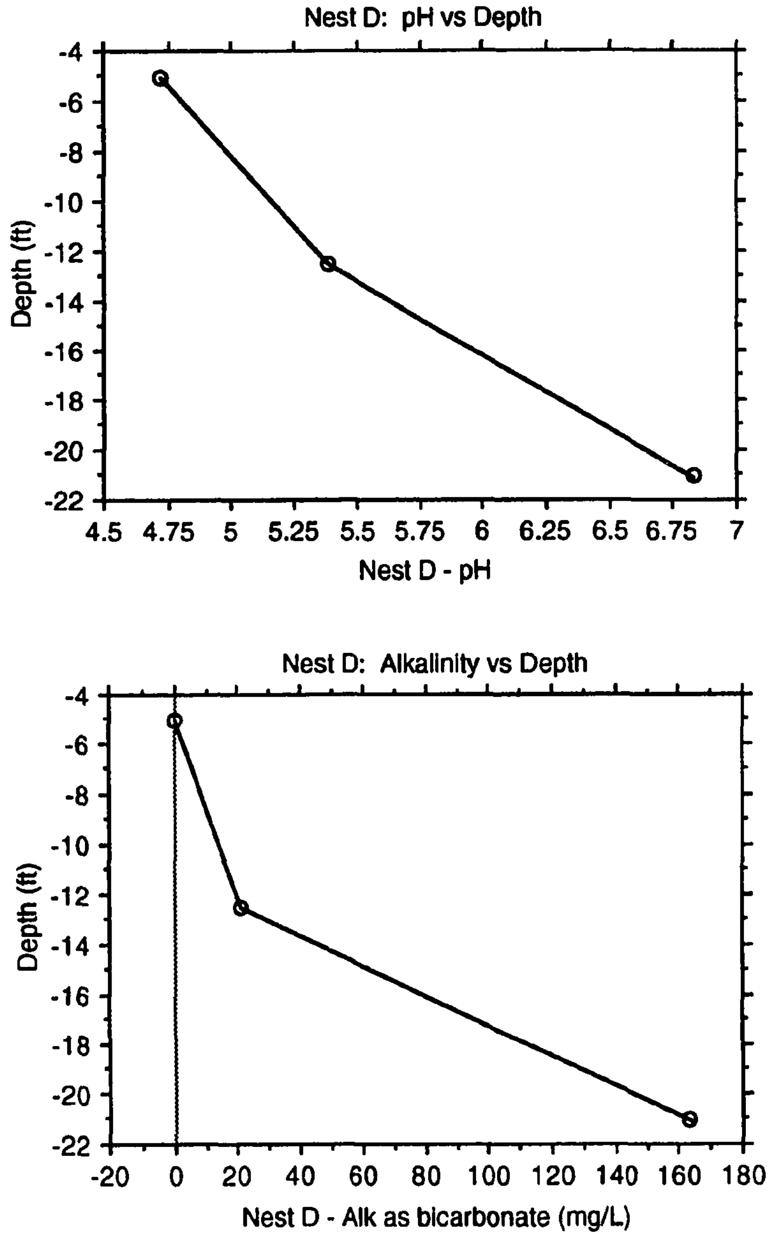
$$CaMg(CO_3)_2 + 2H^+ \rightarrow Ca^{+2} + Mg^{+2} + 2HCO_3^- \quad (4)$$





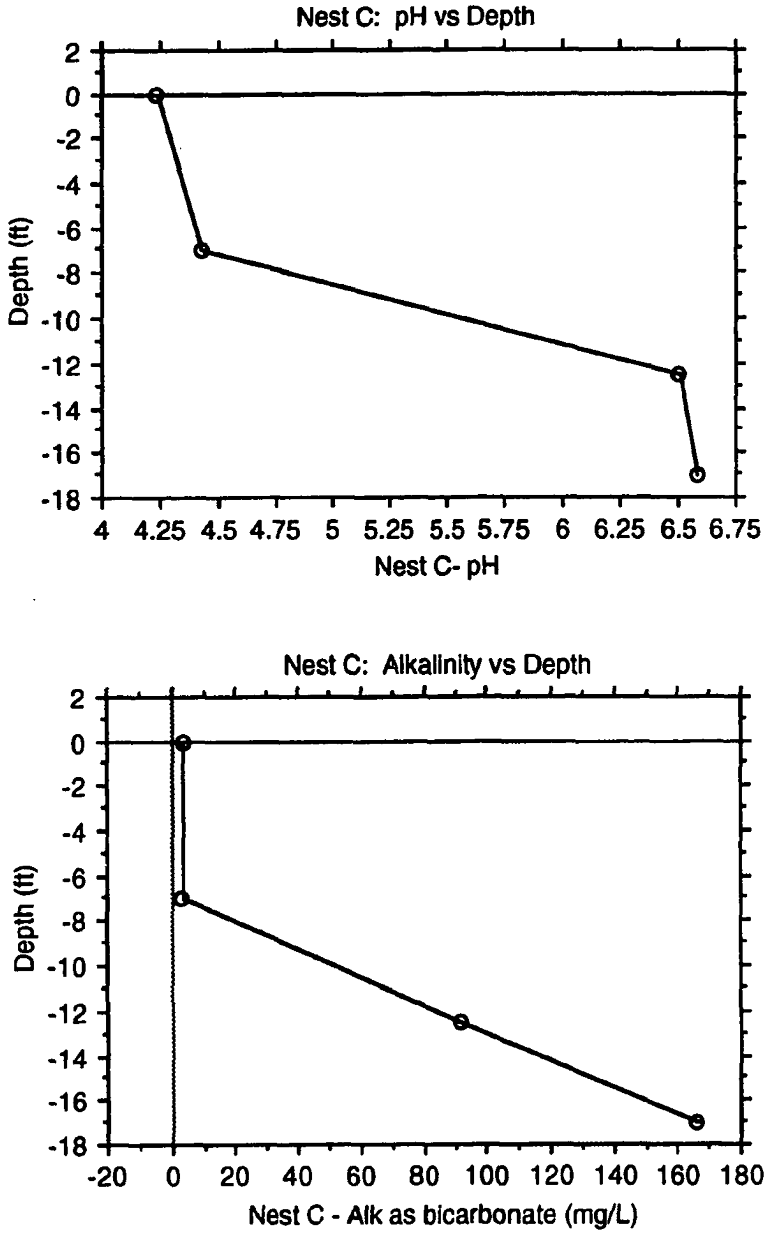
Note. Point above zero depth indicates rain gauge sample. All wells are screened in peat.

Figure 36. Alkalinity and pH Concentrations Compared to Depth for Well Nest F.



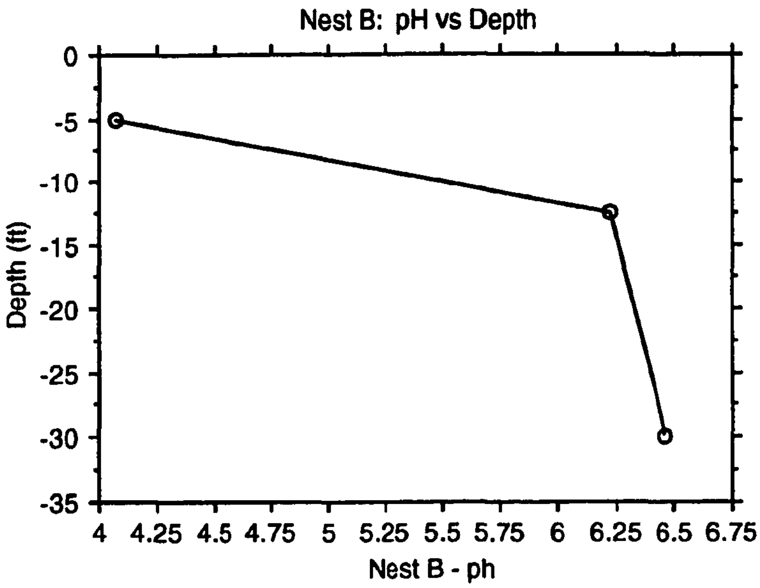
Note. Wells are screened in peat except for wells D-2 and D-3, which are screened in sediment beneath the peat.

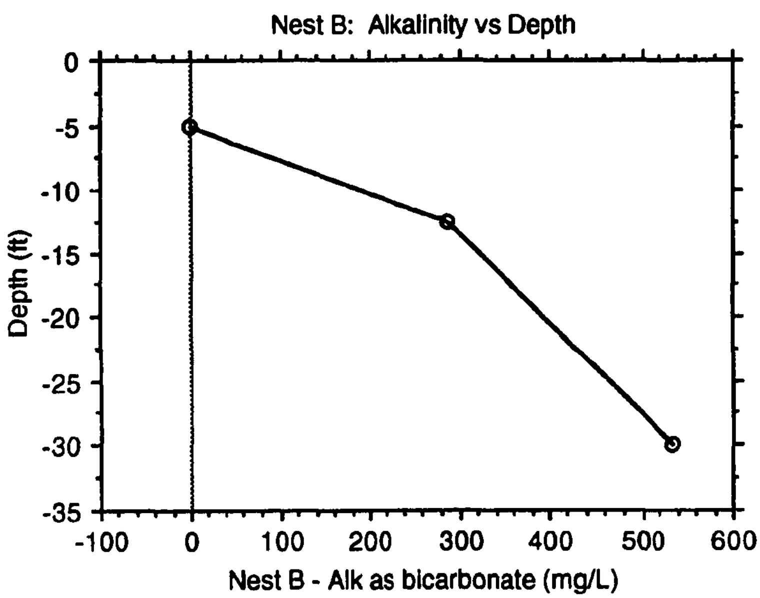
Figure 37. Alkalinity and pH Concentrations Compared to Depth for Well Nest D.



Note. **All wells screened in peat.**

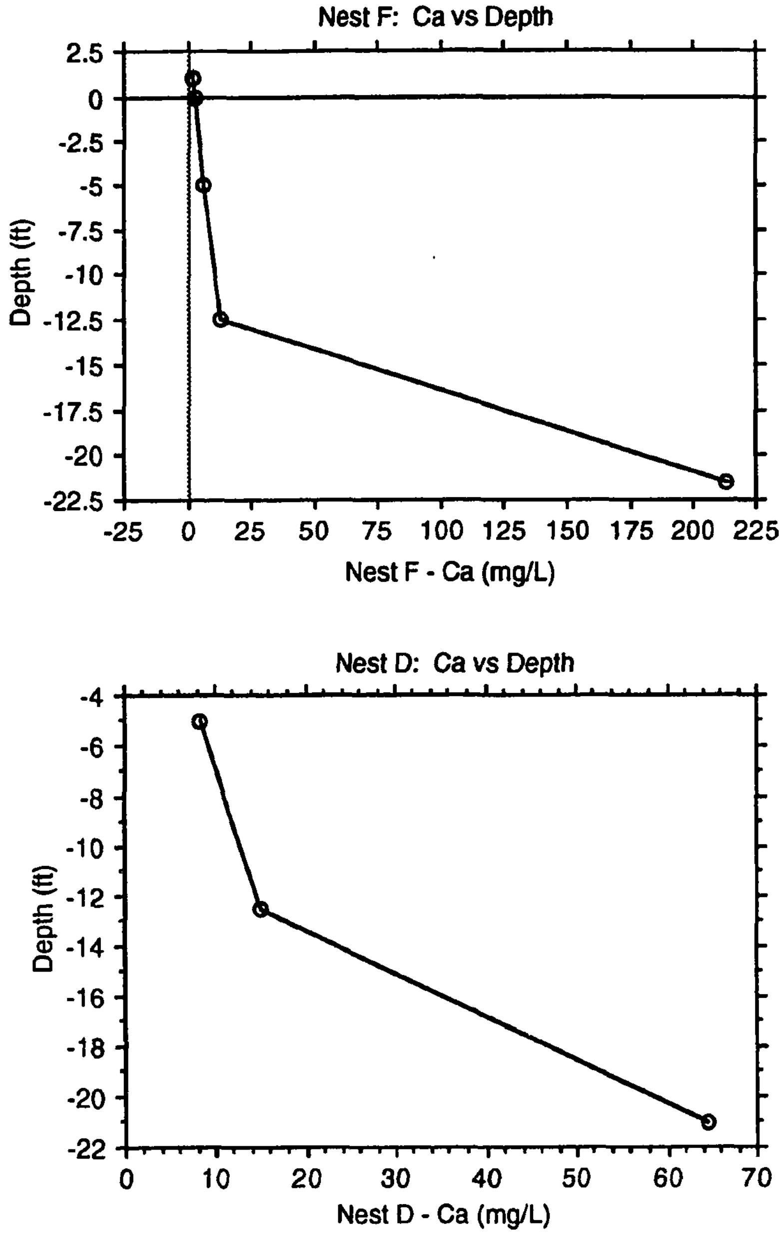
Figure 38. Alkalinity and pH Concentrations Compared to Depth for Well Nest C.





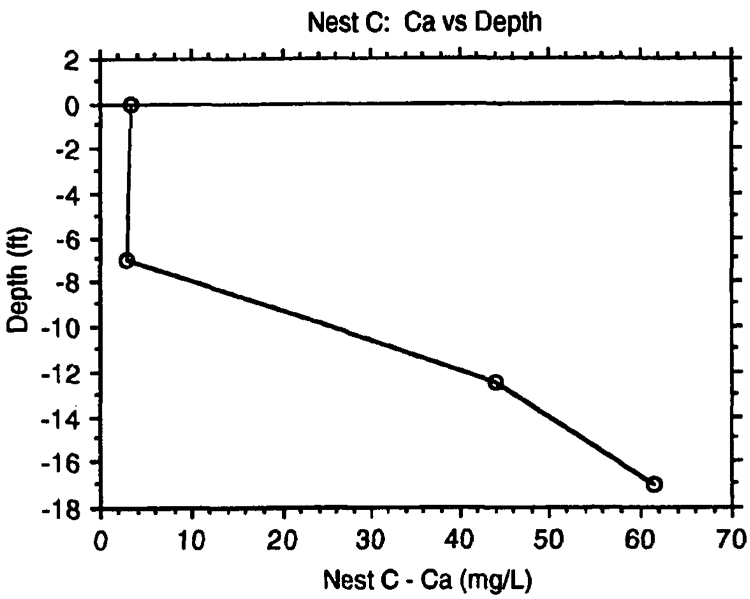
<u>Note.</u> **All wells screened in peat.**

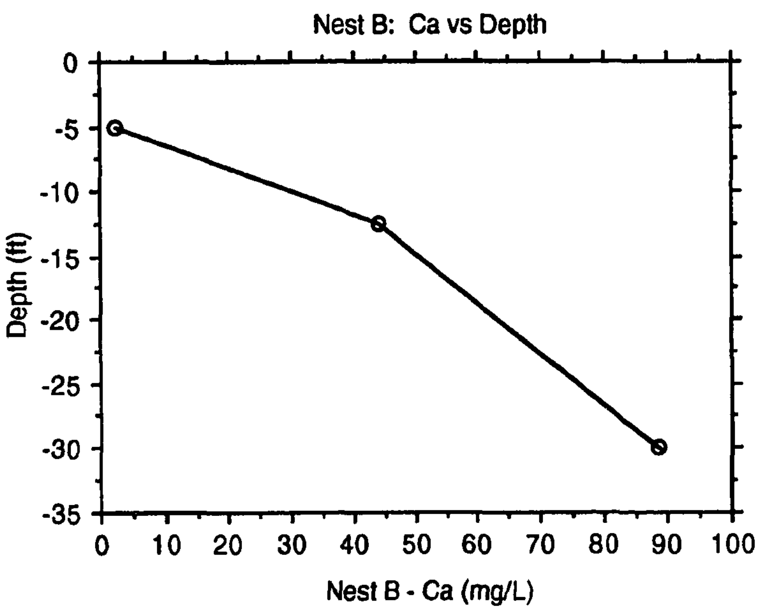
Figure 39. Alkalinity and pH Concentrations Compared to Depth for Well Nest B.



Note. Point above zero depth indicates rain gauge. Wells are screened in peat except for wells D-2 and D-3, which are screened in sediment beneath the peat.

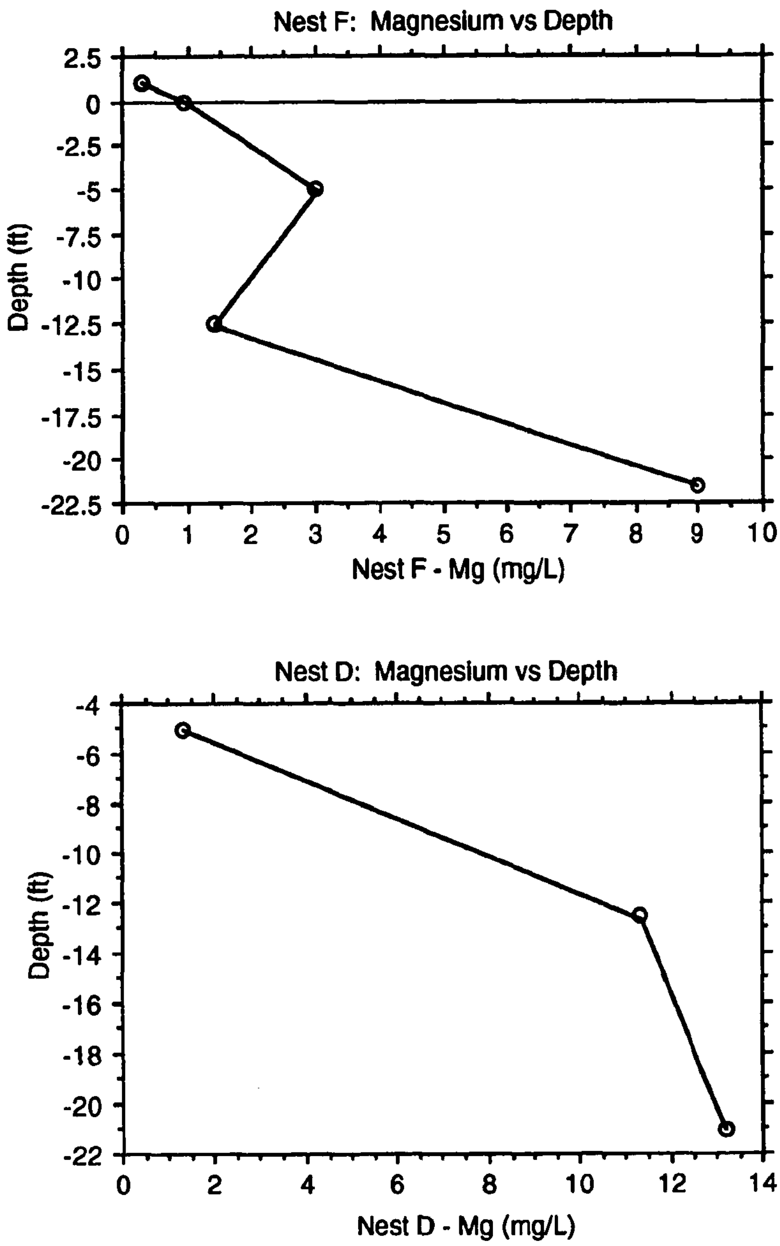
Figure 40. Calcium Concentrations for Well Nest F and Well Nest D.





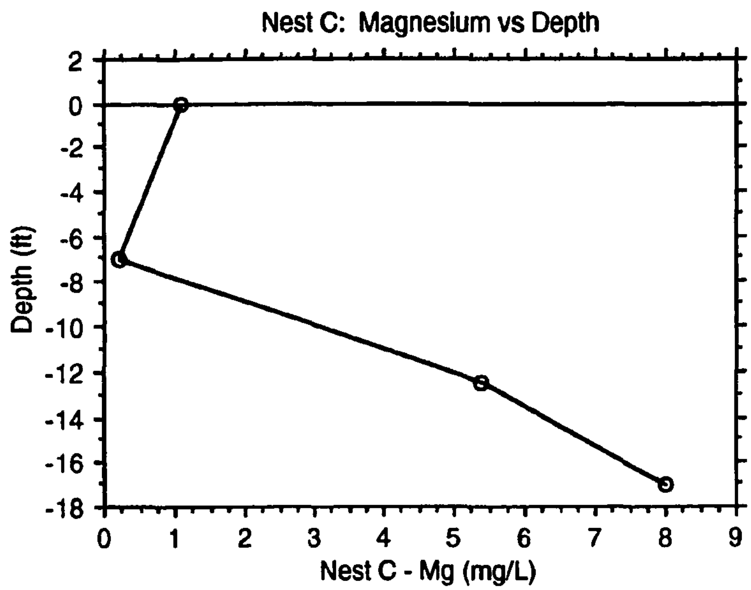
Note. All wells screened in peat.

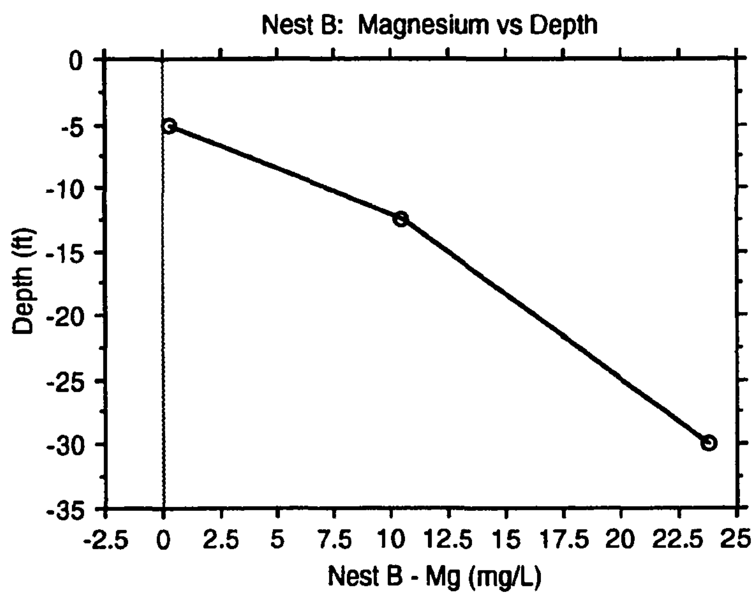
Figure 41. Calcium Concentrations for Well Nest C and Well Nest B.



Note. Point above zero depth indicates rain gauge sample. Wells are screened in peat except for wells D-2 and D-3, which are screened in sediment beneath the peat.

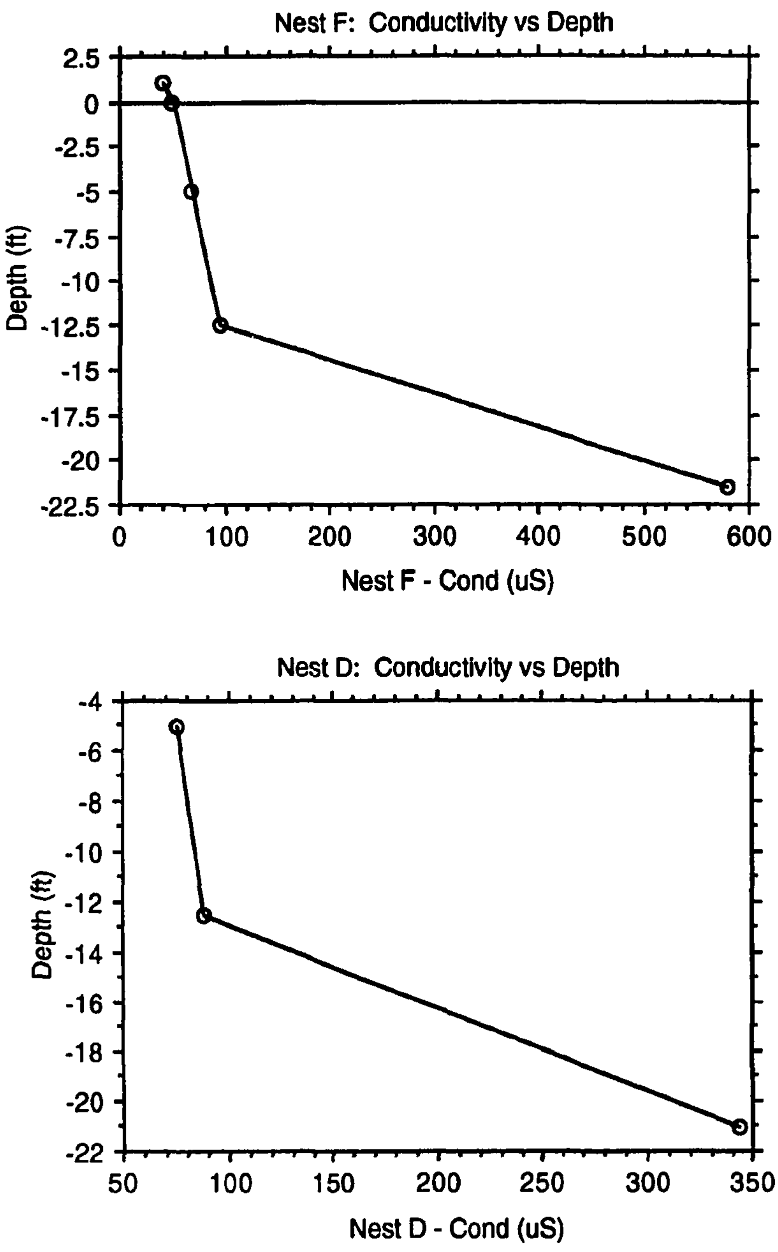
Figure 42. Magnesium Concentrations for Well Nest F and Well Nest D.





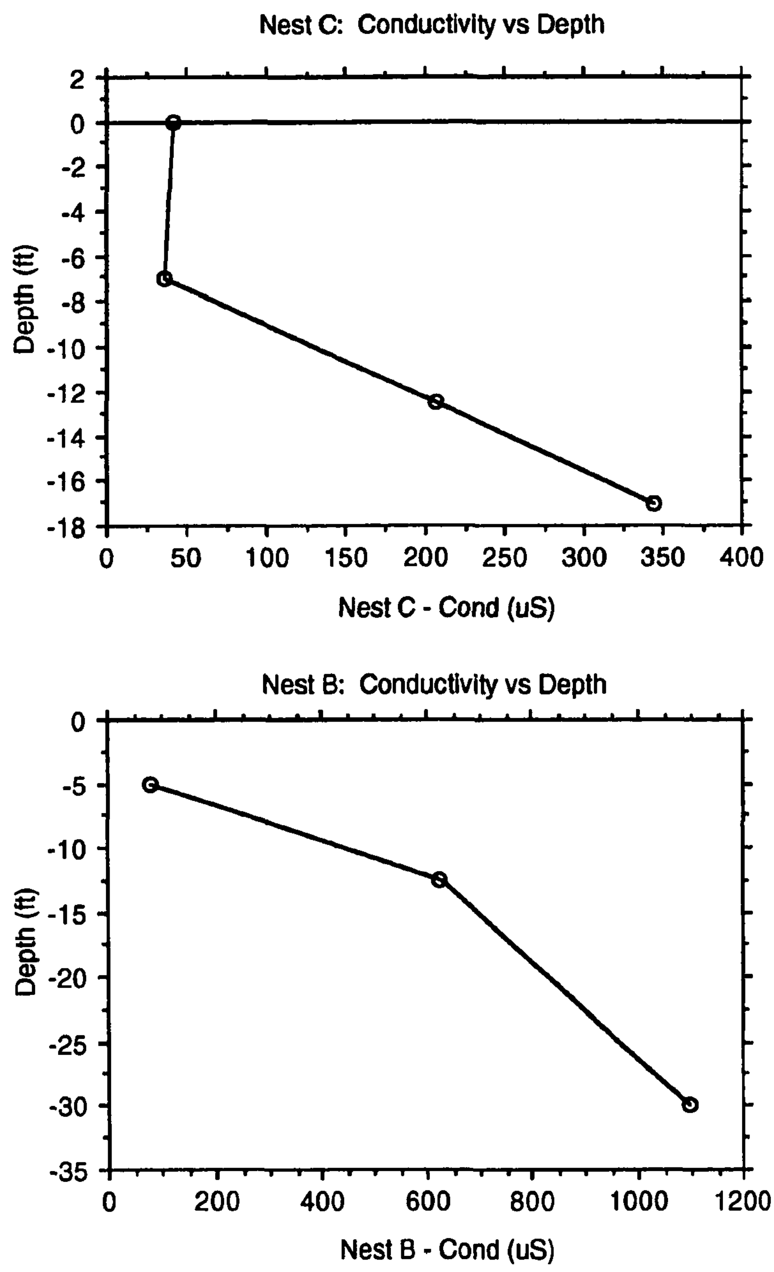
Note. All wells screened in peat.

Figure 43. Magnesium Concentrations for Well Nest C and Well Nest B.



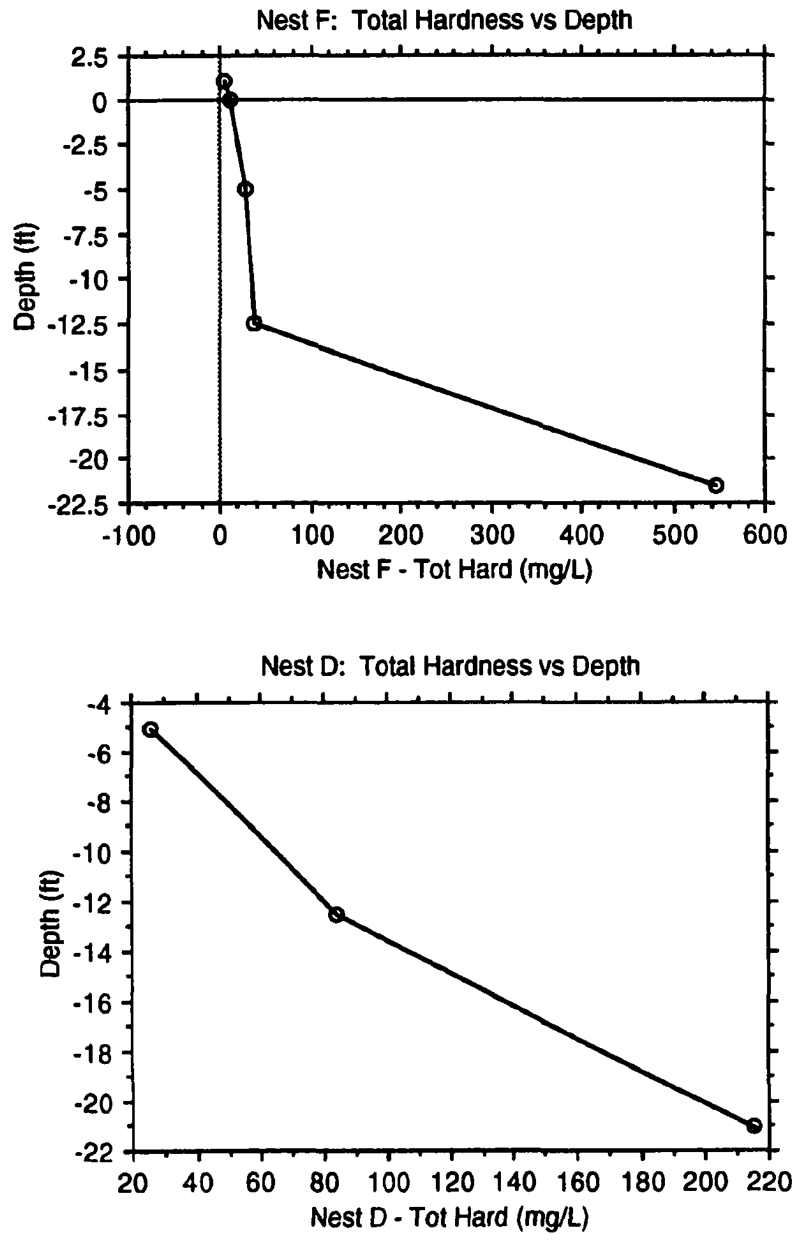
Note. Point above zero depth indicates rain gauge sample. Wells are screened in peat except for wells D-2 and D-3, which are screened in sediment beneath the peat.

Figure 44. Conductivity Concentrations for Well Nest F and Well Nest D.



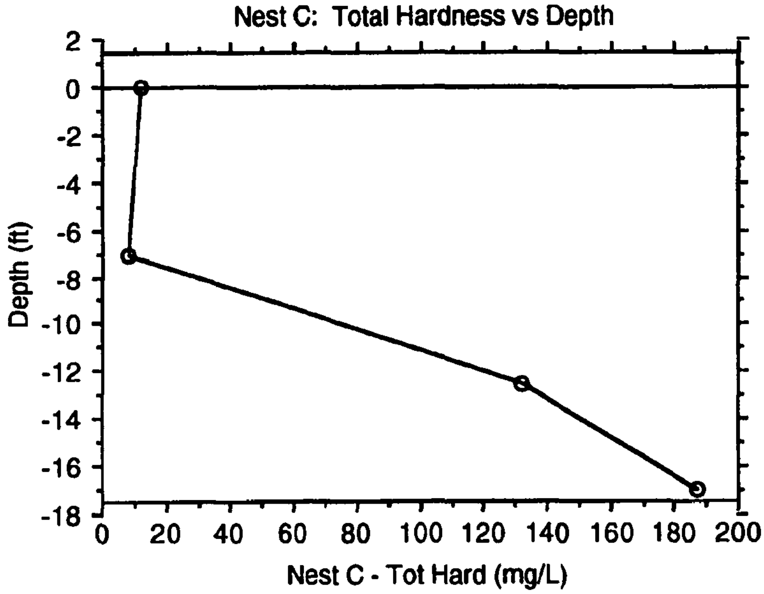
Note. All wells screened in peat.

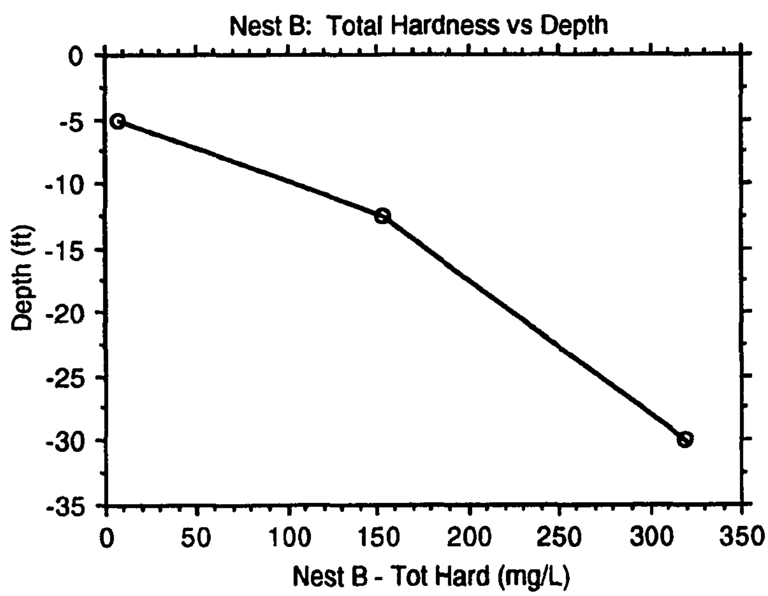
Figure 45. Conductivity Concentrations for Well Nest C and Well Nest B.



Note. Point above zero depth indicates rain gauge sample. Wells are screened in peat except for wells D-2 and D-3, which are screened in sediment beneath the peat.

Figure 46. Total Hardness Concentrations for Well Nest F and Well Nest D.





Note. **All wells screened in peat.**

Figure 47. Total Hardness Concentrations for Well Nest C and Well Nest B.

Clayey marl was identified from core samples collected from nests C, D and F. The SFS carbonate ground-water chemistry has been identified as being under the influence calcite and dolomite dissolution (Barrese, 1991). Elevated concentrations of calcium, magnesium, alklinity, pH, conductivity and total hardness can be explained by reactions (3) and (4) occurring in subsurface waters in the presence of organic and carbonic acids at Government Marsh. Ionic inbalance (Table 24) is evidence that ground water at Government Marsh contains anions from dissociated organic acids and that complexation may be occurring (Kehew & Passero, 1990). This is especially true in nested wells B-1, D-1, C-2, D-2, C-3, D-3 and F-3, where the range of the sum of cations exceeds the sum of anions from 9.83 to 53.04 percent. The large degree of ion inbalance is in agreement with the conclusions of Gorham, Eisenreich, Ford, and Santelmann (1985). They measured the ionic balance in 28 water samples collected from 28 North American bogs, and found a mean inbalance of 53% in favor of cations. The ionic inbalance of cations suggest that organic acid anions make up the difference to balance the solution. The ionic inbalance in wells C-1, F-1 and F-2, which is in favor of anions, can be explained by at least two processes. Amino acids are originally dipolar molecules when released during the decomposition of proteins. The amino acid glycine, $^{+}H_3NCH_2CO_2^{-}$, is typical of this dipolarity, and like all amino acids, forms very stable complexes with some metal ions (Manahan, 1990). Amino acid complexation with a metal would convert the dipolar molecule into a cation. Even if complexation does not occur, the dipolar amino acid is converted into a cation when the solution is acidic as reaction (5) demonstrates (Morrison & Boyd, 1959):

$$^{+}H_3NCHRCOO^{-} + H_3O^{+} \dashrightarrow {}^{+}H_3NCHRCOOH + H_2O \qquad (5)$$

Some amino acids that contain polarized side chains will convert to cations even when pH values are above 7. For example, the amino acids histidine, lysine and arginine

Table 24

Ionic Balance in Samples from Well Nests
B, C, D, & F

Well	Depth of Sample (ft)	Ionic Balance (percent)
B-1	5.0	(+) 37.50
C-1	7.0	(-) 26.80
D-1	5.0	(+) 29.13
F-1	5.0	(-) 26.00
B-2	12.5	---
C-2	12.5	(+) 6.56
D-2	12.5	(+) 53.04
F-2	12.5	(-) 10.80
B-3	30.0	---
C-3	17.0	(+) 9.83
D-3	21.0	(+) 17.20
F-3	21.5	(+) 27.00

(+) Ionic inbalance in favor of cations.

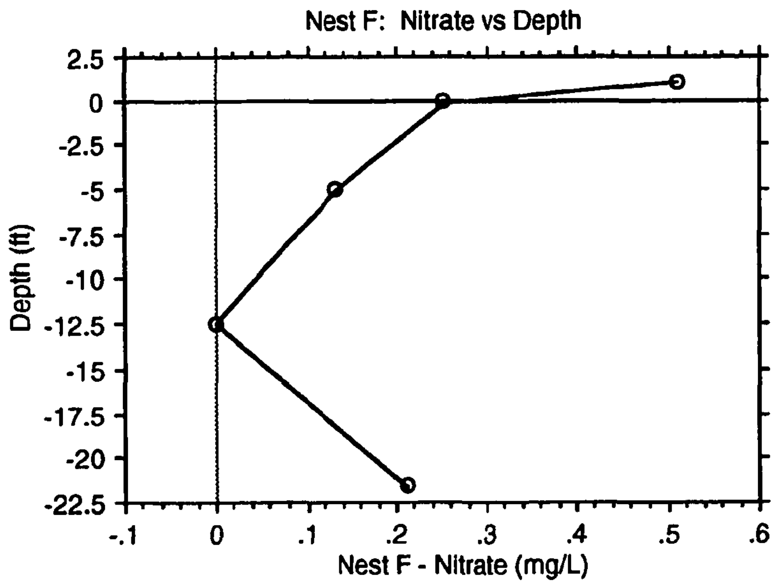
(-) Ionic inbalance in favor of anions.

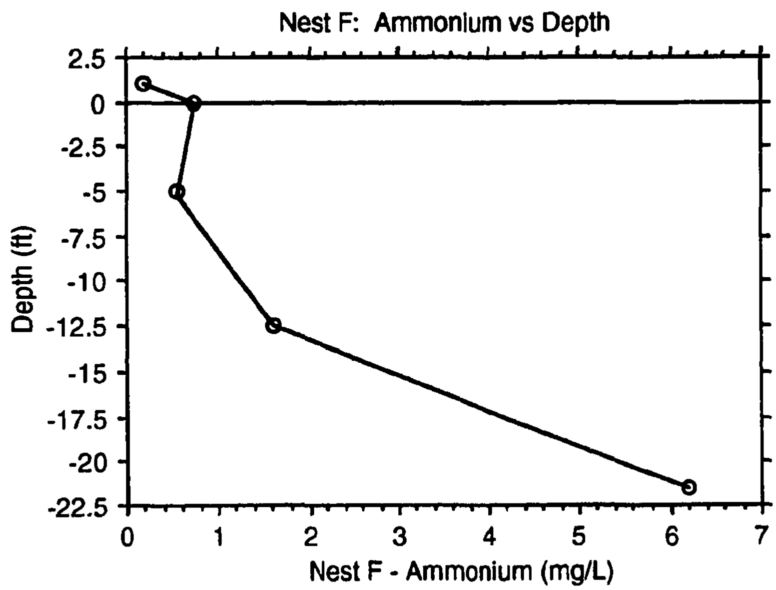
will begin to convert to cations at pH values of 7.64, 9.47 and 10.76, respectively, and conversion increases as pH decreases from these values (Brown, 1982). In addition, free cations or complexed cations may exist in solution that were not part of the analysis. According to Shotyk (1988) bog waters are enriched with aluminum, commonly contain copper and zinc, and contain many trace elements. Organic acids are known to complex with aluminum (Thurmon, 1985). Another source for the elevated

concentrations of bicarbonates in the Government Marsh ground-water samples is the elevated concentrations of ammonium. Kehew, Passero, Rudder, and Howell (1988) have suggested that exchange of ammonium for calcium and magnesium absorbed on aquifer particle surfaces contributes to increases in bicarbonate concentrations in ground water. Nicholson, Cherry, and Reardon (1983) have suggested that ion exchange in ground water at the Borden, Ontario landfill provides a source for magnesium and supersaturated levels of calcium. According to WATEQ4F none of the nested wells are supersaturated with respect to calcite or dolomite, although B-3 and F-3 screened at depths of 30 and 21.5 feet respectively, are near equilibrium with respect to calcite (B-3, SI = -.555; F-3, SI = -.526). Alkalinity concentrations as bicarbonate can also be increased by the chemical process of deamination of amino acids and sufate reduction to sulfide, which will be discussed in the next section.

Nitrate, Ammonium, Sulfate and Sulfide

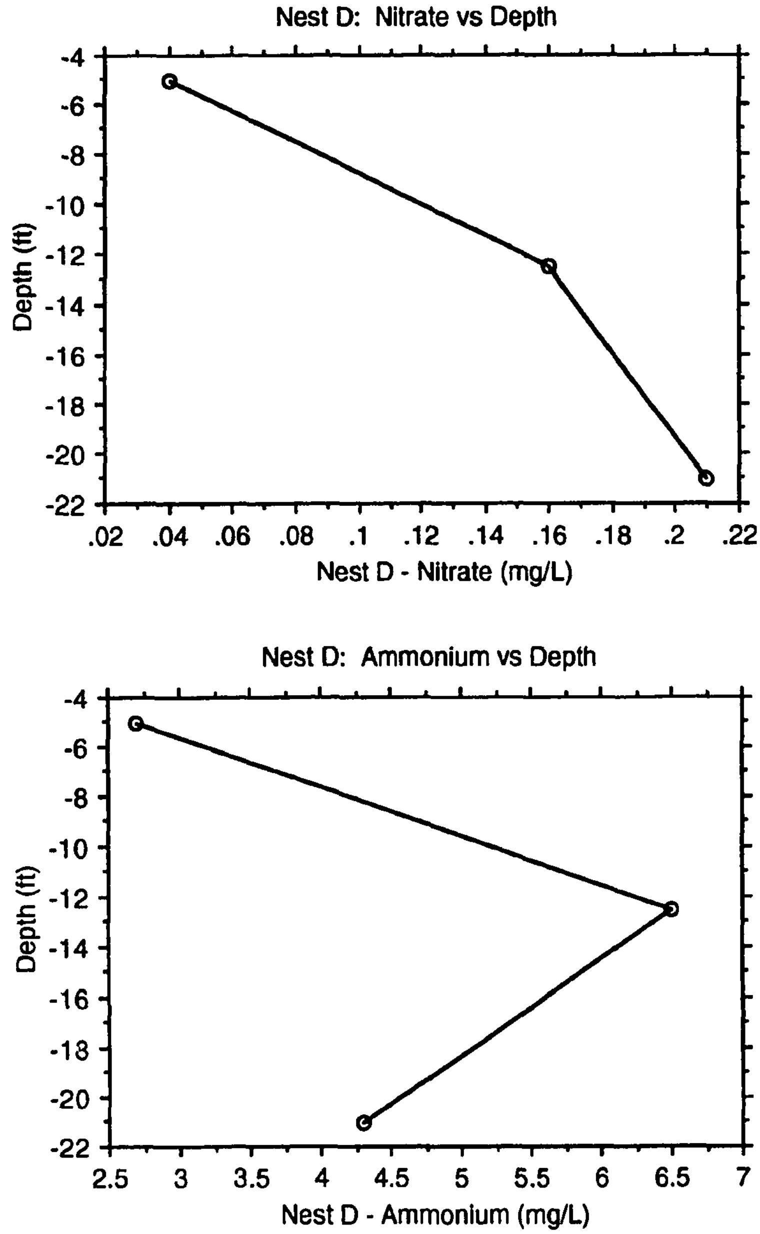
Nitrate is reduced to ammonium in the presence of organic carbon, biomediated by microorganisms. Nitrate concentrations are either stable or are generally decreasing with sample depth in well nests B, C and F, and ammonium concentrations increase with sample depth in well nests B, C and F. Resulting chemical parameters are interpreted as products of the reduction of nitrate to ammonium and deamination (Figures 48, 49, 50, & 51). The decrease in ammonium concentration in a sample collected from nested well D-3 is interpreted as the absorption of ammonium on mineral surfaces, because, according to Hem (1985), ammonium cations are strongly absorbed on mineral surfaces, and are held there until converted to nitrate when aerobic conditions exist. As previously discussed, the exchange of ammonium for calcium and magnesium absorbed on aquifer particle surfaces contributes to increases in carbonate





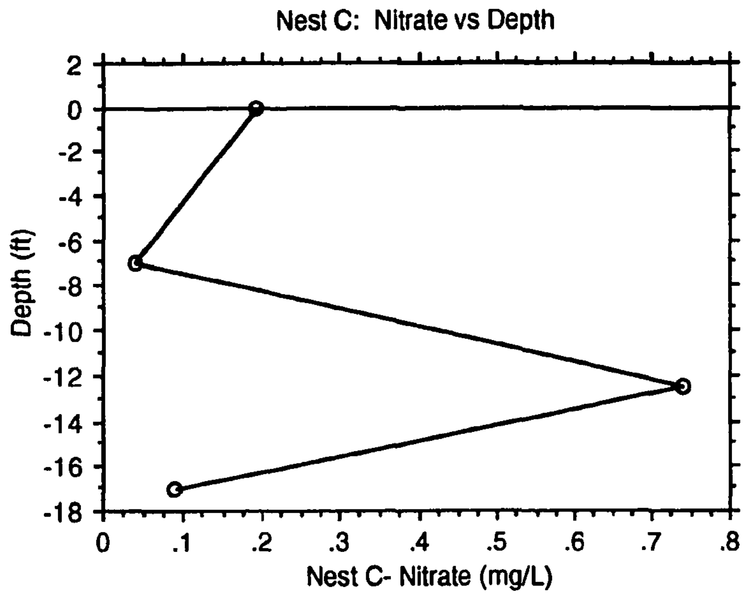
Note. Point above zero depth indicates rain gauge sample. All wells are screened in peat.

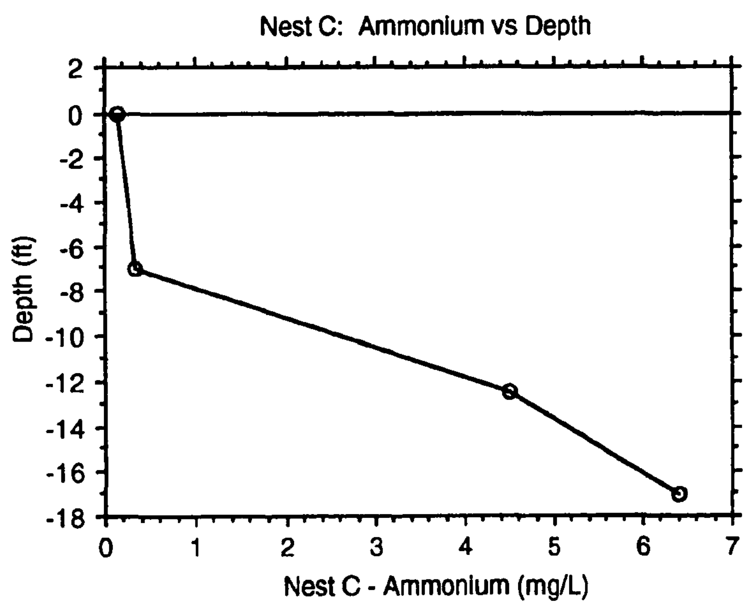
Figure 48. Nitrate and Ammonium Concentrations for Well Nest F.



Note. Wells are screened in peat except for wells D-2 and D-3, which are screened in sediment beneath the peat.

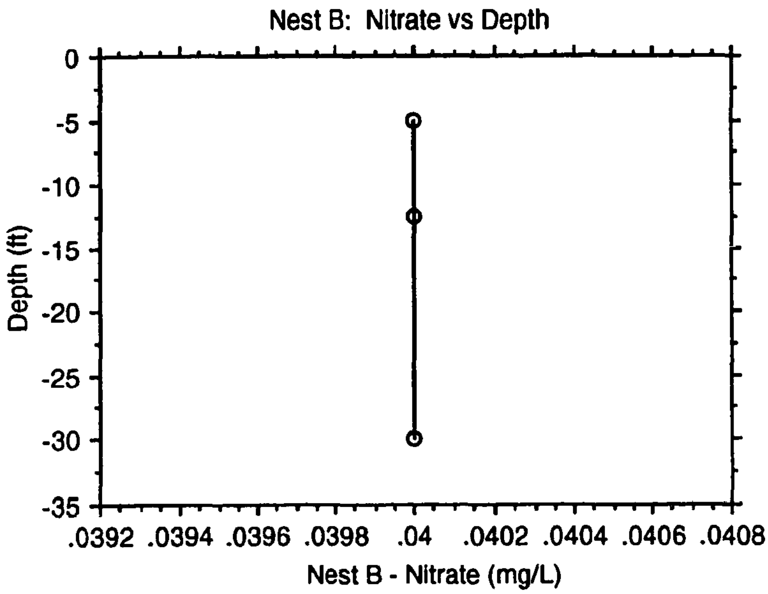
Figure 49. Nitrate and Ammonium Concentrations for Well Nest D.

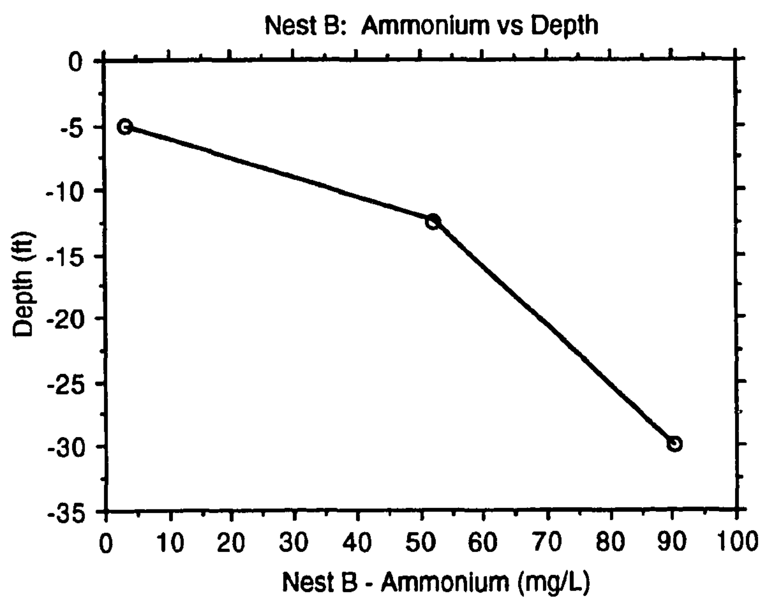




Note. All wells screened in peat.

Figure 50. Nitrate and Ammonium Concentrations for Well Nest C.





Note. All wells screened in peat.

Figure 51. Nitrate and Ammonium Concentrations for Well Nest B.

concentrations in ground water (Kehew, Passero, Rudder, & Howell, 1988). This process may be occurring in the environment near all of the deep nested wells as demonstrated by the consistent increase in calcium concentrations relative to nested well sample depths. The low concentration of nitrate that occurs in samples from nested wells, C-2, F-3 and in all of the well samples from nest D is probably caused by the difficulty in obtaining unaerated ground-water samples from the wells (Siegel, 1988).

Another process must be working in order for the elevated concentrations of ammonium to occur, especially in samples from wells B-2 and B-3, which have NH_4^+ concentrations of 52.10 and 90.30 mg/L, respectively. Bog waters contain decomposing plant material, and in the process of decay, the production of ammonium occurs through a process called deaminiation, which is the breakdown of amino acids as the end product of protein decomposition (Drever, 1982). According to Shotyk (1988) organic nitrogen compounds account for approximately 60 to 90% of total dissolved nitrogen species in mires. Wetzel (1983), using data collected from various water bodies, suggests that dissolved organic nitrogen compounds (DON) account for approximates 50% of total dissolved nitrogen species, and that about 25% of DON is in the form of amino-nitrogen compounds or occurs as free amino nitrogen. Wetzel (1983) also reports that amino-nitrogen compounds increase with eutrophication, and he demonstrates with a study, that approximately 40% of DON can be in the form of amino-nitrogen compounds, acids and sugars. Reaction (6) demonstrates the end product of deaminiation. Ammonium is derived from breakdown of amino acids.

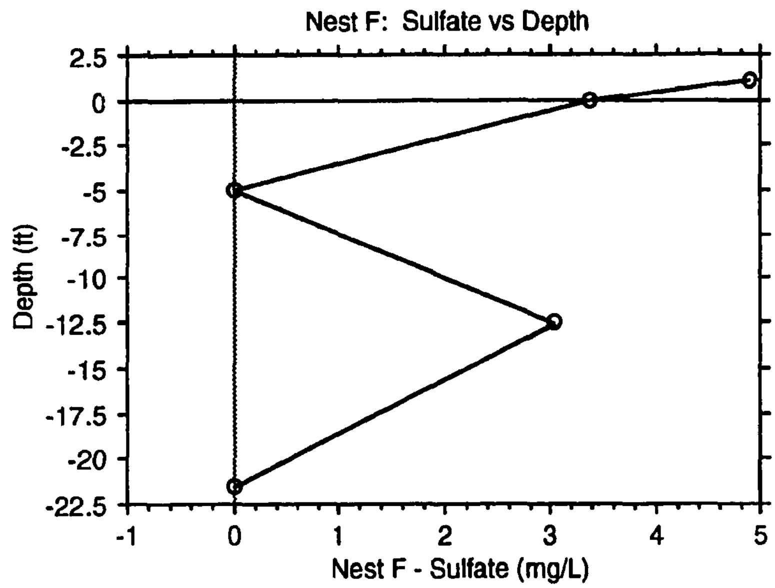
$$NH_3 + H_2O + CO_2 \dashrightarrow NH_4^+ + HCO_3^- \qquad (6)$$

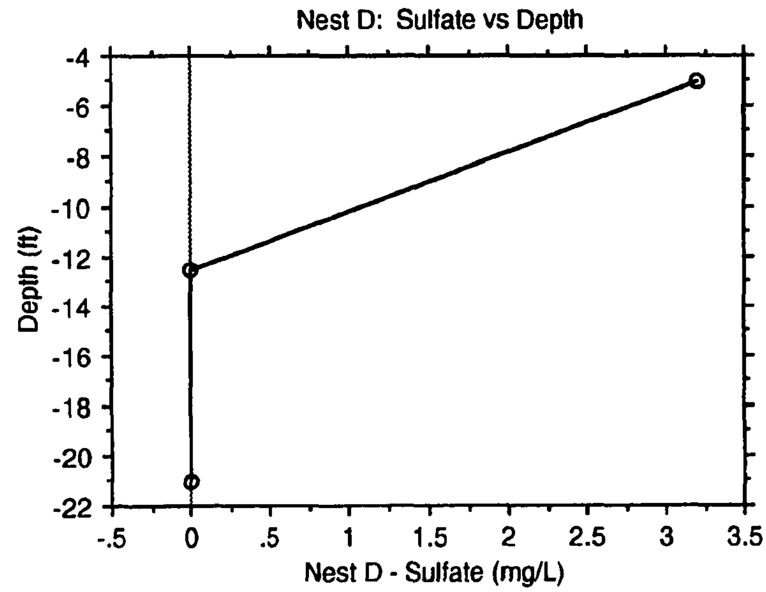
Notice that bicarbonate is also produced in reaction (6), which also helps to explain the high concentration of alkalinity in nested wells B-2, B-3 and F-3 (286, 535 and 302 mg/L, respectively).

Sulfur in bog water is produced by the breakdown of amino acids during the process of plant decomposition. For example, the formulas for cysteine and methionine, amino acids common in plants, are $HSCH_2CH(NH_2)COOH$ and $CH_3SCH_2CH_2CH(NH_2)COOH$, respectively. Compounds such as these break down and contribute sulfur into bog water. Although hydrogen sulfide was not part of the analysis reported by the WMU Water Quality Lab, it was obvious to this researcher, from the odor of "rotten eggs," that the process of sulfate reduction was occurring. The human nose is sensitive to a few tenths of a mg/L of H_2S (Hem, 1985). This simple circumstantial analysis should be appreciated, because higher concentrations are toxic (Shotyk, 1988). Sulfate generally decreases in all of the well nests with increasing sample depth, and is undetected in well samples B-2, B-3, D-2 and D-3 (Figures 52 & 53). Minor concentrations do occur in samples from wells F-2 and C-3. Well C-3 is screened near the bottom of the bog at the base of the peat. The concentration of sulfate from sample C-3 may be the result of SFS aerated ground water interacting with anaerobic bog water. The sulfate concentration in F-2 may again be a consequence of the difficulty in obtaining unaerated ground water samples from the wells. The general decrease in sulfate with sample depth, and the presence of the H_2S odor is interpreted to be the effect of sulfate reduction at Government Marsh. Sulfate reduction is demonstrated by reaction (7), where $C_{organic}$ represents an organic molecule (Drever, 1982).

$$SO_4^{-2} + 2C_{organic} + 2H_2O \dashrightarrow H_2S + 2HCO_3^- \qquad (7)$$

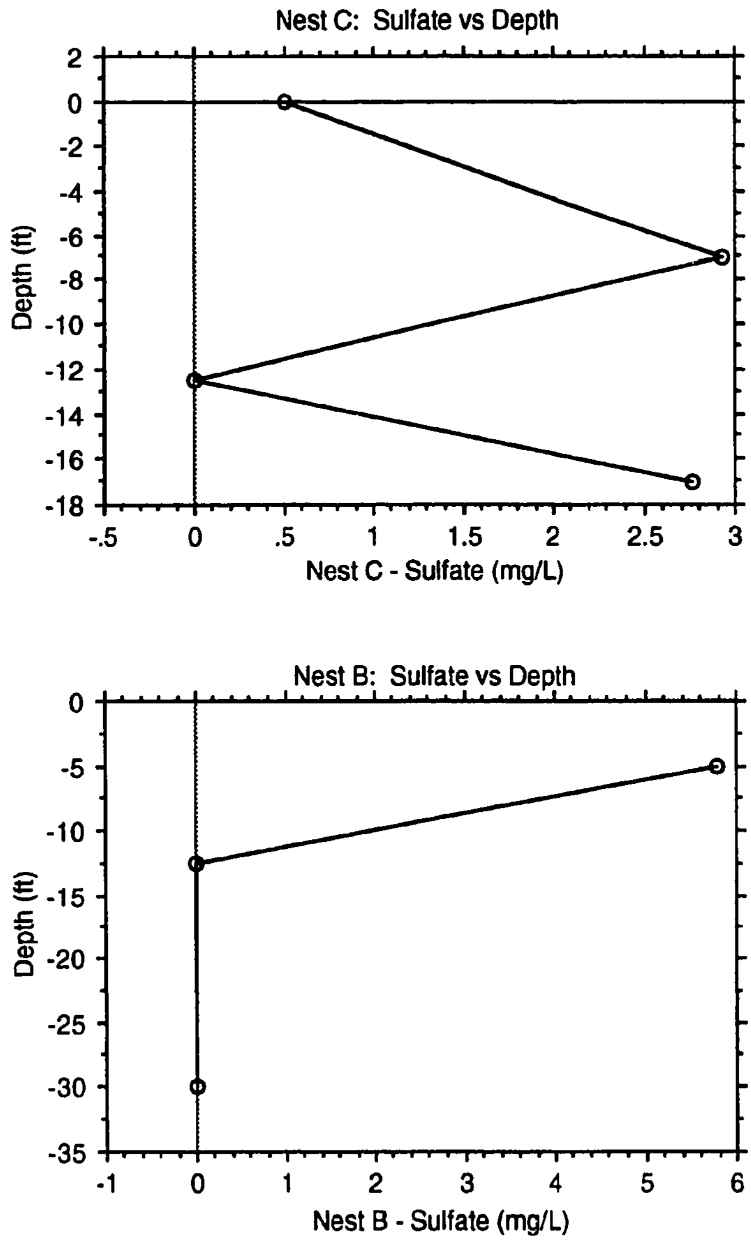
Bicarbonate is also a product of this reaction, which again helps to explain the higher values of alkalinity in the deep nested wells.





Note. **Point above zero depth indicates rain gauge sample. Wells are screened in peat except for wells D-2 and D-3, which are screened in sediment beneath the peat.**

Figure 52. Sulfate Concentrations for Well Nest F and Well Nest D.



Note. All wells screened in peat.

Figure 53. Sulfate Concentrations for Well Nest C and Well Nest B.

Ferrous Iron and Silica

Plants are rich in iron; therefore, bog waters which contain the chemistry of dissolved organic matter are also rich in iron (Shotyk, 1988). In acidic waters iron can be in the form of Fe^{+2}, Fe^{+3}, $FeOH^{+2}$, and $Fe(OH)_2^+$ (Hem, 1985). Iron is also known to complex with organic acids (Thurmon, 1985). Complexes with iron can occur with either ferrous (Theis and Singer, 1974) or ferric species (Stumm & Morgan, 1970). Rudder (1988) obtained evidence of iron complexing with organic ligands in ground water at the KL landfill, Kalamazoo, Michigan. Results from WATEQ4F show that the subsurface waters surrounding nested wells B-2, B-3 and nests C, D, and F are supersaturated in respect to mineral species that contain iron (Table 25). The supersaturation of subsurface bog waters at Government Marsh with respect to mineral species that contain iron is interpreted as a result of complexation. Complexation could retard precipitation by keeping iron in solution beyond the limit that it would precipitate if organic ligands were not present (Kehew & Passero, 1990). The concentration of ferrous iron generally increases with sample depth in wells nests B, C, D, and F (Figures 54 & 55). Exceptions occur in samples collected from wells C-3 and D-3; a decrease occurs relative to ferrous iron concentrations analyzed from samples C-2 and D-2. Precipitation of an iron sulfide species may actually be occurring, because, according to Drever (1982), when reactive iron compounds are in the same reducing environment, H_2S will react with the iron to form solid sulfides. Although iron sulfide species, such as pyrite, are unstable under low pH conditions in bog surface waters, where waters are undersaturated with respect to solid phase sulfides, they have been identified at the bottom of bogs, where minerotrophic conditions and an abundance of carbonate material occur (Shotyk, 1988). Such conditions exist at depth at Government Marsh. In addition, amorphous ferrous carbonate ($FeCO_3$), siderite ($FeCO_3$) and

vivianite ($Fe_3(PO_4)_2 \cdot H_2O$) are commonly identified in mire peats (Shotyk, 1988). The carbonate mineral siderite may control iron concentrations, especially since saturation indices for siderite are above saturation level in wells B-3, C-3, D-3, and F-3 (Table 25). Kehew and Passero have proposed that reaction (8) may also be occurring in the presence of oganic carbon, especially when ground water is undersaturated with respect to ferric hydroxide.

$$4Fe(OH)_3 + 8H^+ + C_{organic} \dashrightarrow 4Fe^{+2} + 11H_2O + CO_2 \qquad (8)$$

If reaction (8) is occurring at Government Marsh, hydrogen ions would be consumed and alkalinity increased.

Most silica in natural waters is a result of aluminosilicate mineral weathering. Because the chemical characteristics of bog surface waters are the result of atmospheric precipitation, dustfall, run-off and plant decay, bog surface waters are anemic in dissolved silica relative to other wetlands that owe their supply of water to ground-water discharge. If the dissolved SiO_2 content in a bog surface water sample is > 4 mg/L, minerotrophic ground water is said to chemically influence the bog surface (Shotyk, 1988). The concentrations of SiO_2 generally increase with sample depth at Government Marsh, and at values that indicate influence of minerotrophc ground water (Figures 56 & 57). Results from WATEQ4F show that the ground water surrounding nested wells B-3, C-1, C-2, and nests D and F is supersaturated with respect to silica species, and is very near saturation in nested well C-3 (Table 25). Realistically, these samples are probably supersaturated and saturated with respect to amorphous silica, which is much more soluble than the species in Table 25, and often the first species to precipitate in a silica rich solution (Hem, 1985; Krauskopf, 1979). Bennett and Siegel (1987) obtained a correlation *($r = 0.83$)* between total dissolved silica and dissolved organic carbon from soil and ground-water samples collected from a site contaminated

Table 25

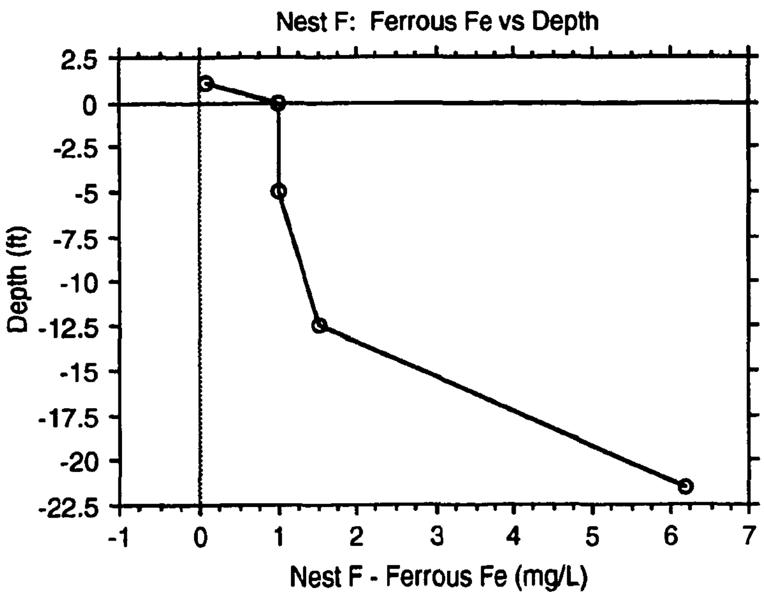
Mineral Saturation Data (log IAP/KT) for Well Nests B, C, D, & F

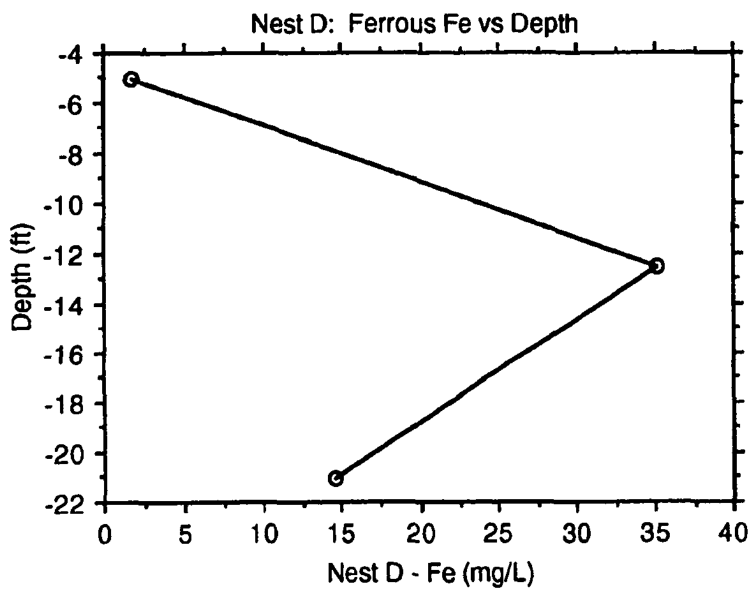
Well	Depth (ft)	Mackinawite FeS	FeS (Amorph.)	Pyrite FeS_2	Greenalite $Fe_3Si_2O_5(OH)_4$
B-2	12.5	.270	---	8.198	---
B-3	30.0	1.039	.306	9.393	.142
C-1	7.0	---	---	.944	---
C-2	12.5	.877	.144	9.315	---
C-3	17.0	.903	.170	9.476	---
D-1	5.0	---	---	2.552	---
D-2	12.5	---	---	5.743	---
D-3	21.0	1.621	.888	10.595	.780
F-1	5.0	---	---	.421	---
F-2	12.5	---	---	2.160	---
F-3	21.5	.337	---	8.472	---

Table 25--Continued

Well	Chalcedony SiO_2	Cristobalite SiO_2	Quartz SiO_2	Siderite $FeCO_3$
B-2	---	---	---	---
B-3	.453	.514	.922	.930
C-1	---	---	.113	---
C-2	.050	.108	.515	-.005
C-3	---	---	-.054	.199
D-1	---	---	-.049	---
D-2	---	---	.301	---
D-3	---	---	.185	.756
F-1	---	---	.135	---
F-2	---	---	.213	---
F-3	-.004	.052	.458	.081

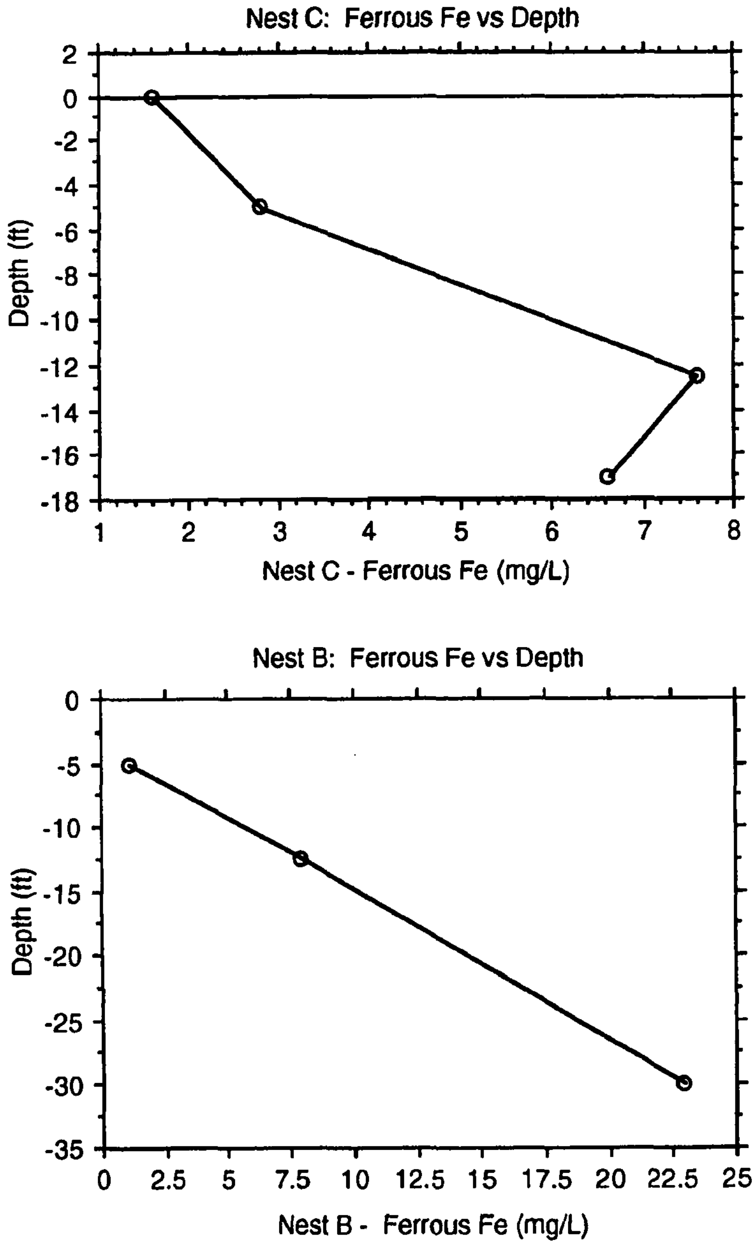
Assumptions: pe input into WATEQ4F at approximate level of sulfate reduction (Eh = -.17v); Sulfide input at 0.1 mg/L





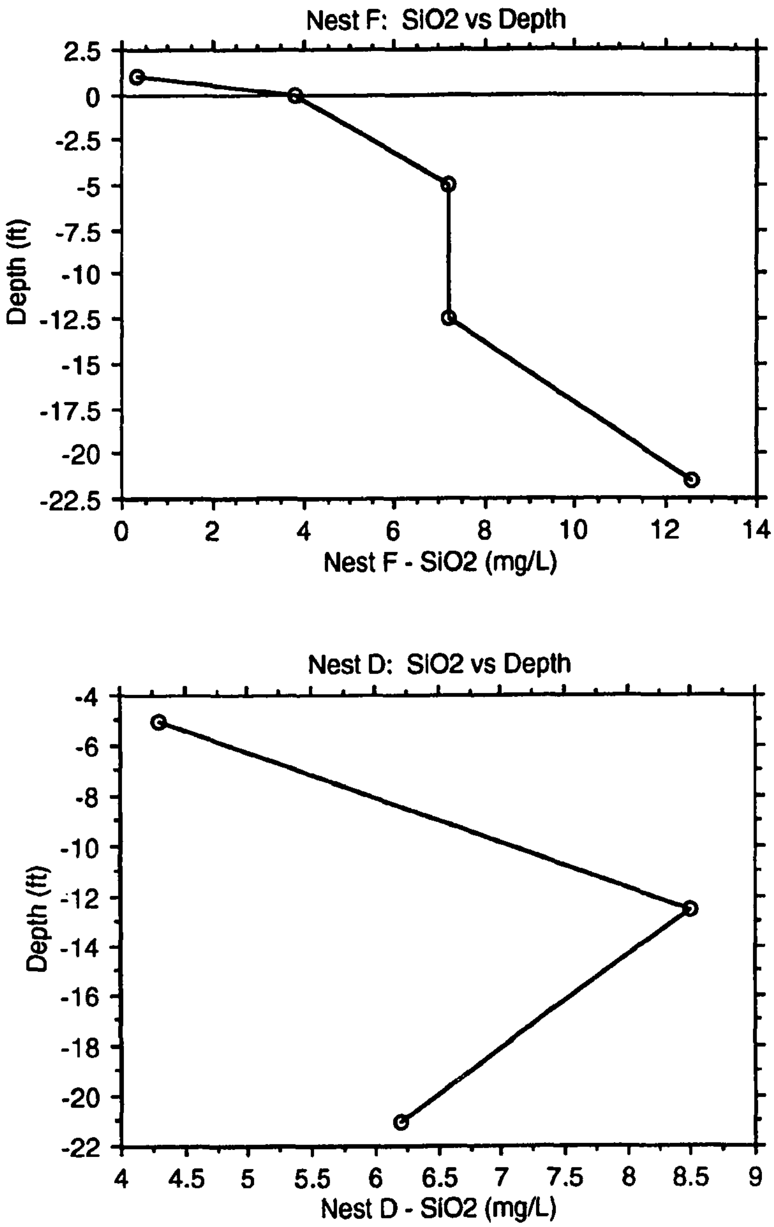
Note. Point above zero depth indicates rain gauge sample. Wells are screened in peat except for wells D-2 and D-3, which are screened in sediment beneath the peat.

Figure 54. Ferrous Fe Concentrations for Well Nest F and Well Nest D.



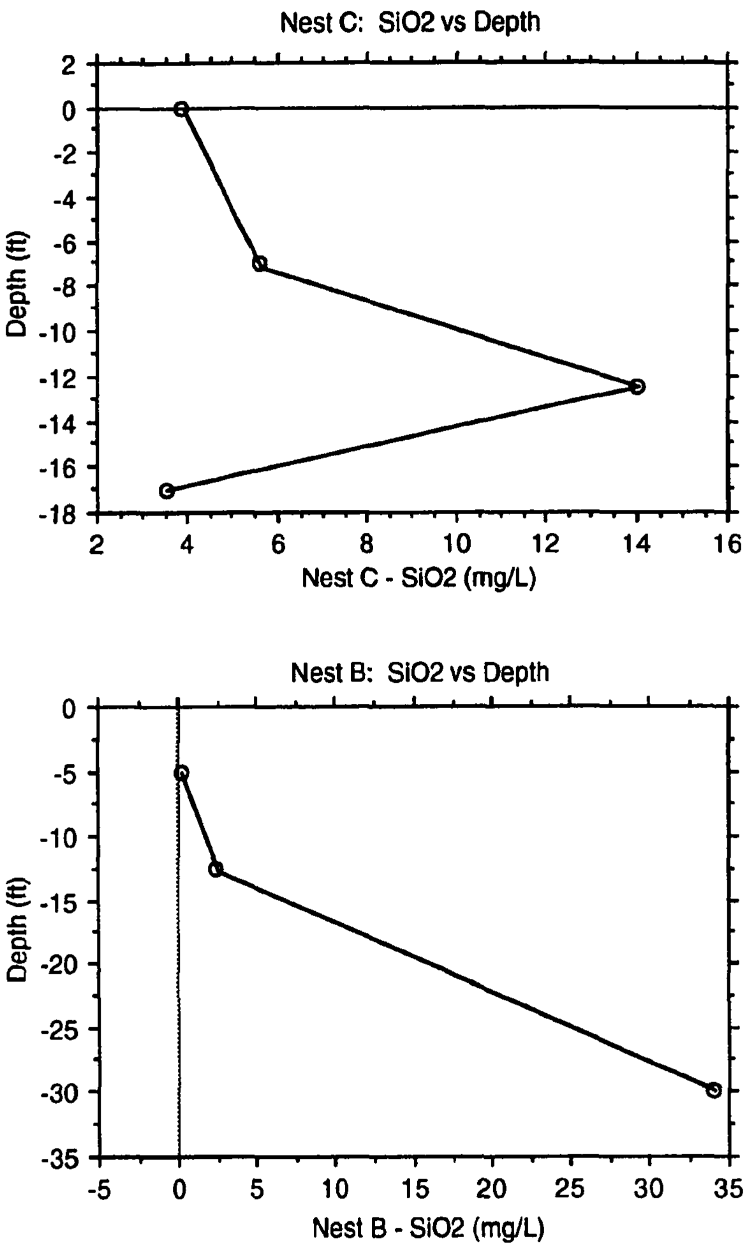
<u>Note</u>. All wells screened in peat.

Figure 55. Ferrour Fe Concentrations for Well Nest C and Well Nest B.



Note. Point above zero depth indicates rain gauge sample. Wells are screened in peat except for wells D-2 and D-3, which are screened in sediment beneath the peat.

Figure 56. Silica Concentrations for Well Nest F and Well Nest D.



Note. All wells screened in peat.

Figure 57. Silica Concentrations for Well Nest C and Well Nest B.

by crude petroleum and consisting largely of a complex mixture of organic acids. They concluded that the organic acids or other organic compounds were complexing the dissolved silica. The supersaturation of the subsurface bog waters at Government Marsh with respect to silica species is interpreted as a result of complexation. Complexation could retard precipitation of silica by keeping SiO_2 in solution beyond the limit that it would precipitate if organic compounds were not present. Precipitation of silica species may actually be occurring in the minerotrophic ground water surrounding the screened depths of some of the nested wells. A decrease in SiO_2 concentration occurs in samples C-3 and D-3 relative to concentrations reported from samples C-2 and D-2. Authigenic silica minerals have been identified in the ash contents of mire peats (Shotyk, 1988).

It should be reported that an assumed Eh reduction value of -.17 V was used in the WATEQ4F calculations. This is the approximate level of sulfate reduction, and is reasonable considering that the odor of hydrogen sufide was identified at Government Marsh. An assumed hydrogen sulfide value of .1 mg/L was also used. These values were assumed with apparent success in another study concerned with a similar hydrogeochemical environment (Kehew & Passero, 1990).

Goose Lake Water Chemistry

A sample of surface water was collected from Goose Lake in mid-August, 1991 and analyzed by the WMU Water Quality Lab. When compared to the mean water chemistry of the Government Marsh surface, Goose Lake water chemistry appears to be greatly influenced, if not a product of, ground water flowing through the peaty bog (Table 26). Conductivity, pH, TDM, total hardness and alkalinity values all indicate that Goose Lake is an ombrotrophic "bog lake".

Table 26

Water Chemistry Data for Goose Lake

Sample	Date sampled	pH	Conductivity (µS)	TDM[1]	Total Hardness
BS_{mean}	1989-1991	3.99	45	7.97	11.6
GL	8/15/91	4.28	44	9.18	9.39

Sample	Cl^-	[2]HCO_3^-	NH_4^+/N	NO_3^-/N	SiO_2	SO_4^{-2}
BS_{mean}	4.28	1.90	0.44	0.22	3.32	1.94
GL	2.00	0.00	0.14	< 0.04	0.25	3.84

Sample	Ba^{+2}	Ca^{+2}	Fe^{+2}	K^+	Mg^{+2}	Mn^{+2}	Na^+
BS_{mean}	0.01	3.00	1.29	1.21	1.01	0.03	1.43
GL	0.01	3.10	1.70	1.20	0.40	0.09	0.14

BS = Bog Surface

GL = Goose Lake

[1]Total dissolved metals

[2]Alkalinity

Canal Water Chemistry

A sample of surface water was collected from the main constructed canal flowing toward pump station 2 in mid-August 1991. The sample was analyzed by the WMU Water Quality Lab. When compared to the mean water chemistry of the deep wells, it appears that the canal water is also a product of the local interstitial, alkaline ground-water system (Table 27). Conductivity, pH, TDS, total hardness and alkalinity

Table 27

Chemical Data for Water Sampled From Constructed Canal Near Pump Station 2

Sample	Date Sampled	pH	Conductivity (µS)	TDS[1]	Total Hardness
DW_{All}	1989-1990	7.51	399	235	215
DW_{mean}	Summer-1989	7.61	400	218	206
Canal	8/16/91	7.55	390	220	209

Sample	Cl^-	[2]HCO_3^-	NO_3^-/N	SiO_2	SO_4^{-2}	NH_4^+/N
DW_{All}	5.51	179	0.35	5.01	24.54	1.69
DW_{mean}	5.23	179	0.50	5.86	25.08	---
Canal	2.49	184	< 0.04	6.40	12.20	1.1

Sample	Ba^{+2}	Ca^{+2}	Fe^{+2}	K^+	Mg^{+2}	Mn^{+2}	Na^+
DW_{All}	0.05	60.77	1.43	0.63	14.56	0.15	2.58
DW_{mean}	0.05	58.33	1.46	0.51	14.78	0.15	2.41
Canal	0.03	61.00	2.00	1.70	13.90	0.10	3.00

[1]Total dissolved solids (as $CaCO_3$)

[2]Alkalinity

values indicate that the waters are similar. Results from WATEQ4F indicate that the principal mineral species contributing to the geochemical character of the canal water are the same as those contributing to the geochemical character of the waters sampled from the deep wells (Appendix H). The Ca^{+2} / Mg^{+2} molar ratio calculated by WATEQ4F is 2.65, which is comparable to the 2.53 Ca^{+2} / Mg^{+2} molar ratio calculated for the deep

wells. Results from WATEQ4F indicate that these waters are saturated with respect to aragonite ($CaCO_3$, SI = .014), and dolomite ($CaMg(CO_3)_2$, SI = .024); and are supersaturated with respect to calcite ($CaCO_3$, SI = .158) and siderite ($FeCO_3$, SI = .838). The supersaturation with respect to calcite and siderite is not surprising, considering that the purpose of the canals is to drain bog waters, which contain an abundance of organic acids. It is interpreted that complexation is occurring with respect to the supersaturation of calcite and siderite in these waters.

Nests A, E, H, I, and J Water Chemistry

The remaining nests have been separated from nests, B, C, D, and F in this discussion, because anthropogenic processes have influenced the ground-water chemistry of nests A, E, H, I, and J; whereas, chemical data collected from nests B, C, D, and F have minor, if any, anthropogenic influence. Nest A is located on a property that contains an abundance of fill material, put there by the home owner in order to reduce wetland area. Nest H is located adjacent to the road leading into the bog, constructed by the Millburn Peat Company. Fill material was used to construct this road. In addition, Nest H is nearest to pump station 2, from which water is being discharged by the Millburn Peat Company to the south. This discharge increases the ground-water gradient near nest H, which reduces the residence time of ground water near this area. Nests E, I and J are located to the south of Government Marsh, in an area which receives discharged water from pump station 2. Water discharged from pump station 2 is a mixture of bog and SFS ground water. In addition, nests, E, I, and J are located down gradient from farms and are probably under influence of surface water run-off containing ions from agricultural fertilizers (Figure 58).

Well nests A, E, H, I and J have extreme variabilities relative to chemical

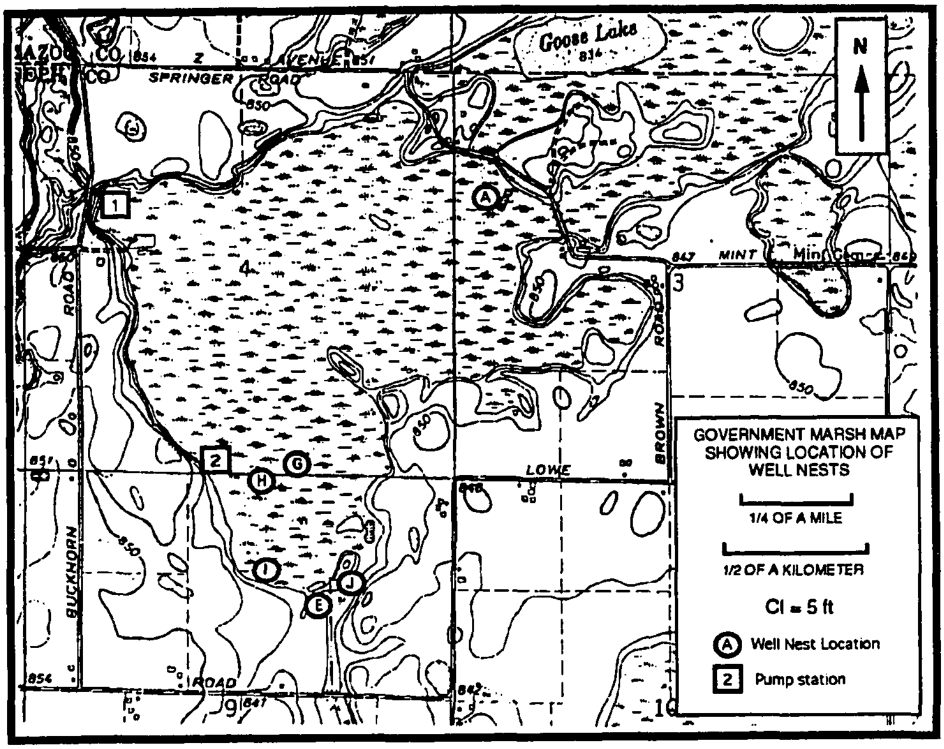


Figure 58. Map Showing Location of Well Nests A, E, G, H, I, & J.

Source: U.S.G.S. Topographic Quadrangle Map of Vicksburg, Michigan, 7.5 Minute Series (1967, photo revised 1973).

parameter concentrations (Tables 28, 29, & 30). Most of the samples show a decrease in chemical concentration from the shallowest to the intermediate depths, then an increase at the greatest depth (except for nest E, because E-3 does not exist). The total hardness of the deepest wells for nests A, I and J is relatively high, ranging from 427 to 703 mg/L. The concentration of iron is extreme in well I-2 (95.4 mg/L). The range of means for potassium and magnesium for all depths is also relatively high (3.6 to 4.4 and 19.0 to 37.7 mg/L, respectively). It should be noted that upon sampling wells E

Table 28

Water Chemistry Data for Nests:
A, E, H, I, & J (mg/L)

Well	Depth of Sample(ft)	Temp[1] C	pH	Conduct. (µS)	Ca^{+2} (mg/L)	Total Hard.[2]
A-1	5.0	20.5	6.75	720	155.3	427
E-1	5.0	17.7	5.94	137	25.1	145
H-1	5.0	19.7	6.84	438	70.1	234
I-1	5.0	18.8	6.00	157	64.1	300
J-1	6.5	20.3	6.50	402	69.3	242
Mean	5.3	19.4	6.41	370	76.8	269

Well	Depth of Sample(ft)	Temp[1] C	pH	Conduct. (µS)	Ca^{+2} (mg/L)	Total Hard.[2]
A-2	12.5	12.4	5.43	315	49.4	142
E-2	12.5	14.6	6.50	374	[K]54.6	[K]206
H-2	8.3	17.8	5.82	393	63.7	218
I-2	10.0	14.8	5.38	157	62.2	320
J-2	10.0	17.4	6.00	366	176.6	641
Mean	10.7	15.4	5.83	321	81.3	305

Well	Depth of Sample(ft)	Temp[1] C	pH	Conduct. (µS)	Ca^{+2} (mg/L)	Total Hard.[2]
A-3	22.5	12.9	7.10	598	97.6	427
E-3	N/A	N/A	N/A	N/A	N/A	N/A
H-3	16.5	15.4	6.24	240	29.7	103
I-3	20.0	11.8	6.70	353	162.9	703
J-3	16.0	14.9	6.73	600	150.1	522
Mean	18.8	13.8	6.69	446	110.1	439

Table 28--Continued

Well	Mean Dept (ft)	Temp[1] C	pH	Conduct. (μS)	Ca^{+2} (mg/L)	Total Hard.[2]
Mean	Shallow	19.4	6.41	370	76.8	269
Mean	Intermediate	15.4	5.83	321	81.3	305
Mean	Deep	13.8	6.69	446	110.1	439

[1] Degrees Celsius

[2] as $CaCO_3$ (mg/L)

[K] Analysis completed by KAR Laboratories on June 23, 1994.

and I, a sour odor would emerge; upon sampling nest J, a sweet odor could be identified.

Alkalinity, pH, Calcium, Magnesium, Conductivity, and Total Hardness

Alkalinity, pH, calcium, magnesium, conductivity, and total hardness generally decrease with increasing sample depth in ground-water samples collected from shallow to intermediate nested wells in nests A, I and J, and increase in ground-water samples collected from deep nested wells (Figures 59 - 76). It is interpreted that production of organic acids from organic decomposition initially decreases pH in wells A-2, I-2, J-3, and nest H and that precipitation of mineral phases lowers parameter concentrations. Results from WATEQ4F indicate that some of the nested wells have parameter concentrations that exceed saturation levels for quartz, siderite, pyrite and other mineral phases (Table 31). Formation of these and other mineral species would remove ionic constituents from ground water.

Increases in parameter concentrations are also interpreted as effects resulting

Table 29

Water Chemistry Data for Nests:
A, E, H, I, & J (mg/L)

Well	Screen Depth (ft)	Ba^{+2}	Fe^{+2}	K^{+}	Mg^{+2}	Mn^{+2}	Na^{+}
A-1	5.0	0.08	3.1	2.1	9.4	0.5	0.5
E-1	5.0	0.50	51.0	6.7	20.1	1.0	2.6
H-1	5.0	0.06	6.0	1.7	14.3	1.0	2.1
I-1	5.0	0.90	70.0	5.8	34.1	2.4	2.6
J-1	6.5	0.20	10.2	5.7	16.9	0.5	3.4
Mean	5.3	0.35	28.1	4.4	19.0	1.1	2.2

Well	Screen Depth (ft)	Ba^{+2}	Fe^{+2}	K^{+}	Mg^{+2}	Mn^{+2}	Na^{+}
A-2	12.5	0.09	2.2	1.7	4.4	0.2	0.9
E-2	12.5	0.20	[KT]5.1	9.1	[K]17.0	3.4	3.2
H-2	8.3	0.07	3.5	1.7	14.4	0.7	2.5
I-2	10.0	1.50	95.4	8.4	40.0	1.2	2.8
J-2	10.0	0.10	23.6	4.7	35.8	0.6	3.2
Mean	10.7	0.39	26.0	5.1	22.3	1.2	2.5

Well	Screen Depth (ft)	Ba^{+2}	Fe^{+2}	K^{+}	Mg^{+2}	Mn^{+2}	Na^{+}
A-3	22.5	0.07	8.2	1.8	6.7	0.2	1.0
E-3	N/A	N/A	N/A	N/A	N/A	N/A	N/A
H-3	16.5	0.06	8.1	1.9	7.0	0.4	2.6
I-3	20.0	0.10	35.2	6.8	72.1	0.9	2.5
J-3	16.0	0.08	19.4	3.8	35.8	0.6	3.2
Mean	18.8	0.08	17.7	3.6	30.4	0.5	2.3

Table 29--Continued

	Mean Depth (ft)	Ba^{+2}	Fe^{+2}	K^{+}	Mg^{+2}	Mn^{+2}	Na^{+}
Mean	Shallow	0.35	28.1	4.4	19.0	1.1	2.2
Mean	Intermediate	0.39	26.0	5.1	22.3	1.2	2.5
Mean	Deep	0.08	17.7	3.6	30.4	0.5	2.3

[T] Total iron

[K] Analysis completed by Kar Laboratories on June 23, 1994.

N/A Not Applicable

from the chemical influence of bog water chemistry. The extreme values of calcium in wells A-1 (155.3 mg/L) and J-2 (176.6 mg/L); and relatively high concentrations of magnesium in most of the nested wells are interpreted as the result of calcite and dolomite dissolution demonstrated by reactions (3) and (4), which would also contribute bicarbonate to alkalinity. Results from WATEQ4F show samples from nested wells A-1, A-3, E-1, H-1, nest J, I-1, and I-3 to be at saturation or supersaturation levels relative to carbonate species (Table 31). Complexation may play an important role in retarding precipitation or saturation levels of carbonate phases, in addition, Baedecker and Back (1979) have suggested that calcium is consumed in the formation of calcium salts of fatty acids in anthropogenic landfill environments and is unavailable for mineral phases. This process is demonstrated by reaction (9).

$$Ca^{+2} + 2RCOO^{-} \longrightarrow Ca(RCOO)_2 \qquad (9)$$

Lignins and lipids are the last plant remains to decompose in wetland, anaerobic environments, and decomposition is rarely complete. The highly organic, anaerobic chemical environment of natural landfills, such as bogs, is analogous to anthropogenic

Table 30

Water Chemistry Data for Nests:
A, E, H, I, & J (mg/L)

Well	Screen Depth (ft)	Cl^-	${}^1HCO_3^-$	SiO_2	SO_4^{-2}	NO_3^-/N	NH_4^+/N
A-1	5.0	2.00	274	9.2	15.4	0.093	2.4
E-1	5.0	3.13	47	3.3	3.63	0.13	0.30
H-1	5.0	2.69	212	9.6	3.61	0.18	0.62
I-1	5.0	3.00	148	4.6	0.00	0.088	4.8
J-1	6.5	2.79	195	3.2	0.00	0.24	2.8
Mean	5.3	2.72	175	6.0	4.53	0.146	2.2

Well	Screen Depth (ft)	Cl^-	${}^1HCO_3^-$	SiO_2	SO_4^{-2}	NO_3^-/N	NH_4^+/N
A-2	12.5	2.00	132	9.5	11.6	0.040	11.0
E-2	12.5	2.76	173	5.5	18.4	0.088	0.40
H-2	8.3	2.82	192	9.3	3.05	0.088	0.84
I-2	10.0	3.30	48	5.6	4.51	0.058	1.60
J-2	10.0	2.48	175	5.6	0.00	0.180	2.40
Mean	10.7	2.67	144	7.1	7.51	0.091	3.25

Well	Screen Depth (ft)	Cl^-	${}^1HCO_3^-$	SiO_2	SO_4^{-2}	NO_3^-/N	NH_4^+/N
A-3	22.5	2.00	312	12.5	2.75	0.21	14.4
E-3	N/A	N/A	N/A	N/A	N/A	N/A	N/A
H-3	16.5	2.00	116	5.7	3.08	0.075	2.20
I-3	20.0	2.80	160	5.4	7.20	0.00	1.30
J-3	16.0	2.61	302	4.4	2.97	0.075	1.10
Mean	18.8	2.35	222	7.0	4.00	0.09	4.75

Table 30--Continued

Well	Mean Depth of Samples (ft)	Cl^-	[1]HCO_3^-	SiO_2	SO_4^{-2}	NO_3^-/N	NH_4^+/N
Mean	Shallow	2.72	175	6.0	4.53	0.146	2.20
Mean	Intermediate	2.67	144	7.1	7.51	0.091	3.25
Mean	Deep	2.35	222	7.0	4.00	0.09	4.75

[1]Alkalinity

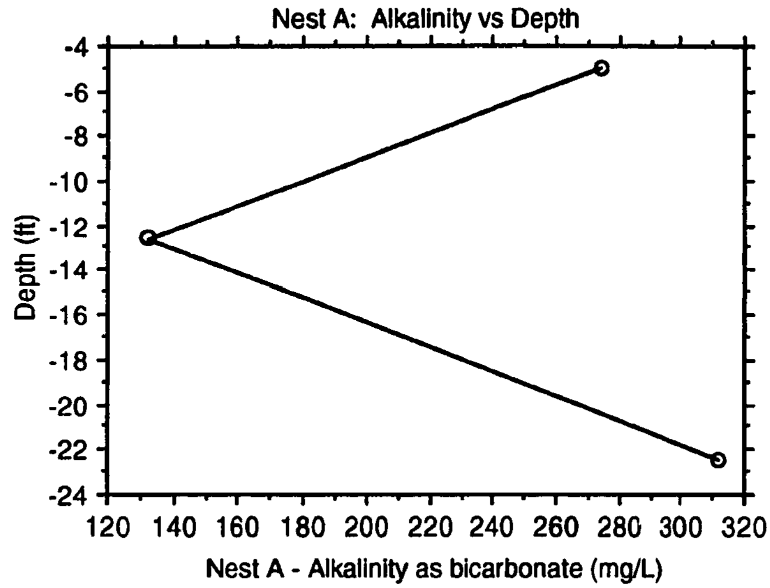
N/A Not Applicable

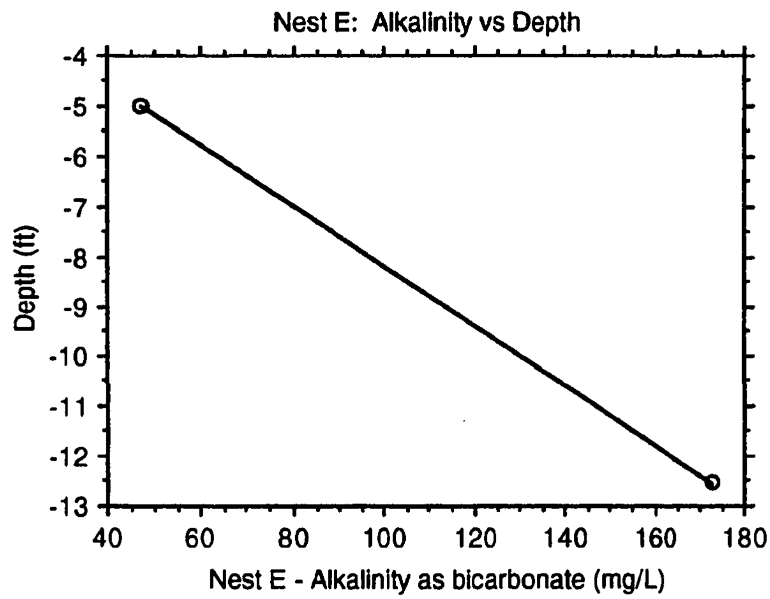
landfill environments, and may also be under the process proposed by Baedecker and Back for anthropogenic landfills. Baedecker and Back (1979) have also suggested that weathering of minerals and increases in dissolved constituents is facilitated in environments where either H^+ or CO_2 is generated, and is higher in environments that contain organic acids due to complexation. Silicate phases, magnesium, bicarbonate and other species can be contributed to ground water as demonstrated by reactions (10) and (11).

$$Mg_2SiO_4 + 4H^+ \dashrightarrow 2Mg^{+2} + H_4SiO_4 \quad (10)$$

$$\text{feldspar} + H_2O + CO_2 \dashrightarrow \text{clay} + \text{cations} + HCO_3^- + SiO_2 \quad (11)$$

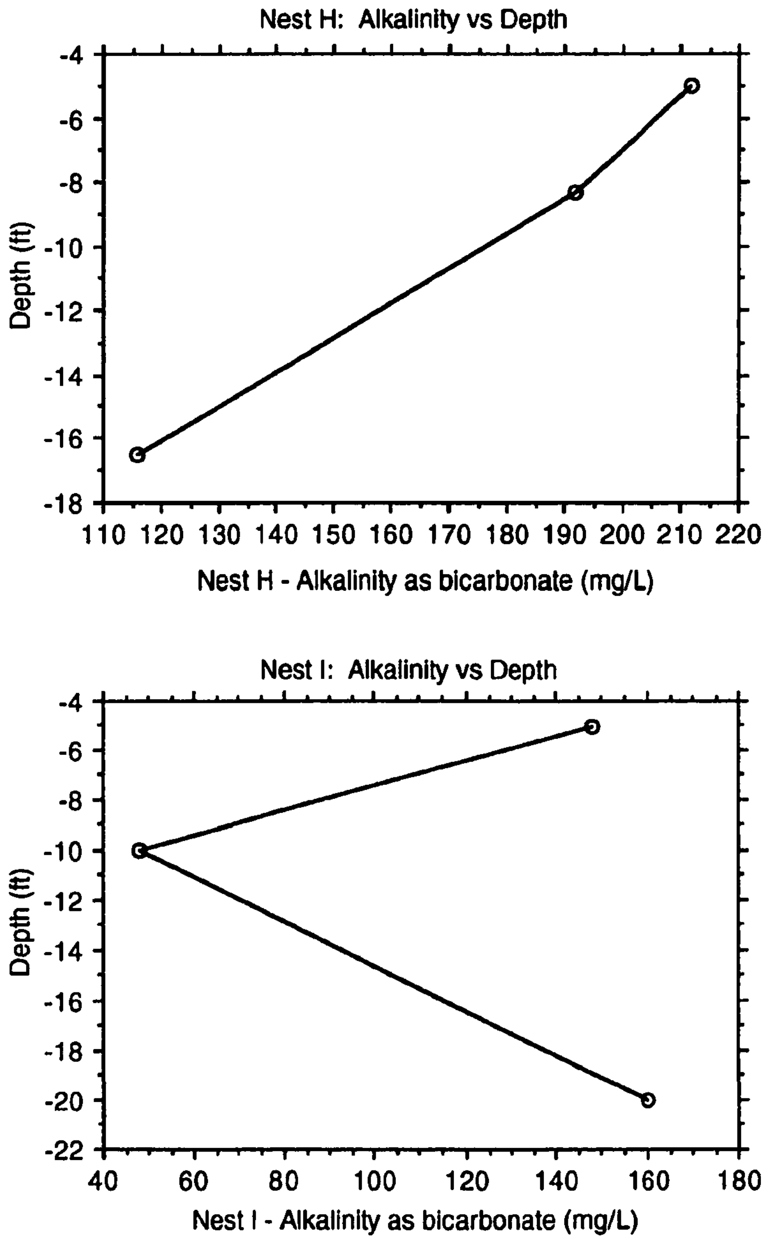
Only wells A-2 and A-3 contain levels of ammonium (11.0 and 14.4 mg/L, respectively) that could significantly contribute calcium and magnesium into ground water through the process of cation exchange. Ionic inbalances in well nest samples indicate that organic acids contribute to alkalinity in wells E-1 and I-2, and that amino acid and cation species exist that were not part of the analysis in the other wells. This is not surprising, considering nests I and J are located downgradient from farms and are susceptible to run-off and agricultural chemical influences. The decreasing





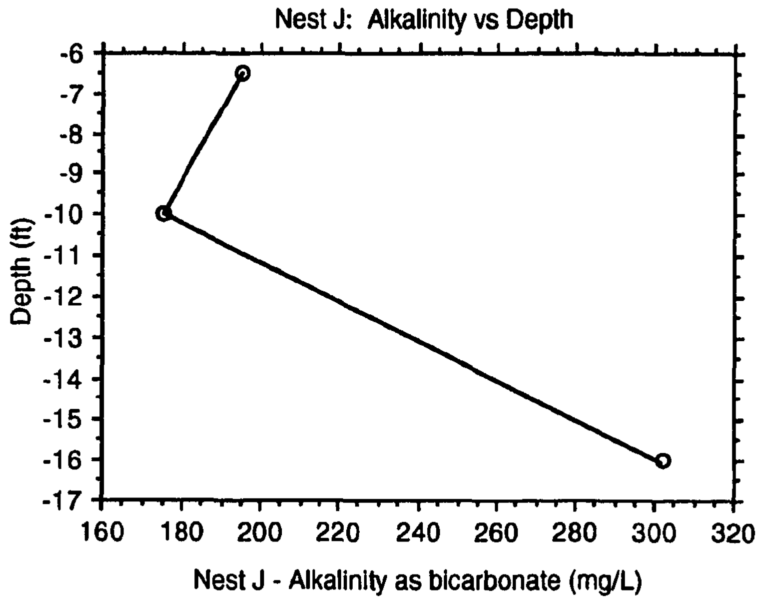
Note. Nest A wells screened in peat. Nest E wells screened in sediment.

Figure 59. Alkalinity as Bicarbonate Concentrations Compared to Depth for Well Nest A and Well Nest E.



Note. H-1 screened in peat. All other wells screened in sediment beneath the peat.

Figure 60. Alkalinity as Bicarbonate Concentrations Compared to Depth for Well Nest H and Well Nest I.



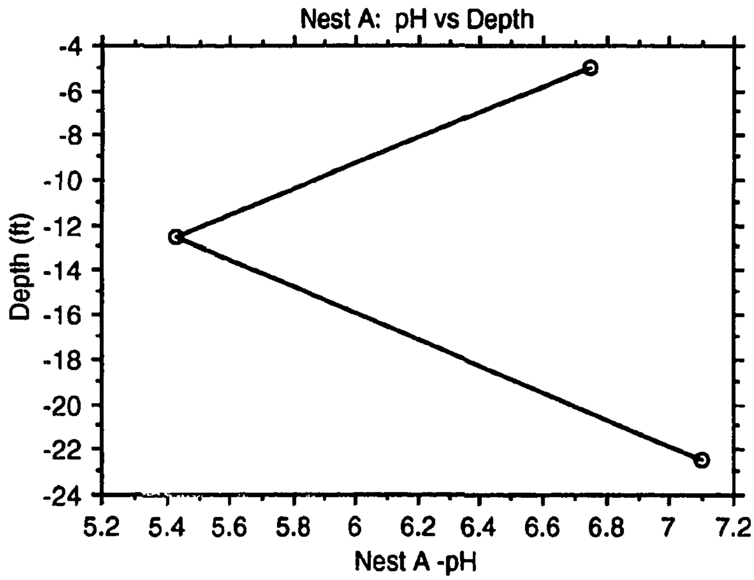
Note. All wells screened in sediment beneath the peat.

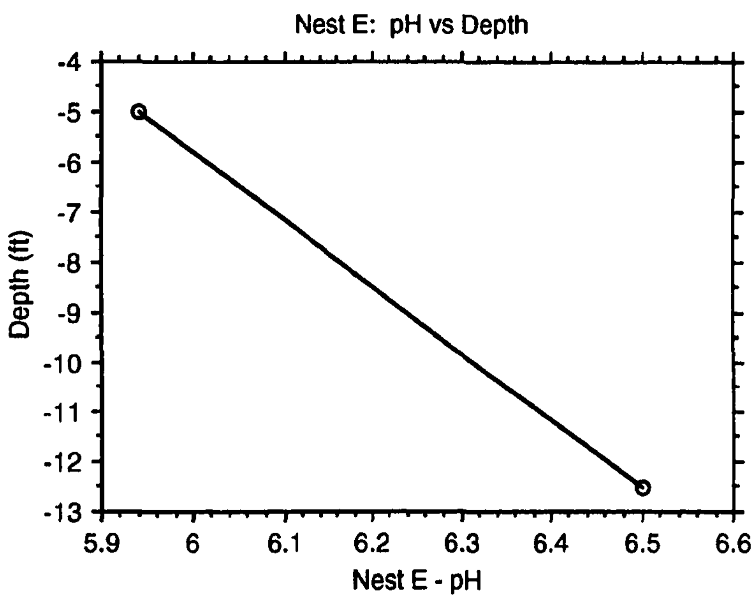
Figure 61. Alkalinity as Bicarbonate Concentrations Compared to Depth for Well Nest J.

concentration of sulfate and increasing concentration of ammonium in nest A indicate that deamination and reduction of sulfate to sulfide is occurring.

Nitrate, Ammonium, Sulfate, and Sulfide

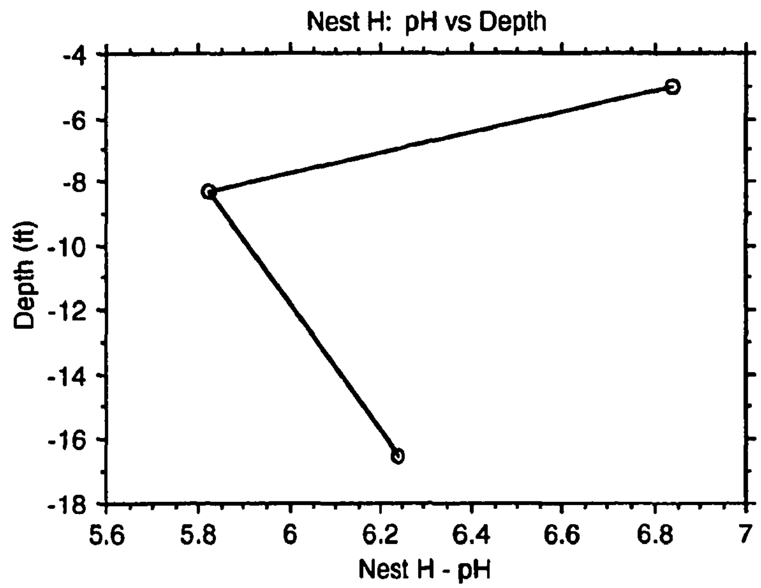
Low concentrations of nitrate and higher concentrations of ammonium in all of the well nests indicate that pe is below the level at which nitrate reduction occurs in redox sequences (Drever, 1982). The relatively extreme and increasing concentrations of ammonium in samples collected from nest A indicate that deaminiation is occurring in ground water surrounding that nest (Figure 77). Sulfate concentrations generally

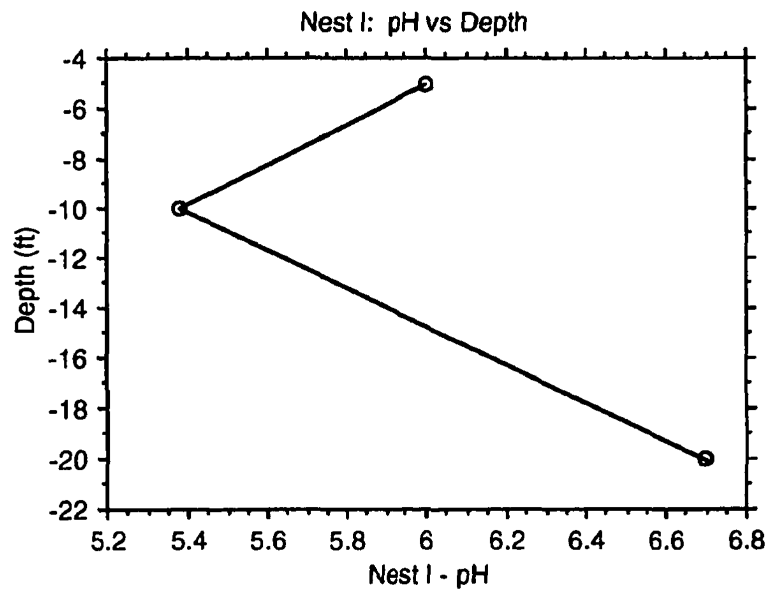




Note. Nest A wells screened in peat. Nest E wells screened in sediment.

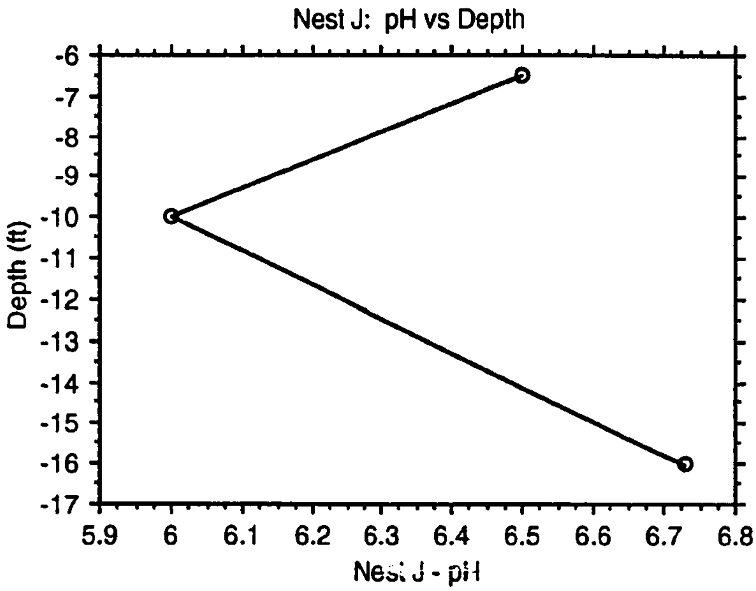
Figure 62. pH Concentrations Compared to Depth for Well Nest A and Well Nest E.





Note. H-1 screened in peat. All other wells screened in sediment beneath the peat.

Figure 63. pH Concentrations Compared to Depth for Well Nest H and Well Nest I.



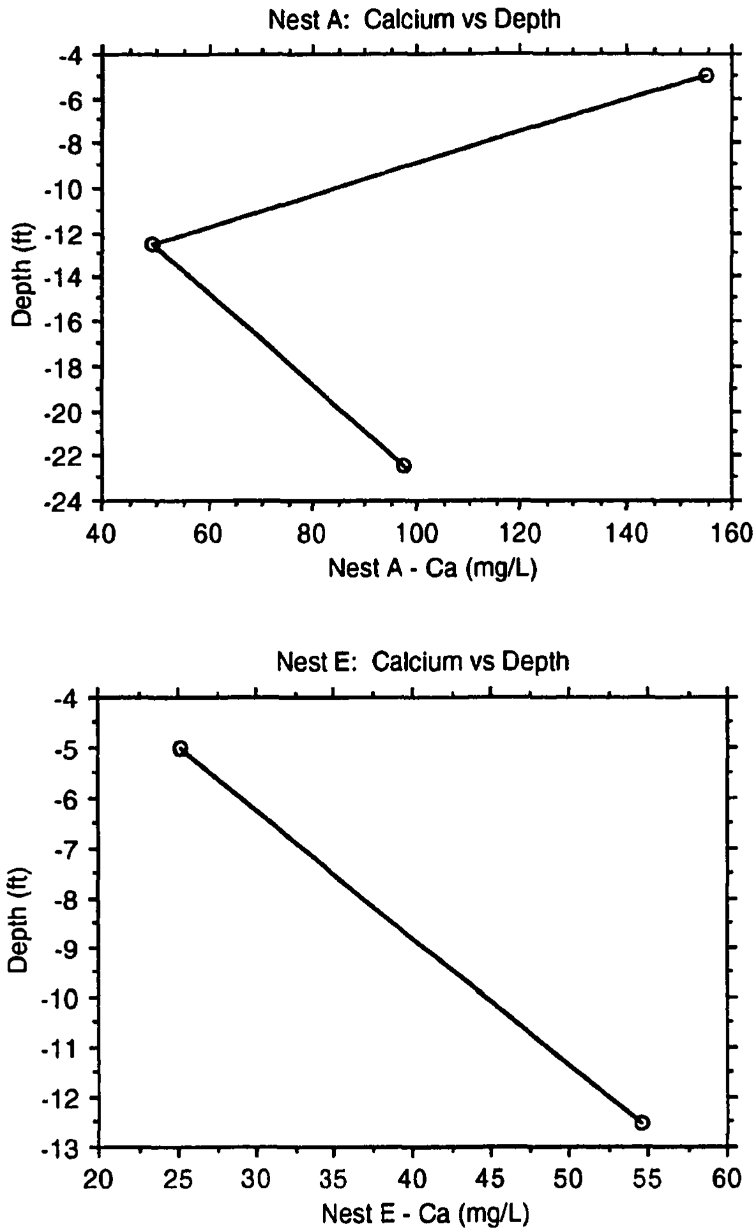
Note. All wells screened in sediment beneath the peat.

Figure 64. pH Concentrations Compared to Depth for Well Nest J.

increase with sample depth, indicating that pe is above the level at which sulfate reduction occurs. The exceptions are the wells in well nest A, where sulfate concentrations decrease with sample depth, an indication that sufate reduction is occurring (Figures 78, 79, & 80), and wells I-1, J-1, and J-2, which have sulfate levels below detection limits, also an indicator that sulfate is being reduced.

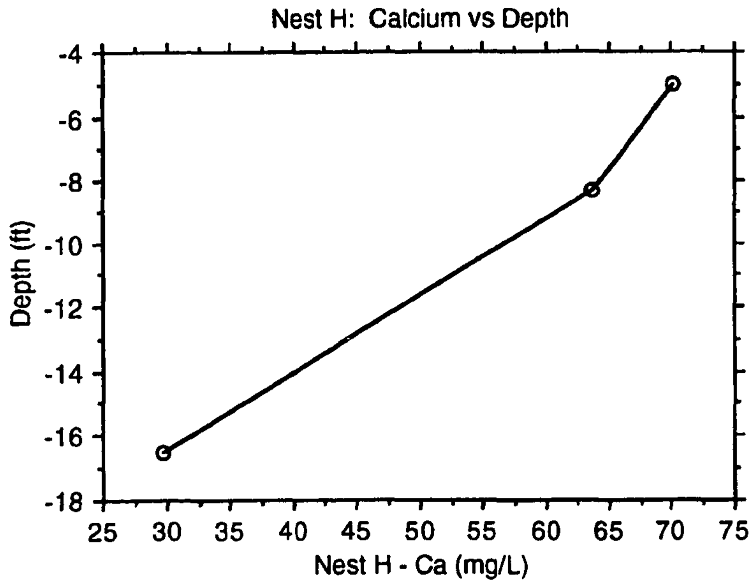
Ferrous Iron and Silica

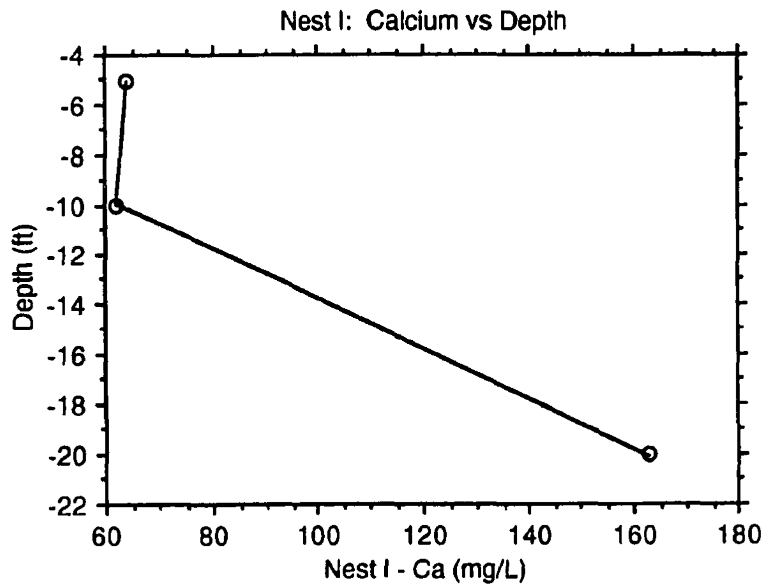
Ferrous iron concentrations generally increase with sample depth; the exceptions are E-2 and J-3, where a decrease occurs (Figures 81, 82, & 83). It is interpreted that precipitation of iron mineral phases is occurring at sample depths E-2 and J-3, which would reduce the concentration of Fe^{+2} as it is consumed. High



Note. Nest A wells screened in peat. Nest E wells screened in sediment.

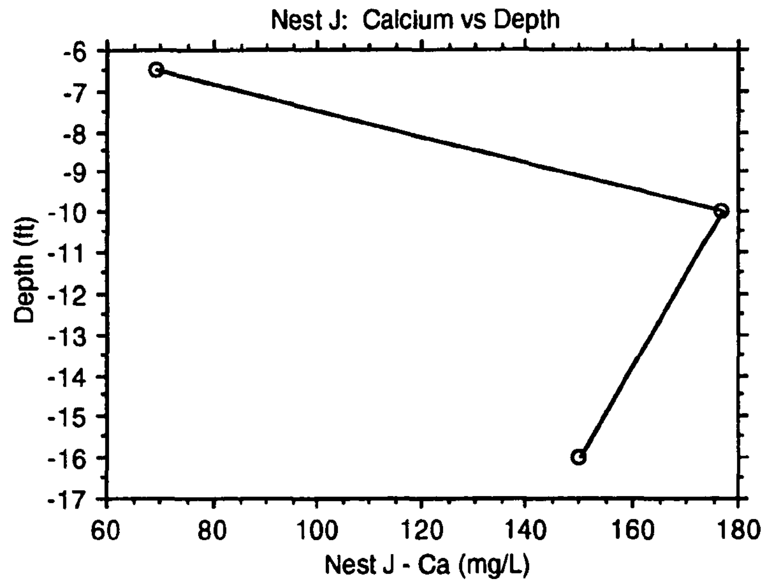
Figure 65. Calcium Concentrations Compared to Depth for Well Nest A and Well Nest E.





Note. H-1 screened in peat. All other wells screened in sediment beneath the peat.

Figure 66. Calcium Concentrations Compared to Depth for Well Nest H and Well Nest I.

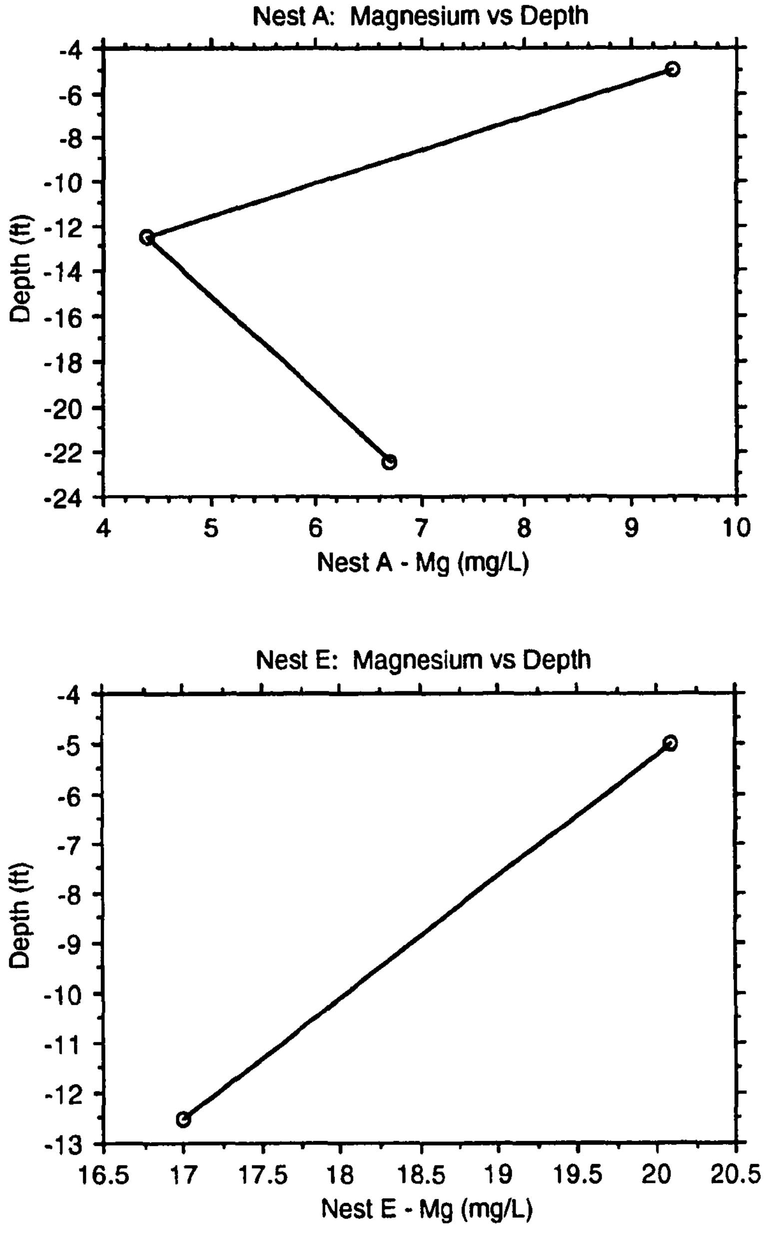


Note. All wells screened in sediment beneath the peat.

Figure 67. Calcium Concentrations Compared to Depth for Well Nest J.

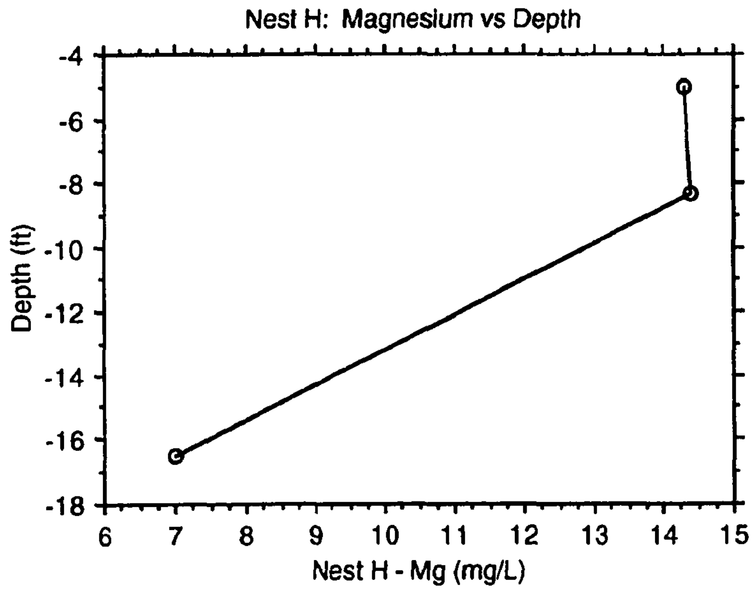
concentrations of ferrous iron occurs in samples collected from nested wells I-1 (70 mg/L), E-2 (103.3 mg/L), I-2 (95.4 mg/L), J-2 (23.6 mg/L), and I-3 (35.2 mg/L). Results from WATEQ4F show that samples collected from nested wells A-1, A-2, H-1, nest J, I-1 and I-3 are supersaturated with iron phases and saturated with iron in E-1. As already discussed complexation may play an important role in sustaining ferrous iron concentrations above the level of saturation in natural waters, especially where organic acids are present.

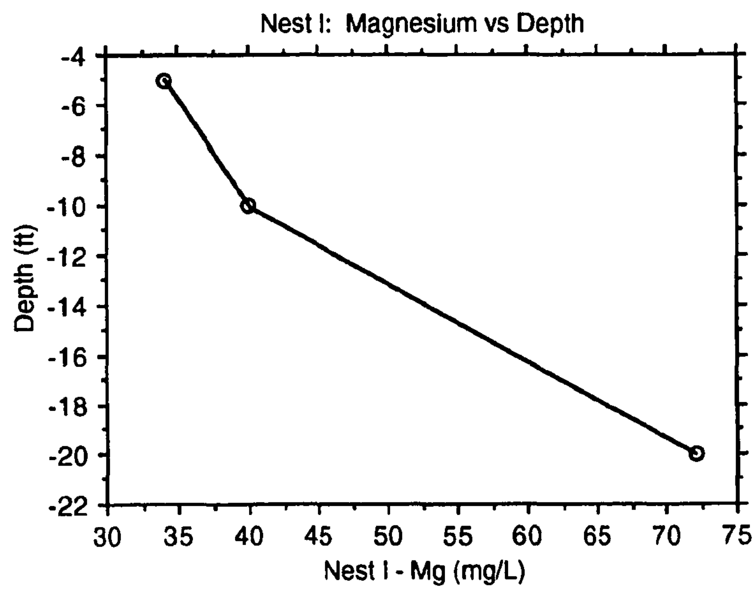
The concentrations of SiO_2 are relatively high in nested wells A-1, H-1, A-2, H-2, and A-3. Concentrations increase with sample depth in nests A and E, decrease in nest H, and show a decrease from intermediate to deep sample depth in nests I and J (Figures 84, 85, & 86). It is interpreted that precipitation of amorphous silica is



Note. Nest A wells screened in peat. Nest E wells screened in sediment.

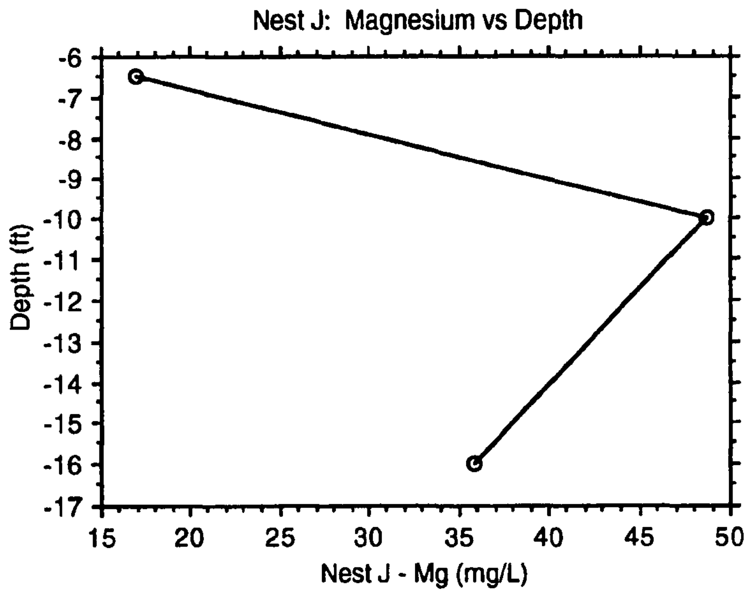
Figure 68. Magnesium Concentrations Compared to Depth for Well Nest A and Well Nest E.





Note. H-1 screened in peat. All other wells screened in sediment beneath the peat.

Figure 69. Magnesium Concentrations Compared to Depth for Well Nest H and Well Nest I.

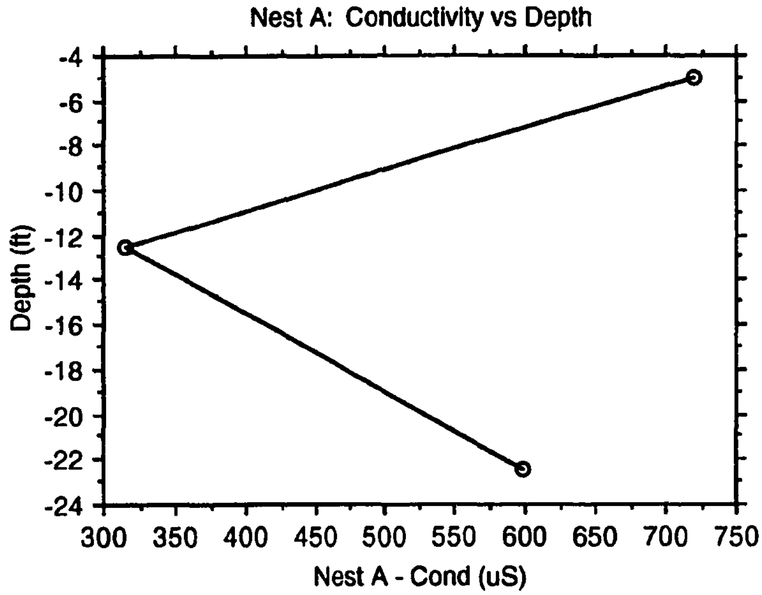


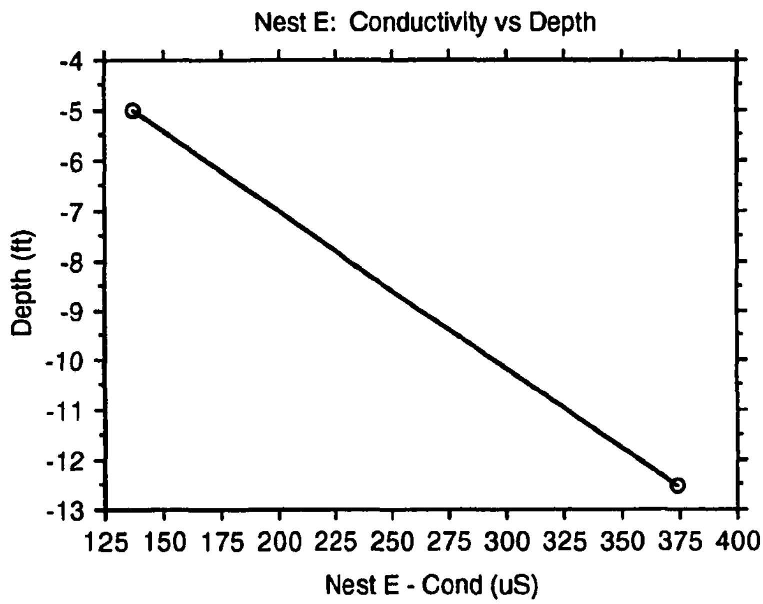
Note. All wells screened in sediment beneath the peat.

Figure 70. Magnesium Concentrations Compared to Depth for Well Nest J.

occurring at sample depth in the last three wells. Results from WATEQ4F show that samples collected from nest A, nest H, J-2, I-2, and I-3 are supersaturated with silica phases and are saturated in J-3. It is interpreted that organic acids in bog waters discharged by the Millburn Peat Company, and from decomposition of organic material at the site of these wells contributes to complexation, which sustains saturated and supersaturated levels of Fe^{+2} and SiO_2 in these waters.

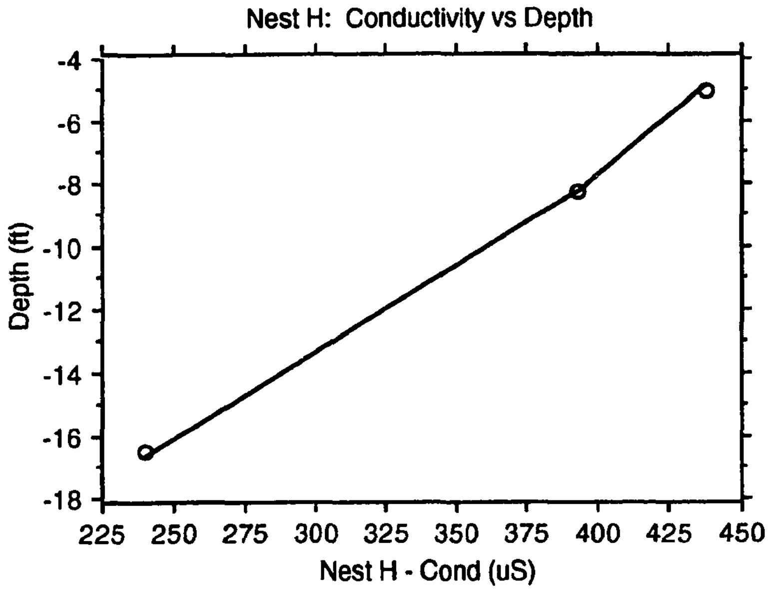
An assumed Eh value of .35 V was used in most of the WATEQ4F calculations previously discussed. This is the approximate level of nitrate reduction (Drever, 1982). This is a reasonable value to use because sulfate values are relatively high and nitrate values low in most of the wells. Exceptions include calculations for well samples A-2,

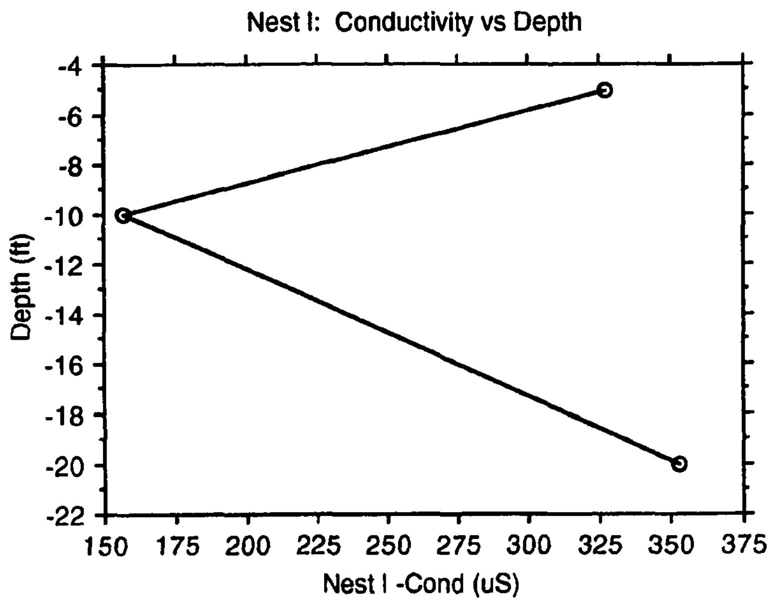




<u>Note.</u> **Nest A wells screened in peat. Nest E wells screened in sediment.**

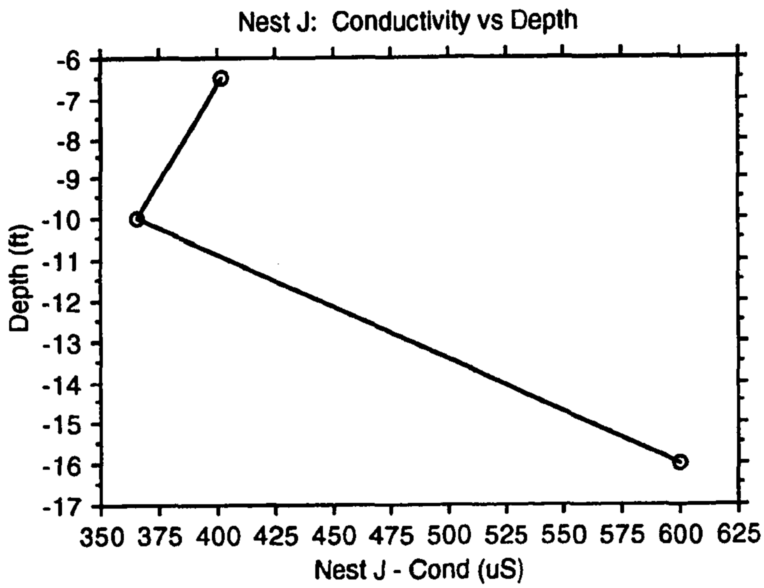
Figure 71. Conductivity Concentrations Compared to Depth for Well Nest A and Well Nest E.





Note. H-1 screened in peat. All other wells screened in sediment beneath the peat.

Figure 72. Conductivity Concentrations Compared to Depth for Well Nest H and Well Nest I.



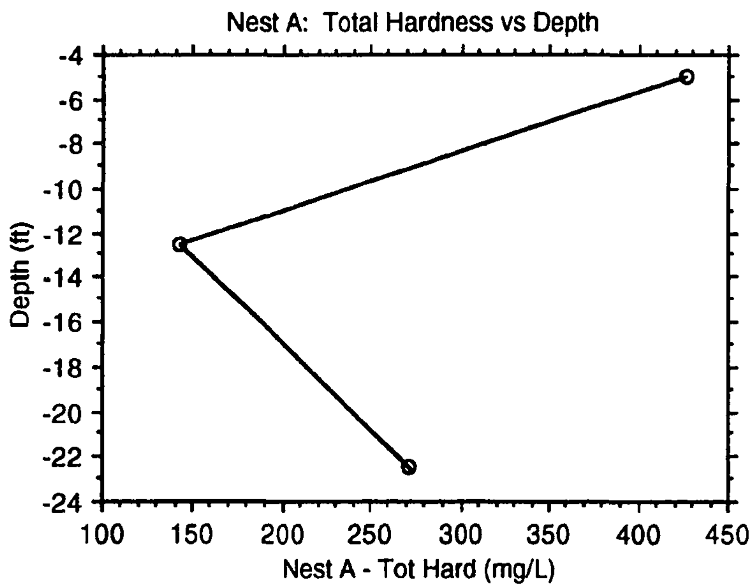
Note. All wells screened in sediment beneath the peat.

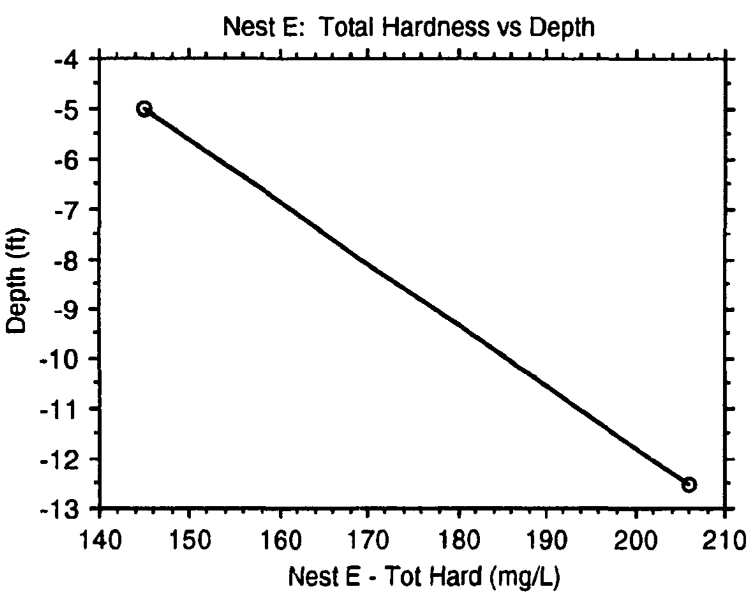
Figure 73. Conductivity Concentrations Compared to Depth for Well Nest J.

A-3, I-1, J-1 and J-2; an assumed Eh reduction value of -.17 V was used. This is the approximate level of sulfate reduction, and was used because sulfate concentrations had dramatically decreased or could not be detected in these wells.

Nest Well G-1

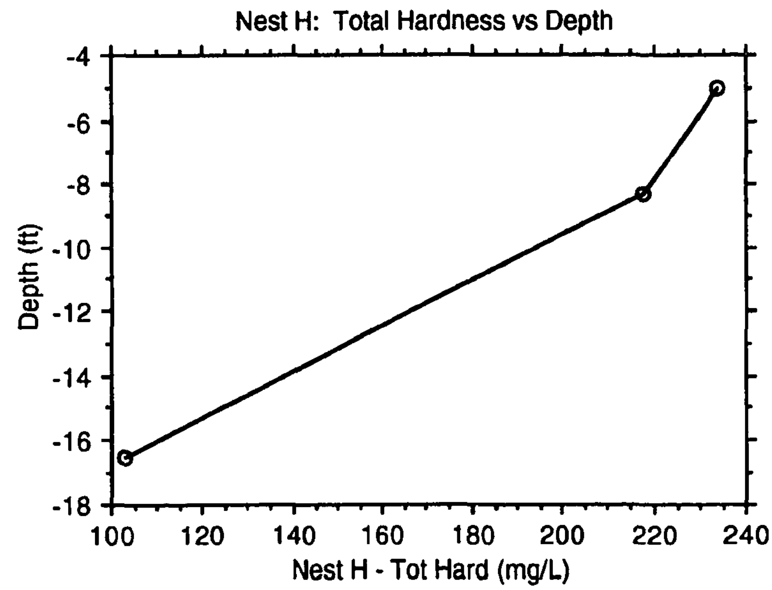
Speculation that canal water discharged into the south pond at pump station 2 is back-flowing into the bog is also evidenced by water analyzed from a sample collected from nest well G-1 on August 21, 1991. Conductivity, pH, TDS, calcium, magnesium and alkalinity concentrations are comparable to deep well and canal water chemistry (Table 33). Elevated levels of ferrous iron (23.6 mg/L) result from decomposition of

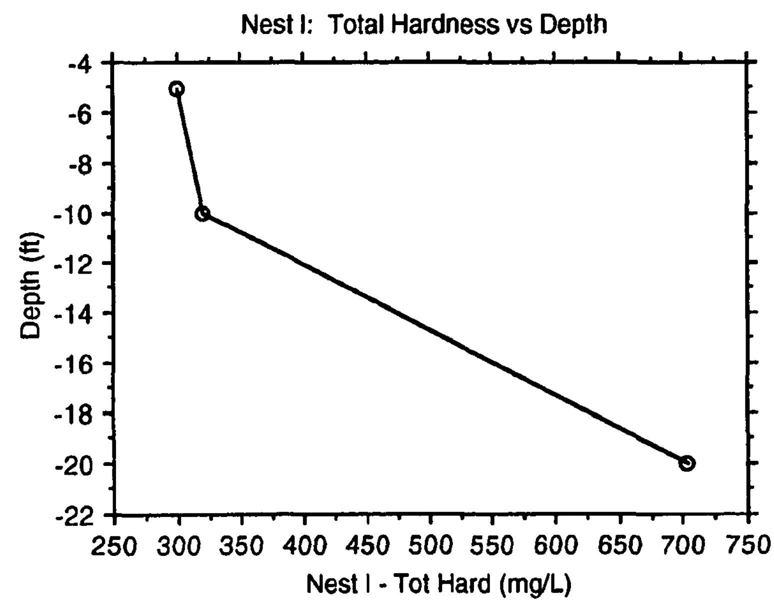




Note. **Nest A wells screened in peat. Nest E wells screened in sediment.**

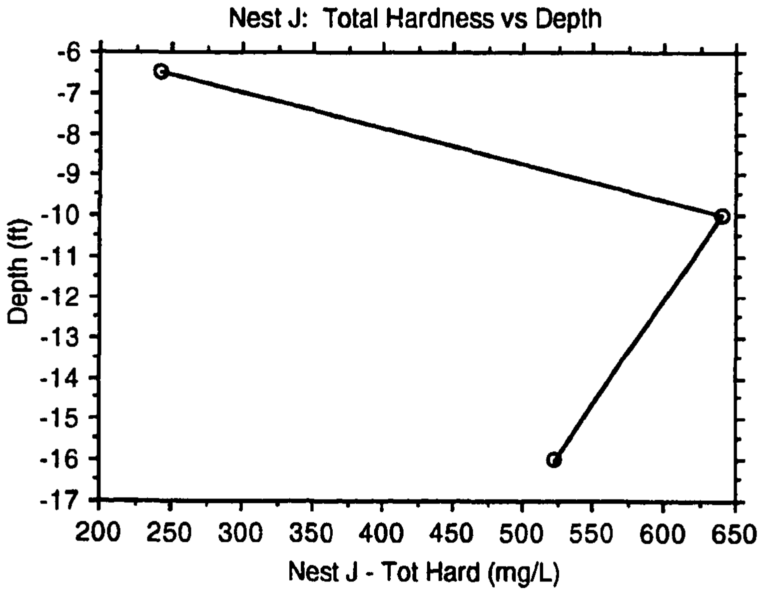
Figure 74. **Total Hardness Concentrations Compared to Depth for Well Nest A and Well Nest E.**





<u>Note.</u> **H-1 screened in peat. All other wells screened in sediment beneath the peat.**

Figure 75. **Total Hardness Concentrations Compared to Depth for Well Nest H and Well Nest I.**



Note. All wells screened in sediment beneath the peat.

Figure 76. Total Hardness Concentrations Compared to Depth for Well Nest J.

organic matter and interaction with iron oxide in sediment. Another indicator of back-flow, is the encroachment of wetland vegetation indicative of high nutrient, alkaline environments upon the poor nutrient, bog vegetation (Figure 7).

Comparing Southern Flow System and Government Marsh Natural Bog Water Chemistry

Southern flow system and Government Marsh bog water chemistry are significantly different. The SFS is a calcium-magnesium-mixed anion type, where Ca^{+2} and Mg^{+2} approach 90% of total cations. Bicarbonate, sulfate and chloride are the dominant anions. Ground water is considered to be oxidizing and alkaline with pH

Table 31

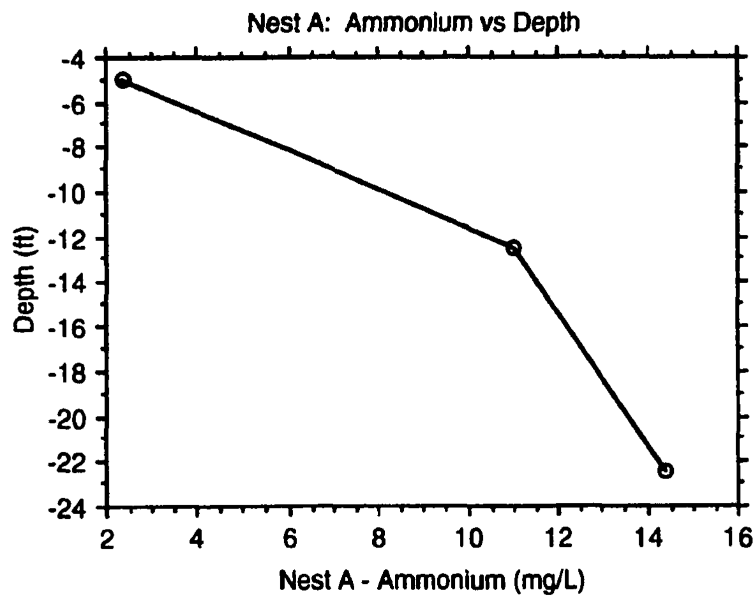
Mineral Saturation Data (log IAP/KT) for Well Nests
A, E, H, I, & J

Well	Depth (ft)	Mackinawite FeS	FeS (Amorph.)	Pyrite FeS_2	Greenalite $Fe_3Si_2O_5(OH)_4$	Chalcedony SiO_2
A-1	5.0	---	---	---	---	---
A-2[1]	12.5	---	---	4.634	---	.096
A-3[1]	22.5	---	---	---	---	.016
E-1	5.0	---	---	---	---	---
H-1	5.0	---	---	---	---	---
H-2	8.3	---	---	---	---	---
H-3	16.5	---	---	---	---	---
I-1[1]	5.0	.862	.129	8.388	---	---
I-2	10.0	---	---	---	---	---
I-3	20.0	---	---	---	.832	---
J-1[1]	6.5	.993	.260	9.440	---	---
J-2[1]	10.0	.372	---	7.899	---	---
J-3	16.0	---	---	----	.027	---

Table 31--Continued

Well	Depth (ft)	Cristobalite SiO_2	Quartz SiO_2	Siderite $FeCO_3$	Calcite $CaCO_3$	Rhodochrosite $MnCO_3$
A-1	5.0	---	.234	.259	---	---
A-2	12.5	-.035	.374	---	---	---
A-3	22.5	.076	.485	---	-.060	---
E-1	5.0	---	---	.011	---	---
H-1	5.0	---	.265	.529	---	.009
H-2	8.3	---	.280	---	---	---
H-3	16.5	---	.104	---	---	---
I-1	5.0	---	-.041	.578	---	---
I-2	10.0	---	.106	---	---	---
I-3	20.0	---	.139	.880	---	---
J-1	6.5	---	---	.465	---	---
J-2	10.0	---	.066	.167	---	---
J-3	16.0	---	.000	.973	---	---

[1]Assumptions: pe input into WATEQ4F at approximate level of sulfate reduction (Eh = -0.17v); sulfide input at 0.1 mg/L. All other samples assumed a pe input at approximate level of nitrate reduction (Eh = .35v).

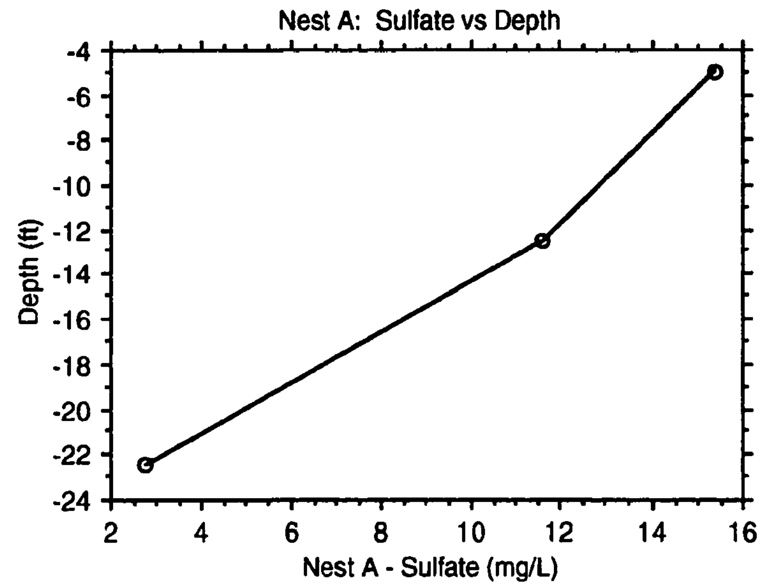


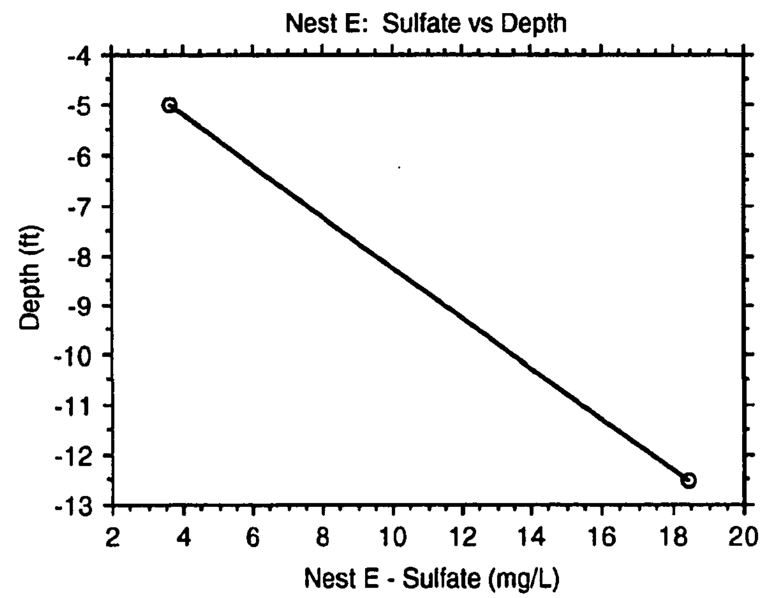
Note. Nest A wells screened in peat. Nest E wells screened in sediment.

Figure 77. Ammonium Concentrations Compared to Depth for Well Nest A.

levels above 7. Dolomite and calcite are the principle minerals contributing to ionic species. Ground water approaches saturation levels with respect to calcite, and complexation does not appear to play a major role in maintaining these levels. Organic matter and decomposition are generally low. Redox levels are generally high, except where denitrification is occurring, and then above the range at which sulfate reduction occurs (Barrese, 1991). Residence time of ground water is short when compared to the hydraulic conductivity of sapric peat at Government Marsh.

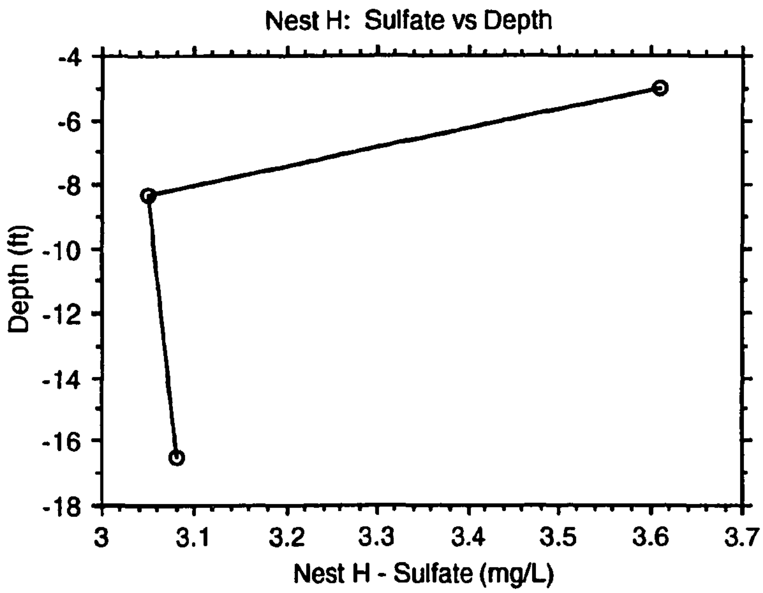
The natural bog waters at Government Marsh are acidic and reducing. Low surface pH levels increase with sample depth, but remain less than 7. Organic decomposition is the major control on the system, contributing organic acids to the bog.

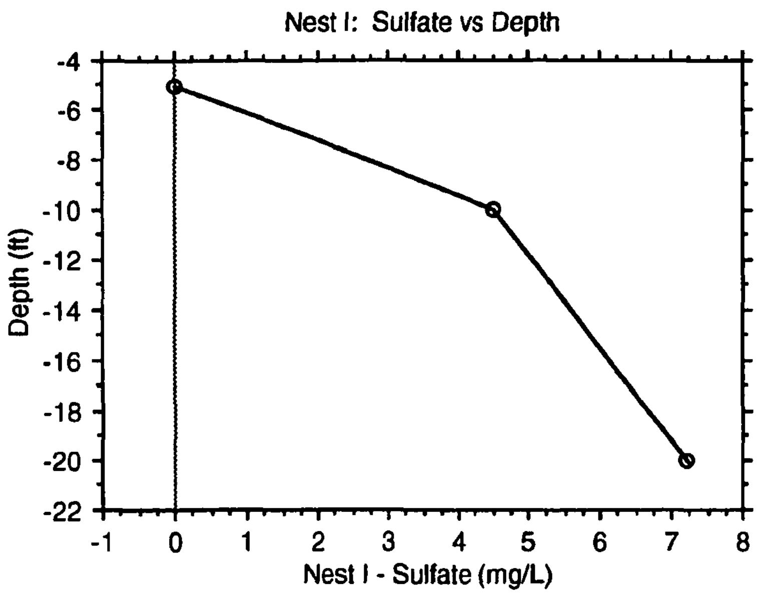




Note. Nest A wells screened in peat. Nest E wells screened in sediment.

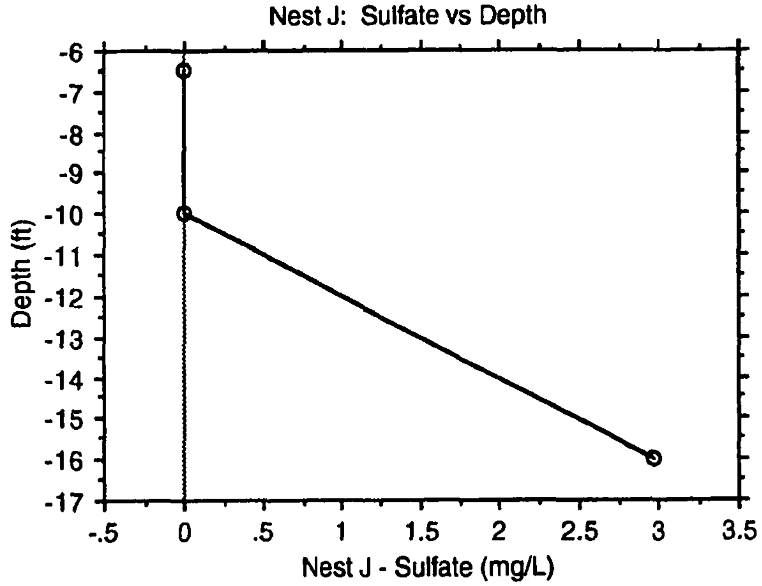
Figure 78. Sulfate Concentrations Compared to Depth for Well Nest A and Well Nest E.





Note. **H-1 screened in peat. All other wells screened in sediment beneath the peat.**

Figure 79. **Sulfate Concentrations Compared to Depth for Well Nest H and Well Nest I.**



Note. All wells screened in sediment beneath the peat.

Figure 80. Sulfate Concentrations Compared to Depth for Well Nest J.

Decomposition of organic matter also produces large concentrations of CO_2, which forms carbonic acid, also contributing to low pH levels. These organic acids contribute to alkalinity or are involved in chemical reactions that contribute to alkalinity. Organic acid complexation and consumption of calcite by salts of fatty acids maintain saturation and supersaturation levels of sulfide, carbonate and silica species. Production of ammonium and reduction of ferric iron at sample depth consume H^+, which raise pH. Redox levels are at least below concentrations at which sulfate reduction occurs ($Eh < -.17$ V), and may approach fermentation levels.

Ground Water Temperature

When ground water discharges into an area it transfers heat from the subsurface

Table 32

Ionic Balance in Samples From Well Nests
A, E, H, I, & J

Well	Sample Depth (ft)	Ionic Balance (percent)
A-1	5.0	---
A-2	12.5	---
A-3	22.5	---
E-1	5.0	(+) 58.3
E-2	12.5	N/A
H-1	5.0	---
H-2	8.3	---
H-3	16.5	---
I-1	5.0	(-) 51.6
I-2	10.0	(+) 74.0
I-3	20.0	(-) 60.9
J-1	6.5	(-) 14.9
J-2	10.2	(-) 55.7
J-3	16.0	(-) 27.7

(+) Ionic inbalance in favor of cations.

(-) Ionic inbalance in favor of anions.

N/A Not available.

to the surface which commonly prevents wells from freezing in the winter; conversely, surface water from a recharging system may freeze at the surface and in shallow wells, because these waters maintain a temperature that resembles the ambient air temperature. Water standing in seven out of the ten shallow wells in the well nests was frozen in late January, 1992 (Table 34). The shallow wells in nest A, C, and F were frozen; these are constructed in thick peat deposits within Government Marsh. All of the water levels

Table 33

Chemical Data for Nest G (mg/L)
Date Sampled: August 21, 1991

Well	TOC[1] (ft)	Depth of Screen(ft)	Temp[2] C	pH	Conductivity (μS)	TDS[3]
G-1	837.78	5.0	20.5	6.04	228	235

Well	Cl^-	*HCO_3^-	NO_3^-/N	SiO_2	SO_4^{-2}	Total Hardness
G-1	< 2	99.6	0.088	2.9	4.02	157

Well	Ba^{+2}	Ca^{+2}	Fe^{+2}	K^+	Mg^{+2}	Mn^{+2}	Na^+	NH_4^+
G-1	0.1	46.0	23.6	3.4	10.3	2.0	2.1	0.27

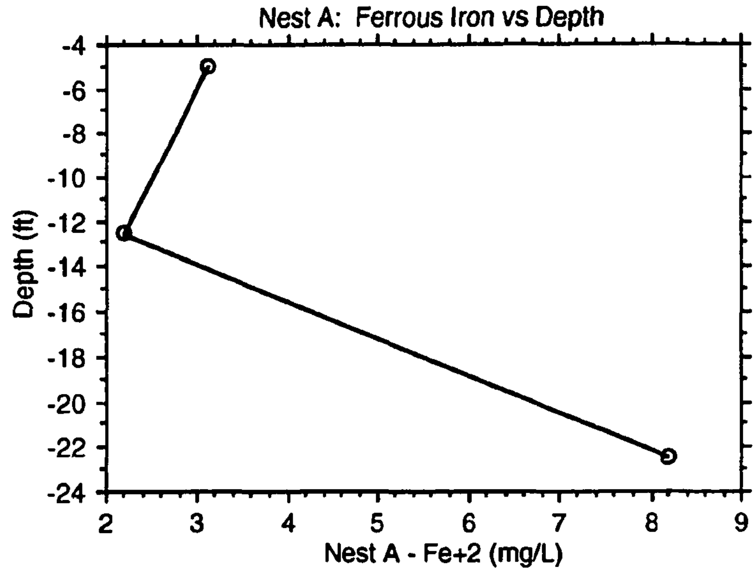
[1]Top of casing

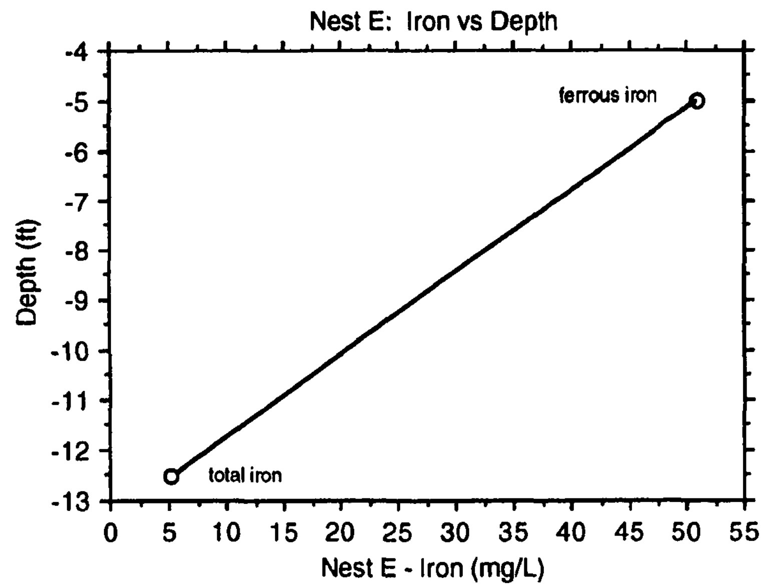
[2]Degrees Celsius

[3]Total dissolved solids

*Alkalinity

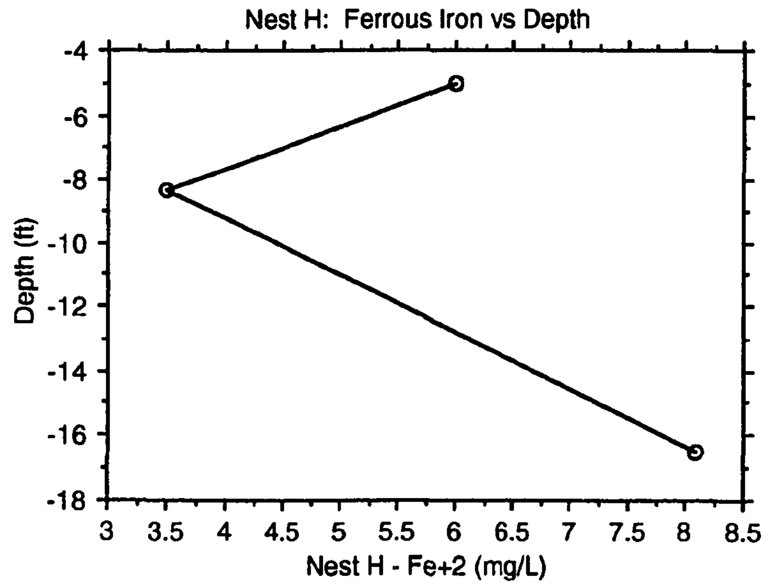
in nest F were frozen. Well nest C-1 and G-1 were also frozen in the last week of December, 1992. If warmer water were upwelling through the base of the peat, then the upper surface would probably have been prevented from freezing (Gore, 1983). In addition water standing in piezometers 17, 29, 34, 37 and 38 was frozen in January 1989. The water standing in piezometer 37 was also frozen in February and December 1989. Piezometers 34, 37 and 38 are constructed within the boundaries of Government Marsh. Wells that maintained unfrozen water columns were generally screened at

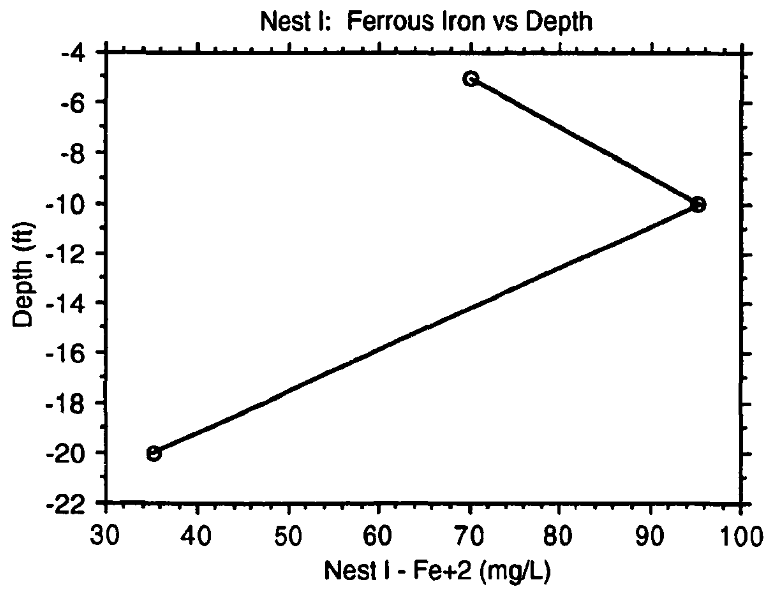




Note. Nest A wells screened in peat. Nest E wells screened in sediment.

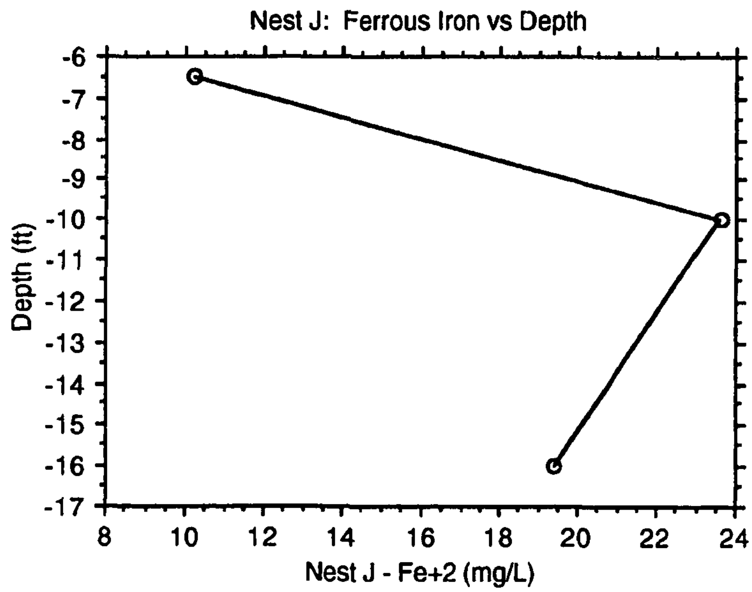
Figure 81. Iron Concentrations Compared to Depth for Well Nest A and Well Nest E.





Note. H-1 screened in peat. All other wells screened in sediment beneath the peat.

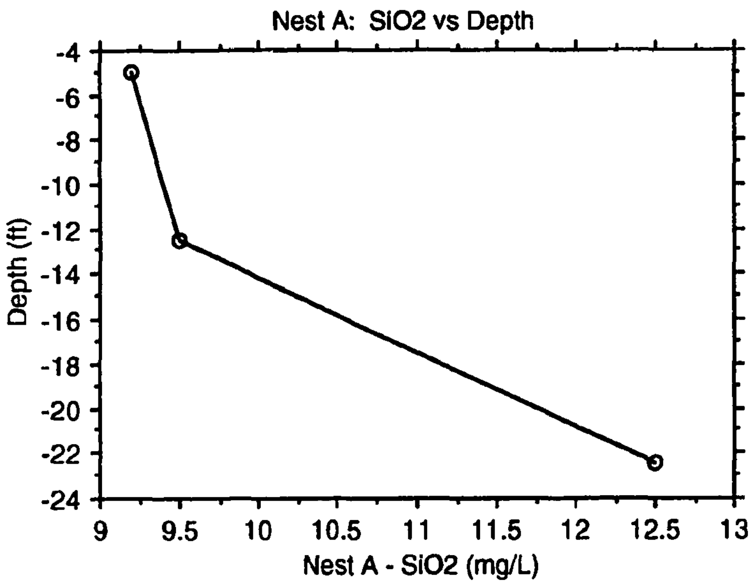
Figure 82. Ferrous Iron Concentrations Compared to Depth for Well Nest H and Well Nest I.

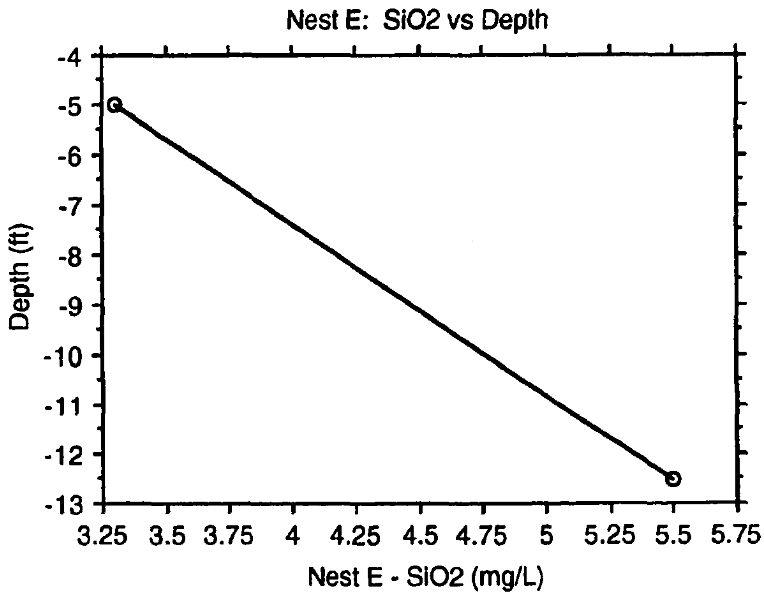


Note. All wells screened in sediment beneath the peat.

Figure 83. Ferrous Iron Concentrations Compared to Depth for Well Nest J.

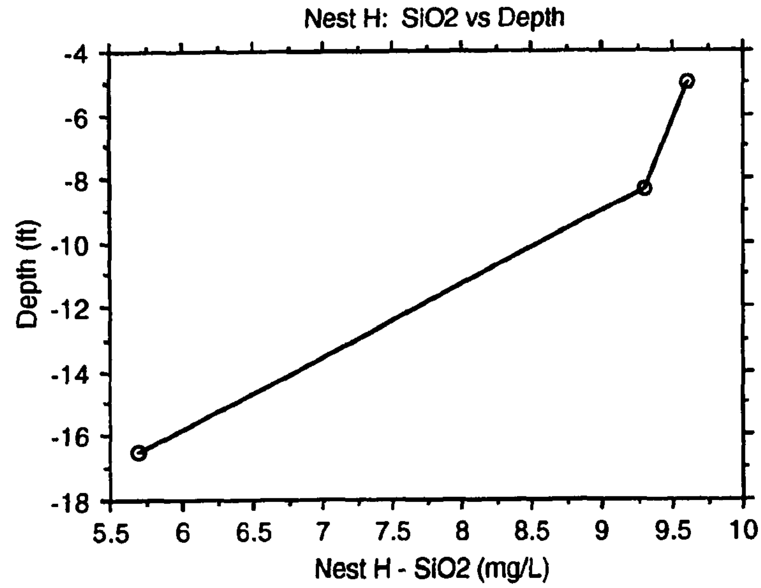
depths greater than five feet and were insulated by peat or were constructed in areas where vegetation protected the wells from winter winds.

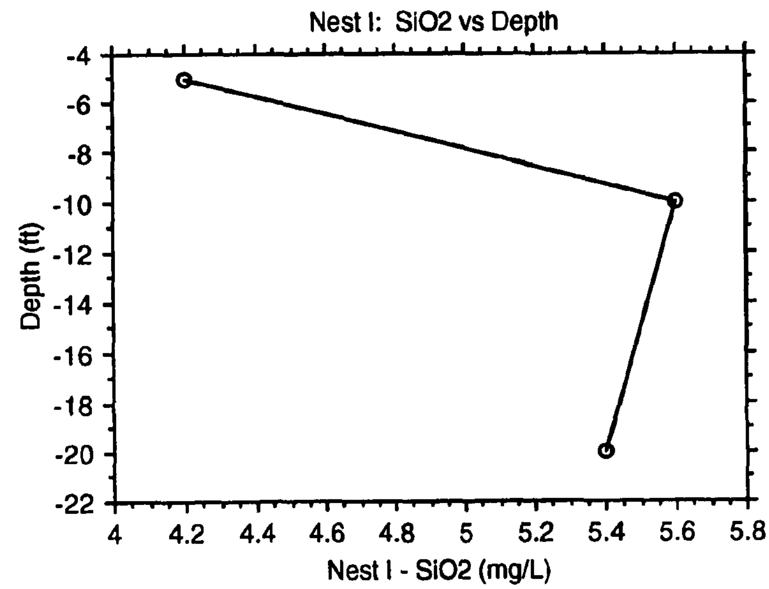




Note. Nest A wells screened in peat. Nest E wells screened in sediment.

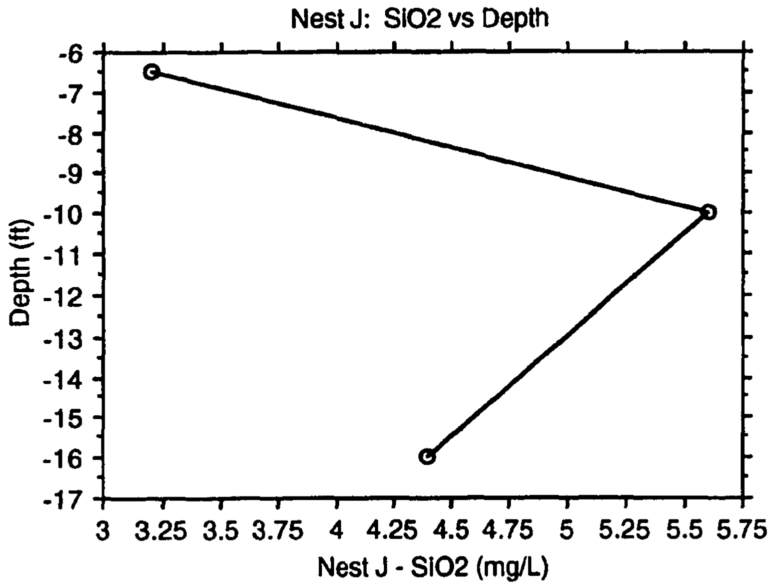
Figure 84. **Silica Concentrations Compared to Depth for Well Nest A and Well Nest E.**





Note. H-1 screened in peat. All other wells screened in sediment beneath the peat.

Figure 85. Silica Concentrations Compared to Depth for Well Nest H and Well Nest I.



Note. All wells screened in sediment beneath the peat.

Figure 86. Silica Concentrations Compared to Depth for Well Nest J.

Table 34

Wells in Well Nests Frozen During the Last Week of January 1992

Nest / Well	Screen Depth (ft)	Condition
A-1	5.0	Frozen
C-1*	8.5	Frozen
F-1	5.0	Frozen
F-2	12.5	Frozen
F-3	22.5	Frozen
G-1*	5.0	Frozen
H-1	4.0	Frozen
I-J	5.0	Frozen
J-1	5.0	Frozen

*Also frozen during the last week of December 1991.

CHAPTER VI

CONCLUSIONS

The following conclusions can be determined from the evaluation of data collected during the hydrogeological and hydrogeochemical investigation of Government Marsh:

1. The chemical analysis of water collected from wells outside the perimeter of Government Marsh and near the terminus of the south pond show that the ground water has a pH above 7 and contains a relatively high amount of dissolved constituents compared to Government Marsh surface water chemistry. Calcite and dolomite are the principal carbonate minerals contributing to the geochemical character of this water. The geochemical relationship is consistent regardless of sample depth.

2. The chemical analysis of water collected from well nests within the boundaries of Government Marsh and north of the south pond show that the water at and near the surface is low in dissolved constituents and has a pH around 4 or less. Rain water collected near these nest sites has a very similar geochemical character; therefore, Government Marsh surface water is derived from atmospheric precipitation and not from ground-water discharge.

3. The mean calcium, conductivity and pH values analyzed from water samples collected from the surface of Government Marsh, north of the south pond, are within ombrotrophic bog criteria limits. The wetland identified as Government Marsh should more appropriately be identified as Government Bog. This would be consistent with vegetation identified near the well nests where Government Marsh surface water was sampled, which is of the type that thrive in low nutrient, bog environments.

4. A consistent and obvious relationship can be observed between increases in pH, dissolved constituents, and ground-water depth in water collected and analyzed from well nests north of the south pond: dissolved constituents and pH increase with increases in ground water depth. This increase is due in part to marly clay, which is often found at the interface between the interstitial ground water system and sapric peat.

5. Yet, the natural bog waters at Government Marsh, which are acidic and reducing, contribute significantly to the geochemical nature of the ombrotrophic system. Low surface pH levels increase with sample depth, but remain less than 7. Organic decomposition is the major control on the system, contributing organic acids to the bog. These organic acids contribute to alkalinity or are involved in chemical reactions that contribute to alkalinity, which also raise the concentrations of calcium and magnesium with sample depth. Organic acid complexation and consumption of calcite into salts of fatty acids maintain saturation and supersaturation levels of sulfide, carbonate and silica species. Production of ammonium and reduction of iron at sample depth consume H^+, which raises pH. Cation exchange involving ammonium contributes to elevated concentrations of calcium and magnesium with sample depth. Redox levels are at least below concentrations at which sulfate reduction occurs ($Eh < -.17$ V), and may approach fermentation levels.

6. Water sampled from Goose Lake shows that the geochemical character of Goose Lake is highly influenced, if not a product of, "bog" waters flowing through the peat into Goose Lake, and that Goose Lake can be classified as a bog lake.

7. Static water level measurements obtained from well nests show a consistent vertical flow away from the surface of Government Marsh into the ground-water subsurface. This vertical flow away from Government Marsh is also demonstrated by

the observation that many of the piezometers and wells in well nests contained ice where static water levels were previously measured, which indicates that warmer ground water was not discharging upward to the wetland surface. Both of these observations offer very good evidence that Government Marsh is recharging the local ground-water flow system.

8. The mean hydraulic conductivity (K) of the interstitial flow system external of Government Marsh ranges between 70 to over 100 ft/day, a good range for aquifer material. No consistent or obvious relationship can be observed with ground-water depth.

9. The hydraulic conductivity (K) of well nests north of the south pond generally shows a decrease with ground-water depth. Values range from very rapid near the surface of the bog, to less than 0.0002 ft/day near the vertical limit of the bog. This decrease in K is due in part to the decrease in fiber content of peat with depth (sapric peat), which gives the peat clay like properties. It is also due in part to the accumulation of marly clay found at the interface between the interstitial ground-water system and sapric peat. The low transmissive property of peat with depth helps to contain water within the wetland.

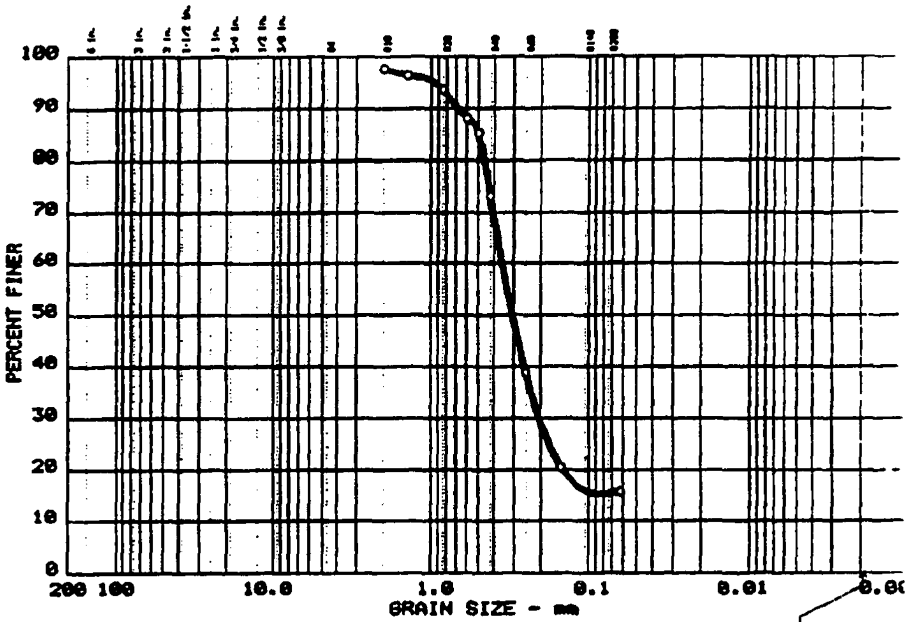
10. Ground water flow maps show a shallow subradial ground water flow emanating from the "bog" area of Government Marsh and flowing to the north, south, and west. It should be understood that the flow fields are under the influence of water being discharged from Government Marsh by the Millburn Peat Company and are therefore inconclusive. A deeper flow field shows ground water flowing in an east to west direction indicating that Government Marsh contributes recharge waters to the Spring Creek Wetland.

11. Considering all of the above, much, if not all of Government Marsh, is an area where ground-water recharge originates.

Appendix A

Grain Size Analysis Data

GRAIN SIZE DISTRIBUTION TEST REPORT



	Test	% +3"	% GRAVEL	% SAND	% SILT	% CLAY
o	1	0.0	0.0	84.7	15.3	

	LL	PI	D_{85}	D_{60}	D_{50}	D_{30}	D_{15}	D_{10}	C_c	C_u
o			0.50	0.35	0.30	0.206				

MATERIAL DESCRIPTION	USCS	AASHTO
o Sand		

Project No.: Deep Well #2
Project: Eastern Michigan University
o Location: 0-3 Ft. below surface

Date: 8-30-92

GRAIN SIZE DISTRIBUTION TEST REPORT
EASTERN MICHIGAN UNIVERSITY

Remarks:
Uncalculated
Mechanical Test

Figure No. 1

GRAIN SIZE DISTRIBUTION TEST DATA   Test No.: 1

Date: 8-30-92
Project No.: Deep Well #2
Project: Eastern Michigan University

Sample Data

Location of Sample: 0-3 Ft. below surface
Sample Description: Sand
USCS Class: Liquid limit:
AASHTO Class: Plasticity index:

Notes

Remarks: Uncalculated Mechanical Test

Fig. No.: 1

Mechanical Analysis Data

Initial
Dry sample and tare= 258.00
Tare = 8.00
Dry sample weight = 250.00
Tare for cumulative weight retained= 8

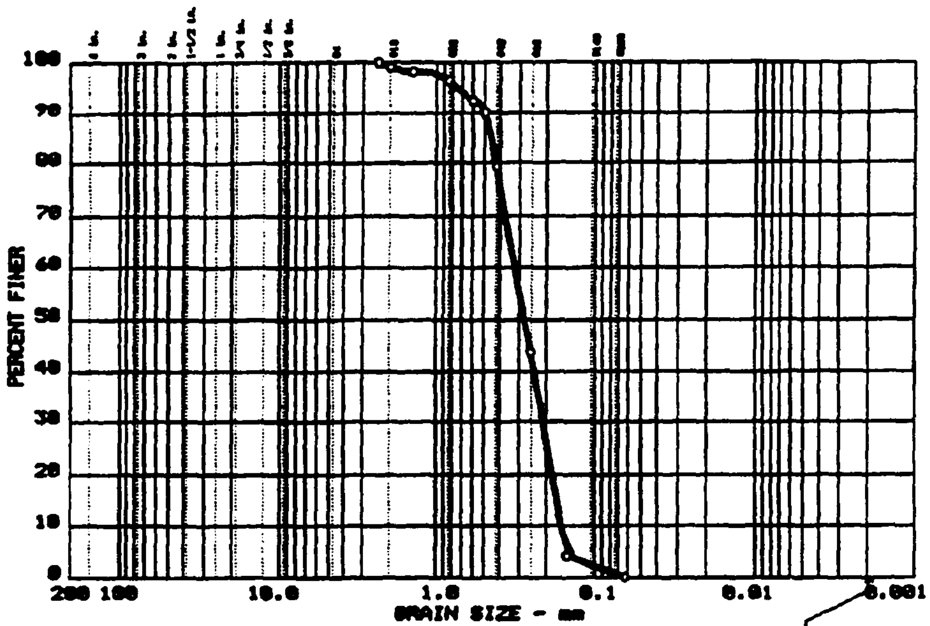
Sieve	Cumul. Wt. retained	Percent finer
# 10	14.00	97.6
# 14	17.00	96.4
# 20	24.00	93.6
# 30	38.00	88.0
# 35	45.00	85.2
# 40	75.00	73.2
# 60	161.00	38.8
# 100	207.00	20.4
# 230	219.00	15.6

Fractional Components

% + 3 in. = 0.0   % GRAVEL = 0.0   % SAND = 84.7
% FINES = 15.3

D85= 0.50 D60= 0.352 D50= 0.304
D30= 0.2056

GRAIN SIZE DISTRIBUTION TEST REPORT



	Test	% +3"	% GRAVEL	% SAND	% SILT	% CLAY
o	17	0.0	0.0	99.4	0.6	

	LL	PI	D_{85}	D_{60}	D_{50}	D_{30}	D_{15}	D_{10}	C_c	C_u
o			0.46	0.32	0.27	0.209	0.1716	0.1607	0.85	2.0

MATERIAL DESCRIPTION	USCS	AASHTO
o		

Project No.:
Project: DEEP WELL #2 3-8 FT
o Location:

Date: 8-92

Remarks:

GRAIN SIZE DISTRIBUTION TEST REPORT
EASTERN MICHIGAN UNIVERSITY

Figure No.____

GRAIN SIZE DISTRIBUTION TEST DATA Test No.: 17

Date: 8-92
Project No.:
Project: DEEP WELL #2 3-8 FT

Sample Data

Location of Sample:
Sample Description:
USCS Class: Liquid limit:
AASHTO Class: Plasticity index:

Notes

Remarks:

Fig. No.:

Mechanical Analysis Data

Initial
Dry sample and tare= 240.00
Tare = 0.00
Dry sample weight = 240.00
Sieve tare method

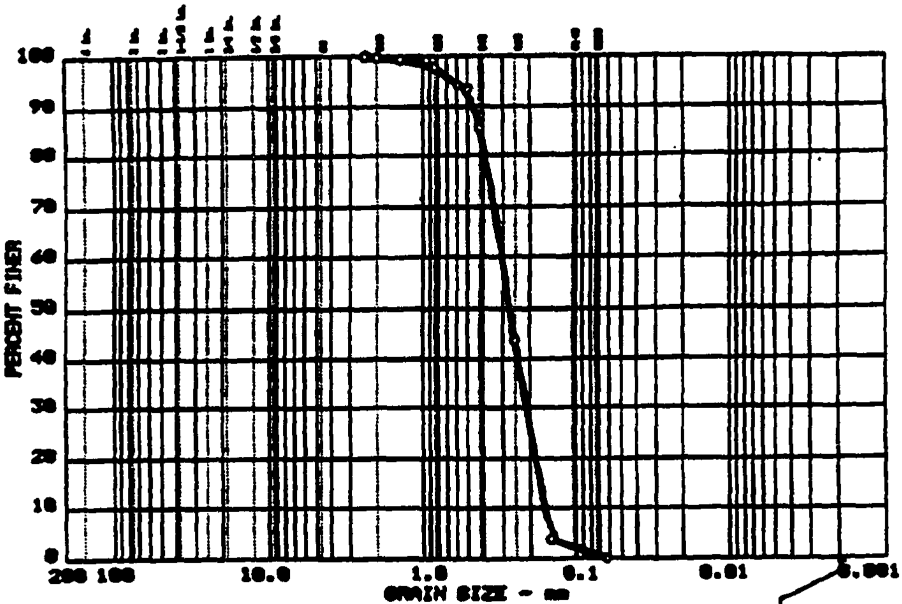
Sieve	Weight retained	Sieve tare	Percent finer
# 8	0.00	0.00	100.0
# 10	2.00	0.00	99.2
# 14	2.00	0.00	98.3
# 20	4.00	0.00	96.7
# 30	10.00	0.00	92.5
# 35	6.00	0.00	90.0
# 40	26.00	0.00	79.2
# 60	85.00	0.00	43.8
# 100	95.00	0.00	4.2
# 230	10.00	0.00	0.0

Fractional Components

% + 3 in. = 0.0 % GRAVEL = 0.8 % SAND = 98.4
% FINES = 0.8

D85= 0.46 D60= 0.319 D50= 0.274
D30= 0.2087 D15= 0.17159 D10= 0.16069
Cc = 0.8492 Cu = 1.9861

GRAIN SIZE DISTRIBUTION TEST REPORT



	Test	% +3"	% GRAVEL	% SAND	% SILT	% CLAY
O	16	0.0	0.3	99.0	0.7	

	LL	PI	D_{85}	D_{60}	D_{50}	D_{30}	D_{15}	D_{10}	C_c	C_u
O			0.42	0.30	0.27	0.209	0.1722	0.1614	0.90	1.9

MATERIAL DESCRIPTION	USCS	AASHTO
O D_{95} = .61 D_5 = .155		

Project No.:
Project: DEEP WELL #2 23-28 FT
O Location:

Date: 8-92

Remarks:

GRAIN SIZE DISTRIBUTION TEST REPORT
EASTERN MICHIGAN UNIVERSITY

Figure No.____

GRAIN SIZE DISTRIBUTION TEST DATA

Test No.: 16

Date: 8-92
Project No.:
Project: DEEP WELL #2 23-28 FT

Sample Data

Location of Sample:
Sample Description:
USCS Class: Liquid limit:
AASHTO Class: Plasticity index:

Notes

Remarks:

Fig. No.:

Mechanical Analysis Data

	Initial
Dry sample and tare=	344.00
Tare =	0.00
Dry sample weight =	344.00

Sieve tare method

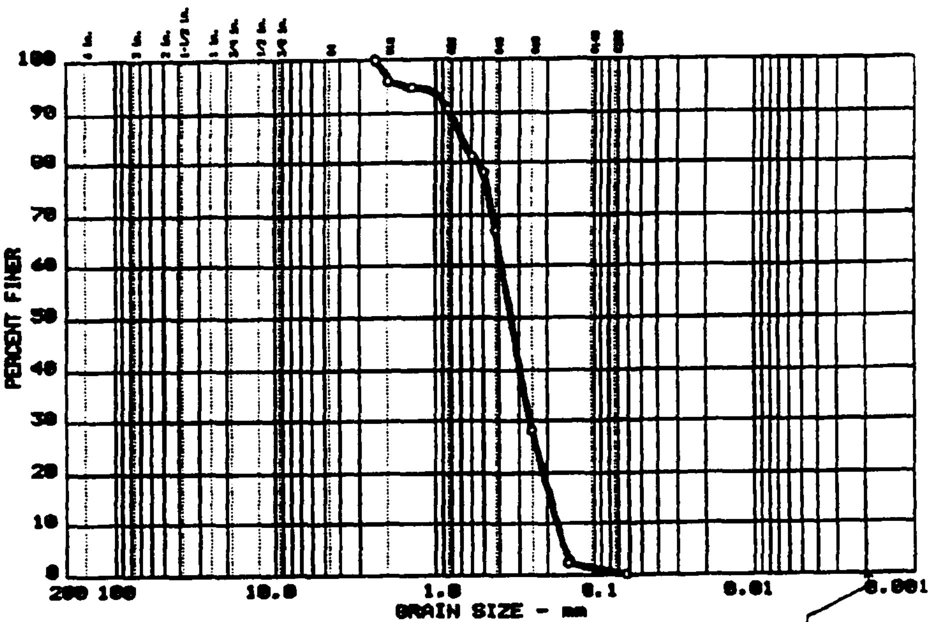
Sieve	Weight retained	Sieve tare	Percent finer
# 8	0.00	0.00	100.0
# 10	1.00	0.00	99.7
# 14	1.00	0.00	99.4
# 20	5.00	0.00	98.0
# 30	12.00	0.00	94.5
# 35	3.00	0.00	93.6
# 40	28.00	0.00	85.5
# 60	144.00	0.00	43.6
# 100	137.00	0.00	3.8
# 230	13.00	0.00	0.0

Fractional Components

% + 3 in. = 0.0 % GRAVEL = 0.3 % SAND = 99.0
% FINES = 0.7

D85= 0.42 D60= 0.301 D50= 0.268
D30= 0.2094 D15= 0.17219 D10= 0.16144
Cc = 0.9026 Cu = 1.8642

GRAIN SIZE DISTRIBUTION TEST REPORT



	Test	% +3"	% GRAVEL	% SAND	% SILT	% CLAY
o	4	0.0	3.9	95.7	0.4	

	LL	PI	D_{85}	D_{60}	D_{50}	D_{30}	D_{15}	D_{10}	C_c	C_u
o			0.69	0.38	0.33	0.256	0.1921	0.1738	0.99	2.2

	MATERIAL DESCRIPTION	USCS	AASHTO
o			

Project No.:
Project: DEEP WELL #2 28-33 FT
o Location:

Date: 8-92

Remarks:

GRAIN SIZE DISTRIBUTION TEST REPORT
EASTERN MICHIGAN UNIVERSITY

Figure No.______

GRAIN SIZE DISTRIBUTION TEST DATA Test No.: 4

Date: 8-92
Project No.:
Project: DEEP WELL #2 28-33 FT

Sample Data

Location of Sample:
Sample Description:
USCS Class: Liquid limit:
AASHTO Class: Plasticity index:

Notes

Remarks:

Fig. No.:

Mechanical Analysis Data

Initial
Dry sample and tare= 486.00
Tare = 0.00
Dry sample weight = 486.00
Sieve tare method

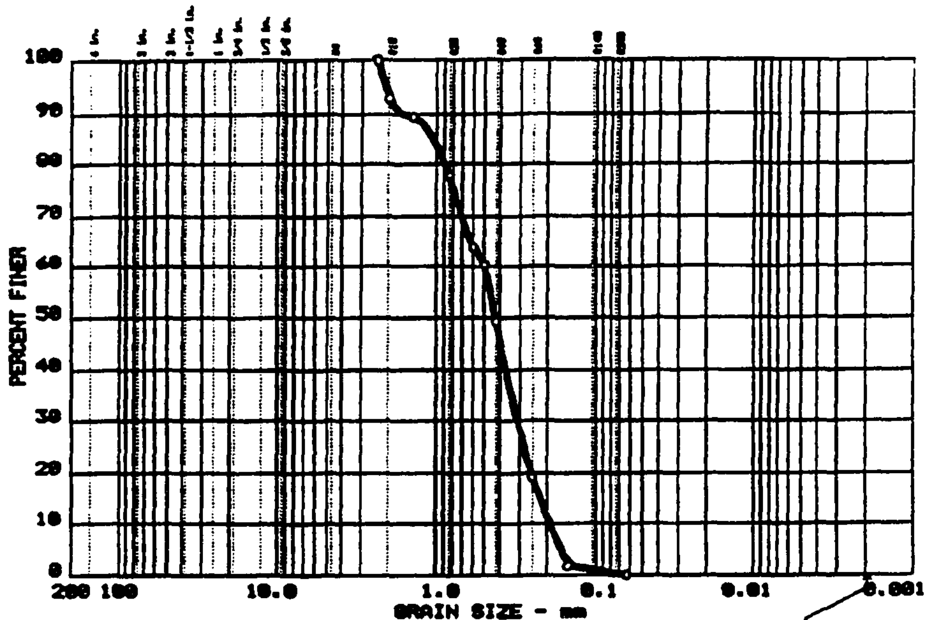
Sieve	Weight retained	Sieve tare	Percent finer
# 8	0.00	0.00	100.0
# 10	19.00	0.00	96.1
# 14	6.00	0.00	94.9
# 20	20.00	0.00	90.7
# 30	46.00	0.00	81.3
# 35	15.00	0.00	78.2
# 40	54.00	0.00	67.1
# 60	189.00	0.00	28.2
# 100	126.00	0.00	2.3
# 230	11.00	0.00	0.0

Fractional Components

% + 3 in. = 0.0 % GRAVEL = 3.9 % SAND = 95.7
% FINES = 0.4

D85= 0.69 D60= 0.382 D50= 0.334
D30= 0.2562 D15= 0.19209 D10= 0.17378
Cc = 0.9897 Cu = 2.1953

GRAIN SIZE DISTRIBUTION TEST REPORT



	Test	% +3"	% GRAVEL	% SAND	% SILT	% CLAY
o	3	0.0	7.1	92.6	0.3	

	LL	PI	D_{85}	D_{60}	D_{50}	D_{30}	D_{15}	D_{10}	C_c	C_u
o			1.04	0.49	0.42	0.307	0.2200	0.1895	1.01	2.6

	MATERIAL DESCRIPTION	USCS	AASHTO
o			

Project No.:
Project: DEEP WELL #2 33-38 FT
o Location:

Date: 8-92

Remarks:

GRAIN SIZE DISTRIBUTION TEST REPORT
EASTERN MICHIGAN UNIVERSITY

Figure No.____

GRAIN SIZE DISTRIBUTION TEST DATA   Test No.: 3

Date: 8-92
Project No.:
Project: DEEP WELL #2   33-38 FT

Sample Data

Location of Sample:
Sample Description:
USCS Class: Liquid limit:
AASHTO Class: Plasticity index:

Notes

Remarks:

Fig. No.:

Mechanical Analysis Data

	Initial
Dry sample and tare=	339.00
Tare =	0.00
Dry sample weight =	339.00

Sieve tare method

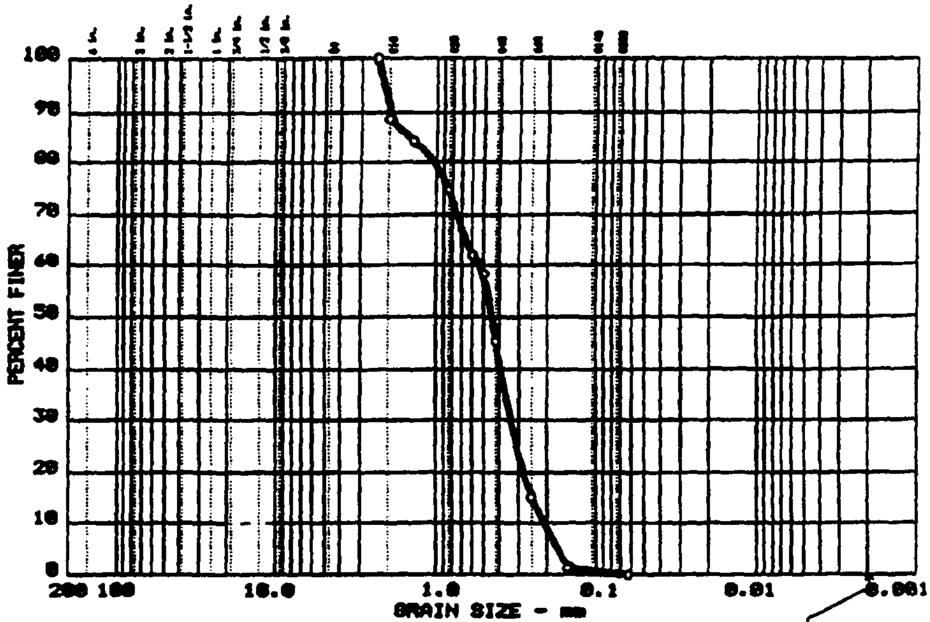
Sieve	Weight retained	Sieve tare	Percent finer
# 8	0.00	0.00	100.0
# 10	24.00	0.00	92.9
# 14	12.00	0.00	89.4
# 20	39.00	0.00	77.9
# 30	47.00	0.00	64.0
# 35	12.00	0.00	60.5
# 40	38.00	0.00	49.3
# 60	102.00	0.00	19.2
# 100	59.00	0.00	1.8
# 230	6.00	0.00	0.0

Fractional Components

% + 3 in. = 0.0   % GRAVEL = 7.1   % SAND = 92.6
% FINES = 0.3

D85= 1.04 D60= 0.494 D50= 0.424
D30= 0.3073 D15= 0.22004 D10= 0.18945
Cc = 1.0093 Cu = 2.6062

GRAIN SIZE DISTRIBUTION TEST REPORT



	Test	% +3"	% GRAVEL	% SAND	% SILT	% CLAY
o	2	0.0	11.3	88.5	0.2	

	LL	PI	D_{85}	D_{60}	D_{50}	D_{30}	D_{15}	D_{10}	C_c	C_u
o			1.40	0.52	0.44	0.335	0.2403	0.2065	1.05	2.5

MATERIAL DESCRIPTION	USCS	AASHTO
o		

Project No.:
Project: DEEP WELL #2 30-43 FT
o Location:

Date: 8-91

Remarks:

GRAIN SIZE DISTRIBUTION TEST REPORT
EASTERN MICHIGAN UNIVERSITY

Figure No.____

GRAIN SIZE DISTRIBUTION TEST DATA

Test No.: 2

Date: 8-9
Project No.:
Project: DEEP WELL #2 38-43 FT

Sample Data

Location of Sample:
Sample Description:
USCS Class: Liquid limit:
AASHTO Class: Plasticity index:

Notes

Remarks:

Fig. No.:

Mechanical Analysis Data

Initial
Dry sample and tare= 416.00
Tare = 0.00
Dry sample weight = 416.00
Sieve tare method

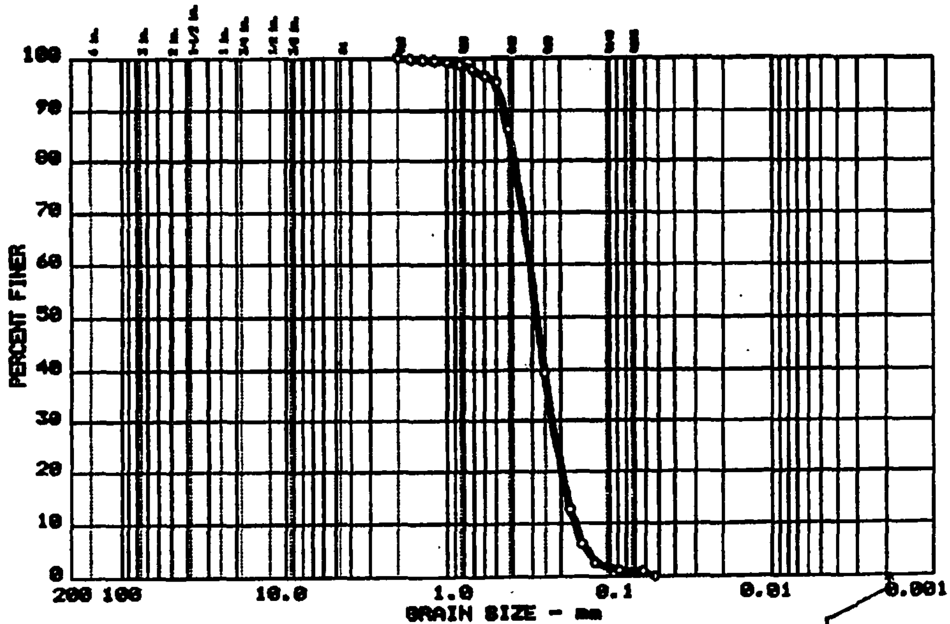
Sieve	Weight retained	Sieve tare	Percent finer
# 8	0.00	0.00	100.0
# 10	47.00	0.00	88.7
# 14	18.00	0.00	84.4
# 20	40.00	0.00	74.8
# 30	52.00	0.00	62.3
# 35	16.00	0.00	58.4
# 40	54.00	0.00	45.4
# 60	126.00	0.00	15.1
# 100	58.00	0.00	1.2
# 230	5.00	0.00	0.0

Fractional Components

% + 3 in. = 0.0 % GRAVEL = 11.3 % SAND = 88.5
% FINES = 0.2

D85= 1.48 D60= 0.519 D50= 0.443
D30= 0.3350 D15= 0.24831 D10= 0.20654
Cc = 1.0471 Cu = 2.5119

GRAIN SIZE DISTRIBUTION TEST REPORT



Test	% +3"	% GRAVEL	% SAND	% SILT	% CLAY
o 4	0.0	0.0	99.0	1.0	

	LL	PI	D_{85}	D_{60}	D_{50}	D_{30}	D_{15}	D_{10}	C_c	C_u
o			0.41	0.31	0.28	0.225	0.1839	0.1658	0.99	1.9

MATERIAL DESCRIPTION	USCS	AASHTO
o $D_{95} = .48$ mm $D_5 = .14$ mm		

Project No.:
Project: DEEP WELL #3 0-5 FT
o Location:

Date: 10-93

GRAIN SIZE DISTRIBUTION TEST REPORT
EASTERN MICHIGAN UNIVERSITY

Remarks:

Figure No.____

GRAIN SIZE DISTRIBUTION TEST DATA   Test No.: 4

Date: 10-93
Project No.:
Project: DEEP WELL #3 0-5 FT

Sample Data

Location of Sample:
Sample Description:
USCS Class: Liquid limit:
AASHTO Class: Plasticity index:

Notes

Remarks:

Fig. No.:

Mechanical Analysis Data

	Initial
Dry sample and tare=	388.40
Tare =	0.00
Dry sample weight =	388.40

Sieve tare method

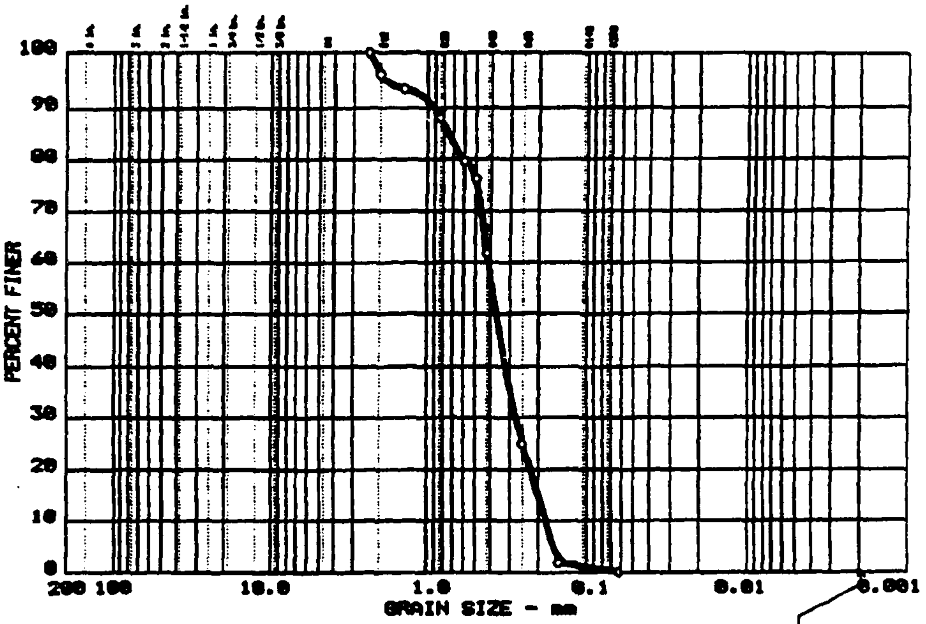
Sieve	Weight retained	Sieve tare	Percent finer
# 10	0.00	0.00	100.0
# 12	0.80	0.00	99.8
# 14	0.60	0.00	99.6
# 16	0.60	0.00	99.5
# 18	1.10	0.00	99.2
# 20	1.60	0.00	98.8
# 25	3.30	0.00	97.9
# 30	5.20	0.00	96.6
# 35	4.30	0.00	95.5
# 40	35.80	0.00	86.3
# 60	182.00	0.00	39.4
# 80	103.20	0.00	12.8
# 100	25.20	0.00	6.4
# 120	14.40	0.00	2.7
# 170	6.10	0.00	1.1
# 230	0.60	0.00	0.9
# 270	3.60	0.00	0.0

Fractional Components

% + 3 in. = 0.0 % GRAVEL = 0.0 % SAND = 99.0
% FINES = 1.0

D85= 0.41 D60= 0.310 D50= 0.279
D30= 0.2252 D15= 0.18387 D10= 0.16577
Cc = 0.9874 Cu = 1.8685

GRAIN SIZE DISTRIBUTION TEST REPORT



	Test	% +3"	% GRAVEL	% SAND	% SILT	% CLAY
o	19	0.0	3.8	95.8	0.4	

	LL	PI	D_{85}	D_{60}	D_{50}	D_{30}	D_{15}	D_{10}	C_c	C_u
o			0.74	0.41	0.36	0.272	0.1991	0.1784	1.01	2.3

MATERIAL DESCRIPTION	USCS	AASHTO
o		

Project No.:
Project: DEEP WELL #3 5-15 FT
o Location:

Date: 8-92

Remarks:

GRAIN SIZE DISTRIBUTION TEST REPORT
EASTERN MICHIGAN UNIVERSITY

Figure No.______

GRAIN SIZE DISTRIBUTION TEST DATA

Test No.: 19

Date: 8-92
Project No.:
Project: DEEP WELL #3 5-15 FT

Sample Data

Location of Sample:
Sample Description:
USCS Class: Liquid limit:
AASHTO Class: Plasticity index:

Notes

Remarks:

Fig. No.:

Mechanical Analysis Data

Initial
Dry sample and tare= 312.00
Tare = 0.00
Dry sample weight = 312.00
Sieve tare method

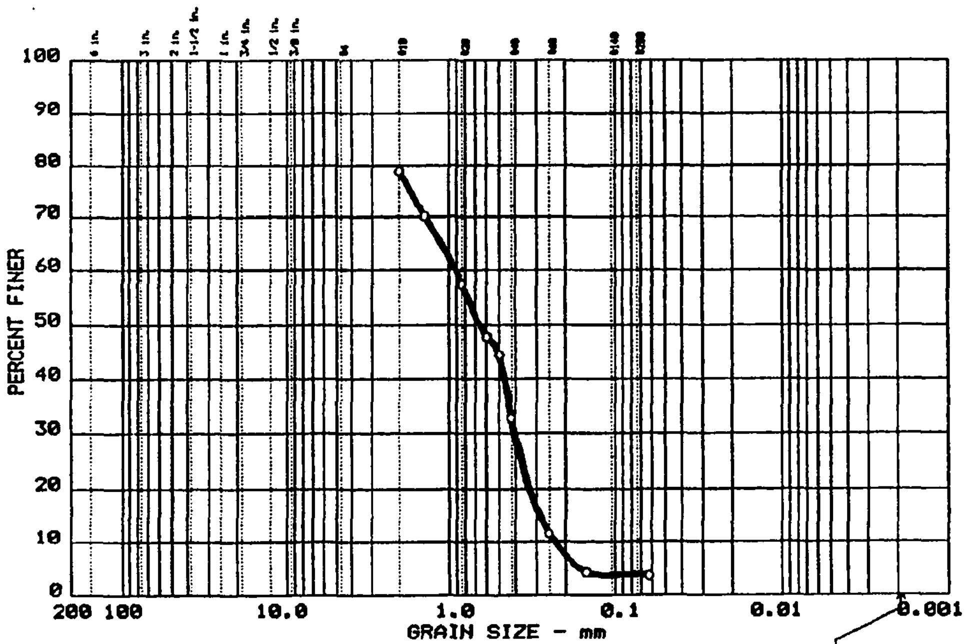
Sieve	Weight retained	Sieve tare	Percent finer
# 8	0.00	0.00	100.0
# 10	12.00	0.00	96.2
# 14	8.00	0.00	93.6
# 20	17.00	0.00	88.1
# 30	26.00	0.00	79.8
# 35	11.00	0.00	76.3
# 40	45.00	0.00	61.9
# 60	115.00	0.00	25.0
# 100	72.00	0.00	1.9
# 230	6.00	0.00	0.0

Fractional Components

% + 3 in. = 0.0 % GRAVEL = 3.8 % SAND = 95.8
% FINES = 0.4

D85= 0.74 D60= 0.411 D50= 0.365
D30= 0.2716 D15= 0.19907 D10= 0.17844
Cc = 1.0058 Cu = 2.3041

GRAIN SIZE DISTRIBUTION TEST REPORT



	Test	% +3"	% GRAVEL	% SAND	% SILT	% CLAY
o	1	0.0	0.0	96.2	3.8	

	LL	PI	D_{85}	D_{60}	D_{50}	D_{30}	D_{15}	D_{10}	C_c	C_u
o			2.00	0.91	0.65	0.403	0.2054	0.2294	0.78	4.0

MATERIAL DESCRIPTION	USCS	AASHTO
o Sand		

Project No.: Deep Well #3
Project: Eastern Michigan University
o Location: 10-15 Ft. below surface

Date: 8-1-92

GRAIN SIZE DISTRIBUTION TEST REPORT
EASTERN MICHIGAN UNIVERSITY

Remarks:
Uncalculated
Mechanical Test

Figure No.1

GRAIN SIZE DISTRIBUTION TEST DATA — Test No.: 1

Date: 8-1-92
Project No.: Deep Well #3
Project: Eastern Michigan University

Sample Data

Location of Sample: 10-15 Ft. below surface
Sample Description: Sand
USCS Class: Liquid limit:
AASHTO Class: Plasticity index:

Notes

Remarks: #2 Uncalculated Mechanical Test

Fig. No.: 2

Mechanical Analysis Data

Initial
Dry sample and tare= 332.00
Tare = 8.00
Dry sample weight = 324.00
Tare for cumulative weight retained= 8

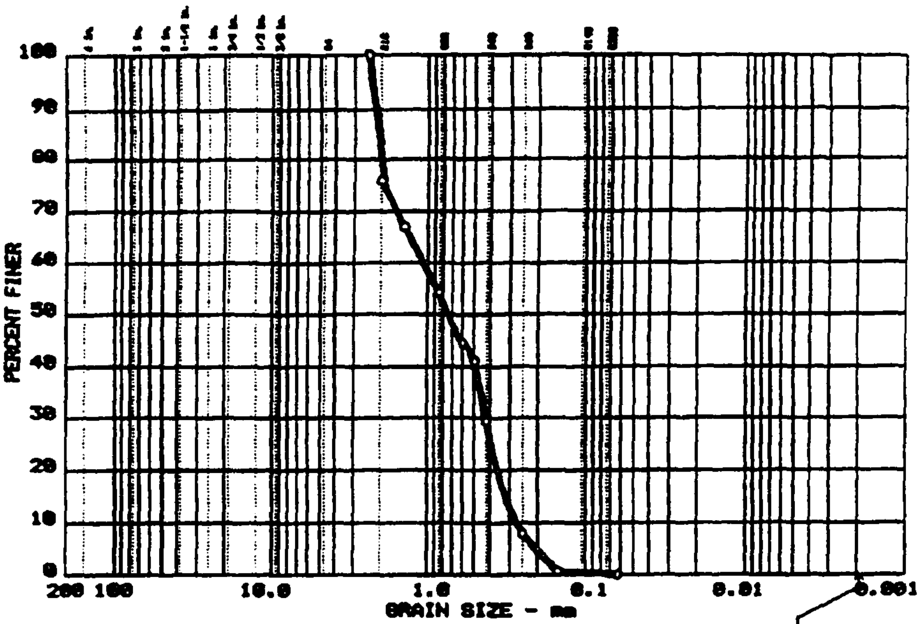
Sieve	Cumul. Wt. retained	Percent finer
# 10	65.00	82.4
# 14	84.00	76.5
# 20	104.00	70.4
# 30	126.00	63.6
# 35	134.00	61.1
# 40	173.00	49.1
# 60	286.00	14.2
# 100	319.00	4.0
# 230	321.00	3.4

Fractional Components

% + 3 in. = 0.0 % GRAVEL = 0.0 % SAND = 96.9
% FINES = 3.1

D85= 2.00 D60= 0.488 D50= 0.425
D30= 0.3281 D15= 0.25440 D10= 0.22158
Cc = 0.9966 Cu = 2.2004

GRAIN SIZE DISTRIBUTION TEST REPORT



Test	% +3"	% GRAVEL	% SAND	% SILT	% CLAY
O 4	0.0	24.1	75.8	0.1	

	LL	PI	D_{85}	D_{60}	D_{50}	D_{30}	D_{15}	D_{10}	C_c	C_u
O			2.14	1.06	0.74	0.424	0.3173	0.2701	0.63	3.9

MATERIAL DESCRIPTION	USCS	AASHTO
O		

Project No.:
Project: DEEP WELL #3 15-35 FT
O Location:

Date: 8-92

Remarks:

GRAIN SIZE DISTRIBUTION TEST REPORT
EASTERN MICHIGAN UNIVERSITY

Figure No.____

GRAIN SIZE DISTRIBUTION TEST DATA   Test No.: 4

Date: 8-92
Project No.:
Project: DEEP WELL #3   15-35 FT

Sample Data

Location of Sample:
Sample Description:
USCS Class: Liquid limit:
AASHTO Class: Plasticity index:

Notes

Remarks:

Fig. No.:

Mechanical Analysis Data

	Initial
Dry sample and tare=	324.00
Tare =	0.00
Dry sample weight =	324.00

Sieve tare method

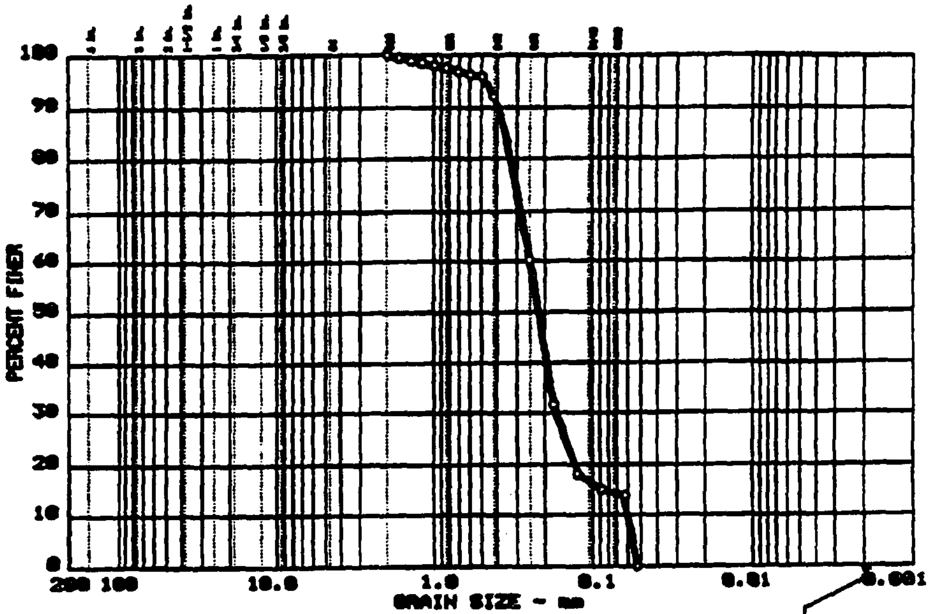
Sieve	Weight retained	Sieve tare	Percent finer
# 8	0.00	0.00	100.0
# 10	78.00	0.00	75.9
# 14	29.00	0.00	67.0
# 20	41.00	0.00	54.3
# 30	32.00	0.00	44.4
# 35	11.00	0.00	41.0
# 40	38.00	0.00	29.3
# 60	69.00	0.00	8.0
# 100	24.00	0.00	0.6
# 230	2.00	0.00	0.0

Fractional Components

% + 3 in. = 0.0   % GRAVEL = 24.1   % SAND = 75.8
% FINES = 0.1

D85= 2.14 D60= 1.058 D50= 0.740
D30= 0.4236 D15= 0.31732 D10= 0.27008
Cc = 0.6281 Cu = 3.9174

GRAIN SIZE DISTRIBUTION TEST REPORT



	Test	% +3"	% GRAVEL	% SAND	% SILT	% CLAY
o	10	0.0	0.0	85.5	14.5	

	LL	PI	D_{85}	D_{60}	D_{50}	D_{30}	D_{15}	D_{10}	C_c	C_u
o			0.35	0.25	0.22	0.169	0.0865	0.0598	1.92	4.2

	MATERIAL DESCRIPTION	USCS	AASHTO
o	D95 = .45 mm D5 = .055 mm		

Project No.:
Project: DEEP WELL #4   0-3 FT
o Location:

Date: 10-93

Remarks:

GRAIN SIZE DISTRIBUTION TEST REPORT
EASTERN MICHIGAN UNIVERSITY

Figure No._____

GRAIN SIZE DISTRIBUTION TEST DATA — Test No.: 18

Date: 10-93
Project No.:
Project: DEEP WELL #4 0-3 FT

Sample Data

Location of Sample:
Sample Description:
USCS Class: Liquid limit:
AASHTO Class: Plasticity index:

Notes

Remarks:

Fig. No.:

Mechanical Analysis Data

Initial
Dry sample and tare= 183.00
Tare = 0.00
Dry sample weight = 183.00
Sieve tare method

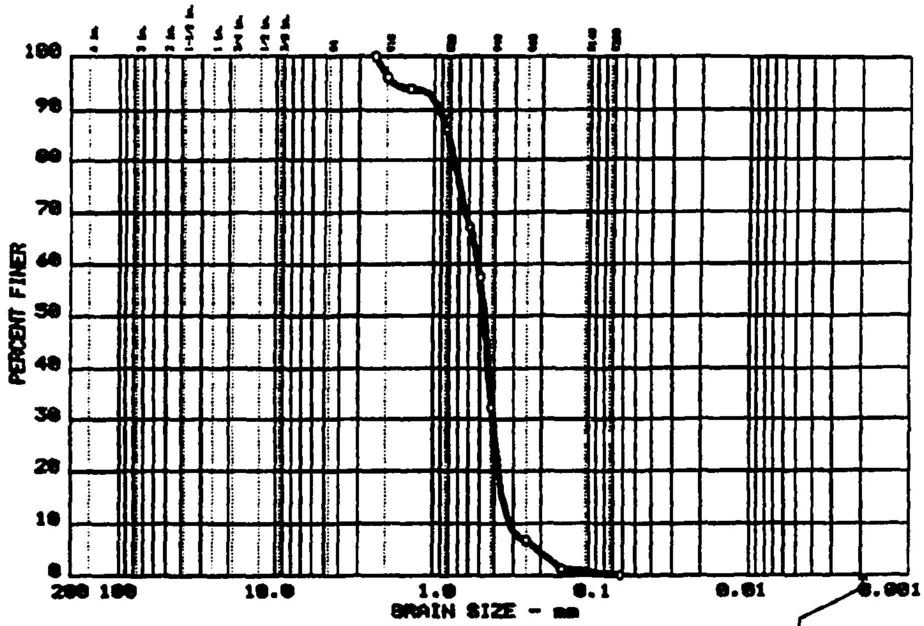
Sieve	Weight retained	Sieve tare	Percent finer
# 10	0.00	0.00	100.0
# 12	1.00	0.00	99.5
# 14	0.90	0.00	99.0
# 16	0.70	0.00	98.6
# 18	1.10	0.00	98.0
# 20	0.60	0.00	97.7
# 25	1.30	0.00	96.9
# 30	1.20	0.00	96.3
# 35	0.70	0.00	95.9
# 40	6.90	0.00	92.1
# 60	58.10	0.00	60.4
# 80	52.40	0.00	31.7
# 120	25.00	0.00	18.1
# 170	5.60	0.00	15.0
# 230	2.00	0.00	13.9
# 270	25.50	0.00	0.0

Fractional Components

% + 3 in. = 0.0 % GRAVEL = 0.0 % SAND = 85.5
% FINES = 14.5

D85= 0.35 D60= 0.248 D50= 0.220
D30= 0.1687 D15= 0.08650 D10= 0.05977
Cc = 1.9165 Cu = 4.1543

GRAIN SIZE DISTRIBUTION TEST REPORT



	Test	% +3"	% GRAVEL	% SAND	% SILT	% CLAY
o	6	0.0	3.8	96.0	0.2	

	LL	PI	D_{85}	D_{60}	D_{50}	D_{30}	D_{15}	D_{10}	C_c	C_u
o			0.82	0.51	0.47	0.413	0.3544	0.3195	1.04	1.6

	MATERIAL DESCRIPTION	USCS	AASHTO
o			

Project No.:
Project: DEEP WELL #4 15-35 FT
o Location:

Date: 8-92

GRAIN SIZE DISTRIBUTION TEST REPORT
EASTERN MICHIGAN UNIVERSITY

Remarks:

Figure No.______

GRAIN SIZE DISTRIBUTION TEST DATA   Test No.: 6

Date: 8-92
Project No.:
Project: DEEP WELL #4 15-35 FT

Sample Data

Location of Sample:
Sample Description:
USCS Class: Liquid limit:
AASHTO Class: Plasticity index:

Notes

Remarks:

Fig. No.:

Mechanical Analysis Data

Initial
Dry sample and tare= 319.00
Tare = 0.00
Dry sample weight = 319.00
Sieve tare method

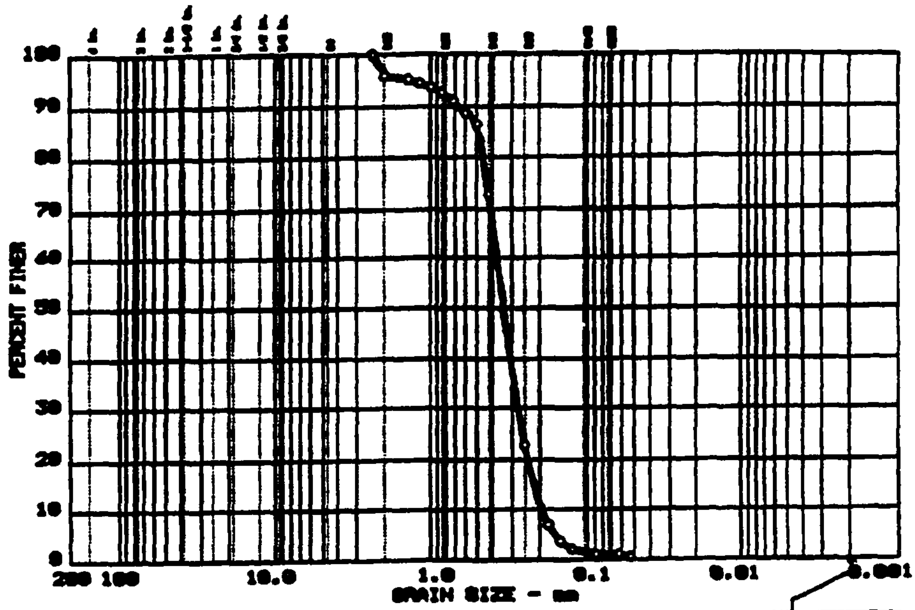
Sieve	Weight retained	Sieve tare	Percent finer
# 8	0.00	0.00	100.0
# 10	12.00	0.00	96.2
# 14	7.00	0.00	94.0
# 20	25.00	0.00	86.2
# 30	61.00	0.00	67.1
# 35	30.00	0.00	57.7
# 40	81.00	0.00	32.3
# 60	81.00	0.00	6.9
# 100	18.00	0.00	1.3
# 230	4.00	0.00	0.0

Fractional Components

% + 3 in. = 0.0 % GRAVEL = 3.8 % SAND = 96.0
% FINES = 0.2

D85= 0.82 D60= 0.512 D50= 0.471
D30= 0.4130 D15= 0.35441 D10= 0.31952
Cc = 1.0423 Cu = 1.6032

GRAIN SIZE DISTRIBUTION TEST REPORT



	Test	% +3"	% GRAVEL	% SAND	% SILT	% CLAY
O	12	0.0	4.1	94.8	1.1	

	LL	PI	D_{85}	D_{60}	D_{50}	D_{30}	D_{15}	D_{10}	C_c	C_u
O			0.40	0.37	0.34	0.273	0.2193	0.1982	1.03	1.9

MATERIAL DESCRIPTION	USCS	AASHTO
O D_{95} = 1.3 mm D_5 = .16 mm		

Project No.:
Project: DEEP WELL #5 0-5 FT
O Location:

Date: 10-93

Remarks:

GRAIN SIZE DISTRIBUTION TEST REPORT
EASTERN MICHIGAN UNIVERSITY

Figure No.____

GRAIN SIZE DISTRIBUTION TEST DATA

Test No.: 12

Date: 10-93
Project No.:
Project: DEEP WELL #5 0-5 FT

Sample Data

Location of Sample:
Sample Description:
USCS Class: Liquid limit:
AASHTO Class: Plasticity index:

Notes

Remarks:

Fig. No.:

Mechanical Analysis Data

	Initial
Dry sample and tare=	315.60
Tare =	0.00
Dry sample weight =	315.60

Sieve tare method

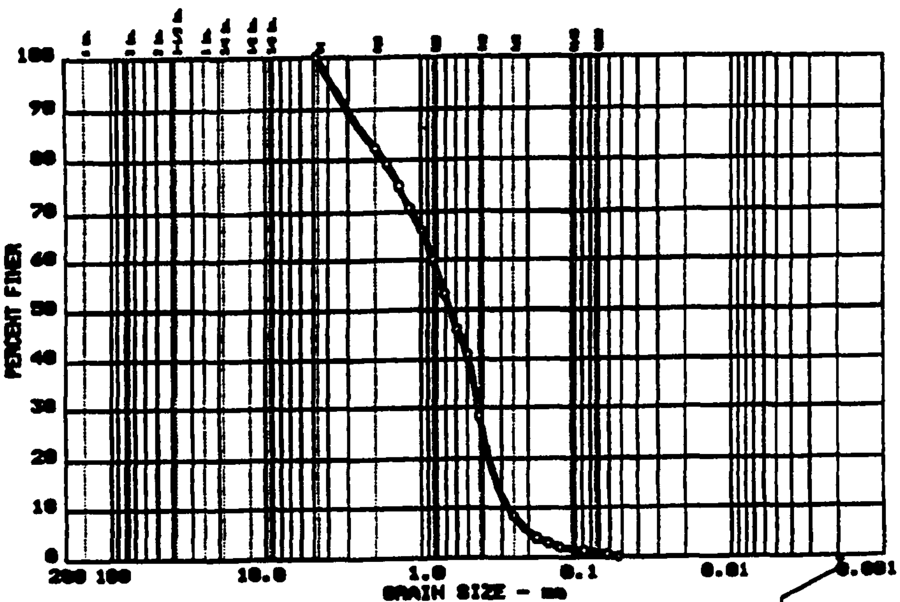
Sieve	Weight retained	Sieve tare	Percent finer
# 8	0.00	0.00	100.0
# 10	12.90	0.00	95.9
# 14	2.00	0.00	95.3
# 16	2.30	0.00	94.6
# 18	2.60	0.00	93.7
# 20	3.20	0.00	92.7
# 25	5.30	0.00	91.0
# 30	7.50	0.00	88.7
# 35	6.70	0.00	86.5
# 40	42.70	0.00	73.0
# 60	158.00	0.00	22.9
# 80	50.20	0.00	7.0
# 100	10.30	0.00	3.8
# 120	5.40	0.00	2.1
# 170	2.70	0.00	1.2
# 230	0.60	0.00	1.0
# 270	1.60	0.00	0.5

Fractional Components

% + 3 in. = 0.0 % GRAVEL = 4.1 % SAND = 94.8
% FINES = 1.1

D85= 0.48 D60= 0.370 D50= 0.336
D30= 0.2732 D15= 0.21928 D10= 0.19521
Cc = 1.0340 Cu = 1.8945

GRAIN SIZE DISTRIBUTION TEST REPORT



	Test	% +3"	% GRAVEL	% SAND	% SILT	% CLAY
o	15	0.0	17.7	81.3	1.0	

	LL	PI	D_{85}	D_{60}	D_{50}	D_{30}	D_{15}	D_{10}	C_c	C_u
o			2.34	0.83	0.66	0.429	0.3251	0.2673	0.83	3.1

	MATERIAL DESCRIPTION	USCS	AASHTO
o	D_{95} = 3.8 mm D_5 = .20 mm		

Project No.:
Project: DEEP WELL #5 5-15 FT
o Location:

Date: 10-93

GRAIN SIZE DISTRIBUTION TEST REPORT
EASTERN MICHIGAN UNIVERSITY

Remarks:

Figure No.____

GRAIN SIZE DISTRIBUTION TEST DATA Test No.: 1

Date: 8-2-92
Project No.: Deep Well #5
Project: Eastern Michigan University

Sample Data

Location of Sample: 5-15 Ft. below surface
Sample Description: Sand
USCS Class: Liquid limit:
AASHTO Class: Plasticity index:

Notes

Remarks: #1 Uncalculated Mechanical Test

Fig. No.: 1

Mechanical Analysis Data

Initial
Dry sample and tare= 333.00
Tare = 9.00
Dry sample weight = 324.00
Tare for cumulative weight retained= 9

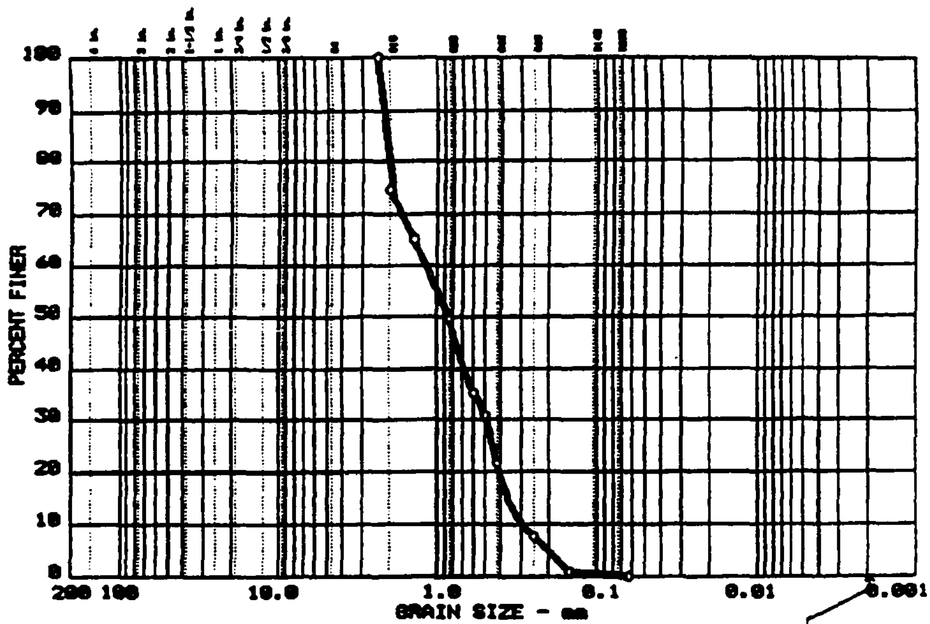
Sieve	Cumul. Wt. retained	Percent finer
# 10	115.00	67.3
# 14	144.00	58.3
# 20	190.00	44.1
# 30	227.00	32.7
# 35	236.00	29.9
# 40	259.00	22.8
# 60	296.00	11.4
# 100	315.00	5.6
# 230	319.00	4.3

Fractional Components

% + 3 in. = 0.0 % GRAVEL = 0.0 % SAND = 96.0
% FINES = 4.0

D85= 2.00 D60= 1.500 D50= 1.013
D30= 0.4995 D15= 0.31880 D10= 0.22056
Cc = 0.7542 Cu = 6.7999

GRAIN SIZE DISTRIBUTION TEST REPORT



	Test	% +3"	% GRAVEL	% SAND	% SILT	% CLAY
o	20	0.0	25.3	74.5	0.2	

	LL	PI	D_{85}	D_{60}	D_{50}	D_{30}	D_{15}	D_{10}	C_c	C_u
o			2.15	1.17	0.85	0.490	0.3587	0.2917	0.70	4.0

MATERIAL DESCRIPTION	USCS	AASHTO
o		

Project No.:
Project: DEEP WELL #5 15-20 FT
o Location:

Date: 8-92

GRAIN SIZE DISTRIBUTION TEST REPORT
EASTERN MICHIGAN UNIVERSITY

Remarks:

Figure No._____

GRAIN SIZE DISTRIBUTION TEST DATA Test No.: 20

Date: 8-92
Project No.:
Project: DEEP WELL #5 15-20 FT

Sample Data

Location of Sample:
Sample Description:
USCS Class: Liquid limit:
AASHTO Class: Plasticity index:

Notes

Remarks:

Fig. No.:

Mechanical Analysis Data

	Initial
Dry sample and tare=	324.00
Tare =	0.00
Dry sample weight =	324.00

Sieve tare method

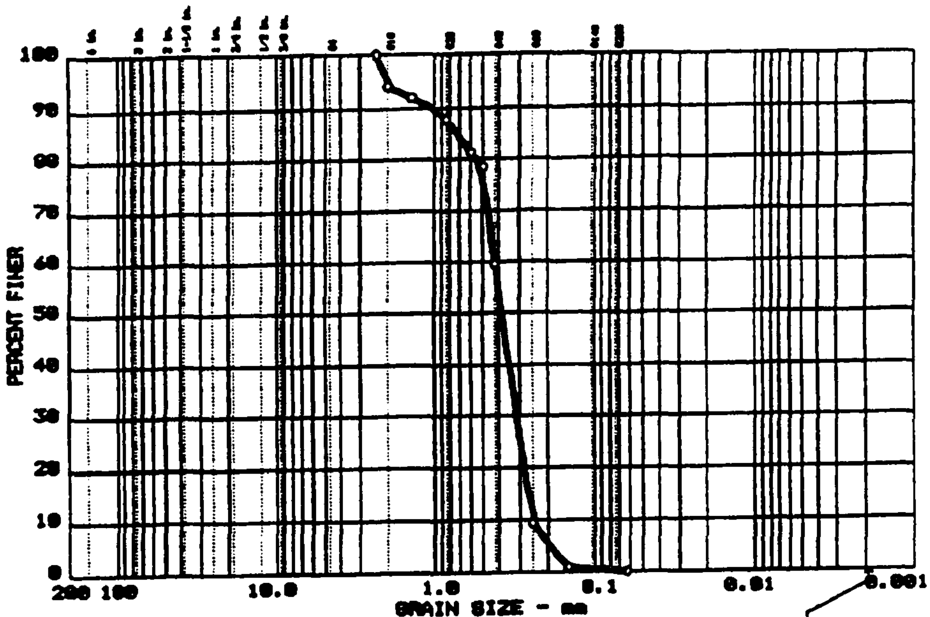
Sieve	Weight retained	Sieve tare	Percent finer
# 8	0.00	0.00	100.0
# 10	82.00	0.00	74.7
# 14	31.00	0.00	65.1
# 20	50.00	0.00	49.7
# 30	47.00	0.00	35.2
# 35	14.00	0.00	30.9
# 40	30.00	0.00	21.6
# 60	45.00	0.00	7.7
# 100	22.00	0.00	0.9
# 230	3.00	0.00	0.0

Fractional Components

% + 3 in. = 0.0 % GRAVEL = 25.3 % SAND = 74.5
% FINES = 0.2

D85= 2.15 D60= 1.174 D50= 0.847
D30= 0.4898 D15= 0.35892 D10= 0.29174
Cc = 0.7006 Cu = 4.0225

GRAIN SIZE DISTRIBUTION TEST REPORT



	Test	% +3"	% GRAVEL	% SAND	% SILT	% CLAY
o	5	0.0	5.0	94.8	0.2	

	LL	PI	D_{85}	D_{60}	D_{50}	D_{30}	D_{15}	D_{10}	C_c	C_u
o			0.72	0.42	0.38	0.309	0.2644	0.2500	0.91	1.7

MATERIAL DESCRIPTION	USCS	AASHTO
o		

Project No.:
Project: DEEP WELL #5 20-30 FT
o Location:

Date: 8-92

GRAIN SIZE DISTRIBUTION TEST REPORT
EASTERN MICHIGAN UNIVERSITY

Remarks:

Figure No.____

GRAIN SIZE DISTRIBUTION TEST DATA

Test No.: 5

Date: 8-92
Project No.:
Project: DEEP WELL #5 20-30 FT

Sample Data

Location of Sample:
Sample Description:
USCS Class: Liquid limit:
AASHTO Class: Plasticity index:

Notes

Remarks:

Fig. No.:

Mechanical Analysis Data

Initial
Dry sample and tare= 327.00
Tare = 0.00
Dry sample weight = 327.00
Sieve tare method

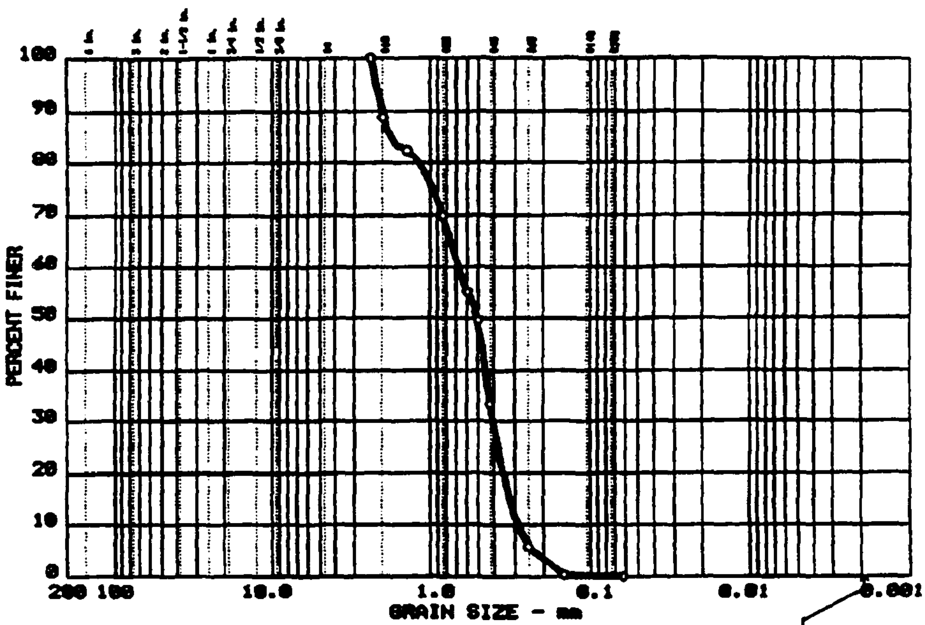
Sieve	Weight retained	Sieve tare	Percent finer
# 8	0.00	0.00	100.0
# 10	19.00	0.00	94.2
# 14	7.00	0.00	92.0
# 20	14.00	0.00	87.8
# 30	21.00	0.00	81.3
# 35	9.00	0.00	78.6
# 40	62.00	0.00	59.6
# 60	164.00	0.00	9.5
# 100	28.00	0.00	0.9
# 230	3.00	0.00	0.0

Fractional Components

% + 3 in. = 0.0 % GRAVEL = 5.8 % SAND = 94.0
% FINES = 0.2

D85= 0.72 D60= 0.420 D50= 0.380
D30= 0.3088 D15= 0.26439 D10= 0.25000
Cc = 0.9085 Cu = 1.6800

GRAIN SIZE DISTRIBUTION TEST REPORT



	Test	% +3"	% GRAVEL	% SAND	% SILT	% CLAY
o	3	0.0	11.2	88.7	0.1	

	LL	PI	D_{85}	D_{60}	D_{50}	D_{30}	D_{15}	D_{10}	C_c	C_u
o			1.79	0.67	0.50	0.404	0.3202	0.2048	0.85	2.4

MATERIAL DESCRIPTION	USCS	AASHTO
o		

Project No.:
Project: DEEP WELL #5 30-33 FT
o Location:

Date: 8-92

GRAIN SIZE DISTRIBUTION TEST REPORT
EASTERN MICHIGAN UNIVERSITY

Remarks:

Figure No.____

GRAIN SIZE DISTRIBUTION TEST DATA Test No.: 3

Date: 8-92
Project No.:
Project: DEEP WELL #5 30-33 FT

Sample Data

Location of Sample:
Sample Description:
USCS Class: Liquid limit:
AASHTO Class: Plasticity index:

Notes

Remarks:

Fig. No.:

Mechanical Analysis Data

Initial
Dry sample and tare= 329.00
Tare = 0.00
Dry sample weight = 329.00
Sieve tare method

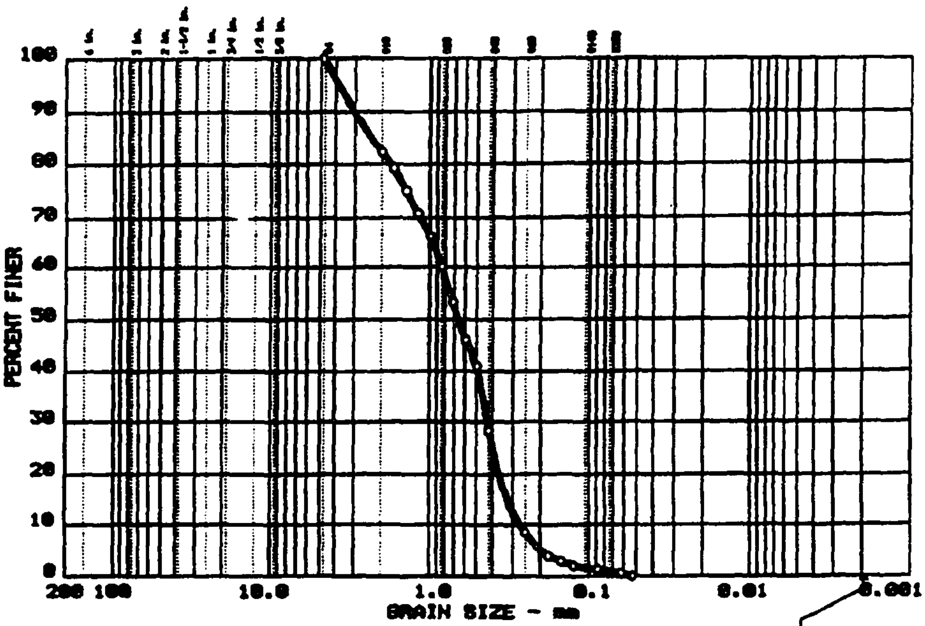
Sieve	Weight retained	Sieve tare	Percent finer
# 8	0.00	0.00	100.0
# 10	37.00	0.00	88.8
# 14	21.00	0.00	82.4
# 20	41.00	0.00	69.9
# 30	48.00	0.00	55.3
# 35	19.00	0.00	49.5
# 40	53.00	0.00	33.4
# 60	91.00	0.00	5.8
# 100	18.00	0.00	0.3
# 230	1.00	0.00	0.0

Fractional Components

% + 3 in. = 0.0 % GRAVEL = 11.2 % SAND = 88.7
% FINES = 0.1

D85= 1.79 D60= 0.673 D50= 0.500
D30= 0.4036 D15= 0.32024 D10= 0.28475
Cc = 0.8501 Cu = 2.3634

GRAIN SIZE DISTRIBUTION TEST REPORT



	Test	% +3"	% GRAVEL	% SAND	% SILT	% CLAY
o	13	0.0	17.7	81.3	1.0	

	LL	PI	D_{85}	D_{60}	D_{50}	D_{30}	D_{15}	D_{10}	C_c	C_u
o			2.34	0.83	0.66	0.429	0.3251	0.2673	0.83	3.1

MATERIAL DESCRIPTION	USCS	AASHTO
o		

Project No.:
Project: DEEP WELL #5 5-15 FT
o Location:

Date: 10-93

GRAIN SIZE DISTRIBUTION TEST REPORT
EASTERN MICHIGAN UNIVERSITY

Remarks:

Figure No._____

GRAIN SIZE DISTRIBUTION TEST DATA — Test No.: 13

Date: 10-93
Project No.:
Project: DEEP WELL #5 5-15 FT

Sample Data

Location of Sample:
Sample Description:
USCS Class: Liquid limit:
AASHTO Class: Plasticity index:

Notes

Remarks:

Fig. No.:

Mechanical Analysis Data

Initial
Dry sample and tare= 586.80
Tare = 0.00
Dry sample weight = 586.80
Sieve tare method

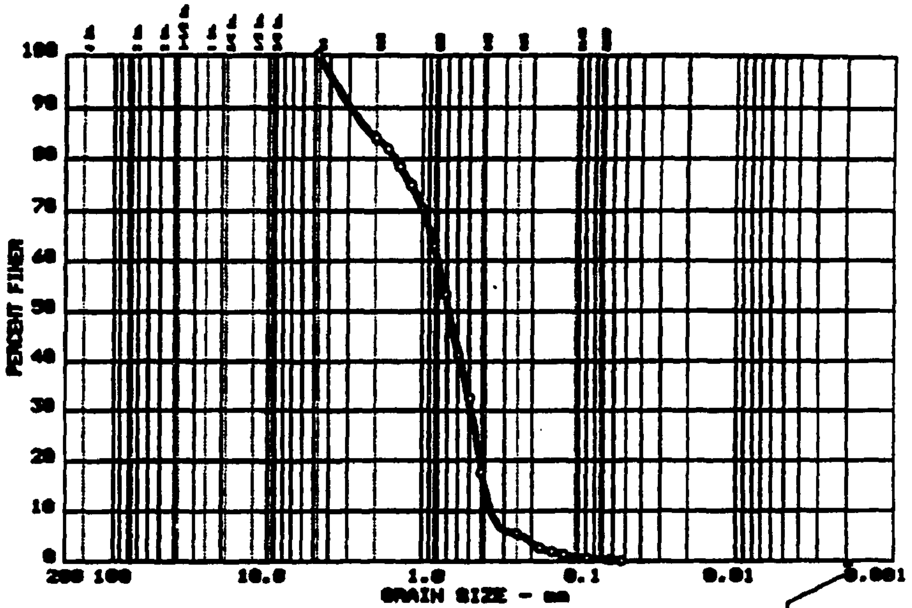
Sieve	Weight retained	Sieve tare	Percent finer
# 4	0.00	0.00	100.0
# 10	104.00	0.00	82.3
# 12	17.50	0.00	79.3
# 14	24.90	0.00	75.1
# 16	24.70	0.00	70.8
# 18	26.90	0.00	66.3
# 20	35.20	0.00	60.3
# 25	40.60	0.00	53.3
# 30	42.80	0.00	46.0
# 35	29.70	0.00	41.0
# 40	73.80	0.00	28.4
# 60	116.40	0.00	8.6
# 80	26.90	0.00	4.0
# 100	6.10	0.00	2.9
# 120	5.40	0.00	2.0
# 170	4.40	0.00	1.3
# 230	4.40	0.00	0.5
# 270	3.10	0.00	0.0

Fractional Components

% + 3 in. = 0.0 % GRAVEL = 17.7 % SAND = 81.3
% FINES = 1.0

D85= 2.34 D60= 0.831 D50= 0.657
D30= 0.4285 D15= 0.32509 D10= 0.26730
Cc = 0.8270 Cu = 3.1081

GRAIN SIZE DISTRIBUTION TEST REPORT



	Test	% +3"	% GRAVEL	% SAND	% SILT	% CLAY
o	10	0.0	15.8	83.7	0.5	

	LL	PI	D_{85}	D_{60}	D_{50}	D_{30}	D_{15}	D_{10}	C_c	C_u
o			2.14	0.79	0.60	0.483	0.4032	0.3635	0.81	2.2

MATERIAL DESCRIPTION	USCS	AASHTO
o $D_{95} = 3.8$ mm $D_5 = .23$ mm		

Project No.:
Project: DEEP WELL 06 0-10 FT
o Location:

Date: 10-93

Remarks:

GRAIN SIZE DISTRIBUTION TEST REPORT
EASTERN MICHIGAN UNIVERSITY

Figure No._____

GRAIN SIZE DISTRIBUTION TEST DATA Test No.: 10

Date: 10-93
Project No.:
Project: DEEP WELL #6 0-10 FT

Sample Data

Location of Sample:
Sample Description:
USCS Class: Liquid limit:
AASHTO Class: Plasticity index:

Notes

Remarks:

Fig. No.:

Mechanical Analysis Data

Initial
Dry sample and tare= 689.00
Tare = 0.00
Dry sample weight = 689.00
Sieve tare method

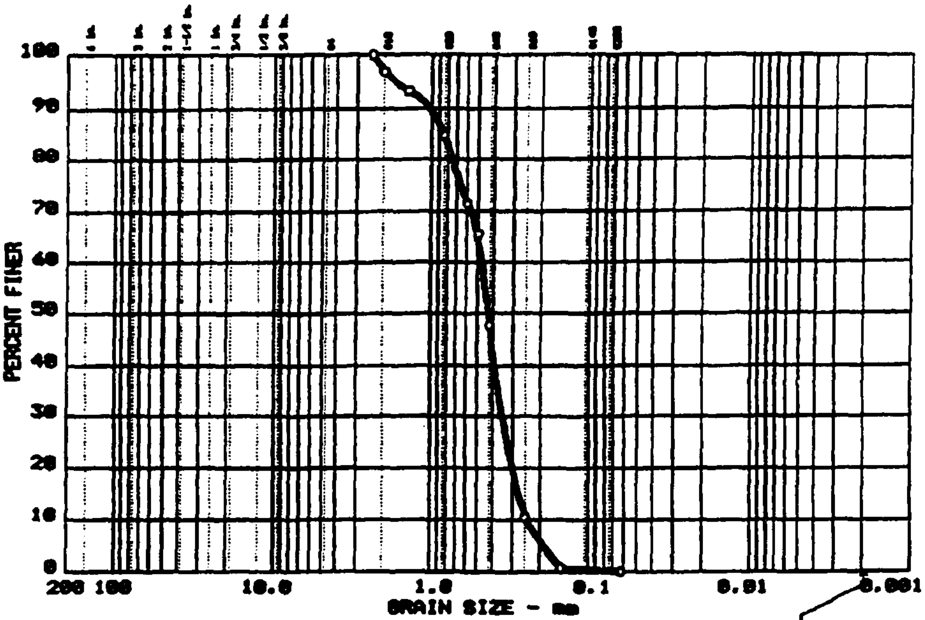
Sieve	Weight retained	Sieve tare	Percent finer
# 4	0.00	0.00	100.0
# 10	109.10	0.00	84.2
# 12	14.50	0.00	82.1
# 14	23.10	0.00	78.7
# 16	25.10	0.00	75.1
# 18	31.20	0.00	70.5
# 20	50.40	0.00	63.2
# 25	67.40	0.00	53.4
# 30	84.20	0.00	41.2
# 35	59.30	0.00	32.6
# 40	101.80	0.00	17.8
# 60	84.20	0.00	5.6
# 80	20.20	0.00	2.7
# 100	5.50	0.00	1.9
# 120	4.20	0.00	1.3
# 170	4.50	0.00	0.6
# 230	2.10	0.00	0.3
# 270	2.00	0.00	0.0

Fractional Components

% + 3 in. = 0.0 % GRAVEL = 15.8 % SAND = 83.7
% FINES = 0.5

D85= 2.14 D60= 0.790 D50= 0.675
D30= 0.4831 D15= 0.40318 D10= 0.36350
Cc = 0.8128 Cu = 2.1727

GRAIN SIZE DISTRIBUTION TEST REPORT



	Test	% +3"	% GRAVEL	% SAND	% SILT	% CLAY
o	1	0.0	3.2	96.7	0.1	

	LL	PI	D_{85}	D_{60}	D_{50}	D_{30}	D_{15}	D_{10}	C_c	C_u
o			0.84	0.47	0.43	0.344	0.2732	0.2435	1.04	1.9

	MATERIAL DESCRIPTION	USCS	AASHTO
o			

Project No.:
Project: DEEP WELL #6 10-20 FT
o Location:

Date: 8-92

GRAIN SIZE DISTRIBUTION TEST REPORT

EASTERN MICHIGAN UNIVERSITY

Remarks:

Figure No.____

GRAIN SIZE DISTRIBUTION TEST DATA   Test No.: 1

Date: 8-92
Project No.:
Project: DEEP WELL #6 10-20 FT

Sample Data

Location of Sample:
Sample Description:
USCS Class: Liquid limit:
AASHTO Class: Plasticity index:

Notes

Remarks:

Fig. No.:

Mechanical Analysis Data

	Initial
Dry sample and tare=	315.00
Tare =	0.00
Dry sample weight =	315.00

Sieve tare method

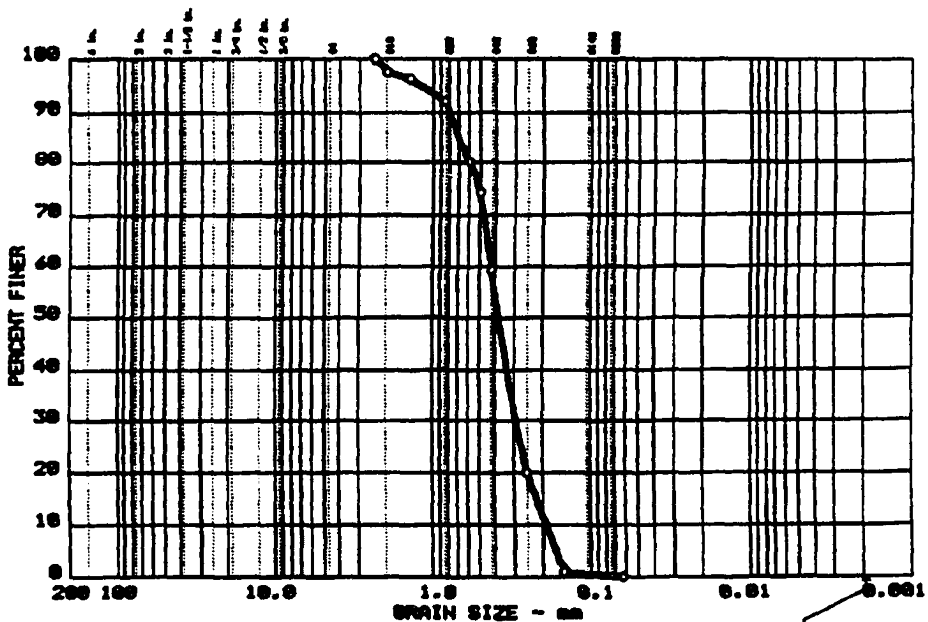
Sieve	Weight retained	Sieve tare	Percent finer
# 8	0.00	0.00	100.0
# 10	10.00	0.00	96.8
# 14	11.00	0.00	93.3
# 20	27.00	0.00	84.8
# 30	42.00	0.00	71.4
# 35	19.00	0.00	65.4
# 40	56.00	0.00	47.6
# 60	117.00	0.00	10.5
# 100	31.00	0.00	0.6
# 230	2.00	0.00	0.0

Fractional Components

% + 3 in. = 0.0 % GRAVEL = 3.2 % SAND = 96.7
% FINES = 0.1

D85= 0.84 D60= 0.469 D50= 0.429
D30= 0.3443 D15= 0.27321 D10= 0.24350
Cc = 1.0375 Cu = 1.9275

GRAIN SIZE DISTRIBUTION TEST REPORT



	Test	% +3"	% GRAVEL	% SAND	% SILT	% CLAY
o	2	0.0	2.4	97.4	0.2	

	LL	PI	D_{85}	D_{60}	D_{50}	D_{30}	D_{15}	D_{10}	C_c	C_u
o			0.69	0.42	0.38	0.290	0.2175	0.1985	1.04	2.2

	MATERIAL DESCRIPTION	USCS	AASHTO
o			

Project No.:
Project: DEEP WELL #6 20-33 FT
o Location:

Date: 8-92

Remarks:

GRAIN SIZE DISTRIBUTION TEST REPORT
EASTERN MICHIGAN UNIVERSITY

Figure No.____

GRAIN SIZE DISTRIBUTION TEST DATA Test No.: 2

Date: 8-92
Project No.:
Project: DEEP WELL #6 20-33 FT

Sample Data

Location of Sample:
Sample Description:
USCS Class: Liquid limit:
AASHTO Class: Plasticity index:

Notes

Remarks:

Fig. No.:

Mechanical Analysis Data

	Initial
Dry sample and tare=	330.00
Tare =	0.00
Dry sample weight =	330.00

Sieve tare method

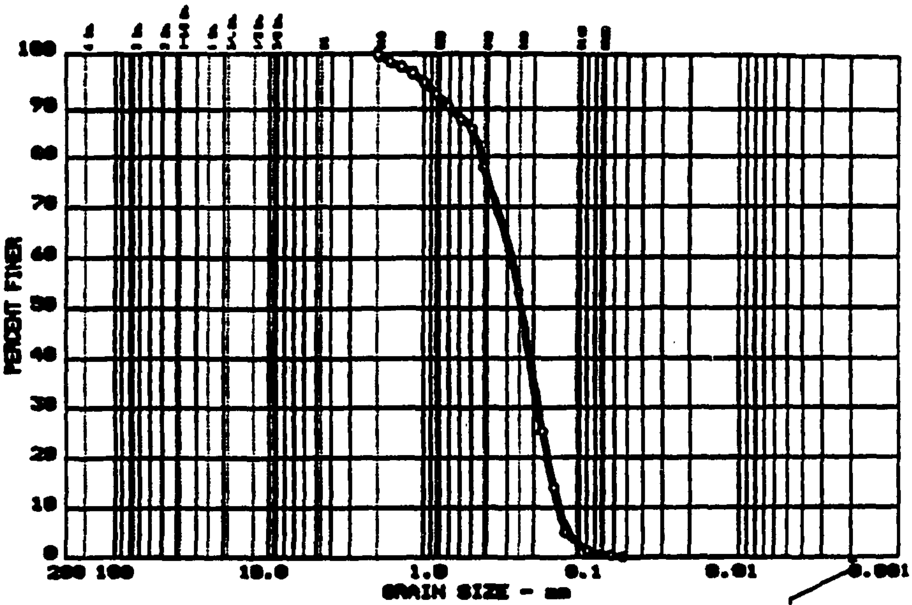
Sieve	Weight retained	Sieve tare	Percent finer
# 8	0.00	0.00	100.0
# 10	8.00	0.00	97.6
# 14	4.00	0.00	96.4
# 20	14.00	0.00	92.1
# 30	39.00	0.00	80.3
# 35	20.00	0.00	74.2
# 40	49.00	0.00	59.4
# 60	130.00	0.00	20.0
# 100	63.00	0.00	0.9
# 230	3.00	0.00	0.0

Fractional Components

% + 3 in. = 0.0 % GRAVEL = 2.4 % SAND = 97.4
% FINES = 0.2

D85= 0.69 D60= 0.423 D50= 0.376
D30= 0.2901 D15= 0.21752 D10= 0.19055
Cc = 1.0447 Cu = 2.2182

GRAIN SIZE DISTRIBUTION TEST REPORT



	Test	% +3"	% GRAVEL	% SAND	% SILT	% CLAY
O	9	0.0	0.0	99.3	0.7	

	LL	PI	D_{85}	D_{60}	D_{50}	D_{30}	D_{15}	D_{10}	C_c	C_u
O			0.40	0.28	0.24	0.180	0.1510	0.1374	0.92	2.0

	MATERIAL DESCRIPTION	USCS	AASHTO
O	D_{95} = 1.0 mm D_5 = .125 mm		

Project No.:
Project: DEEP WELL 07 0-15 FT
O Location:

Date: 10-93

GRAIN SIZE DISTRIBUTION TEST REPORT
EASTERN MICHIGAN UNIVERSITY

Remarks:

Figure No.____

GRAIN SIZE DISTRIBUTION TEST DATA — Test No.: 9

Date: 10-93
Project No.:
Project: DEEP WELL #7 0-15 FT

Sample Data

Location of Sample:
Sample Description:
USCS Class: Liquid limit:
AASHTO Class: Plasticity index:

Notes

Remarks:

Fig. No.:

Mechanical Analysis Data

Initial
Dry sample and tare= 741.60
Tare = 0.00
Dry sample weight = 741.60
Sieve tare method

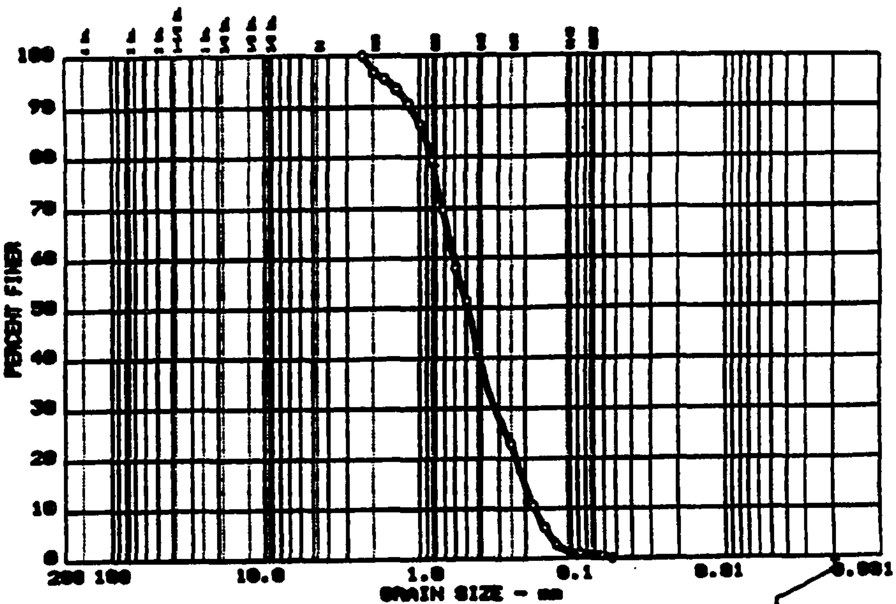
Sieve	Weight retained	Sieve tare	Percent finer
# 10	0.00	0.00	100.0
# 12	9.00	0.00	98.8
# 14	6.70	0.00	97.9
# 16	9.10	0.00	96.7
# 18	12.40	0.00	95.0
# 20	15.50	0.00	92.9
# 25	17.20	0.00	90.6
# 30	19.30	0.00	88.0
# 35	14.20	0.00	86.1
# 40	59.40	0.00	78.0
# 60	183.50	0.00	53.3
# 80	207.70	0.00	25.3
# 100	83.20	0.00	14.1
# 120	66.30	0.00	5.1
# 170	28.40	0.00	1.3
# 230	6.90	0.00	0.4
# 270	2.80	0.00	0.0

Fractional Components

% + 3 in. = 0.0 % GRAVEL = 0.0 % SAND = 99.3
% FINES = 0.7

D85= 0.48 D60= 0.279 D50= 0.239
D30= 0.1879 D15= 0.15101 D10= 0.13740
Cc = 0.9226 Cu = 2.0277

GRAIN SIZE DISTRIBUTION TEST REPORT



Test	% +3"	% GRAVEL	% SAND	% SILT	% CLAY
o 7	0.0	3.2	96.8	0.0	

	LL	PI	D_{85}	D_{60}	D_{50}	D_{30}	D_{15}	D_{10}	C_c	C_u
o			0.95	0.61	0.49	0.318	0.2004	0.1726	0.96	3.5

MATERIAL DESCRIPTION	USCS	AASHTO
o D_{95} = 1.6 mm D_5 .14 mm	D_{20}=	

Project No.:
Project: DEEP WELL #7 15-20 FT
o Location:

Date: 10-93

Remarks:

GRAIN SIZE DISTRIBUTION TEST REPORT
EASTERN MICHIGAN UNIVERSITY

Figure No.______

GRAIN SIZE DISTRIBUTION TEST DATA　　Test No.: 7

Date: 10-93
Project No.:
Project: DEEP WELL #7 15-20 FT

Sample Data

Location of Sample:
Sample Description:
USCS Class: Liquid limit:
AASHTO Class: Plasticity index:

Notes

Remarks:

Fig. No.:

Mechanical Analysis Data

Initial
Dry sample and tare= 707.50
Tare = 0.00
Dry sample weight = 707.50
Sieve tare method

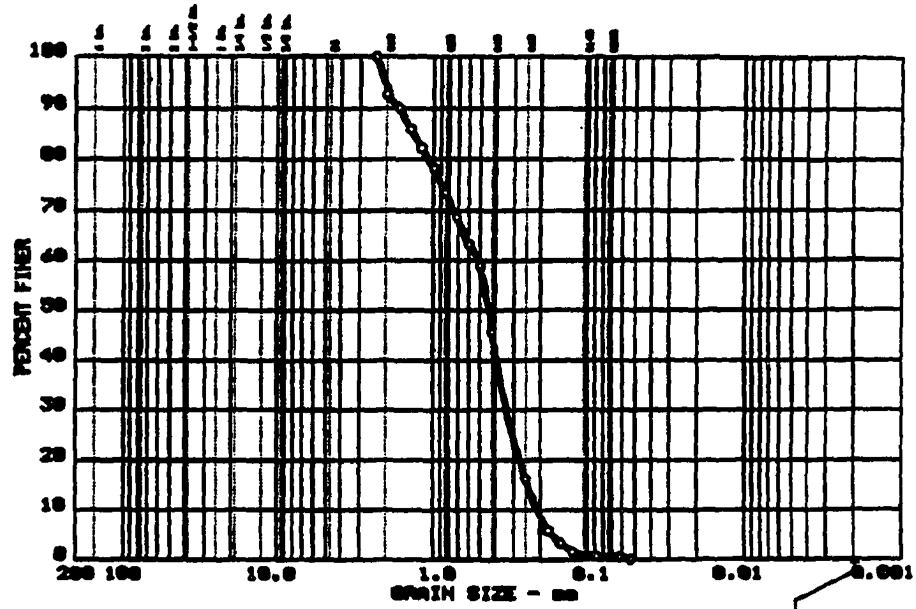
Sieve	Weight retained	Sieve tare	Percent finer
# 8	0.00	0.00	100.0
# 10	22.70	0.00	96.8
# 12	8.40	0.00	95.6
# 14	15.00	0.00	93.5
# 16	20.20	0.00	90.6
# 18	29.60	0.00	86.4
# 20	49.20	0.00	79.5
# 25	69.20	0.00	69.7
# 30	81.50	0.00	58.2
# 35	48.20	0.00	51.4
# 40	71.10	0.00	41.3
# 60	130.10	0.00	22.9
# 80	86.20	0.00	10.8
# 100	32.10	0.00	6.2
# 120	24.40	0.00	2.8
# 170	12.80	0.00	1.0
# 230	3.10	0.00	0.5
# 270	3.70	0.00	0.0

Fractional Components

% + 3 in. = 0.0　% GRAVEL = 3.2　% SAND = 96.0
% FINES = 0.8

D85= 0.95 D60= 0.610 D50= 0.486
D30= 0.3177 D15= 0.20045 D10= 0.17258
Cc = 0.9594 Cu = 3.5318

GRAIN SIZE DISTRIBUTION TEST REPORT



Test	% +3"	% GRAVEL	% SAND	% SILT	% CLAY
o 5	0.0	7.3	92.0	0.7	

	LL	PI	D_{85}	D_{60}	D_{50}	D_{30}	D_{15}	D_{10}	C_c	C_u
o			1.35	0.51	0.44	0.335	0.2410	0.2075	1.06	2.5

MATERIAL DESCRIPTION	USCS	AASHTO
o D_{95} = 2.1mm D_5 = .17mm	D_{20} = .27	mm

Project No.:
Project: DEEP WELL 07 20-30 FT
o Location:

Date: 10-93

Remarks:

GRAIN SIZE DISTRIBUTION TEST REPORT
EASTERN MICHIGAN UNIVERSITY

Figure No._____

GRAIN SIZE DISTRIBUTION TEST DATA   Test No.: 5

Date: 10-93
Project No.:
Project: DEEP WELL #7 20-30 FT

Sample Data

Location of Sample:
Sample Description:
USCS Class: Liquid limit:
AASHTO Class: Plasticity index:

Notes

Remarks:

Fig. No.:

Mechanical Analysis Data

Initial
Dry sample and tare= 859.40
Tare = 0.00
Dry sample weight = 859.40
Sieve tare method

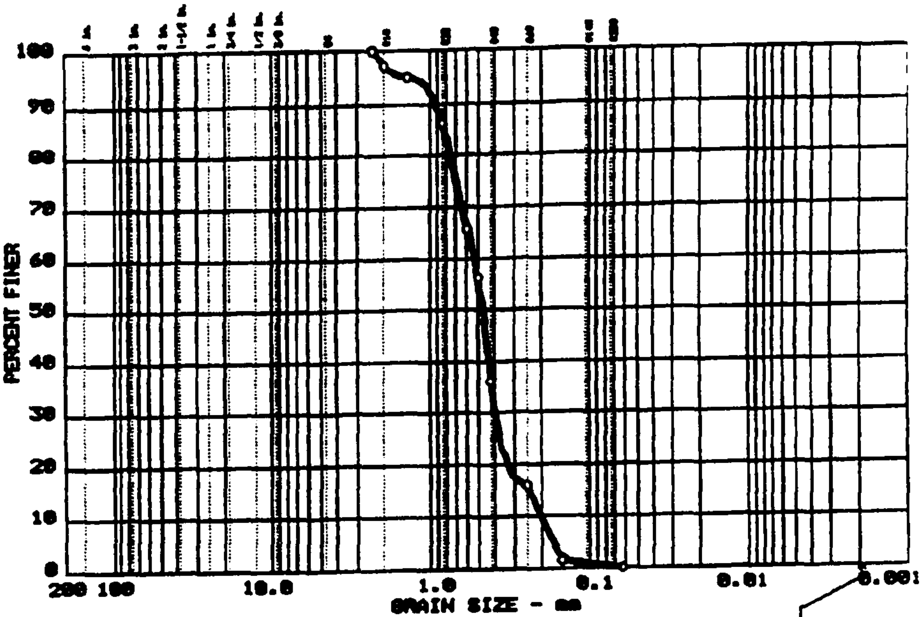
Sieve	Weight retained	Sieve tare	Percent finer
# 8	0.00	0.00	100.0
# 10	63.00	0.00	92.7
# 12	22.00	0.00	90.1
# 14	34.90	0.00	86.0
# 16	32.80	0.00	82.2
# 18	33.10	0.00	78.4
# 20	41.70	0.00	73.5
# 25	41.20	0.00	68.7
# 30	45.70	0.00	63.4
# 35	38.30	0.00	59.0
# 40	113.60	0.00	45.7
# 60	252.50	0.00	16.4
# 80	89.20	0.00	6.0
# 100	21.70	0.00	3.5
# 120	15.40	0.00	1.7
# 170	8.20	0.00	0.7
# 230	2.00	0.00	0.5
# 270	4.00	0.00	0.0

Fractional Components

% + 3 in. = 0.0 % GRAVEL = 7.3 % SAND = 92.0
% FINES = 0.7

D85= 1.35 D60= 0.511 D50= 0.442
D30= 0.3346 D15= 0.24099 D10= 0.20749
Cc = 1.0556 Cu = 2.4632

GRAIN SIZE DISTRIBUTION TEST REPORT



Test	% +3"	% GRAVEL	% SAND	% SILT	% CLAY
o 7	0.0	2.7	97.0	0.3	

	LL	PI	D_{85}	D_{60}	D_{50}	D_{30}	D_{15}	D_{10}	C_c	C_u
o			0.82	0.52	0.47	0.395	0.2402	0.2011	1.40	2.6

	MATERIAL DESCRIPTION	USCS	AASHTO
o			

Project No.:
Project: DEEP WELL #7 30-43 FT
o Location:

Date: 8-92

GRAIN SIZE DISTRIBUTION TEST REPORT
EASTERN MICHIGAN UNIVERSITY

Remarks:

Figure No.____

GRAIN SIZE DISTRIBUTION TEST DATA

Test No.: 7

Date: 8-92
Project No.:
Project: DEEP WELL #7 30-43 FT

Sample Data

Location of Sample:
Sample Description:
USCS Class: Liquid limit:
AASHTO Class: Plasticity index:

Notes

Remarks:

Fig. No.:

Mechanical Analysis Data

	Initial
Dry sample and tare=	329.00
Tare =	0.00
Dry sample weight =	329.00

Sieve tare method

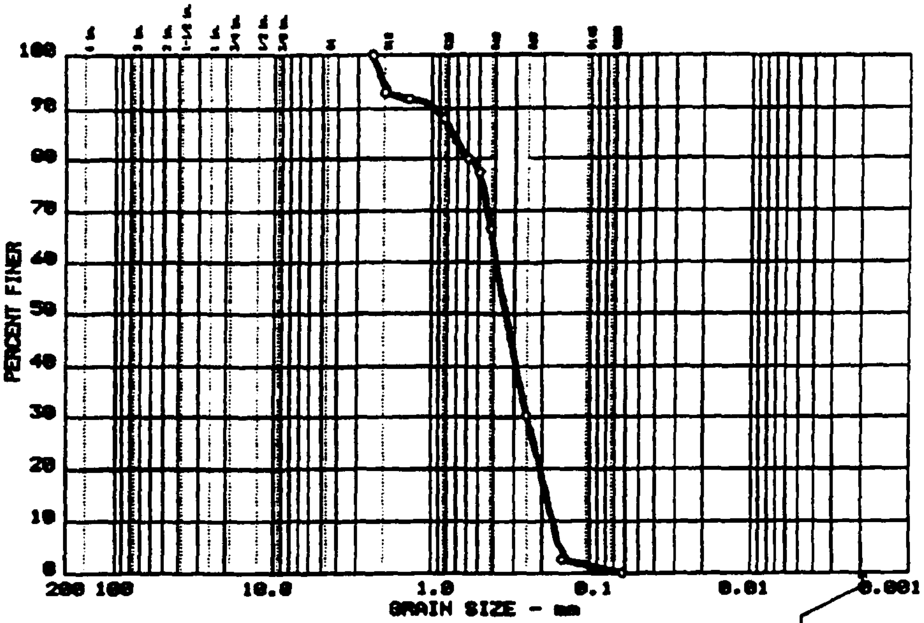
Sieve	Weight retained	Sieve tare	Percent finer
# 8	0.00	0.00	100.0
# 10	9.00	0.00	97.3
# 14	7.00	0.00	95.1
# 20	29.00	0.00	86.3
# 30	68.00	0.00	65.7
# 35	30.00	0.00	56.5
# 40	67.00	0.00	36.2
# 60	66.00	0.00	16.1
# 100	48.00	0.00	1.5
# 230	5.00	0.00	0.0

Fractional Components

% + 3 in. = 0.0 % GRAVEL = 2.7 % SAND = 97.0
% FINES = 0.3

D85= 0.82 D60= 0.524 D50= 0.470
D30= 0.3954 D15= 0.24016 D10= 0.20114
Cc = 1.4842 Cu = 2.6032

GRAIN SIZE DISTRIBUTION TEST REPORT



Test	% +3"	% GRAVEL	% SAND	% SILT	% CLAY
O 0	0.0	6.9	92.6	0.5	

	LL	PI	D_{85}	D_{60}	D_{50}	D_{30}	D_{15}	D_{10}	C_c	C_u
O			0.74	0.38	0.33	0.240	0.1875	0.1700	0.93	2.3

MATERIAL DESCRIPTION	USCS	AASHTO
O		

Project No.:
Project: DEEP WELL #8 25-35 FT
O Location:

Date: 8-92

GRAIN SIZE DISTRIBUTION TEST REPORT
EASTERN MICHIGAN UNIVERSITY

Remarks:

Figure No.____

GRAIN SIZE DISTRIBUTION TEST DATA

Test No.: 8

Date: 8-92
Project No.:
Project: DEEP WELL #8 25-35 FT

Sample Data

Location of Sample:
Sample Description:
USCS Class: Liquid limit:
AASHTO Class: Plasticity index:

Notes

Remarks:

Fig. No.:

Mechanical Analysis Data

	Initial
Dry sample and tare=	333.00
Tare =	0.00
Dry sample weight =	333.00

Sieve tare method

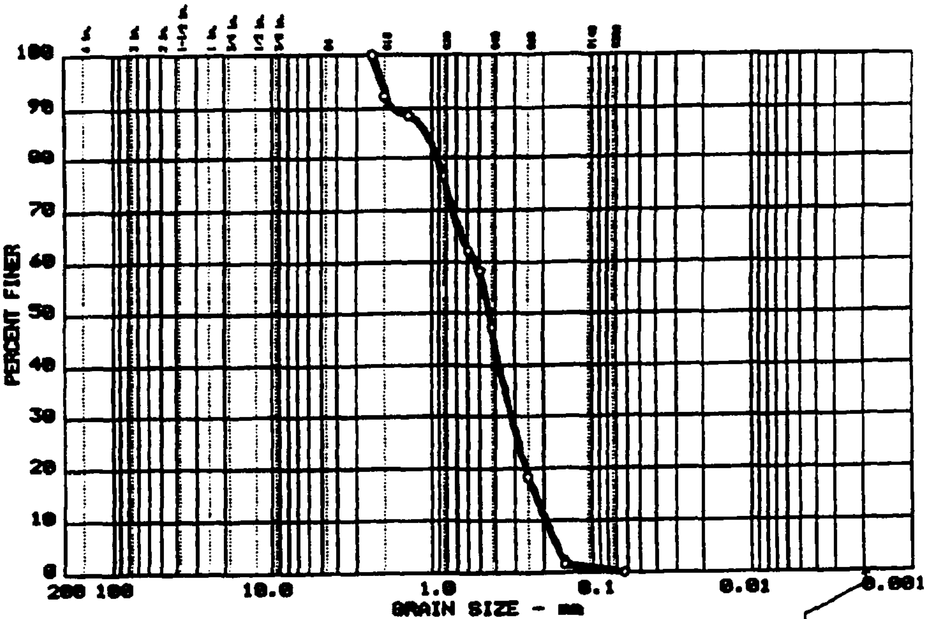
Sieve	Weight retained	Sieve tare	Percent finer
# 8	0.00	0.00	100.0
# 10	23.00	0.00	93.1
# 14	4.00	0.00	91.9
# 20	13.00	0.00	88.0
# 30	26.00	0.00	80.2
# 35	9.00	0.00	77.5
# 40	37.00	0.00	66.4
# 60	120.00	0.00	30.3
# 100	92.00	0.00	2.7
# 230	9.00	0.00	0.0

Fractional Components

% + 3 in. = 0.0 % GRAVEL = 6.9 % SAND = 92.6
% FINES = 0.5

D85= 0.74 D60= 0.385 D50= 0.334
D30= 0.2477 D15= 0.18750 D10= 0.17080
Cc = 0.9343 Cu = 2.2516

GRAIN SIZE DISTRIBUTION TEST REPORT



	Test	% +3"	% GRAVEL	% SAND	% SILT	% CLAY
o	9	0.0	7.7	92.0	0.3	

	LL	PI	D_{85}	D_{60}	D_{50}	D_{30}	D_{15}	D_{10}	C_c	C_u
o			1.00	0.52	0.44	0.316	0.2234	0.1923	0.99	2.7

MATERIAL DESCRIPTION	USCS	AASHTO
o		

Project No.:
Project: DEEP WELL #0 35-40 FT
o Location:

Date: 8-92

GRAIN SIZE DISTRIBUTION TEST REPORT

EASTERN MICHIGAN UNIVERSITY

Remarks:

Figure No.______

GRAIN SIZE DISTRIBUTION TEST DATA Test No.: 9

Date: 8-92
Project No.:
Project: DEEP WELL #8 35-40 FT

Sample Data

Location of Sample:
Sample Description:
USCS Class: Liquid limit:
AASHTO Class: Plasticity index:

Notes

Remarks:

Fig. No.:

Mechanical Analysis Data

	Initial
Dry sample and tare=	324.00
Tare =	0.00
Dry sample weight =	324.00

Sieve tare method

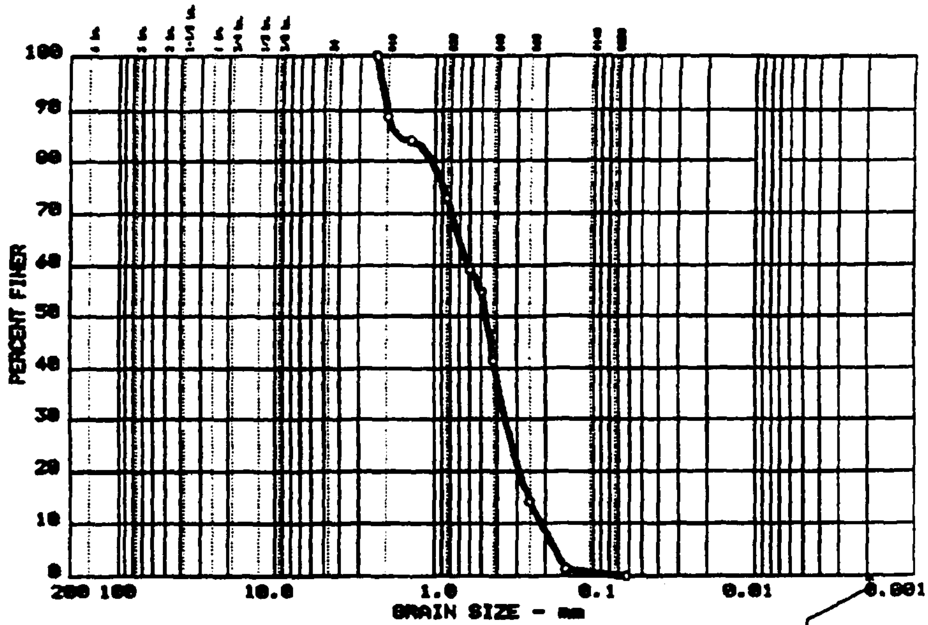
Sieve	Weight retained	Sieve tare	Percent finer
# 8	0.00	0.00	100.0
# 10	25.00	0.00	92.3
# 14	12.00	0.00	88.6
# 20	39.00	0.00	76.5
# 30	46.00	0.00	62.3
# 35	13.00	0.00	58.3
# 40	36.00	0.00	47.2
# 60	93.00	0.00	18.5
# 100	55.00	0.00	1.5
# 230	5.00	0.00	0.0

Fractional Components

% + 3 in. = 0.0 % GRAVEL = 7.7 % SAND = 92.0
% FINES = 0.3

D85= 1.08 D60= 0.525 D50= 0.436
D30= 0.3155 D15= 0.22336 D10= 0.19231
Cc = 0.9863 Cu = 2.7290

GRAIN SIZE DISTRIBUTION TEST REPORT



	Test	% +3"	% GRAVEL	% SAND	% SILT	% CLAY
O	10	0.0	11.3	88.5	0.2	

	LL	PI	D_{85}	D_{60}	D_{50}	D_{30}	D_{15}	D_{10}	C_c	C_u
O			1.74	0.61	0.46	0.356	0.2547	0.2094	0.99	2.9

	MATERIAL DESCRIPTION	USCS	AASHTO
O			

Project No.:
Project: DEEP WELL 08 40-45 FT
O Location:

Date: 8-92

GRAIN SIZE DISTRIBUTION TEST REPORT
EASTERN MICHIGAN UNIVERSITY

Remarks:

Figure No._____

GRAIN SIZE DISTRIBUTION TEST DATA   Test No.: 10

Date: 8-92
Project No.:
Project: DEEP WELL #8 40-45 FT

Sample Data

Location of Sample:
Sample Description:
USCS Class: Liquid limit:
AASHTO Class: Plasticity index:

Notes

Remarks:

Fig. No.:

Mechanical Analysis Data

	Initial
Dry sample and tare=	328.00
Tare =	0.00
Dry sample weight =	328.00

Sieve tare method

Sieve	Weight retained	Sieve tare	Percent finer
# 8	0.00	0.00	100.0
# 10	37.00	0.00	88.7
# 14	15.00	0.00	84.1
# 20	37.00	0.00	72.9
# 30	45.00	0.00	59.1
# 35	14.00	0.00	54.9
# 40	44.00	0.00	41.5
# 60	89.00	0.00	14.3
# 100	43.00	0.00	1.2
# 230	4.00	0.00	0.0

Fractional Components

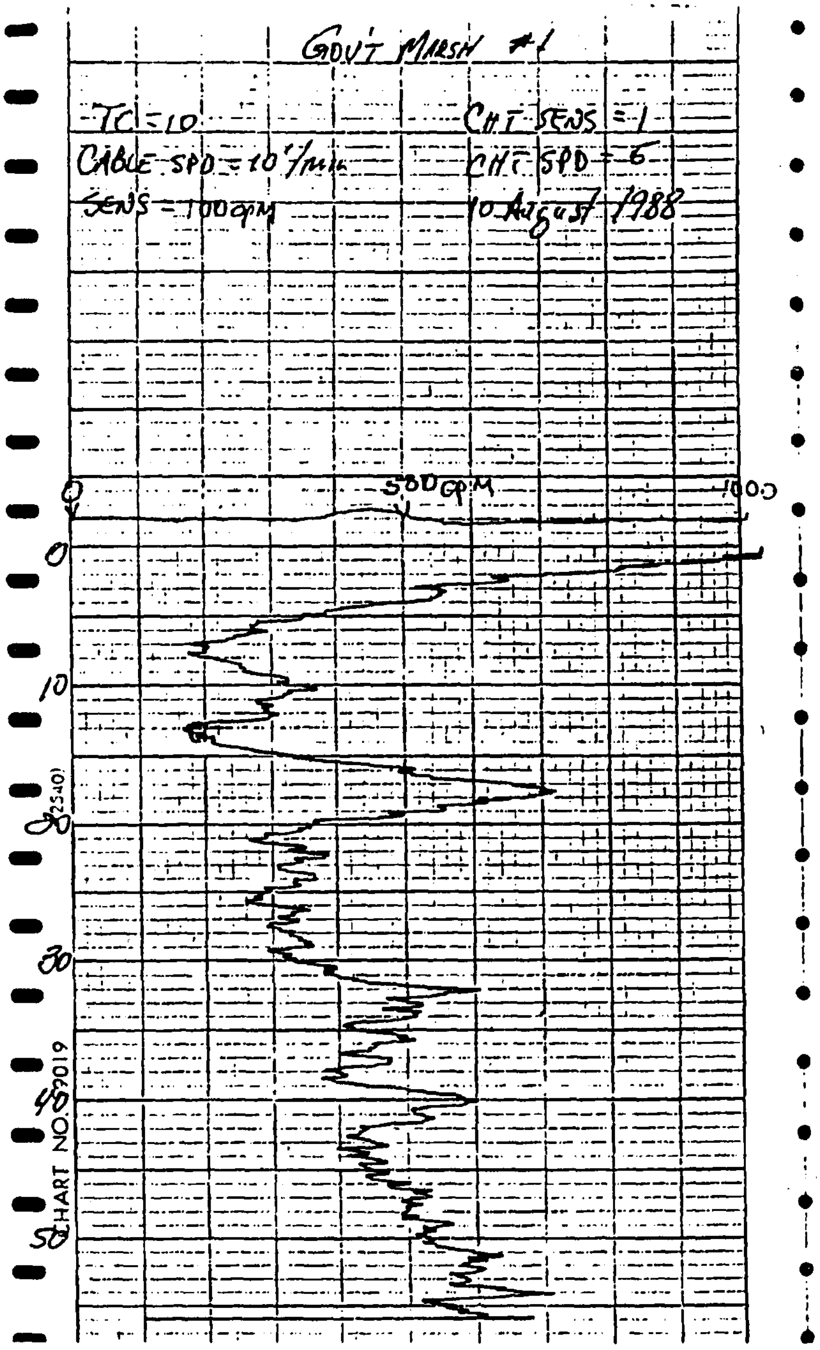
% + 3 in. = 0.0   % GRAVEL = 11.3   % SAND = 88.5
% FINES = 0.2

D85= 1.74 D60= 0.610 D50= 0.465
D30= 0.3556 D15= 0.25468 D10= 0.20941
Cc = 0.9908 Cu = 2.9107

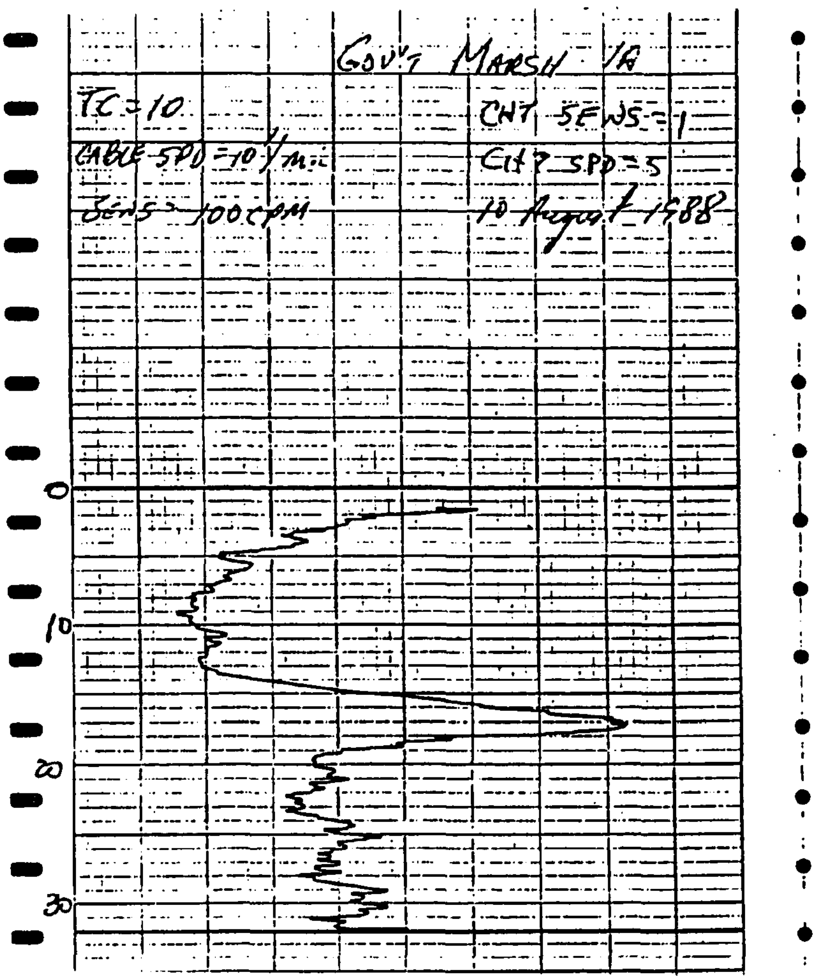
Appendix B

Gamma Ray Logs

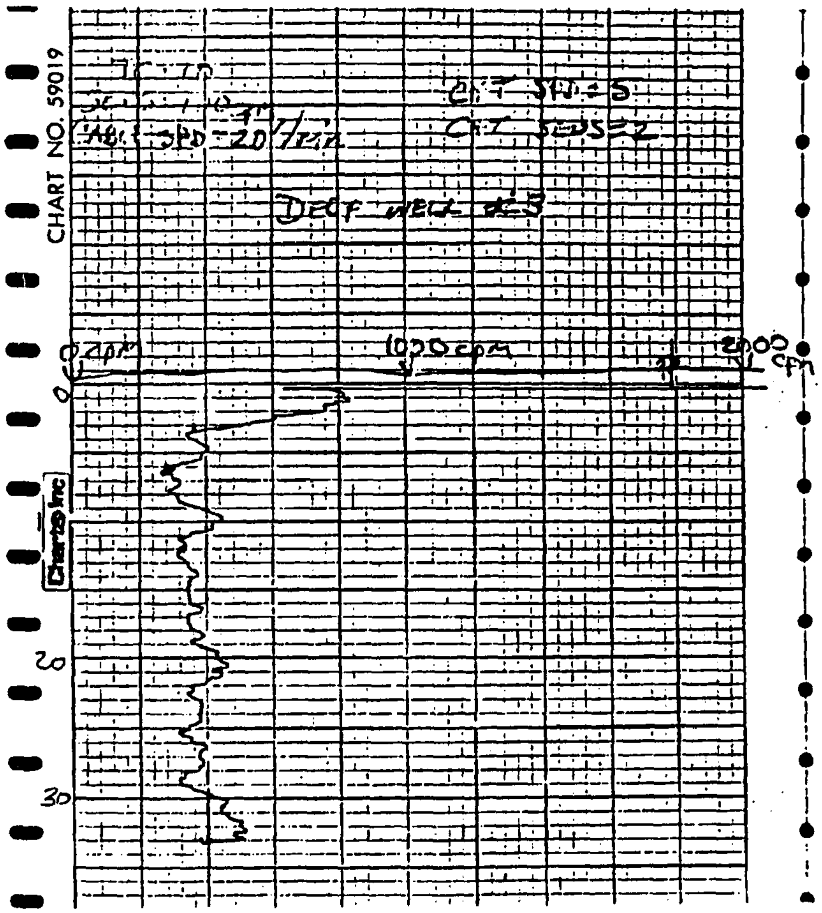
Gamma Ray Log For Deep Well One



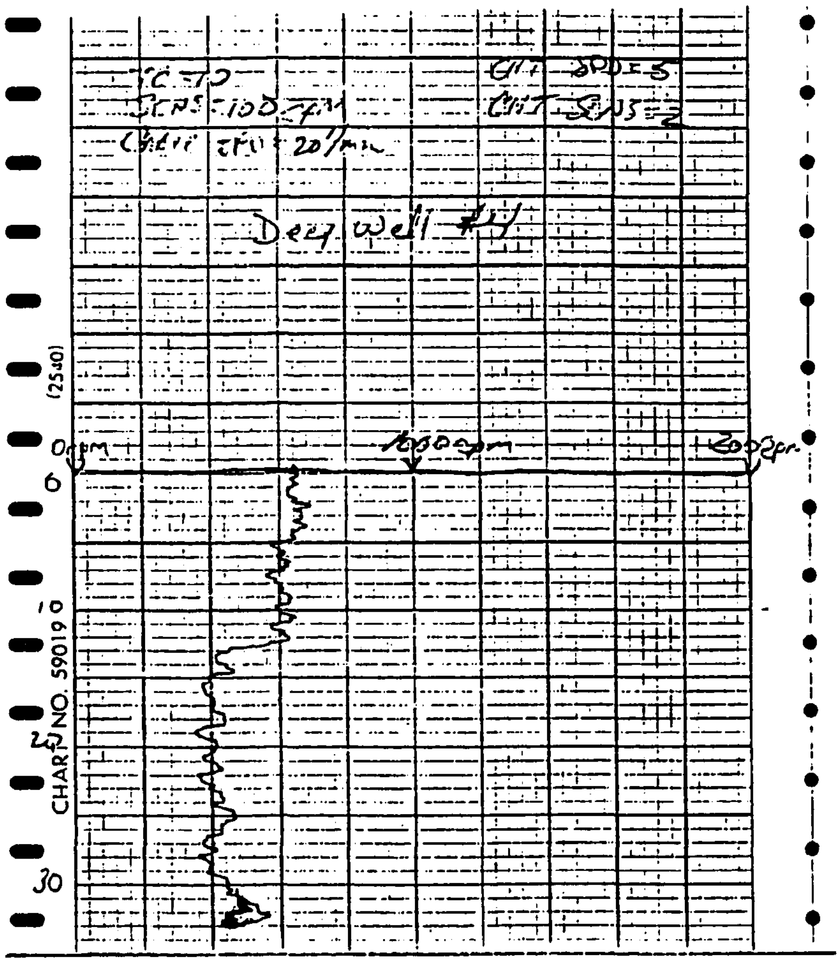
Gamma Ray Log For Deep Well Two



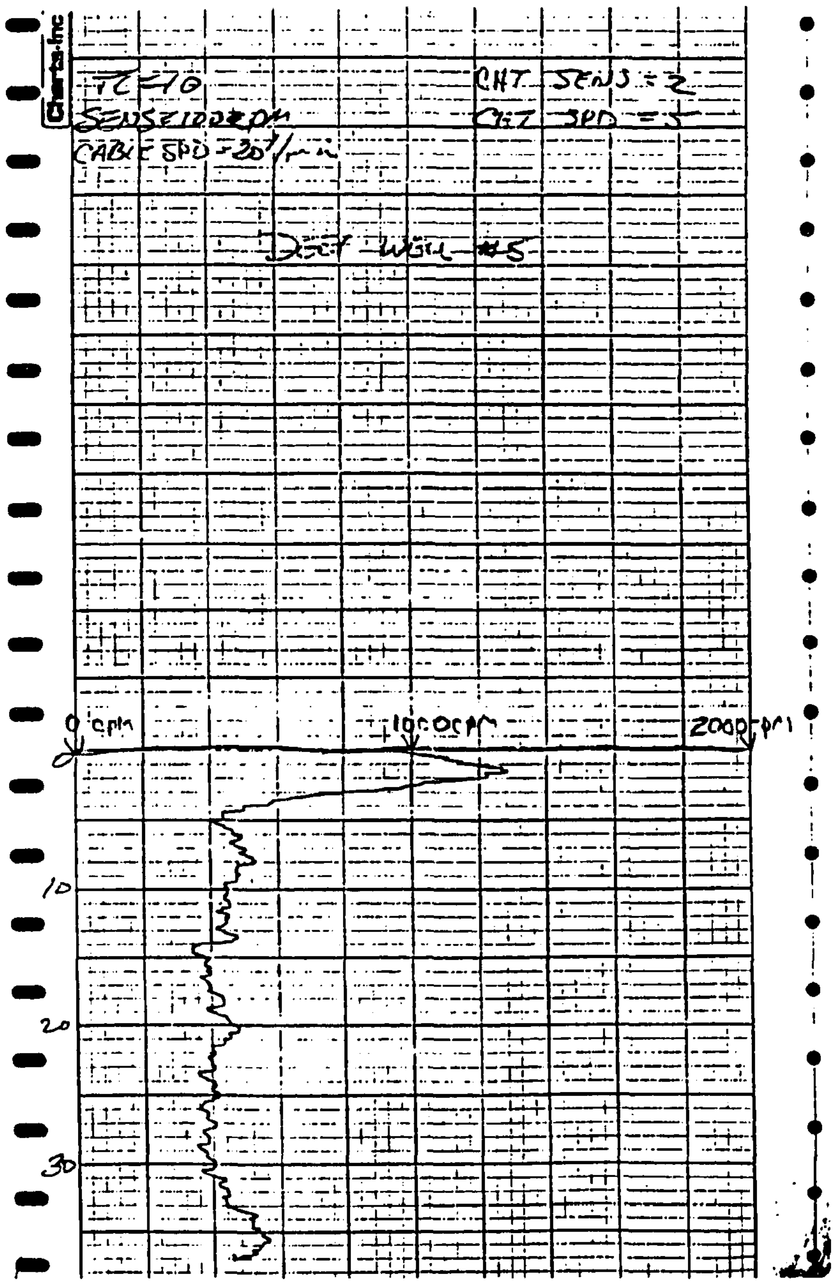
Gamma Ray Log For Deep Well Three



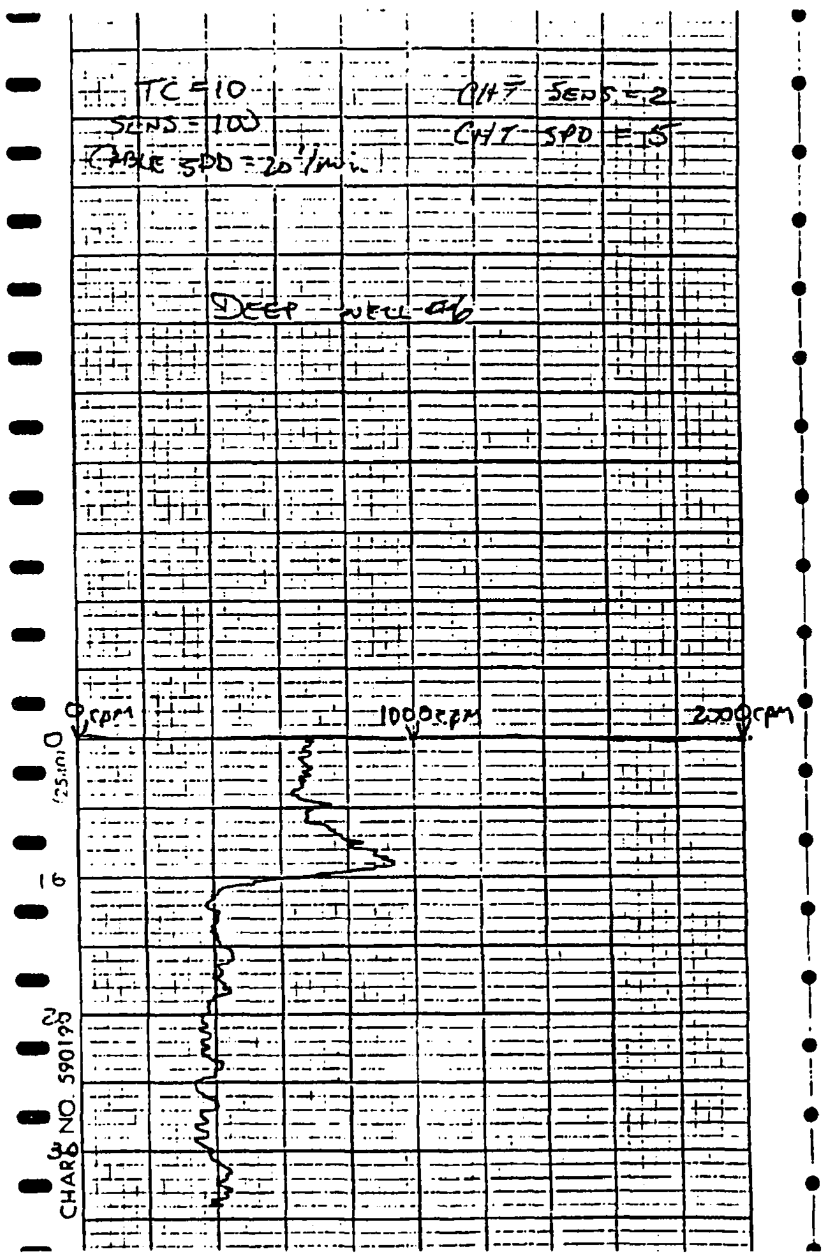
Gamma Ray Log For Deep Well Four



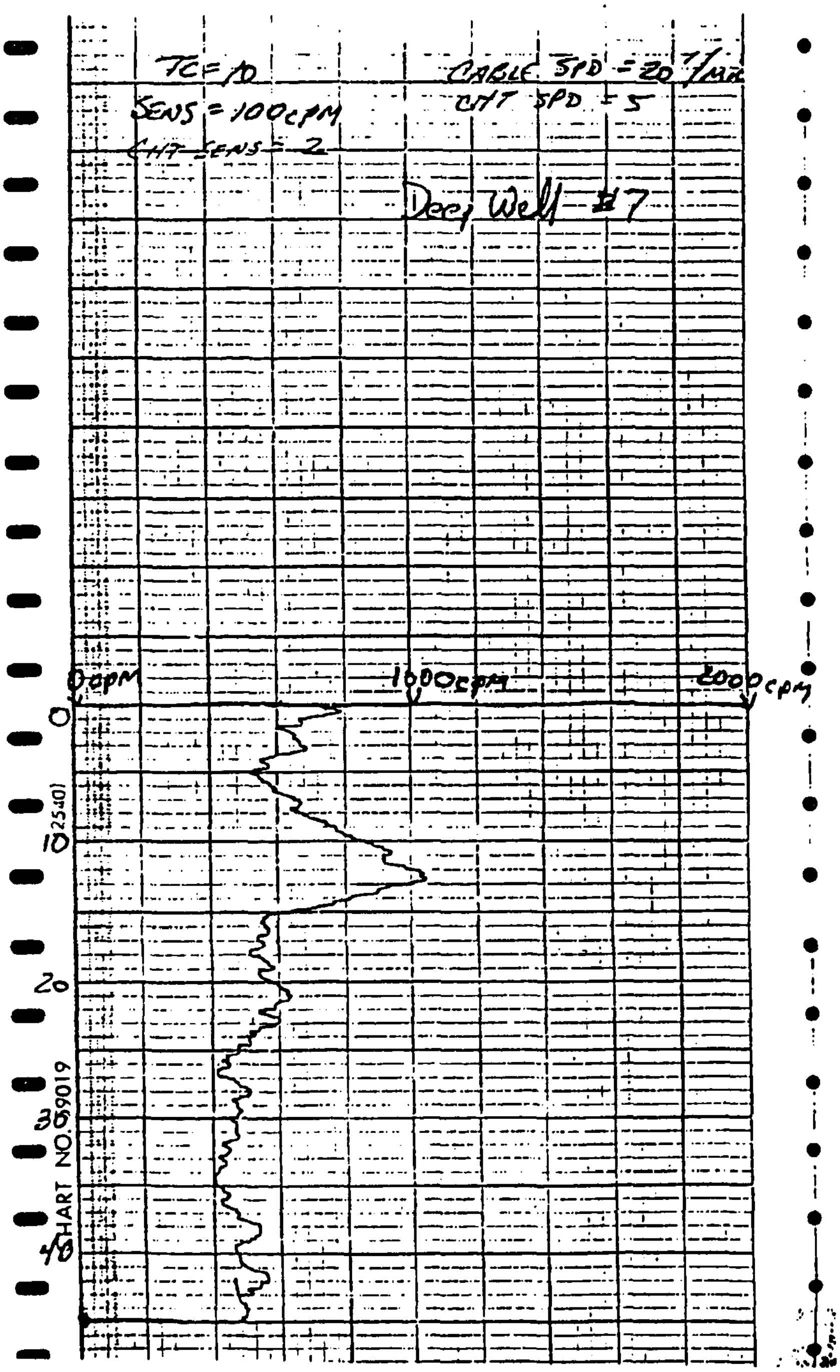
Gamma Ray Log For Deep Well Five



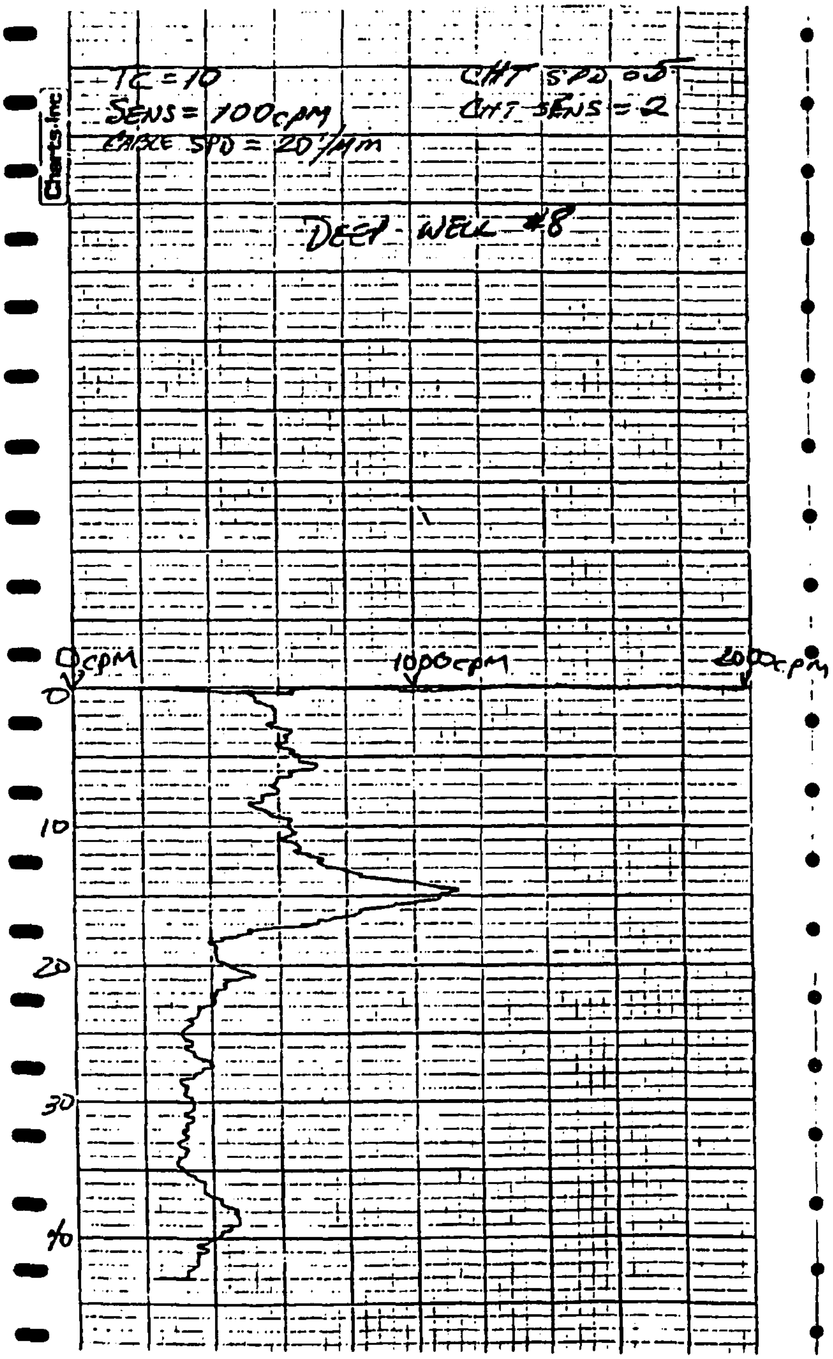
Gamma Ray Log For Deep Well Six



Gamma Ray Log For Deep Well Seven



Gamma Ray Log For Deep Well Eight



Appendix C

Deep Wells and Piezometers Static Water Table Data 1989

Static Water Table Data: January 1989

Piez / DW	Elevation TOC (ft)	Depth to Water (ft)	Water Table (ft)
Piez-1	841.19	5.6	835.59
Piez-2	844.03	10.8	833.23
Piez-3	844.28	11.2	833.08
Piez-4	840.71	6.95	833.76
Piez-5	844.36	10.35	834.01
Piez-6	842.13	8.75	833.38
Piez-7	841.94	8	833.94
Piez-8	852.97	18.6	834.37
Piez-9	842.43	8.4	834.03
Piez-10	845.16	11.1	834.06
Piez-13	841.06	6.98	834.08
Piez-15	842.7	8.3	834.4
Piez-17	846.21	frozen	frozen
Piez-18	842.81	8.05	834.76
Piez-20	841.78	6.9	834.88
Piez-21	842.14	7.15	834.99
Piez-22	844.32	9.2	835.12
Piez-23	841.44	6.33	835.11
Piez-24	846.08	9.95	836.13
Piez-25	850.99	15.8	835.19
Piez-26	843.67	7.93	835.74
Piez-27	845.09	11.15	833.94
Piez-28	843.15	7.1	836.05
Piez-29	842.3	frozen	frozen
Piez-34	836.46	frozen	frozen
Piez-35	847.22	12.43	834.79
Piez-37	839.28	frozen	frozen
Piez-38	839.95	frozen	frozen
Piez-39	839.64	6.15	833.49
DW-1	837.46	N/A	837.46
DW-2	837.32	5.25	832.07
DW-3	841.31	8.45	832.86
DW-4	849.38	14.15	835.23
DW-5	839.48	6.08	833.4
DW-6	846.8	12.3	834.5
DW-7	860.54	29.45	831.09
DW-8	858.28	26.85	831.43

Static Water Table Data: February 1989

Piez / DW	Elevation TOC (ft)	Depth to Water (ft)	Water Table (ft)
Piez-1	841.19	5.3	835.89
Piez-2	844.03	10.88	833.15
Piez-3	844.28	11.53	832.75
Piez-4	840.71	7.25	833.46
Piez-5	844.36	10.7	833.66
Piez-6	842.13	8.4	833.73
Piez-7	841.94	8.33	833.61
Piez-8	852.97	19	833.97
Piez-9	842.43	8.85	833.58
Piez-10	845.16	11.5	833.66
Piez-13	841.06	7.33	833.73
Piez-15	842.7	7.2	835.5
Piez-17	846.21	11.85	834.36
Piez-18	842.81	8.4	834.41
Piez-20	841.78	6.95	834.83
Piez-21	842.14	7.4	834.74
Piez-22	844.32	9.3	835.02
Piez-23	841.44	6.4	835.04
Piez-24	846.08	10.1	835.98
Piez-25	850.99	16.18	834.81
Piez-26	843.67	7.85	835.82
Piez-27	845.09	11.5	833.59
Piez-28	843.15	7.55	835.6
Piez-29	842.3	6.75	835.55
Piez-34	836.46	4.9	831.56
Piez-35	847.22	12.78	834.44
Piez-37	839.28	frozen	839.28
Piez-38	839.95	5.6	834.35
Piez-39	839.64	6.35	833.29
DW-1	837.46	5.8	831.66
DW-2	837.32	5.68	831.64
DW-3	841.31	8.85	832.46
DW-4	849.38	14.5	834.88
DW-5	839.48	6.3	833.18
DW-6	846.8	12.6	834.2
DW-7	860.54	30.03	830.51
DW-8	858.28	27.4	830.88

Static Water Table Data: March 1989

Piez / DW	Elevation TOC (ft)	Depth to Water (ft)	Water Table (ft)
Piez-1	841.19	5.15	836.04
Piez-2	844.03	11.05	832.98
Piez-3	844.28	11.35	832.93
Piez-4	840.71	6.85	833.86
Piez-5	844.36	10.25	834.11
Piez-6	842.13	7.93	834.2
Piez-7	841.94	7.85	834.09
Piez-8	852.97	18.75	834.22
Piez-9	842.43	8.4	834.03
Piez-10	845.16	11.05	834.11
Piez-13	841.06	6.65	834.41
Piez-15	842.7	6.6	836.1
Piez-17	846.21	11.45	834.76
Piez-18	842.81	8	834.81
Piez-20	841.78	6.9	834.88
Piez-21	842.14	7.2	834.94
Piez-22	844.32	8.95	835.37
Piez-23	841.44	6.45	834.99
Piez-24	846.08	9.9	836.18
Piez-25	850.99	15.9	835.09
Piez-26	843.67	8	835.67
Piez-27	845.09	9.7	835.39
Piez-28	843.15	7.58	835.57
Piez-29	842.3	6.65	835.65
Piez-34	836.46	4.8	831.66
Piez-35	847.22	12.55	834.67
Piez-37	839.28	4.27	835.01
Piez-38	839.95	5.5	834.45
Piez-39	839.64	6.25	833.39
DW-1	837.46	5.2	832.26
DW-2	837.32	5.3	832.02
DW-3	841.31	8.6	832.71
DW-4	849.38	14.2	835.18
DW-5	839.48	6.13	833.35
DW-6	846.8	12.35	834.45
DW-7	860.54	29.75	830.79
DW-8	858.28	27.45	830.83

Static Water Table Data: April 1989

Piez / DW	Elevation TOC (ft)	Depth to Water (ft)	Water Table (ft)
Piez-1	841.19	5.3	835.89
Piez-2	844.03	10.93	833.1
Piez-3	844.28	11.18	833.1
Piez-4	840.71	6.78	833.93
Piez-5	844.36	10.18	834.18
Piez-6	842.13	7.8	834.33
Piez-7	841.94	7.7	834.24
Piez-8	852.97	18.4	834.57
Piez-9	842.43	8.23	834.2
Piez-10	845.16	10.9	834.26
Piez-13	841.06	6.65	834.41
Piez-15	842.7	6.55	836.15
Piez-17	846.21	11.33	834.88
Piez-18	842.81	7.85	834.96
Piez-20	841.78	6.7	835.08
Piez-21	842.14	6.85	835.29
Piez-22	844.32	9	835.32
Piez-23	841.44	6.1	835.34
Piez-24	846.08	9.95	836.13
Piez-25	850.99	15.65	835.34
Piez-26	843.67	7.75	835.92
Piez-27	845.09	9.4	835.69
Piez-28	843.15	7.15	836
Piez-29	842.3	6.38	835.92
Piez-34	836.46	4.6	831.86
Piez-35	847.22	12.5	834.72
Piez-37	839.28	4.17	835.11
Piez-38	839.95	5.35	834.6
Piez-39	839.64	6.15	833.49
DW-1	837.46	5.5	831.96
DW-2	837.32	5.4	831.92
DW-3	841.31	8.5	832.81
DW-4	849.38	14	835.38
DW-5	839.48	6.05	833.43
DW-6	846.8	12.3	834.5
DW-7	860.54	30	830.54
DW-8	858.28	27.45	830.83

Static Water Table Data: May 1989

Piez / DW	Elevation TOC (ft)	Depth to Water (ft)	Water Table (ft)
Piez-1	841.19	5.53	835.66
Piez-2	844.03	10.93	833.1
Piez-3	844.28	11.48	832.8
Piez-4	840.71	7.08	833.63
Piez-5	844.36	10.5	833.86
Piez-6	842.13	8.15	833.98
Piez-7	841.94	8.05	833.89
Piez-8	852.97	18.88	834.09
Piez-9	842.43	8.65	833.78
Piez-10	845.16	11.375	833.785
Piez-13	841.06	7.1	833.96
Piez-15	842.7	6.98	835.72
Piez-17	846.21	11.78	834.43
Piez-18	842.81	8.35	834.46
Piez-20	841.78	6.85	834.93
Piez-21	842.14	6.98	835.16
Piez-22	844.32	9.13	835.19
Piez-23	841.44	6.25	835.19
Piez-24	846.08	10	836.08
Piez-25	850.99	16.15	834.84
Piez-26	843.67	7.9	835.77
Piez-27	845.09	9.93	835.16
Piez-28	843.15	7.3	835.85
Piez-29	842.3	6.5	835.8
Piez-34	836.46	4.8	831.66
Piez-35	847.22	12.8	834.42
Piez-37	839.28	4.4	834.88
Piez-38	839.95	5.65	834.3
Piez-39	839.64	6.38	833.26
DW-1	837.46	5.8	831.66
DW-2	837.32	5.7	831.62
DW-3	841.31	8.78	832.53
DW-4	849.38	14.45	834.93
DW-5	839.48	6.3	833.18
DW-6	846.8	12.6	834.2
DW-7	860.54	30.2	830.34
DW-8	858.28	27.65	830.63

Static Water Table Data: June 1989

Piez / DW	Elevation TOC (ft)	Depth to Water (ft)	Water Table (ft)
Piez-1	841.19	5.35	835.84
Piez-2	844.03	10.9	833.13
Piez-3	844.28	10.98	833.3
Piez-4	840.71	6.55	834.16
Piez-5	844.36	9.95	834.41
Piez-6	842.13	7.6	834.53
Piez-7	841.94	7.55	834.39
Piez-8	852.97	18.28	834.69
Piez-9	842.43	8.08	834.35
Piez-10	845.16	10.83	834.33
Piez-13	841.06	6.7	834.36
Piez-15	842.7	6.45	836.25
Piez-17	846.21	11.28	834.93
Piez-18	842.81	7.78	835.03
Piez-20	841.78	6.58	835.2
Piez-21	842.14	6.88	835.26
Piez-22	844.32	9	835.32
Piez-23	841.44	6.03	835.41
Piez-24	846.08	10	836.08
Piez-25	850.99	15.6	835.39
Piez-26	843.67	7.65	836.02
Piez-27	845.09	9.3	835.79
Piez-28	843.15	7.08	836.07
Piez-29	842.3	6.28	836.02
Piez-34	836.46	4.4	832.06
Piez-35	847.22	12.4	834.82
Piez-37	839.28	4	835.28
Piez-38	839.95	5.2	834.75
Piez-39	839.64	5.98	833.66
DW-1	837.46	5.4	832.06
DW-2	837.32	5.28	832.04
DW-3	841.31	8.28	833.03
DW-4	849.38	13.9	835.48
DW-5	839.48	5.95	833.53
DW-6	846.8	12.15	834.65
DW-7	860.54	29.8	830.74
DW-8	858.28	27.35	830.93

Static Water Table Data: July 1989

Piez / DW	Elevation TOC (ft)	Depth to Water (ft)	Water Table (ft)
Piez-1	841.19	5.35	835.84
Piez-2	844.03	10.78	833.25
Piez-3	844.28	11.1	833.18
Piez-4	840.71	6.6	834.11
Piez-5	844.36	9.98	834.38
Piez-6	842.13	7.48	834.65
Piez-7	841.94	7.3	834.64
Piez-8	852.97	18.73	834.24
Piez-9	842.43	7.95	834.48
Piez-10	845.16	10.98	834.18
Piez-13	841.06	6.83	834.23
Piez-15	842.7	6.9	835.8
Piez-17	846.21	11.93	834.28
Piez-18	842.81	8.45	834.36
Piez-20	841.78	7.2	834.58
Piez-21	842.14	7	835.14
Piez-22	844.32	9.35	834.97
Piez-23	841.44	6.35	835.09
Piez-24	846.08	10	836.08
Piez-25	850.99	16.45	834.54
Piez-26	843.67	8	835.67
Piez-27	845.09	10.23	834.86
Piez-28	843.15	7.83	835.32
Piez-29	842.3	6.55	835.75
Piez-34	836.46	5.25	831.21
Piez-35	847.22	13.3	833.92
Piez-37	839.28	4.05	835.23
Piez-38	839.95	6.1	833.85
Piez-39	839.64	6.63	833.01
DW-1	837.46	4.8	832.66
DW-2	837.32	4.7	832.62
DW-3	841.31	8.45	832.86
DW-4	849.38	14.73	834.65
DW-5	839.48	6.63	832.85
DW-6	846.8	13.23	833.57
DW-7	860.54	30.05	830.49
DW-8	858.28	27.63	830.65

Static Water Table Data: August 1989

Piez / DW	Elevation TOC (ft)	Depth to Water (ft)	Water Table (ft)
Piez-1	841.19	5.3	835.89
Piez-2	844.03	11.2	832.83
Piez-3	844.28	11.4	832.88
Piez-4	840.71	7.15	833.56
Piez-5	844.36	10.58	833.78
Piez-6	842.13	8.1	834.03
Piez-7	841.94	7.95	833.99
Piez-8	852.97	19.1	833.87
Piez-9	842.43	8.6	833.83
Piez-10	845.16	11.4	833.76
Piez-13	841.06	7.2	833.86
Piez-15	842.7	7.35	835.35
Piez-17	846.21	7.88	838.33
Piez-18	842.81	8.78	834.03
Piez-20	841.78	7.63	834.15
Piez-21	842.14	7.1	835.04
Piez-22	844.32	9.5	834.82
Piez-23	841.44	6.5	834.94
Piez-24	846.08	10.1	835.98
Piez-25	850.99	16.8	834.19
Piez-26	843.67	8.3	835.37
Piez-27	845.09	10.65	834.44
Piez-28	843.15	8.25	834.9
Piez-29	842.3	6.95	835.35
Piez-34	836.46	5.7	830.76
Piez-35	847.22	13.7	833.52
Piez-37	839.28	4.2	835.08
Piez-38	839.95	6.3	833.65
Piez-39	839.64	6.85	832.79
DW-1	837.46	5.23	832.23
DW-2	837.32	5.15	832.17
DW-3	841.31	8.83	832.48
DW-4	849.38	15.1	834.28
DW-5	839.48	6.85	832.63
DW-6	846.8	13.5	833.3
DW-7	860.54	30.3	830.24
DW-8	858.28	27.8	830.48

Static Water Table Data: September 1989

Piez / DW	Elevation TOC (ft)	Depth to Water (ft)	Water Table (ft)
Piez-1	841.19	5.33	835.86
Piez-2	844.03	11.08	832.95
Piez-3	844.28	11.4	832.88
Piez-4	840.71	7.15	833.56
Piez-5	844.36	10.55	833.81
Piez-6	842.13	8.1	834.03
Piez-7	841.94	8	833.94
Piez-8	852.97	19.18	833.79
Piez-9	842.43	8.65	833.78
Piez-10	845.16	11.45	833.71
Piez-13	841.06	7.3	833.76
Piez-15	842.7	7.35	835.35
Piez-17	846.21	7.78	838.43
Piez-18	842.81	4.9	837.91
Piez-20	841.78	7.6	834.18
Piez-21	842.14	7.13	835.01
Piez-22	844.32	9.58	834.74
Piez-23	841.44	6.6	834.84
Piez-24	846.08	10.13	835.95
Piez-25	850.99	16.85	834.14
Piez-26	843.67	8.45	835.22
Piez-27	845.09	10.68	834.41
Piez-28	843.15	8.3	834.85
Piez-29	842.3	7.2	835.1
Piez-34	836.46	5.65	830.81
Piez-35	847.22	13.68	833.54
Piez-37	839.28	3.98	835.3
Piez-38	839.95	6.33	833.62
Piez-39	839.64	6.68	832.96
DW-1	837.46	5.35	832.11
DW-2	837.32	5.23	832.09
DW-3	841.31	8.85	832.46
DW-4	849.38	15.13	834.25
DW-5	839.48	6.85	832.63
DW-6	846.8	13.48	833.32
DW-7	860.54	30.38	830.16
DW-8	858.28	27.85	830.43

Static Water Table Data: October 1989

Piez / DW	Elevation TOC (ft)	Depth to Water (ft)	Water Table (ft)
Piez-1	841.19	5.2	835.99
Piez-2	844.03	11.1	832.93
Piez-3	844.28	11.6	832.68
Piez-4	840.71	7.18	833.53
Piez-5	844.36	10.55	833.81
Piez-6	842.13	7.98	834.15
Piez-7	841.94	7.95	833.99
Piez-8	852.97	19.48	833.49
Piez-9	842.43	8.55	833.88
Piez-10	845.16	11.625	833.535
Piez-13	841.06	7.28	833.78
Piez-15	842.7	7.5	835.2
Piez-17	846.21	8.08	838.13
Piez-18	842.81	9.08	833.73
Piez-20	841.78	7.83	833.95
Piez-21	842.14	7.23	834.91
Piez-22	844.32	9.75	834.57
Piez-23	841.44	6.8	834.64
Piez-24	846.08	10.2	835.88
Piez-25	850.99	17.23	833.76
Piez-26	843.67	8.8	834.87
Piez-27	845.09	11.1	833.99
Piez-28	843.15	8.65	834.5
Piez-29	842.3	7.7	834.6
Piez-34	836.46	6.1	830.36
Piez-35	847.22	13.98	833.24
Piez-37	839.28	4.58	834.7
Piez-38	839.95	6.6	833.35
Piez-39	839.64	7	832.64
DW-1	837.46	5.4	832.06
DW-2	837.32	5.28	832.04
DW-3	841.31	9	832.31
DW-4	849.38	15.53	833.85
DW-5	839.48	7	832.48
DW-6	846.8	13.8	833
DW-7	860.54	30.05	830.49
DW-8	858.28	27.7	830.58

Static Water Table Data: December 1989

Piez / DW	Elevation TOC (ft)	Depth to Water (ft)	Water Table (ft)
Piez-1	841.19	5	836.19
Piez-2	844.03	11.13	832.9
Piez-3	844.28	11.63	832.65
Piez-4	840.71	7.1	833.61
Piez-5	844.36	10.55	833.81
Piez-6	842.13	8.15	833.98
Piez-7	841.94	8.15	833.79
Piez-8	852.97	19.65	833.32
Piez-9	842.43	8.9	833.53
Piez-10	845.16	12	833.16
Piez-13	841.06	7.95	833.11
Piez-15	842.7	7.98	834.72
Piez-17	846.21	8.4	837.81
Piez-18	842.81	9.38	833.43
Piez-20	841.78	8.2	833.58
Piez-21	842.14	7.35	834.79
Piez-22	844.32	9.9	834.42
Piez-23	841.44	6.73	834.71
Piez-24	846.08	10.3	835.78
Piez-25	850.99	17.5	833.49
Piez-26	843.67	9.2	834.47
Piez-27	845.09	11.35	833.74
Piez-28	843.15	9	834.15
Piez-29	842.3	8.05	834.25
Piez-34	836.46	6.35	830.11
Piez-35	847.22	14.15	833.07
Piez-37	839.28	frozen	frozen
Piez-38	839.95	6.78	833.17
Piez-39	839.64	7.18	832.46
DW-1	837.46	5.98	831.48
DW-2	837.32	5.85	831.47
DW-3	841.31	9.15	832.16
DW-4	849.38	15.78	833.6
DW-5	839.48	7.2	832.28
DW-6	846.8	13.95	832.85
DW-7	860.54	30.33	830.21
DW-8	858.28	27.95	830.33

Appendix D

Well Nests and Deep Wells Static Water Table Data 1992

Static Water Table Data For Well Nests: January 1992

Nest /Well	Elevation TOC (ft)	Depth to Water (ft)	Water Table (ft)	Δ WT Elevation Relative to Shallow Well (ft)
A-1	836.28	frozen	N/A	N/A
A-2	837.68	2.2	835.48	N/A
A-3	837.65	3.05	834.6	-0.88
B-1	835.82	1.59	834.23	N/A
B-2	836.83	3.2	833.63	-0.6
B-3	836.97	2.8	834.17	-0.06
C-1	837.98	frozen	N/A	N/A
C-2	837.59	2.02	835.57	N/A
C-3	838.17	3.57	834.6	-0.97
D-1	838.33	2.27	836.06	N/A
D-2	838.42	3.6	834.82	-1.24
D-3	838.07	3.4	834.67	-1.39
E-1	838.71	3.15	835.56	N/A
E-2	838.77	3.94	834.93	-0.63
F-1	838.31	frozen	N/A	N/A
F-2	838.27	frozen	N/A	N/A
F-3	838.43	frozen	N/A	N/A
G-1	837.78	frozen	N/A	N/A
G-2	835.75	1.3	834.43	N/A
H-1	838.41	frozen	N/A	N/A
H-2	838.35	2	836.35	N/A
H-3	837.65	4.86	832.79	-3.56
I-1	837.46	frozen	N/A	N/A
I-2	838.42	4.18	834.24	N/A
I-3	838.11	3.95	834.16	-0.08
J-1	837.08	frozen	N/A	N/A
J-2	839.15	2.15	837	N/A
J-3	837.06	2.08	834.98	-2.02

Negative sign (-) indicates head loss (a decrease in the static water table).
Positive sign (+) indicates head gain (an increase in the static water table).
TOC = top of casing; WT = water table; N/A = not available.
Change in static water table elevation is relative to the shallowest well in each nest.

Static Water Table Data For Well Nests: February 1992

Nest /Well	Elevation TOC (ft)	Depth to Water (ft)	Water Table (ft)	Δ WT Elevation Relative to Shallow Well (ft)
A-1	836.28	0.6	835.68	N/A
A-2	837.68	2.22	835.46	-0.22
A-3	837.65	3.14	834.51	-1.17
B-1	835.82	1.6	834.22	N/A
B-2	836.83	2.02	833.65	-0.57
B-3	836.97	3.75	834.01	-0.21
C-1	837.98	2.4	835.58	N/A
C-2	837.59	2.02	835.57	-0.01
C-3	838.17	3.75	834.42	-1.16
D-1	838.33	2.2	836.13	N/A
D-2	838.42	3.6	834.82	-1.31
D-3	838.07	3.45	834.62	-1.51
E-1	838.71	3.51	835.2	N/A
E-2	838.77	4.2	834.57	-0.63
F-1	838.31	2.6	835.71	N/A
F-2	838.27	2.63	835.64	-0.07
F-3	838.43	2.88	835.55	-0.16
G-1	837.78	2.37	835.41	N/A
G-2	835.75	1.38	834.35	-1.06
H-1	838.41	1.79	836.62	N/A
H-2	838.35	2.2	836.15	-0.47
H-3	837.65	5.11	832.54	-4.08
I-1	837.46	1.12	836.34	N/A
I-2	838.42	4.51	833.91	-2.43
I-3	838.11	4.22	833.89	-2.45
J-1	837.08	0.51	836.57	N/A
J-2	839.15	2.39	836.76	+0.19
J-3	837.06	2.3	834.76	-1.81

Negative sign (-) indicates head loss (a decrease in the static water table).
Positive sign (+) indicates head gain (an increase in the static water table).
TOC = top of casing; WT = water table; N/A = not available.
Change in static water table elevation is relative to the shallowest well in each nest.

Static Water Table Data For Well Nests: March 1992

Nest /Well	Elevation TOC (ft)	Depth to Water (ft)	Water Table (ft)	Δ W T Elevation Relative to Shallow Well (ft)
A-1	836.28	0.55	835.73	N/A
A-2	837.68	2.13	835.55	-0.18
A-3	837.65	3.18	834.47	-1.26
B-1	835.82	1.5	834.32	N/A
B-2	836.83	3.2	833.63	-0.69
B-3	836.97	2.78	834.19	-0.13
C-1	837.98	2.34	835.64	N/A
C-2	837.59	1.98	835.61	-0.03
C-3	838.17	3.48	834.69	-0.95
D-1	838.33	2.16	836.17	N/A
D-2	838.42	3.8	834.62	-1.55
D-3	838.07	3.44	834.63	-1.54
E-1	838.71	3.42	835.29	N/A
E-2	838.77	4.23	834.54	-0.75
F-1	838.31	2.58	835.73	N/A
F-2	838.27	2.57	835.7	-0.03
F-3	838.43	2.82	835.61	-0.12
G-1	837.78	2.35	835.43	N/A
G-2	835.75	1.37	834.36	-1.07
H-1	838.41	1.81	836.6	N/A
H-2	838.35	2.08	836.27	-0.33
H-3	837.65	5.83	831.82	-4.78
I-1	837.46	1.2	836.26	N/A
I-2	838.42	4.32	834.1	-2.16
I-3	838.11	4.58	833.53	-2.73
J-1	837.08	0.56	836.52	N/A
J-2	839.15	2.42	836.73	+0.21
J-3	837.06	2.4	834.66	-1.86

Negative sign (-) indicates head loss (a decrease in the static water table).
Positive sign (+) indicates head gain (an increase in the static water table).
TOC = top of casing; WT = water table; N/A = not available.
Change in static water table elevation is relative to the shallowest well.

Static Water Table Data For Well Nests: April 1992

Nest /Well	Elevation TOC (ft)	Depth to Water (ft)	Water Table (ft)	Δ W T Elevation Relative to Shallow Well (ft)
A-1	836.28	0.72	835.56	N/A
A-2	837.68	2.25	835.43	-0.13
A-3	837.65	3.21	834.44	-1.12
B-1	835.82	1.54	834.28	N/A
B-2	836.83	3.25	833.58	-0.7
B-3	836.97	2.87	834.1	-0.18
C-1	837.98	2.4	835.58	N/A
C-2	837.59	1.96	835.63	+0.05
C-3	838.17	3.56	834.61	-0.97
D-1	838.33	2.26	836.07	N/A
D-2	838.42	3.71	834.71	-1.36
D-3	838.07	3.6	834.47	-1.6
E-1	838.71	3.71	835	N/A
E-2	838.77	4.28	834.49	-0.51
F-1	838.31	2.53	835.78	N/A
F-2	838.27	2.58	835.69	-0.09
F-3	838.43	2.86	835.57	-0.21
G-1	837.78	2.46	835.32	N/A
G-2	835.75	1.51	834.22	-1.1
H-1	838.41	1.8	836.61	N/A
H-2	838.35	2.03	836.32	-0.29
H-3	837.65	5.81	831.84	-4.77
I-1	837.46	1.21	836.25	N/A
I-2	838.42	4.64	833.78	-2.47
I-3	838.11	4.25	833.86	-2.39
J-1	837.08	0.56	836.52	N/A
J-2	839.15	2.46	836.69	+0.17
J-3	837.06	2.38	834.68	-1.84

Negative sign (-) indicates head loss (a decrease in the static water table).
Positive sign (+) indicates head gain (an increase in the static water table).
TOC = top of casing; WT = water table; N/A = not available.
Change in static water table elevation is relative to the shallowest well in each nest.

Static Water Table Data For Well Nests: May 1992

Nest /Well	Elevation TOC (ft)	Depth to Water (ft)	Water Table (ft)	Δ W T Elevation Relative to Shallow Well (ft)
A-1	836.28	1.4	834.88	N/A
A-2	837.68	2.49	835.19	+0.31
A-3	837.65	3.45	834.2	-0.68
B-1	835.82	1.97	833.85	N/A
B-2	836.83	3.4	833.43	-0.42
B-3	836.97	2.96	834.01	-0.16
C-1	837.98	2.61	835.37	N/A
C-2	837.59	2.32	835.27	-0.1
C-3	838.17	3.64	834.53	-0.84
D-1	838.33	2.62	835.71	N/A
D-2	838.42	4.08	834.34	-0.97
D-3	838.07	4.02	834.05	-1.66
E-1	838.71	4.13	834.58	N/A
E-2	838.77	4.47	834.3	-0.28
F-1	838.31	2.75	835.56	N/A
F-2	838.27	2.88	835.39	-0.17
F-3	838.43	3.06	835.37	-0.19
G-1	837.78	2.88	834.9	N/A
G-2	835.75	1.6	834.13	-0.77
H-1	838.41	1.8	836.61	N/A
H-2	838.35	2.11	836.24	-0.37
H-3	837.65	6.04	831.61	-5
I-1	837.46	1.26	836.2	N/A
I-2	838.42	4.83	833.59	-2.61
I-3	838.11	4.56	833.55	-2.65
J-1	837.08	0.56	836.52	N/A
J-2	839.15	2.63	836.52	0
J-3	837.06	2.55	834.51	-2.01

Negative sign (-) indicates head loss (a decrease in the static water table).
Positive sign (+) indicates head gain (an increase in the static water table).
TOC = top of casing; WT = water table; N/A = not available.
Change in static water table elevation is relative to the shallowest well in each nest.

Static Water Table Data For Well Nests: June 1992

Nest /Well	Elevation TOC (ft)	Depth to Water (ft)	Water Table (ft)	Δ W T Elevation Relative to Shallow Well (ft)
A-1	836.28	2.42	833.86	N/A
A-2	837.68	2.84	834.84	+0.98
A-3	837.65	3.78	833.87	+0.01
B-1	835.82	2.22	833.6	N/A
B-2	836.83	3.54	833.29	-0.31
B-3	836.97	3.08	833.89	-0.29
C-1	837.98	2.62	835.36	N/A
C-2	837.59	2.35	835.24	-0.12
C-3	838.17	3.92	834.25	-1.11
D-1	838.33	4.13	834.2	N/A
D-2	838.42	4.6	833.82	-0.38
D-3	838.07	4.5	833.57	-0.63
E-1	838.71	4.84	833.87	N/A
E-2	838.77	4.75	834.02	+0.15
F-1	838.31	2.68	835.63	N/A
F-2	838.27	3.02	835.25	-0.38
F-3	838.43	3.4	835.03	-0.6
G-1	837.78	2.71	835.07	N/A
G-2	835.75	1.81	833.92	-1.15
H-1	838.41	1.8	836.61	N/A
H-2	838.35	2.15	836.2	-0.41
H-3	837.65	6.26	831.39	-5.22
I-1	837.46	1.16	836.3	N/A
I-2	838.42	5.22	833.2	-3.1
I-3	838.11	4.76	833.35	-2.95
J-1	837.08	0.86	836.22	N/A
J-2	839.15	2.97	836.18	-0.04
J-3	837.06	2.9	834.16	-2.06

Negative sign (-) indicates head loss (a decrease in the static water table).
Positive sign (+) indicates head gain (an increase in the static water table).
TOC = top of casing; WT = water table; N/A = not available.
Change in static water table elevation is relative to the shallowest well.

Static Water Table Data For Well Nests: July 1992

Nest /Well	Elevation TOC (ft)	Depth to Water (ft)	Water Table (ft)	Δ W T Elevation Relative to Shallow Well (ft)
A-1	836.28	1.11	835.17	N/A
A-2	837.68	2.68	835	-0.17
A-3	837.65	3.7	833.95	-1.22
B-1	835.82	1.8	834.02	N/A
B-2	836.83	3.46	833.37	-0.65
B-3	836.97	3.09	833.88	-0.14
C-1	837.98	2.52	835.46	N/A
C-2	837.59	2.2	835.39	-0.07
C-3	838.17	4	834.17	-1.29
D-1	838.33	2.9	835.43	N/A
D-2	838.42	4.7	833.72	-1.71
D-3	838.07	4.58	833.49	-1.94
E-1	838.71	4.3	834.41	N/A
E-2	838.77	4.88	833.89	-0.52
F-1	838.31	2.7	835.61	N/A
F-2	838.27	2.92	835.35	-0.26
F-3	838.43	3.19	835.24	-0.37
G-1	837.78	2.59	835.19	N/A
G-2	835.75	1.81	833.92	-1.27
H-1	838.41	1.87	836.54	N/A
H-2	838.35	2.08	836.27	-0.27
H-3	837.65	6.28	831.37	-5.17
I-1	837.46	1.21	836.25	N/A
I-2	838.42	5.21	833.31	-2.94
I-3	838.11	4.85	833.26	-2.99
J-1	837.08	0.6	836.48	N/A
J-2	839.15	3.02	836.13	-0.35
J-3	837.06	2.94	834.12	-2.36

Negative sign (-) indicates head loss (a decrease in the static water table).
Positive sign (+) indicates head gain (an increase in the static water table).
TOC = top of casing; WT = water table; N/A = not available.
Change in static water table elevation is relative to the shallowest well in each nest.

Static Water Table Data For Well Nests: August 1992

Nest /Well	Elevation TOC (ft)	Depth to Water (ft)	Water Table (ft)	Δ W T Elevation Relative to Shallow Well (ft)
A-1	836.28	0.74	835.54	N/A
A-2	837.68	2.37	835.31	-0.23
A-3	837.65	3.55	834.1	-1.44
B-1	835.82	1.63	834.19	N/A
B-2	836.83	3.37	833.46	-0.73
B-3	836.97	3.1	833.87	-0.32
C-1	837.98	2.44	835.54	N/A
C-2	837.59	2.07	835.52	-0.02
C-3	838.17	3.7	834.47	-1.07
D-1	838.33	2.5	835.83	N/A
D-2	838.42	4.7	833.72	-2.11
D-3	838.07	4.24	833.83	-2
E-1	838.71	4.1	834.61	N/A
E-2	838.77	4.58	834.19	-0.42
F-1	838.31	2.62	835.69	N/A
F-2	838.27	2.77	835.5	-0.19
F-3	838.43	3	835.43	-0.26
G-1	837.78	2.34	835.44	N/A
G-2	835.75	1.8	833.93	-1.51
H-1	838.41	1.79	836.62	N/A
H-2	838.35	2.08	836.27	-0.35
H-3	837.65	5.98	831.67	-4.95
I-1	837.46	1.17	836.29	N/A
I-2	838.42	4.91	833.51	-2.78
I-3	838.11	4.64	833.47	-2.82
J-1	837.08	0.55	836.53	N/A
J-2	839.15	2.71	836.44	-0.09
J-3	837.06	2.64	834.42	-2.11

Negative sign (-) indicates head loss (a decrease in the static water table).
Positive sign (+) indicates head gain (an increase in the static water table).
TOC = top of casin; WT = water table
TOC = top of casing; WT = water table; N/A = not available.
Change in static water table elevation is relative to the shallowest well in each nest.

Static Water Table Data For Well Nests: September 1992

Nest /Well	Elevation TOC (ft)	Depth to Water (ft)	Water Table (ft)	Δ W T Elevation Relative to Shallow Well (ft)
A-1	836.28	0.81	835.47	N/A
A-2	837.68	2.46	835.22	-0.25
A-3	837.65	3.66	833.99	-1.48
B-1	835.82	1.59	834.23	N/A
B-2	836.83	3.45	833.38	-0.85
B-3	836.97	3.03	833.94	-0.29
C-1	837.98	2.52	835.46	N/A
C-2	837.59	2.12	835.47	+0.01
C-3	838.17	3.77	834.4	-1.06
D-1	838.33	2.64	835.69	N/A
D-2	838.42	4.67	833.75	-1.94
D-3	838.07	4.55	833.52	-2.17
E-1	838.71	4.28	834.43	N/A
E-2	838.77	4.94	833.83	-0.6
F-1	838.31	2.5	835.81	N/A
F-2	838.27	2.82	835.45	-0.36
F-3	838.43	3.18	835.25	-0.56
G-1	837.78	2.37	835.41	N/A
G-2	835.75	1.72	834.01	-1.4
H-1	838.41	1.82	836.59	N/A
H-2	838.35	2.1	836.25	-0.34
H-3	837.65	6.13	831.52	-5.07
I-1	837.46	1.18	836.28	N/A
I-2	838.42	5.23	833.19	-3.09
I-3	838.11	4.92	833.19	-3.09
J-1	837.08	0.59	836.49	N/A
J-2	839.15	3.08	836.07	-0.42
J-3	837.06	3	834.06	-2.43

Negative sign (-) indicates head loss (a decrease in the static water table).
Positive sign (+) indicates head gain (an increase in the static water table).
TOC = top of casin; WT = water table
TOC = top of casing; WT = water table; N/A = not available.
Change in static water table elevation is relative to the shallowest well in each nest.

Static Water Table Data For Well Nests: October 1992

Nest /Well	Elevation TOC (ft)	Depth to Water (ft)	Water Table (ft)	Δ W T Elevation Relative to Shallow Well (ft)
A-1	836.28	0.63	835.65	N/A
A-2	837.68	2.33	835.35	-0.3
A-3	837.65	3.59	834.06	-1.59
B-1	835.82	1.62	834.2	N/A
B-2	836.83	3.36	833.47	-0.73
B-3	836.97	3.02	833.95	-0.25
C-1	837.98	2.43	835.55	N/A
C-2	837.59	2.08	835.51	-0.04
C-3	838.17	3.96	834.21	-1.34
D-1	838.33	2.4	835.93	N/A
D-2	838.42	4.54	833.88	-2.05
D-3	838.07	4.4	833.67	-2.26
E-1	838.71	4.16	834.55	N/A
E-2	838.77	4.94	833.83	-0.72
F-1	838.31	2.49	835.82	N/A
F-2	838.27	2.78	835.49	-0.33
F-3	838.43	3.05	835.38	-0.44
G-1	837.78	2.39	835.39	N/A
G-2	835.75	1.67	834.06	-1.33
H-1	838.41	1.81	836.6	N/A
H-2	838.35	2.04	836.61	+0.01
H-3	837.65	6.08	831.57	-5.03
I-1	837.46	1.17	836.29	N/A
I-2	838.42	5.32	833.1	-3.19
I-3	838.11	4.9	833.21	-3.08
J-1	837.08	0.55	836.53	N/A
J-2	839.15	3.09	836.06	-0.47
J-3	837.06	3.02	834.04	-2.49

Negative sign (-) indicates head loss (a decrease in the static water table).
Positive sign (+) indicates head gain (an increase in the static water table).
TOC = top of casing; WT = water table; N/A = not available.
Change in static water table elevation is relative to the shallowest well in each nest.

Static Water Table Data For Well Nests: December 1992

Nest /Well	Elevation TOC (ft)	Depth to Water (ft)	Water Table (ft)	Δ W T Elevation Relative to Shallow Well (ft)
A-1	836.28	0.66	835.62	N/A
A-2	837.68	2.2	835.48	-0.14
A-3	837.65	2.96	834.69	-0.93
B-1	835.82	1.52	834.3	N/A
B-2	836.83	3.21	833.62	-0.68
B-3	836.97	2.9	834.07	-0.23
C-1	837.98	frozen	N/A	N/A
C-2	837.59	1.98	835.61	N/A
C-3	838.17	3.85	834.32	-1.29
D-1	838.33	2.18	836.15	N/A
D-2	838.42	3.68	834.74	-1.41
D-3	838.07	3.17	834.9	-1.25
E-1	838.71	3.08	835.63	N/A
E-2	838.77	3.8	834.97	-0.66
F-1	838.31	2.6	835.71	N/A
F-2	838.27	2.56	835.71	0
F-3	838.43	2.66	835.77	+0.06
G-1	837.78	frozen	N/A	N/A
G-2	835.75	1.39	834.34	N/A
H-1	838.41	1.72	836.69	N/A
H-2	838.35	1.94	836.41	-0.28
H-3	837.65	4.64	833.01	-3.68
I-1	837.46	1.05	836.41	N/A
I-2	838.42	4.04	834.38	-2.03
I-3	838.11	3.81	834.3	-2.11
J-1	837.08	0.77	836.31	N/A
J-2	839.15	1.99	837.16	+0.85
J-3	837.06	1.92	835.14	-1.17

Negative sign (-) indicates head loss (a decrease in the static water table).
Positive sign (+) indicates head gain (an increase in the static water table).
TOC = top of casing; WT = water table; N/A = not available.
Change in static water table elevation is relative to the shallowest well in each nest.

Static Water Table Data: January 1992

Piez / DW	Elevation TOC (ft)	Depth to Water (ft)	Water Table (ft)
DW-1	837.46	4.4	833.06
DW-2	837.32	4.3	833.02
DW-3	841.31	7.2	834.11
DW-4	849.38	13.75	835.63
DW-5	839.48	5.82	833.66
DW-6	846.8	12.34	834.46
DW-7	860.54	28.38	832.16
DW-8	858.28	25.87	832.41

Static Water Table Data: February 1992

Piez / DW	Elevation TOC (ft)	Depth to Water (ft)	Water Table (ft)
DW-1	837.46	4.75	832.71
DW-2	837.32	4.64	832.68
DW-3	841.31	7.51	833.8
DW-4	849.38	14	835.38
DW-5	839.48	6.2	833.28
DW-6	846.8	12.58	834.22
DW-7	860.54	27.95	832.59
DW-8	858.28	25.1	833.18

Static Water Table Data: March 1989

Piez / DW	Elevation TOC (ft)	Depth to Water (ft)	Water Table (ft)
DW-1	837.46	5.08	832.38
DW-2	837.32	4.97	832.35
DW-3	841.31	7.58	833.73
DW-4	849.38	14.03	835.35
DW-5	839.48	6.22	833.26
DW-6	846.8	12.77	834.03
DW-7	860.54	28.3	832.24
DW-8	858.28	25.22	833.06

Static Water Table Data: April 1992

Piez / DW	Elevation TOC (ft)	Depth to Water (ft)	Water Table (ft)
DW-1	837.46	5.03	832.43
DW-2	837.32	4.91	832.41
DW-3	841.31	7.63	833.68
DW-4	849.38	14.01	835.37
DW-5	839.48	6.29	833.19
DW-6	846.8	12.95	833.85
DW-7	860.54	28.42	832.12
DW-8	858.28	25.4	832.88

Static Water Table Data: May 1992

Piez / DW	Elevation TOC (ft)	Depth to Water (ft)	Water Table (ft)
DW-1	837.46	5.08	832.38
DW-2	837.32	5.11	832.21
DW-3	841.31	7.85	833.46
DW-4	849.38	14.4	834.98
DW-5	839.48	6.46	833.02
DW-6	846.8	12.92	833.88
DW-7	860.54	28.7	831.84
DW-8	858.28	25.77	832.51

Static Water Table Data: June 1992

Piez / DW	Elevation TOC (ft)	Depth to Water (ft)	Water Table (ft)
DW-1	837.46	5.39	832.07
DW-2	837.32	5.28	832.04
DW-3	841.31	8.25	833.06
DW-4	849.38	14.97	834.41
DW-5	839.48	6.82	832.66
DW-6	846.8	13.38	833.42
DW-7	860.54	29.16	831.38
DW-8	858.28	26.26	832.02

Static Water Table Data: July 1992

Piez / DW	Elevation TOC (ft)	Depth to Water (ft)	Water Table (ft)
DW-1	837.46	5.4	832.06
DW-2	837.32	5.3	832.02
DW-3	841.31	8.24	833.07
DW-4	849.38	15.16	834.22
DW-5	839.48	6.85	832.63
DW-6	846.8	13.46	833.34
DW-7	860.54	29.21	831.33
DW-8	858.28	26.29	831.99

Static Water Table Data: August 1992

Piez / DW	Elevation TOC (ft)	Depth to Water (ft)	Water Table (ft)
DW-1	837.46	5.12	832.34
DW-2	837.32	5.02	832.3
DW-3	841.31	7.93	833.38
DW-4	849.38	14.79	834.59
DW-5	839.48	N/A	N/A
DW-6	846.8	13.15	833.65
DW-7	860.54	N/A	N/A
DW-8	858.28	N/A	N/A

Static Water Table Data: September 1992

Piez / DW	Elevation TOC (ft)	Depth to Water (ft)	Water Table (ft)
DW-1	837.46	5.44	832.02
DW-2	837.32	5.34	831.98
DW-3	841.31	8.24	833.07
DW-4	849.38	15.22	834.16
DW-5	839.48	6.85	832.63
DW-6	846.8	13.69	833.11
DW-7	860.54	29.23	831.31
DW-8	858.28	26.41	831.87

Static Water Table Data: October 1992

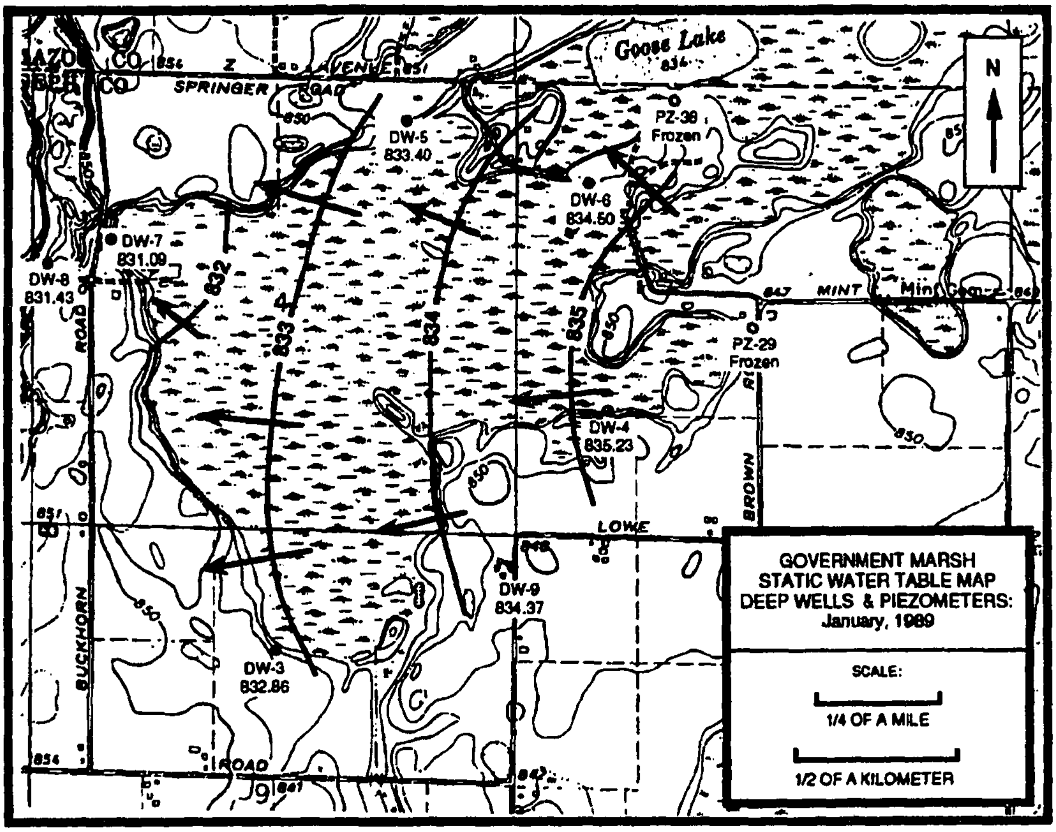
Piez / DW	Elevation TOC (ft)	Depth to Water (ft)	Water Table (ft)
DW-1	837.46	5.36	832.1
DW-2	837.32	5.24	832.08
DW-3	841.31	8.3	833.01
DW-4	849.38	15.08	834.3
DW-5	839.48	6.7	832.78
DW-6	846.8	13.29	833.51
DW-7	860.54	29.21	831.33
DW-8	858.28	26.48	831.8

Static Water Table Data: December 1992

Piez / DW	Elevation TOC (ft)	Depth to Water (ft)	Water Table (ft)
DW-1	837.46	4.13	833.33
DW-2	837.32	4.02	833.3
DW-3	841.31	7.04	834.27
DW-4	849.38	13.54	835.84
DW-5	839.48	5.7	833.78
DW-6	846.8	12.21	834.59
DW-7	860.54	28.33	832.21
DW-8	858.28	25.82	832.46

Appendix E

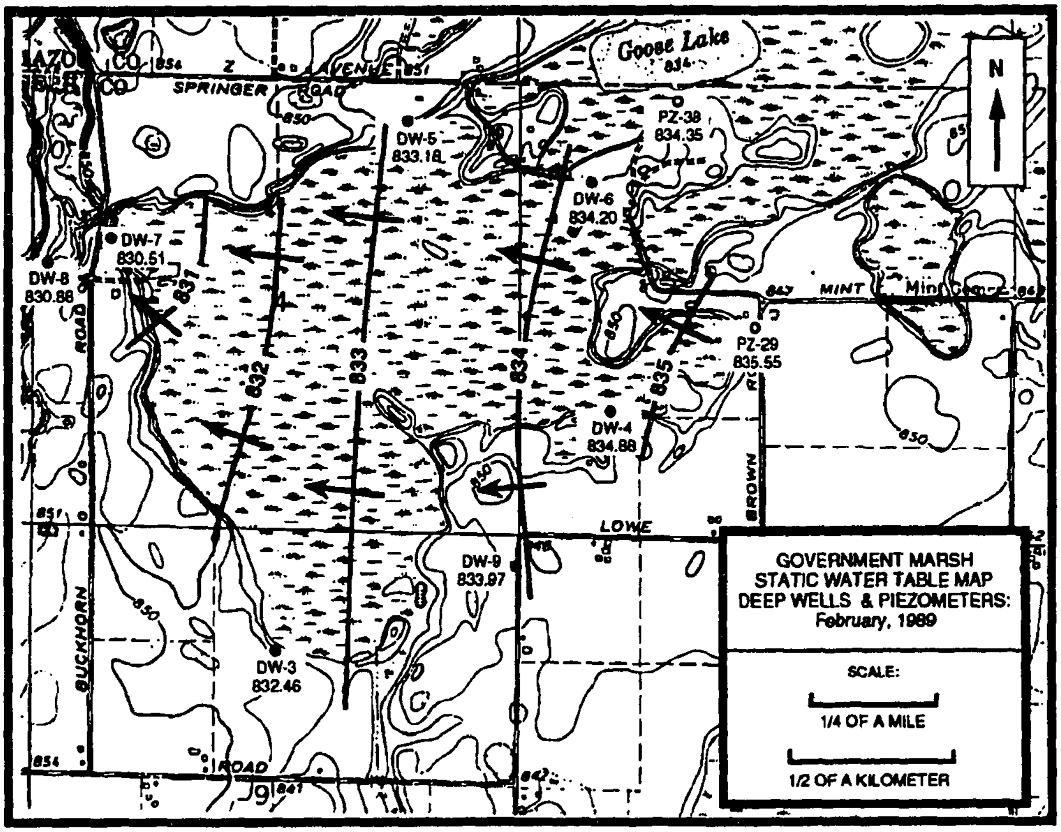
Deep Wells Static Water Table Maps 1989



Base map taken U.S.G.S. topographic quadrangle map of Vicksburg, Michigan, 7.5 Minute Series.

LEGEND:

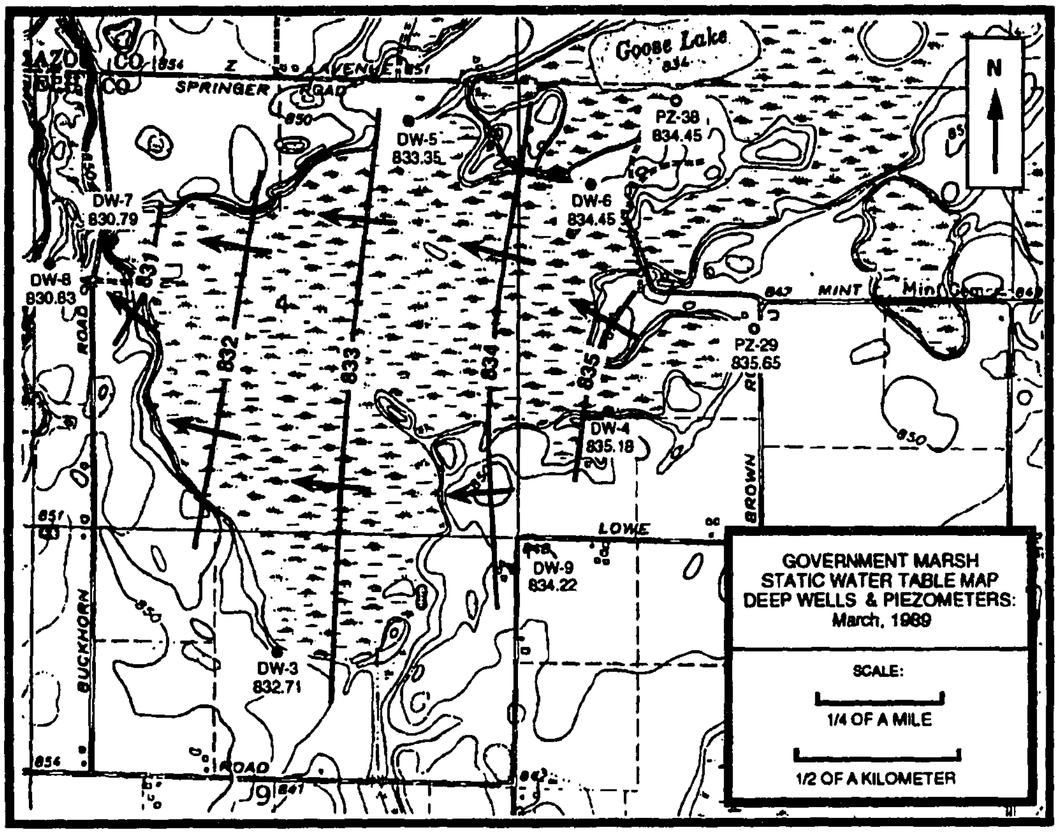
- ● DW-3 832.86 — Deep Well Location, Identification & Measured Static Water Level Elevation
- ○ PZ-38 834.17 — Piezometer Location, Identification & Measured Static Water Level Elevation
- Topographic Contour: CI = 5 ft
- Static Water Table Contour: CI = 1.0 ft; Direction of Ground Water Flow



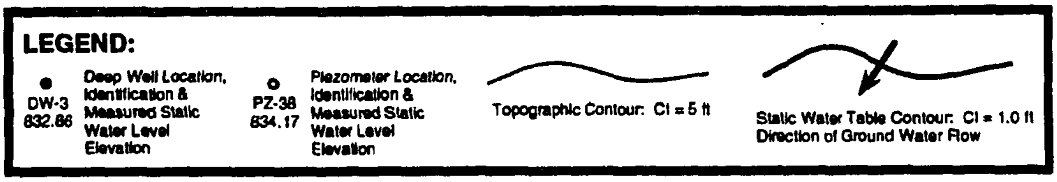
Base map taken U.S.G.S. topographic quadrangle map of Vicksburg, Michigan, 7.5 Minute Series.

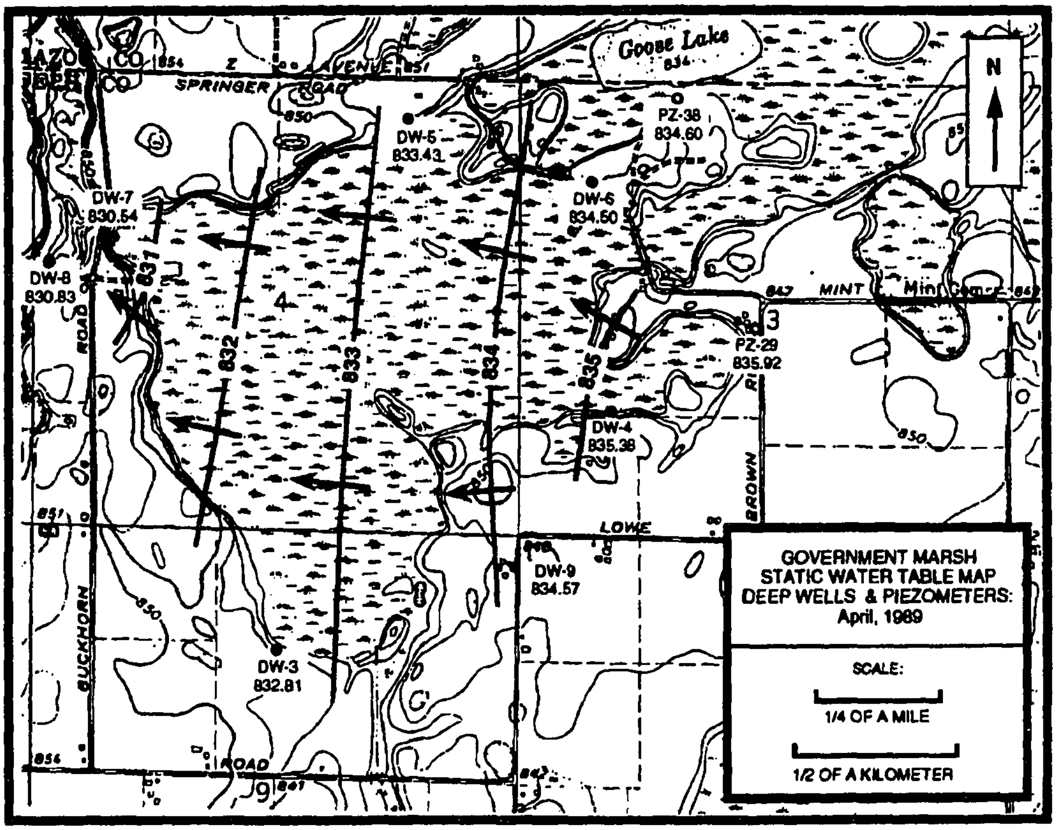
LEGEND:

DW-3 832.86 — Deep Well Location, Identification & Measured Static Water Level Elevation	PZ-38 834.17 — Piezometer Location, Identification & Measured Static Water Level Elevation	Topographic Contour: CI = 5 ft	Static Water Table Contour: CI = 1.0 ft; Direction of Ground Water Flow

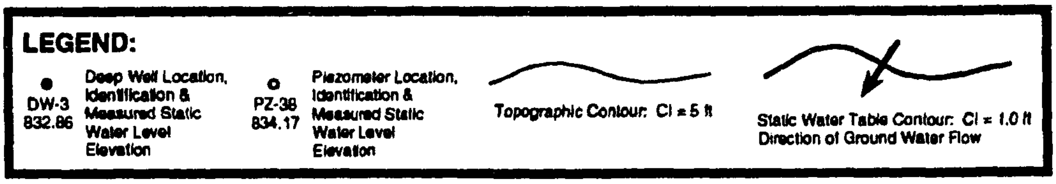


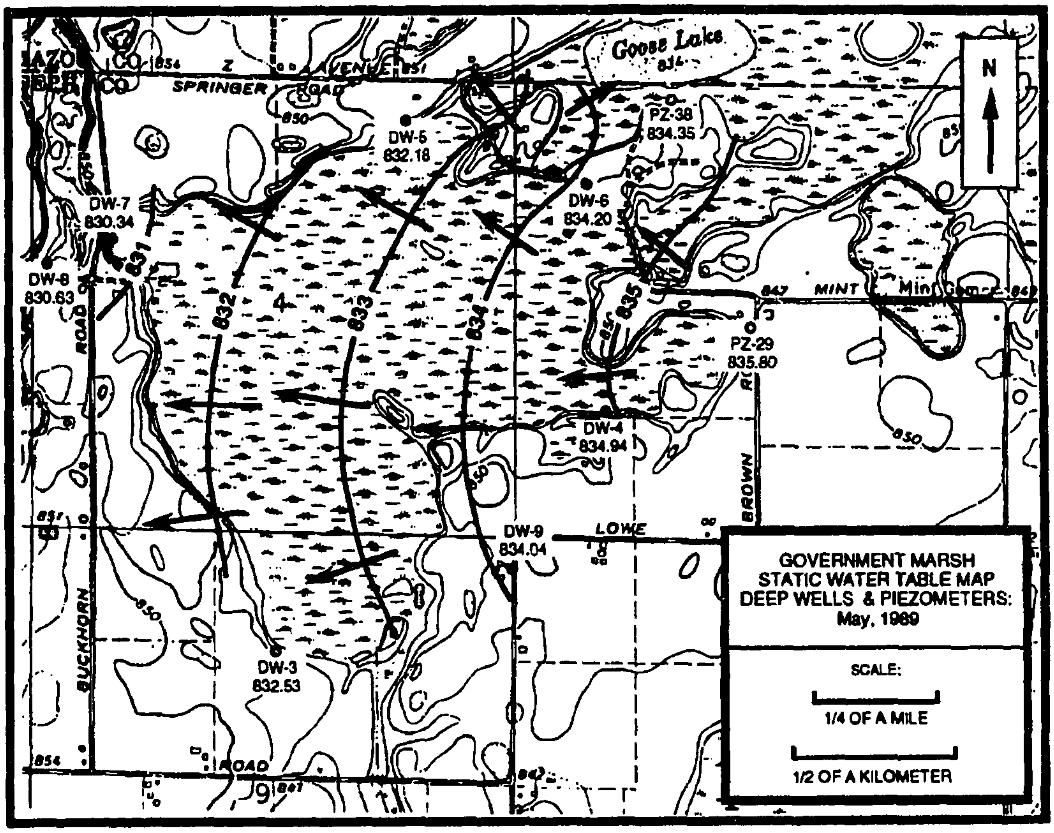
Base map taken U.S.G.S. topographic quadrangle map of Vicksburg, Michigan, 7.5 Minute Series.





Base map taken U.S.G.S. topographic quadrangle map of Vicksburg, Michigan, 7.5 Minute Series.





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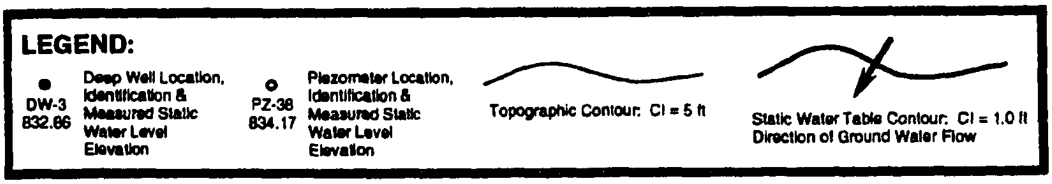

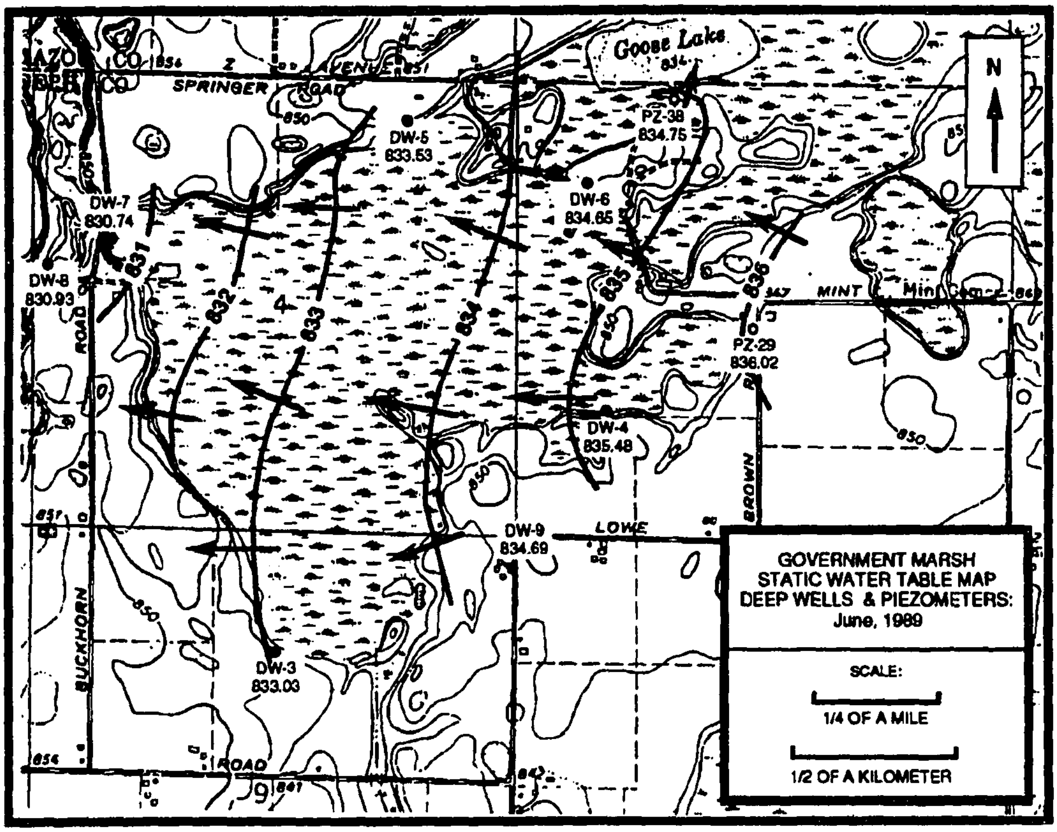

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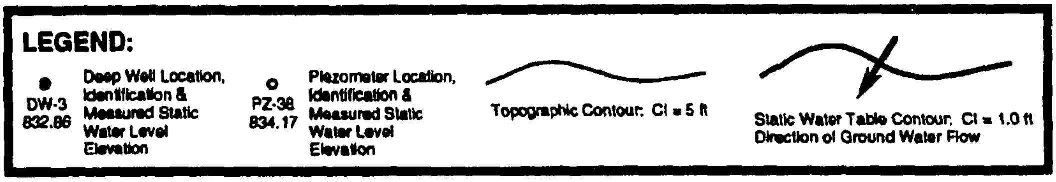
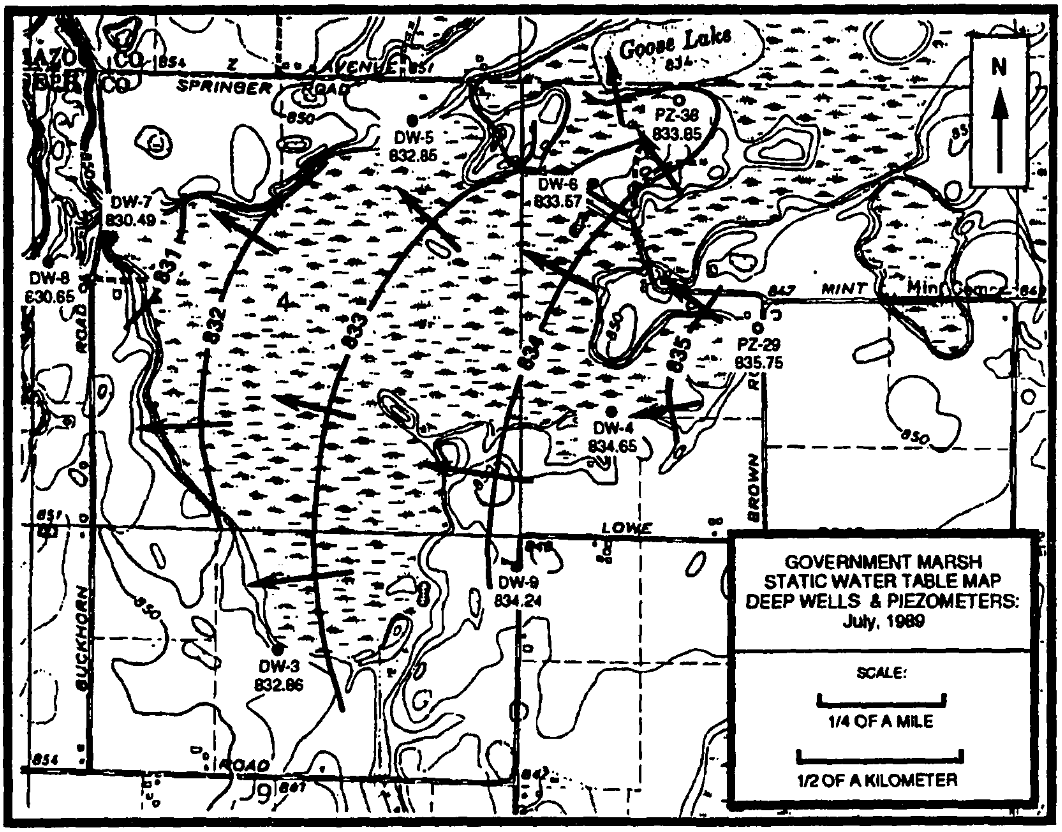
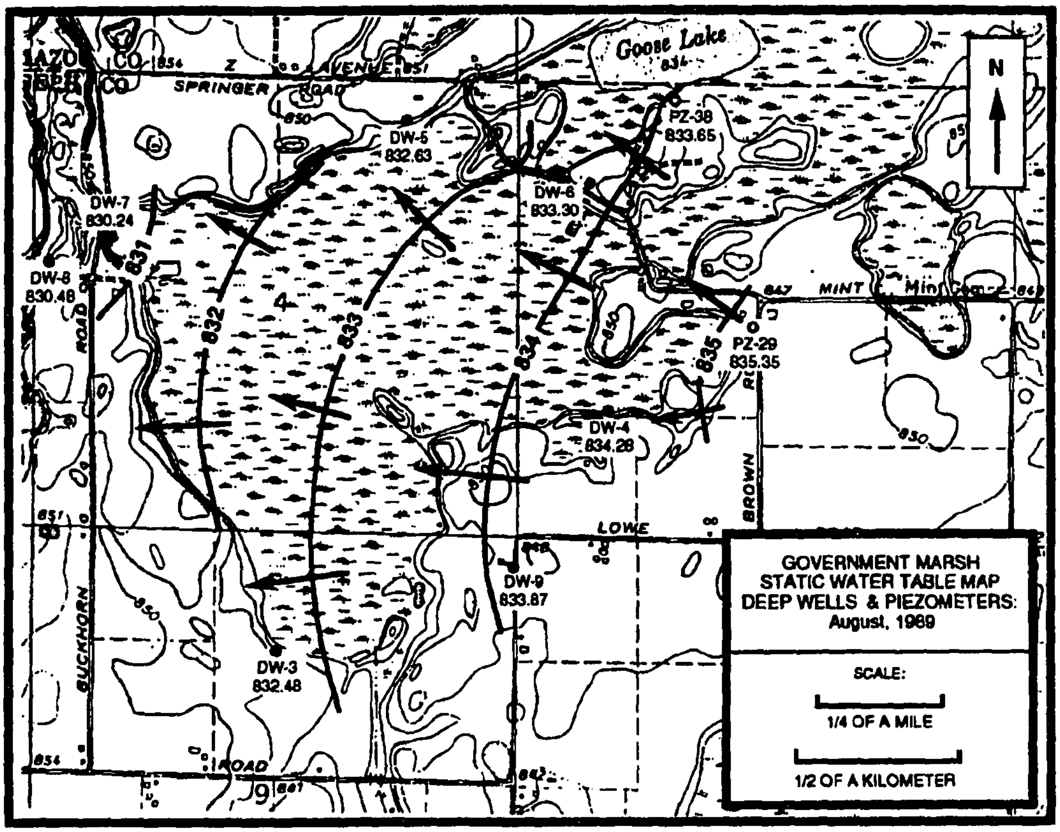




Base map taken U.S.G.S. topographic quadrangle map of Vicksburg, Michigan, 7.5 Minute Series.

LEGEND:

- DW-3 832.86 — Deep Well Location, Identification & Measured Static Water Level Elevation
- PZ-38 834.17 — Piezometer Location, Identification & Measured Static Water Level Elevation
- Topographic Contour: CI = 5 ft
- Static Water Table Contour: CI = 1.0 ft
- Direction of Ground Water Flow



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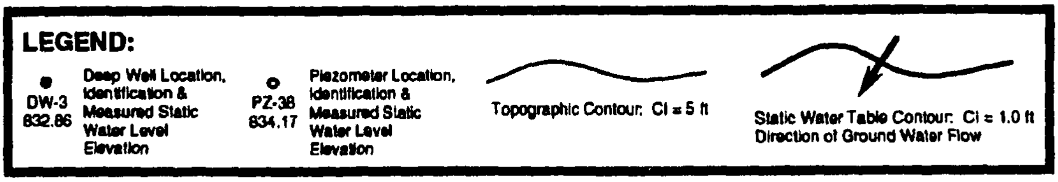
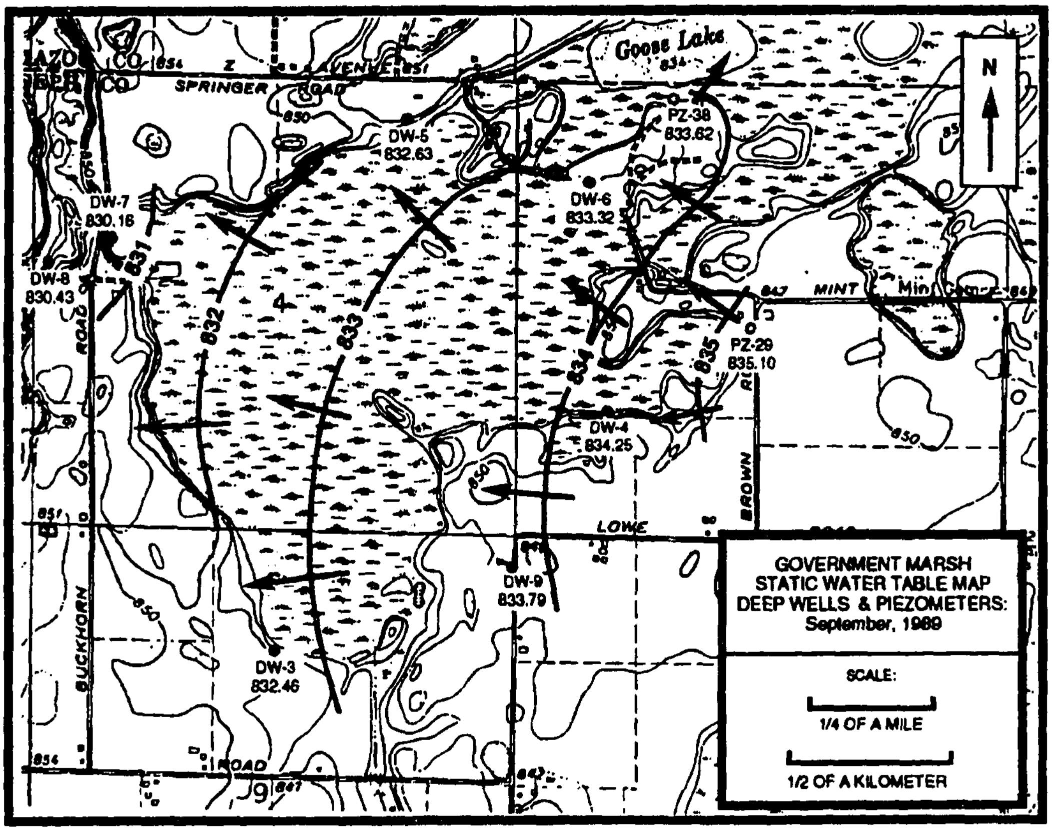
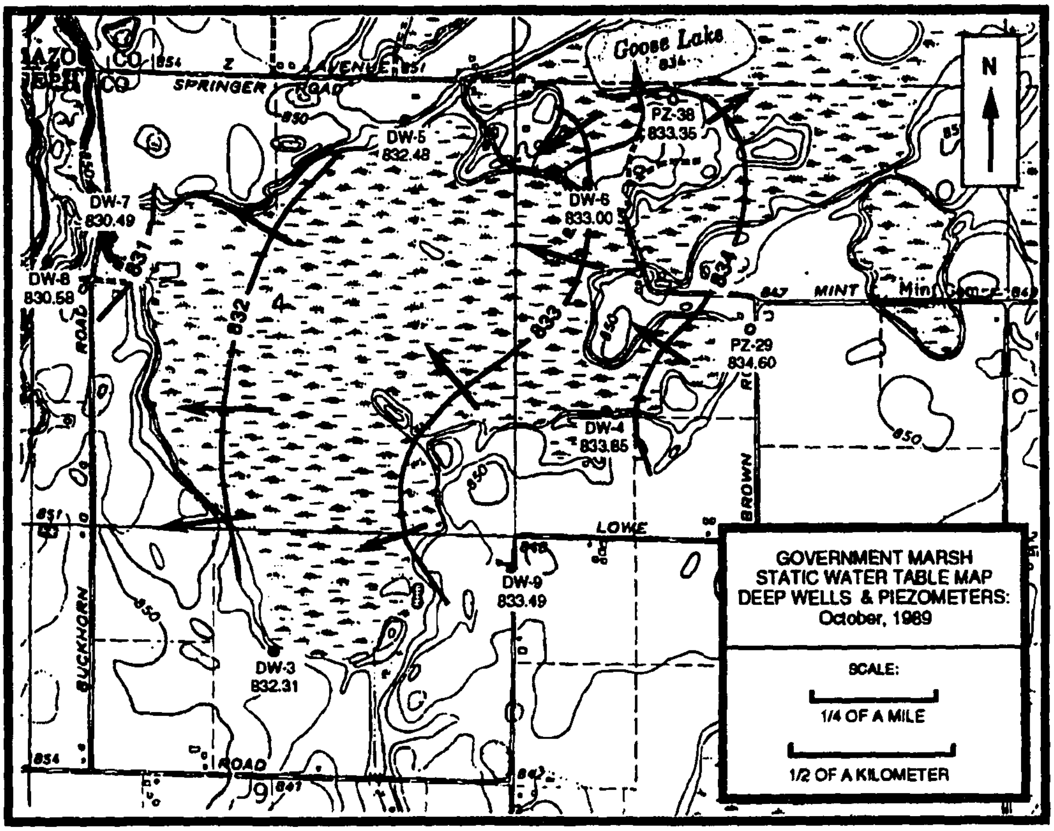




Base map taken U.S.G.S. topographic quadrangle map of Vicksburg, Michigan, 7.5 Minute Series.

LEGEND:

- DW-3 832.86 — Deep Well Location, Identification & Measured Static Water Level Elevation
- PZ-38 834.17 — Piezometer Location, Identification & Measured Static Water Level Elevation
- Topographic Contour: CI = 5 ft
- Static Water Table Contour: CI = 1.0 ft; Direction of Ground Water Flow



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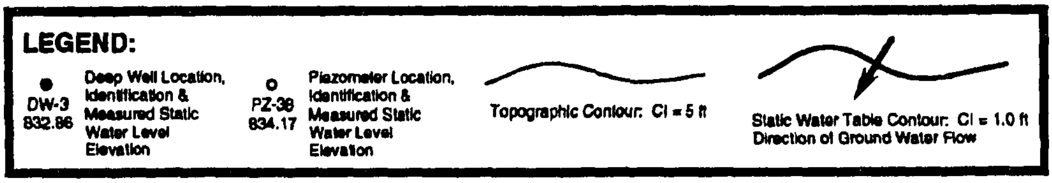
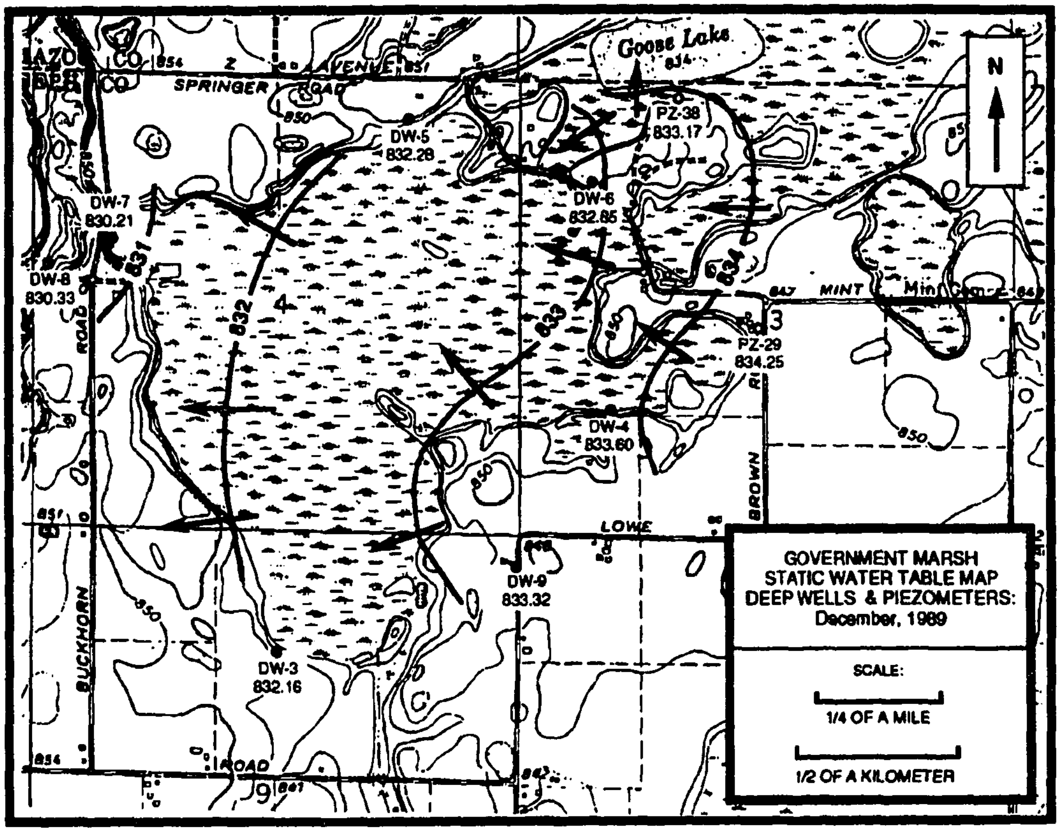




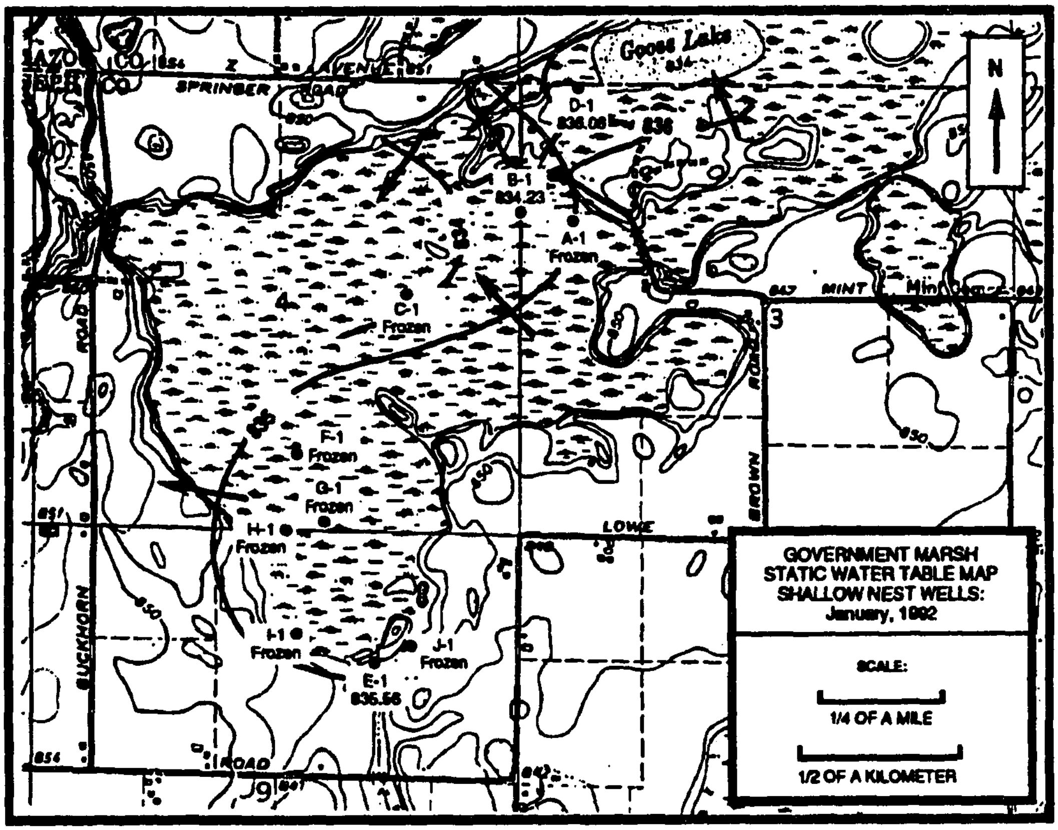
Base map taken U.S.G.S. topographic quadrangle map of Vicksburg, Michigan, 7.5 Minute Series.

LEGEND:

- DW-3 832.86 — Deep Well Location, Identification & Measured Static Water Level Elevation
- PZ-38 834.17 — Piezometer Location, Identification & Measured Static Water Level Elevation
- Topographic Contour: CI = 5 ft
- Static Water Table Contour: CI = 1.0 ft; Direction of Ground Water Flow

Appendix F

Well Nests Static Water Table Maps 1992



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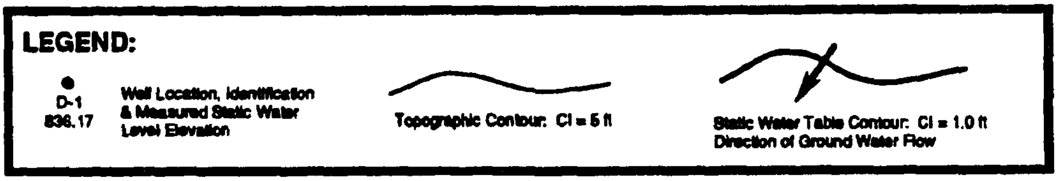

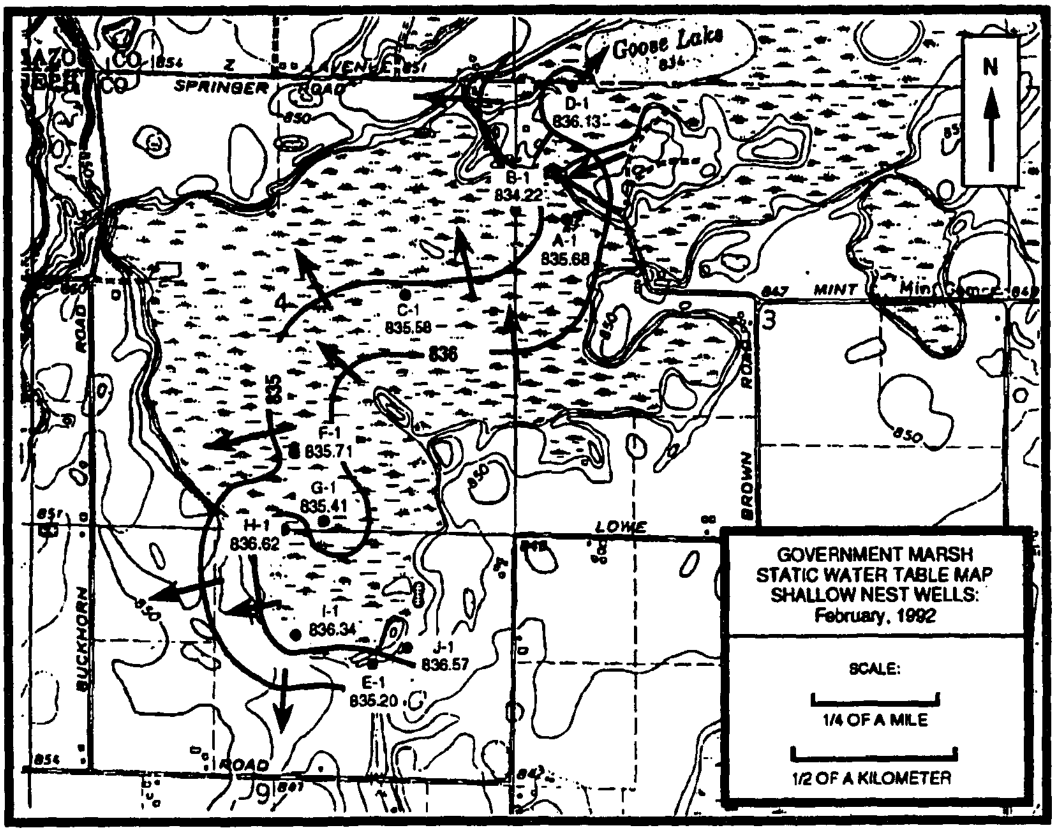

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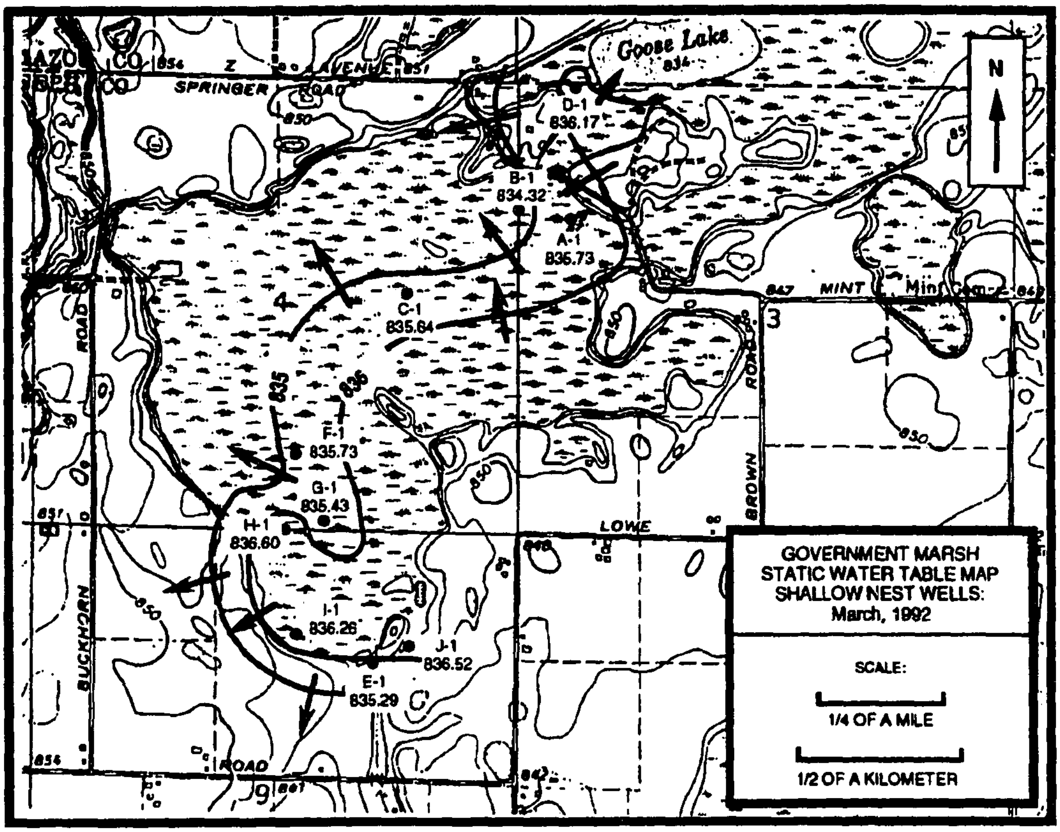
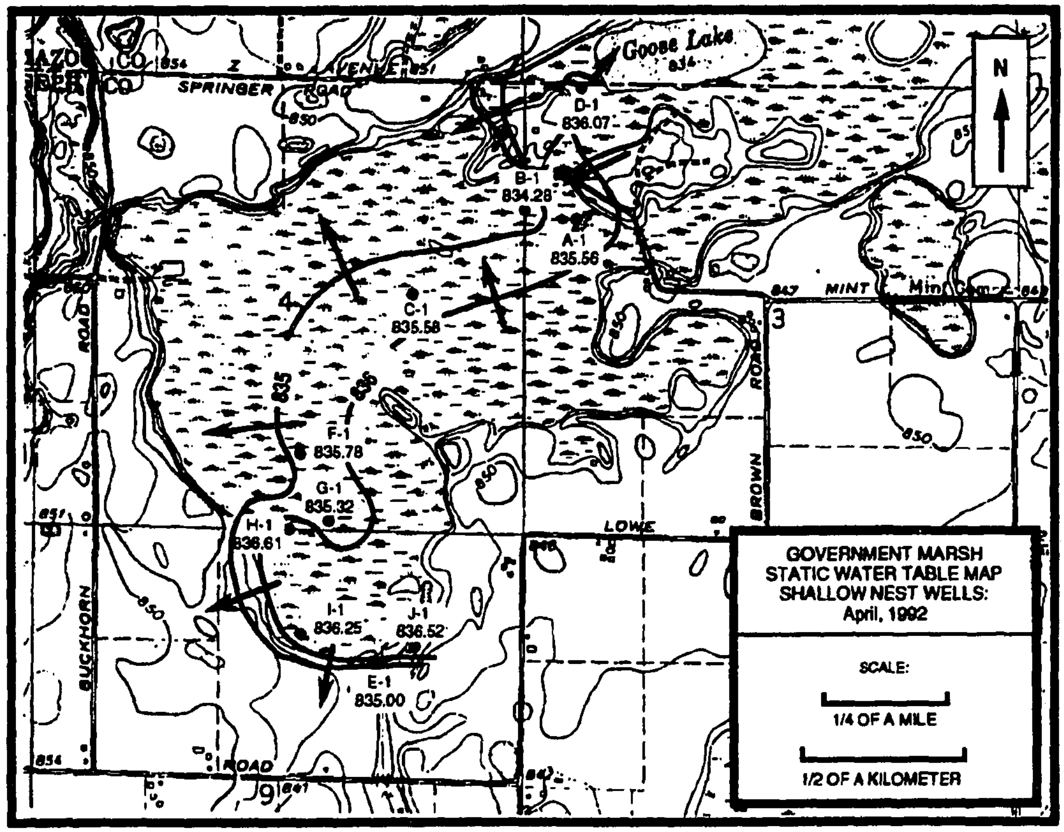


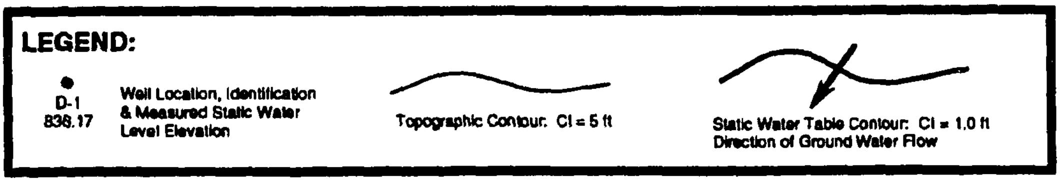
Base map taken U.S.G.S. topographic quadrangle map of Vicksburg, Michigan, 7.5 Minute Series.

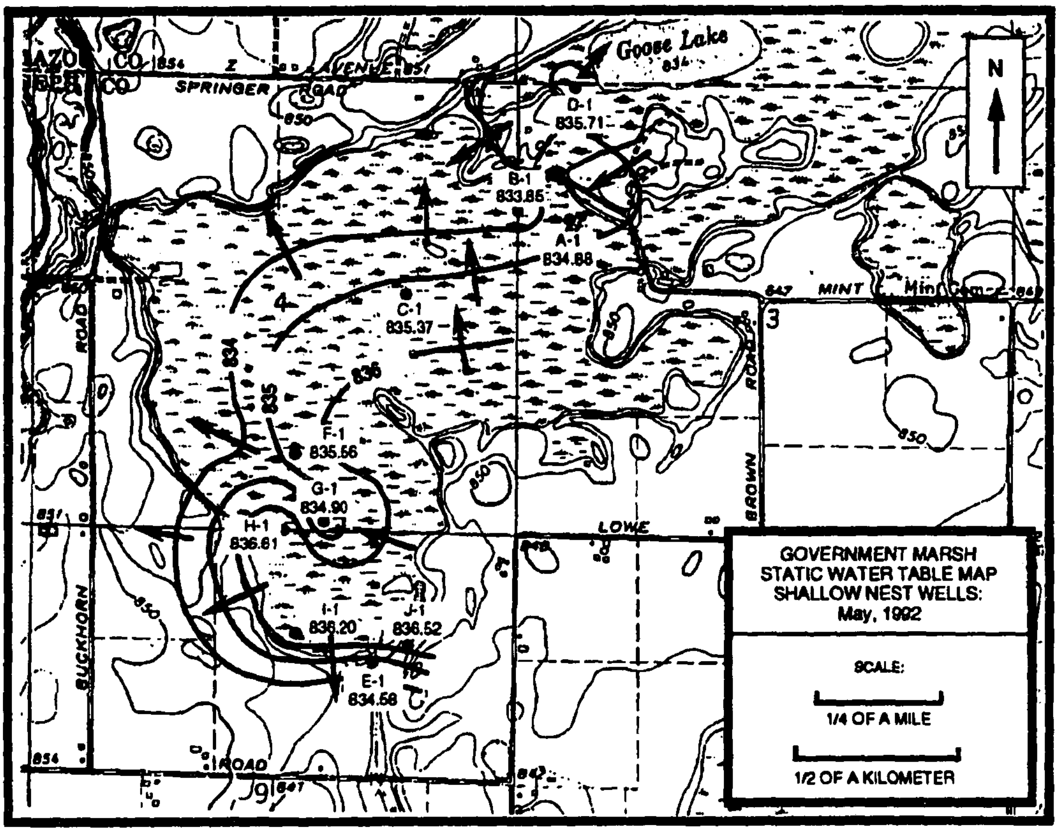
LEGEND:

- D-1 836.17 — Well Location, Identification & Measured Static Water Level Elevation
- Topographic Contour: CI = 5 ft
- Static Water Table Contour: CI = 1.0 ft; Direction of Ground Water Flow

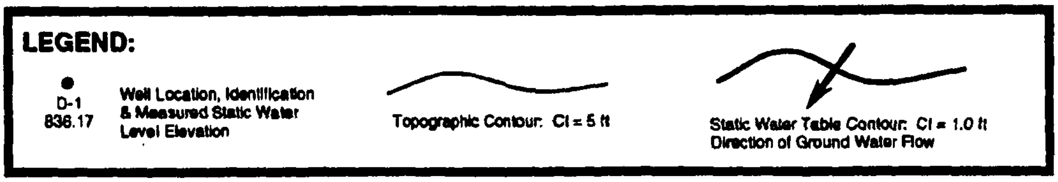


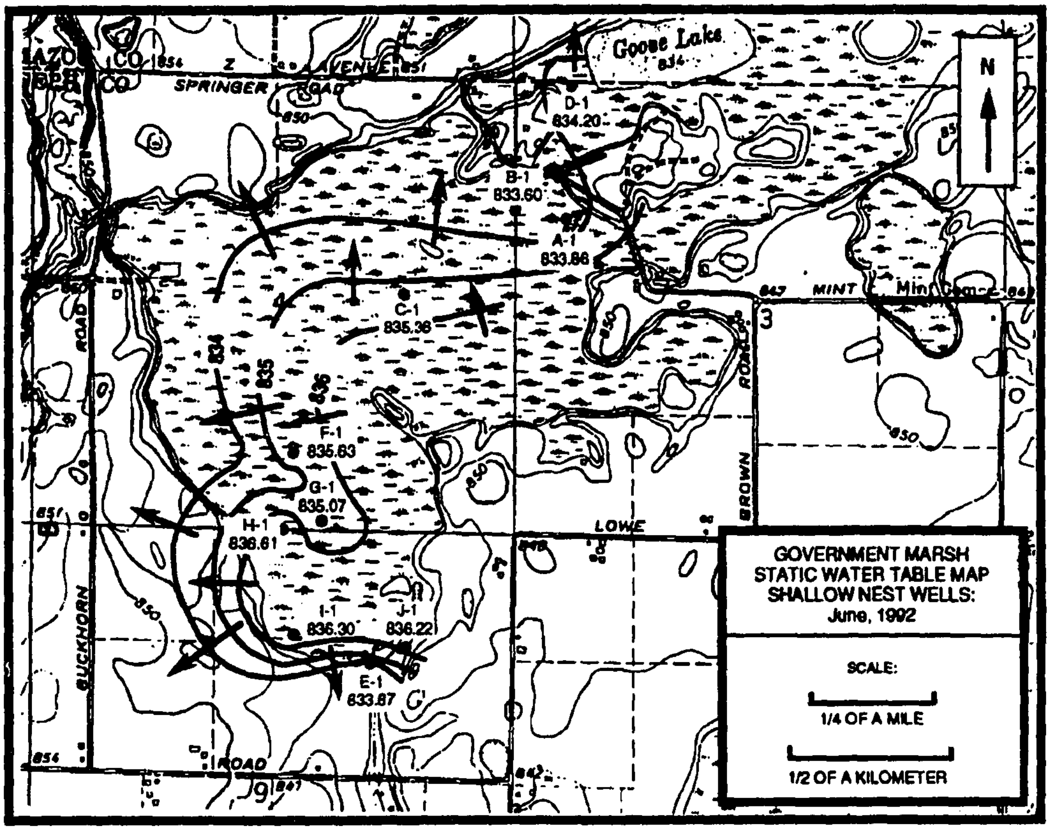
Base map taken U.S.G.S. topographic quadrangle map of Vicksburg, Michigan, 7.5 Minute Series.



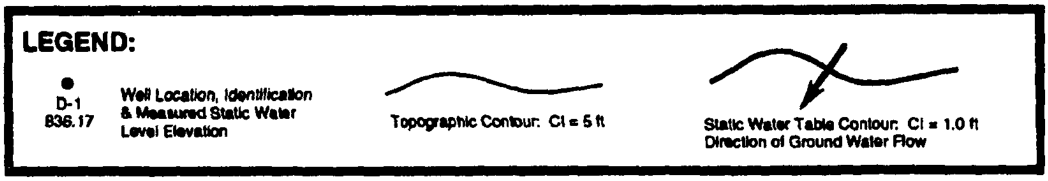


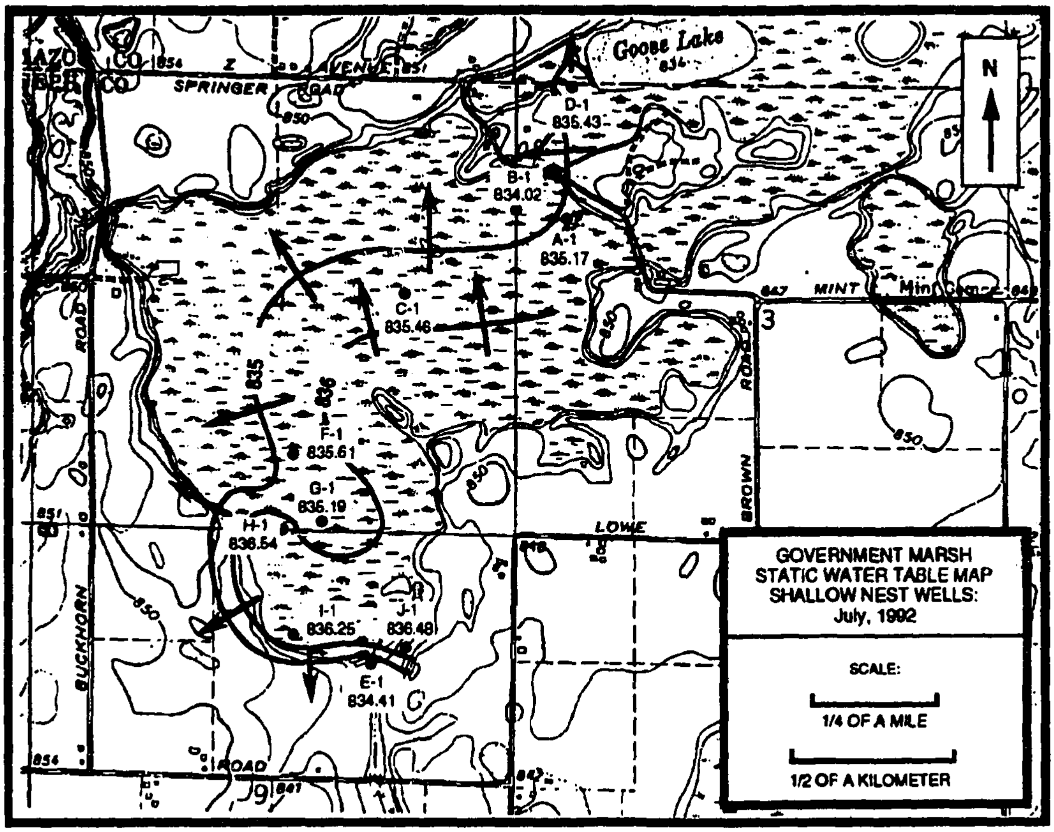
Base map taken U.S.G.S. topographic quadrangle map of Vicksburg, Michigan, 7.5 Minute Series.



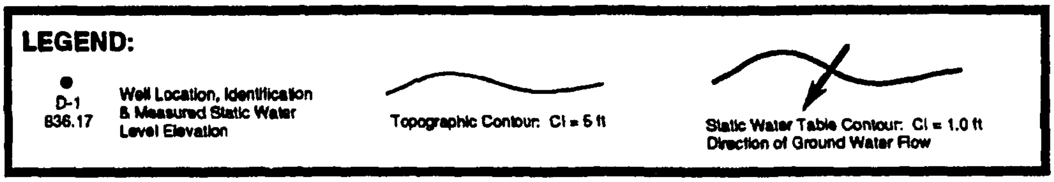


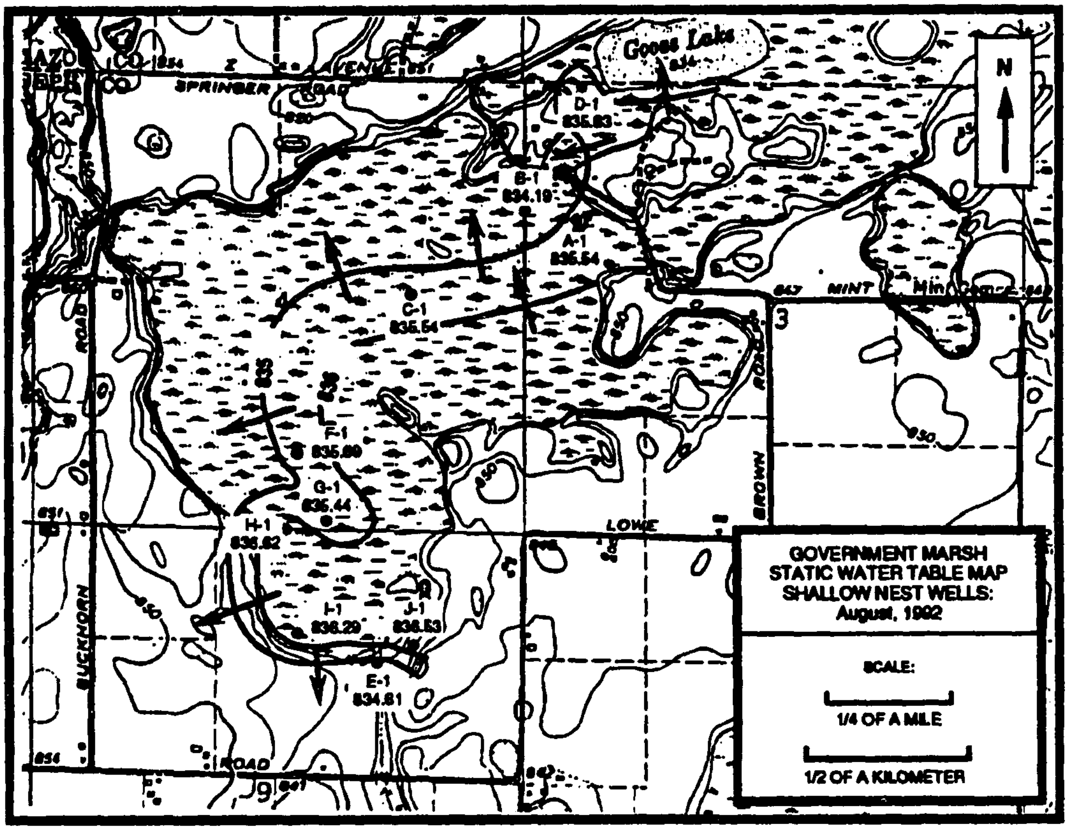
Base map taken U.S.G.S. topographic quadrangle map of Vicksburg, Michigan, 7.5 Minute Series.





Base map taken U.S.G.S. topographic quadrangle map of Vicksburg, Michigan, 7.5 Minute Series.

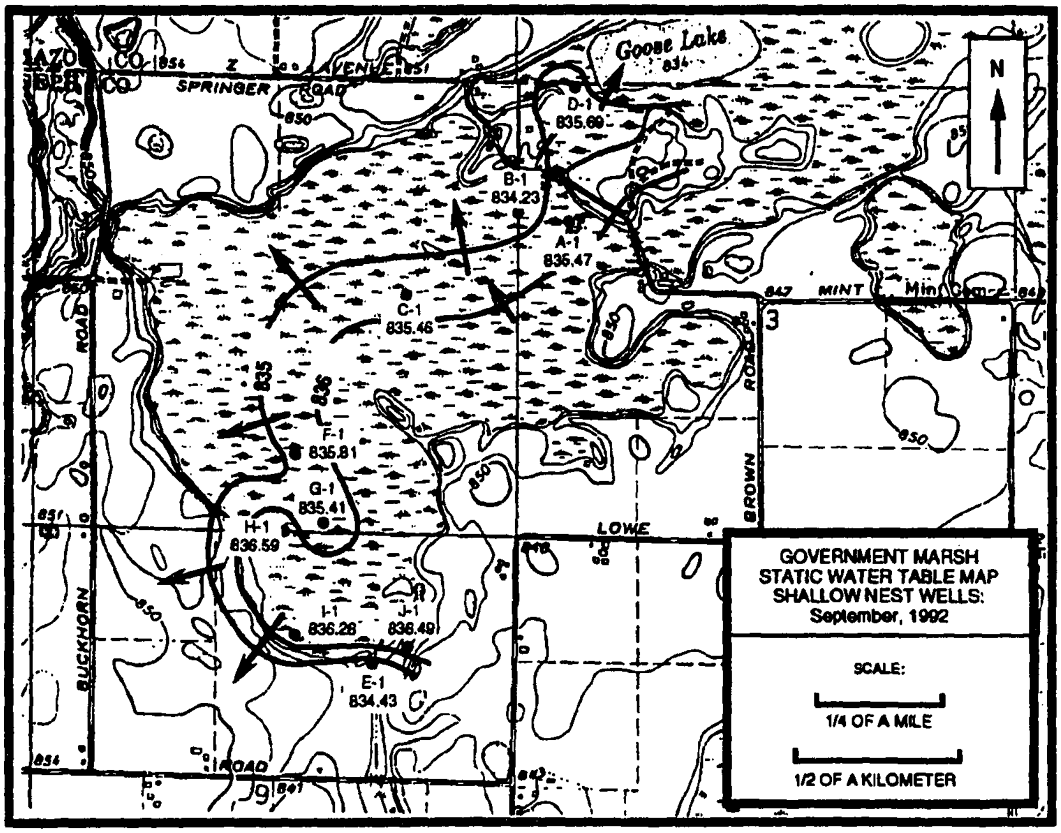




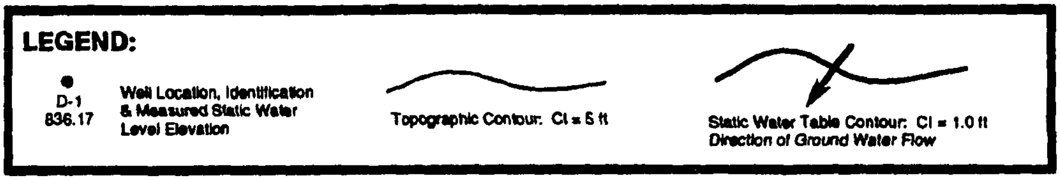
Base map taken U.S.G.S. topographic quadrangle map of Vicksburg, Michigan, 7.5 Minute Series.

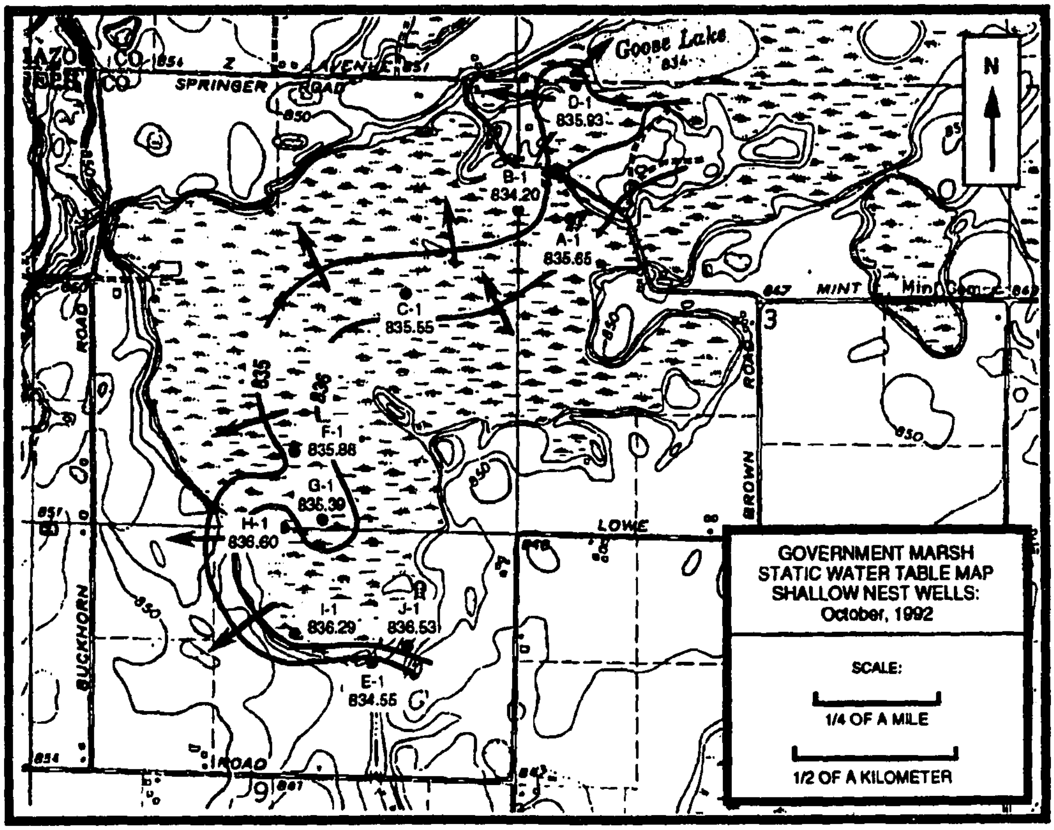
LEGEND:

● D-1 836.17 — Well Location, Identification & Measured Static Water Level Elevation	Topographic Contour: CI = 5 ft	Static Water Table Contour: CI = 1.0 ft; Direction of Ground Water Flow



Base map taken U.S.G.S. topographic quadrangle map of Vicksburg, Michigan, 7.5 Minute Series.





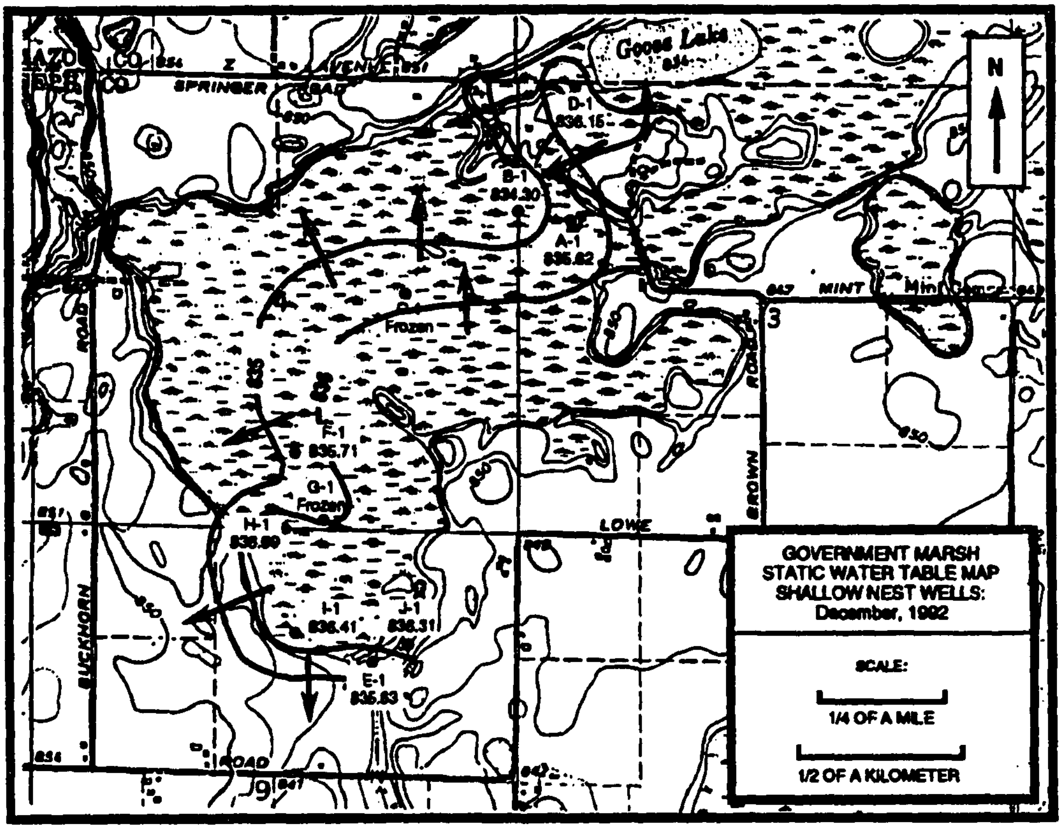
Base map taken U.S.G.S. topographic quadrangle map of Vicksburg, Michigan, 7.5 Minute Series.

LEGEND:

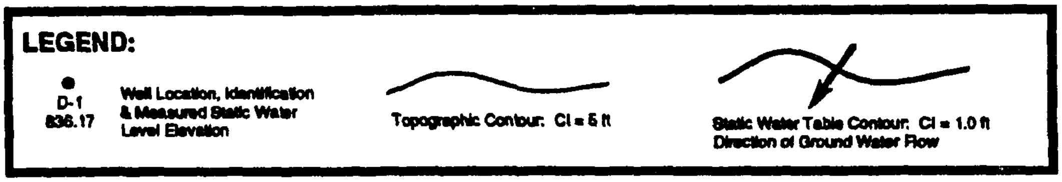
D-1 836.17 — Well Location, Identification & Measured Static Water Level Elevation

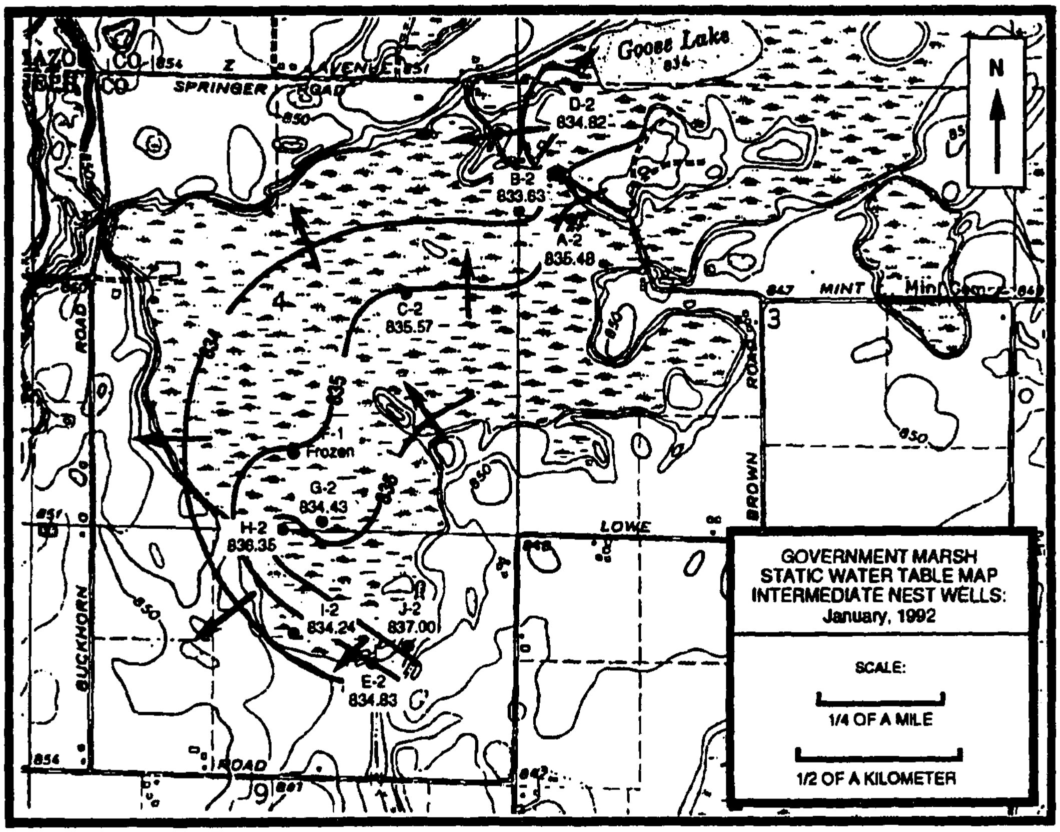
Topographic Contour: CI = 5 ft

Static Water Table Contour: CI = 1.0 ft
Direction of Ground Water Flow



Base map taken U.S.G.S. topographic quadrangle map of Vicksburg, Michigan, 7.5 Minute Series.





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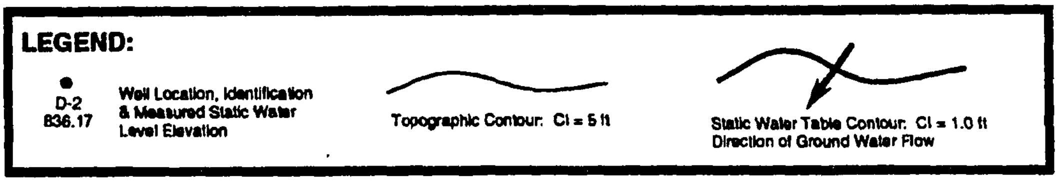

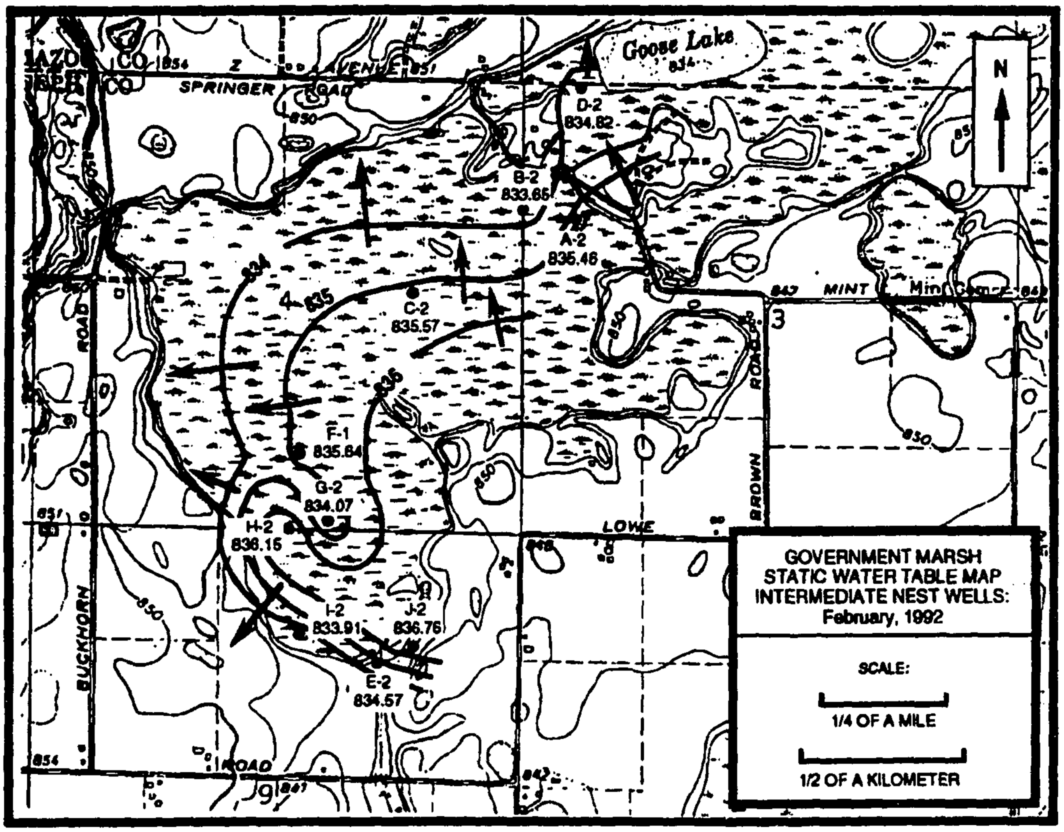

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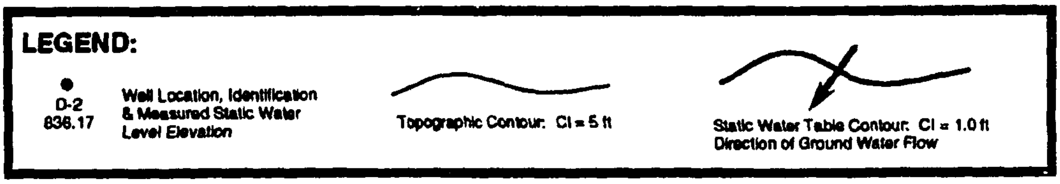

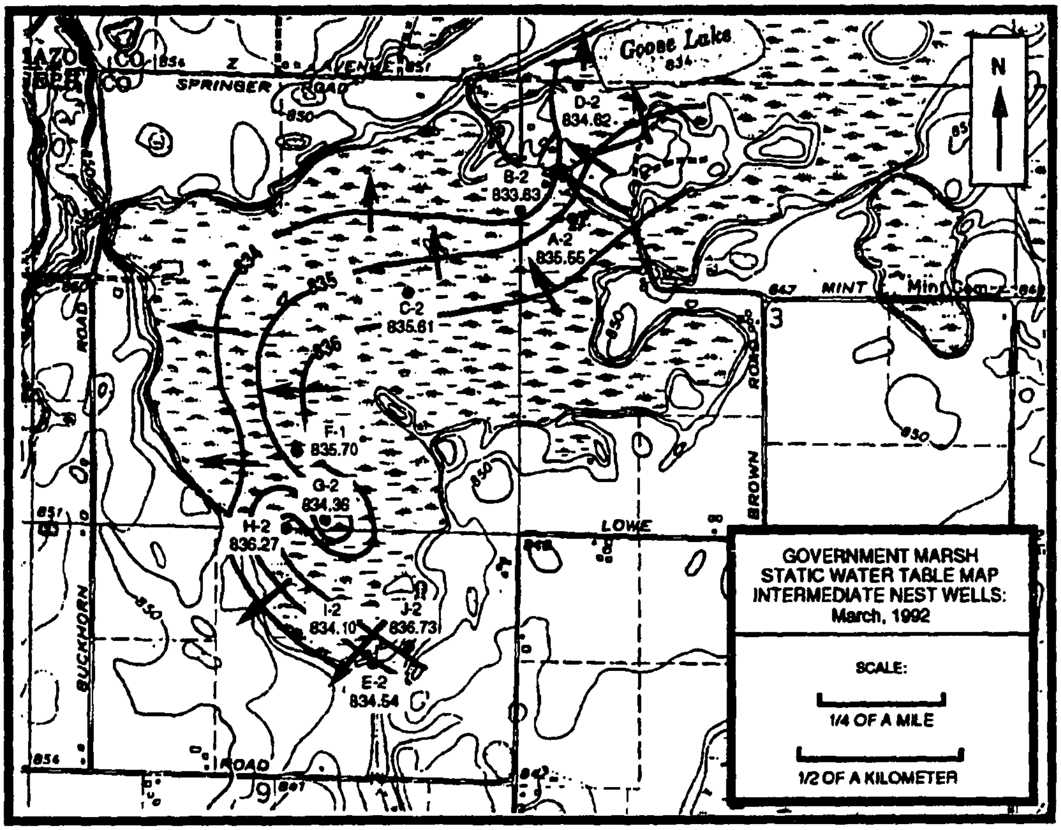

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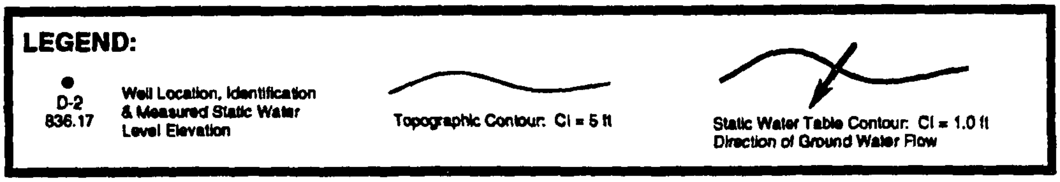
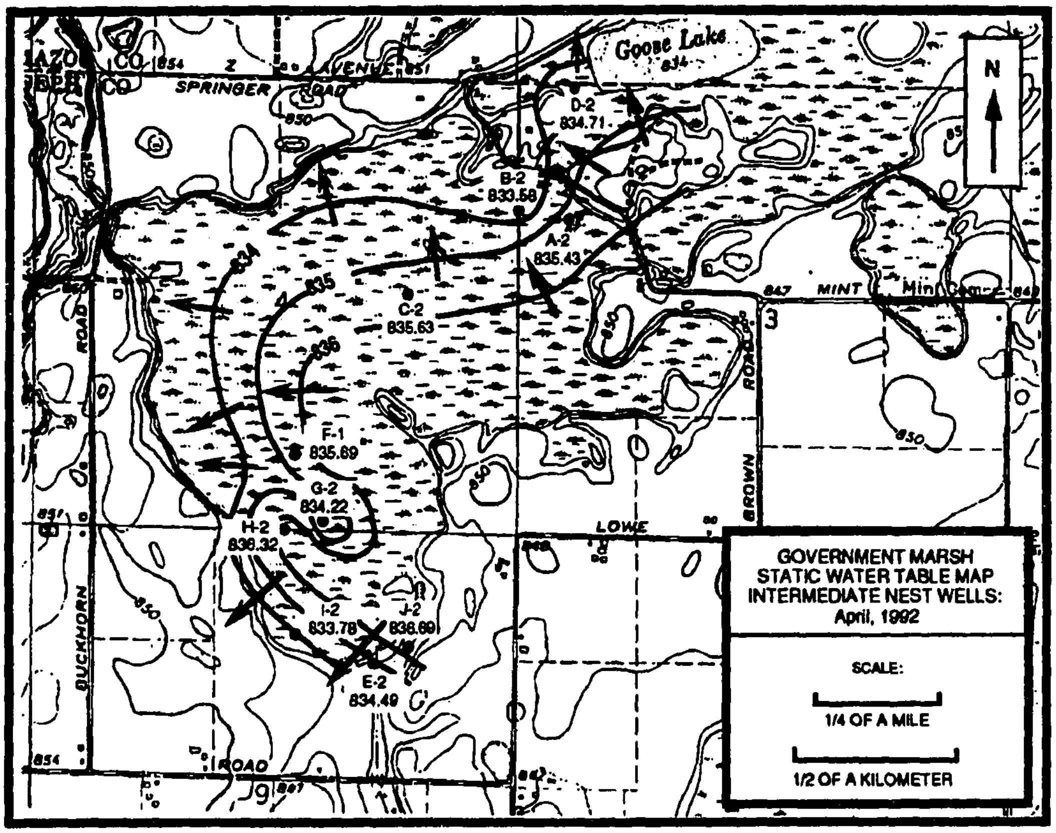
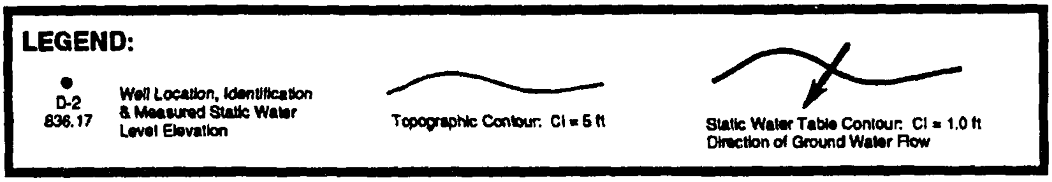
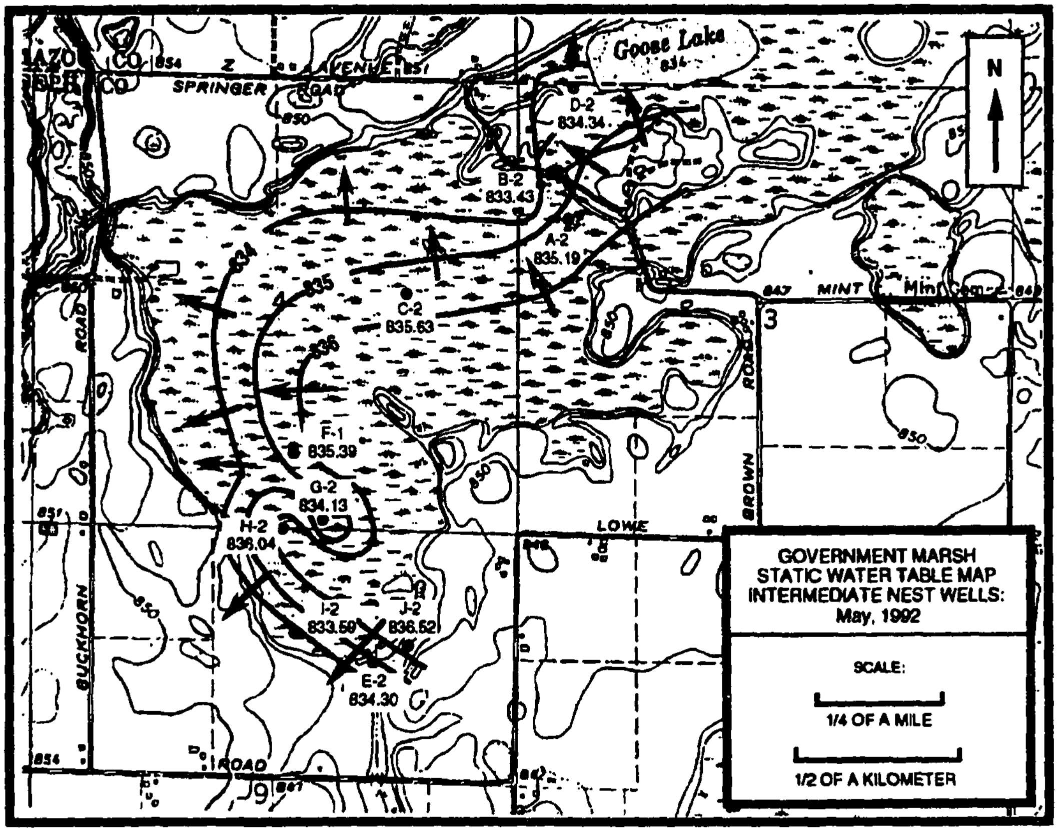


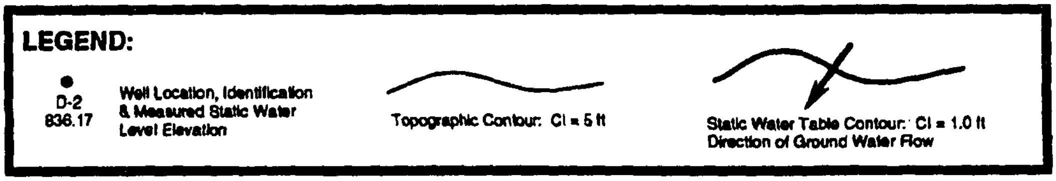


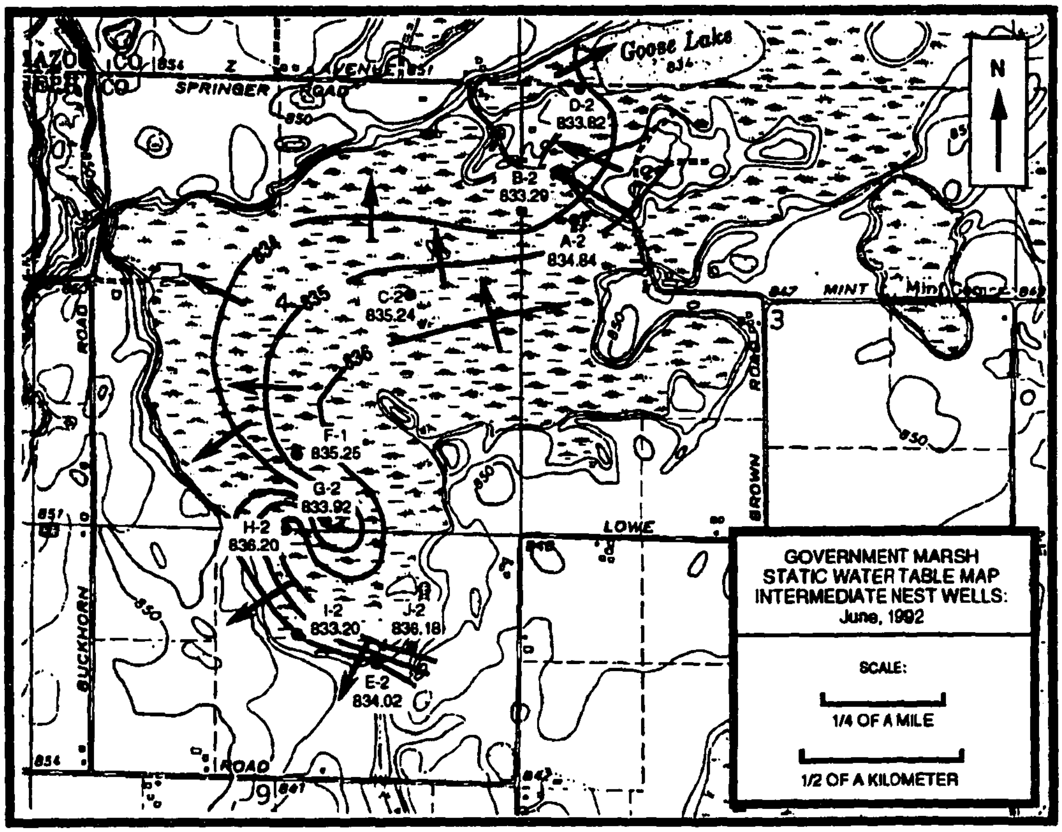
Base map taken U.S.G.S. topographic quadrangle map of Vicksburg, Michigan, 7.5 Minute Series.





Base map taken U.S.G.S. topographic quadrangle map of Vicksburg, Michigan, 7.5 Minute Series.





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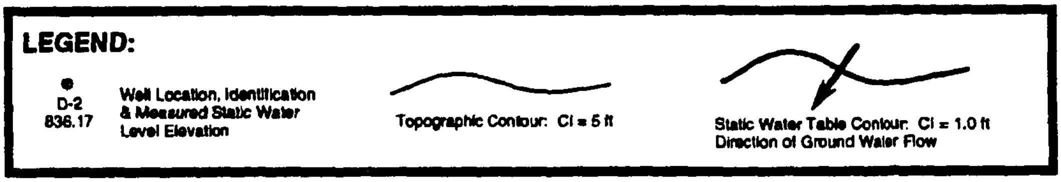

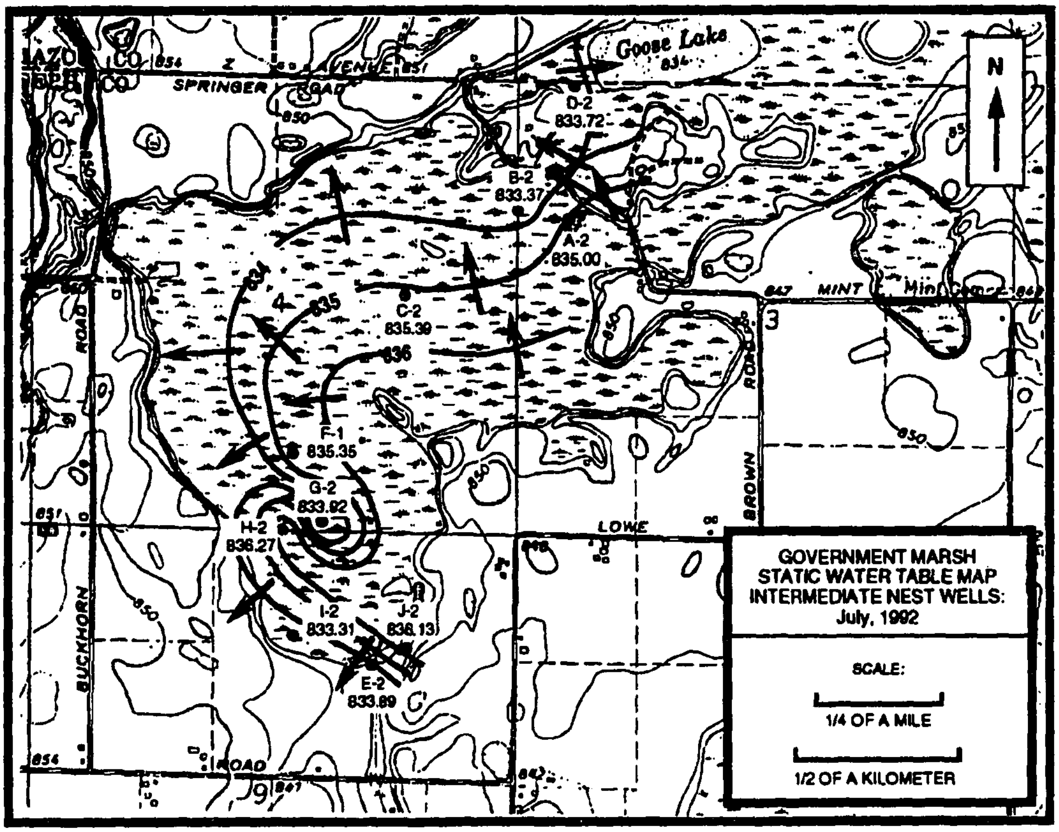

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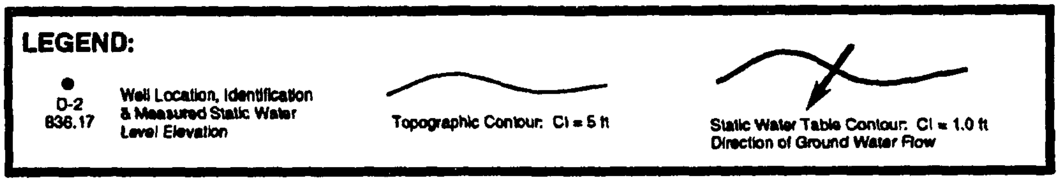
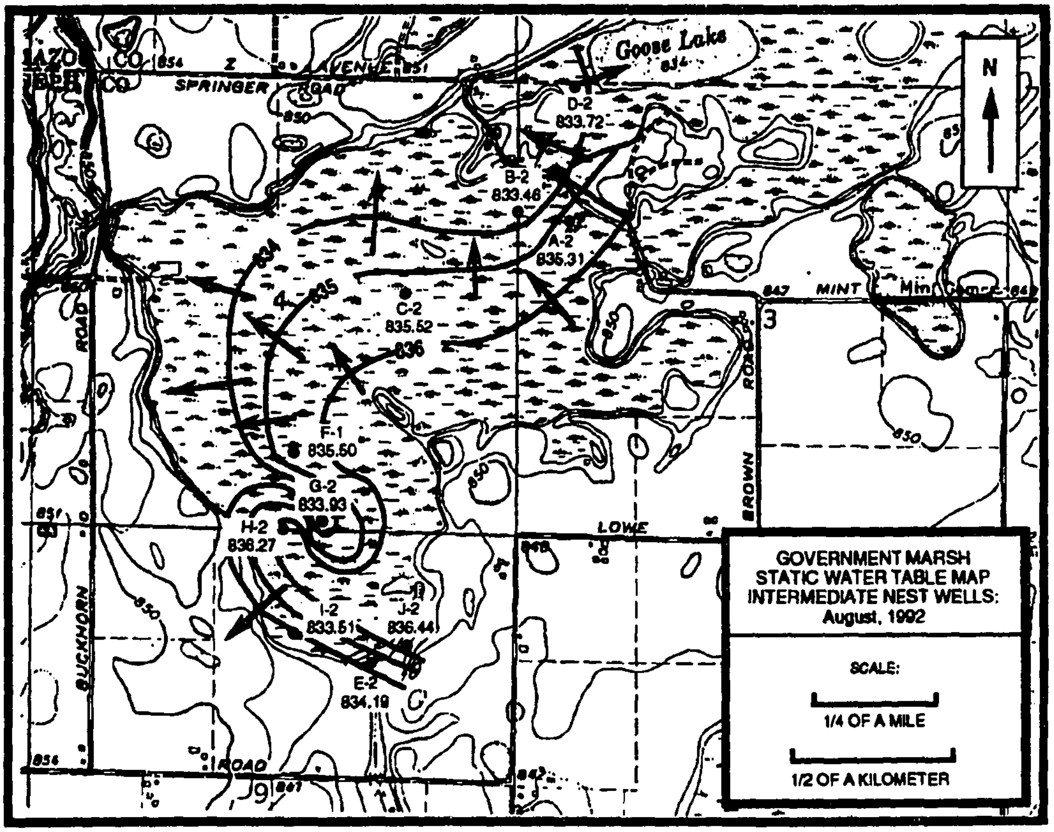
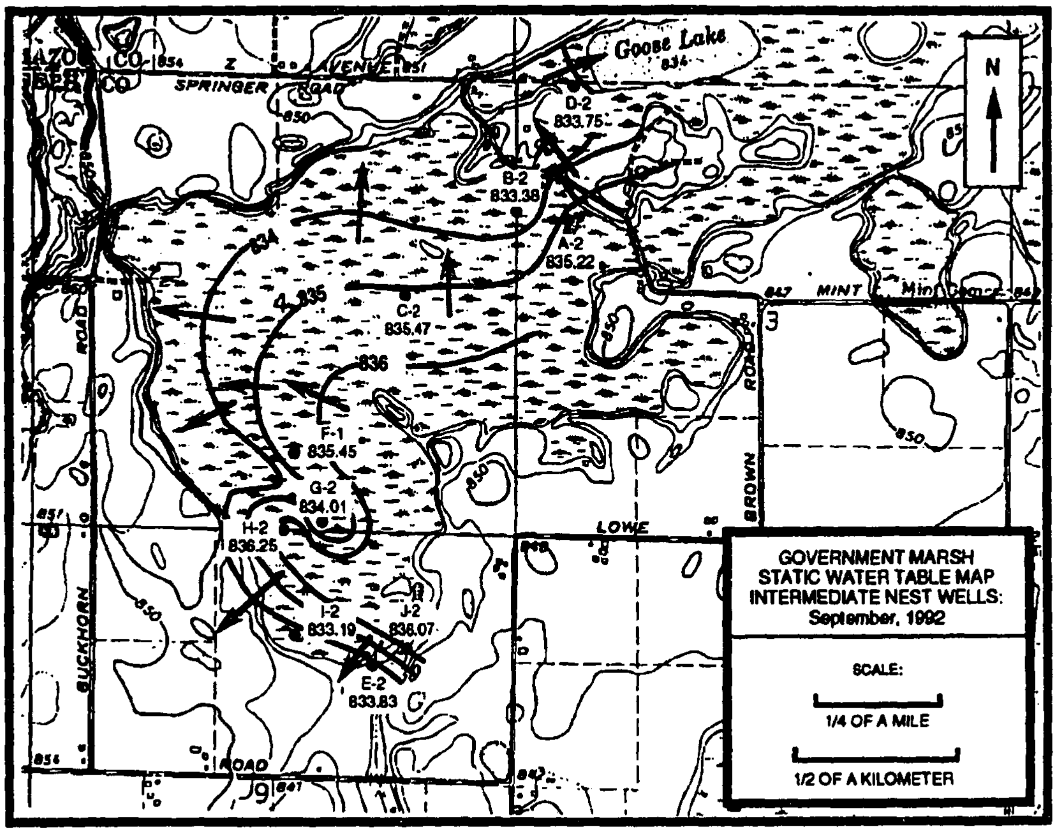




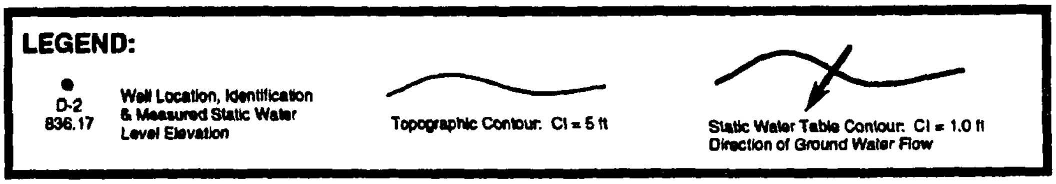
Base map taken U.S.G.S. topographic quadrangle map of Vicksburg, Michigan, 7.5 Minute Series.

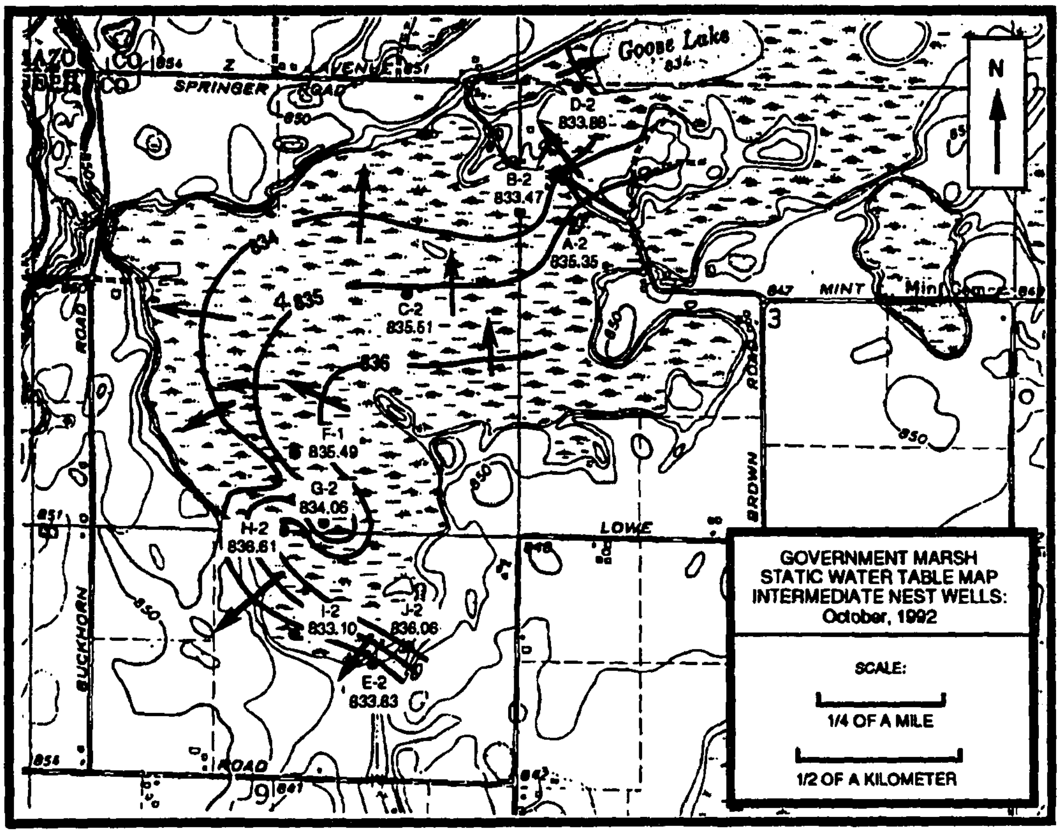
LEGEND:

D-2 836.17 — Well Location, Identification & Measured Static Water Level Elevation	Topographic Contour: CI = 5 ft	Static Water Table Contour: CI = 1.0 ft Direction of Ground Water Flow

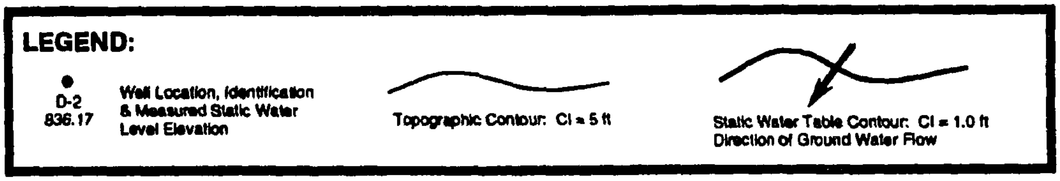


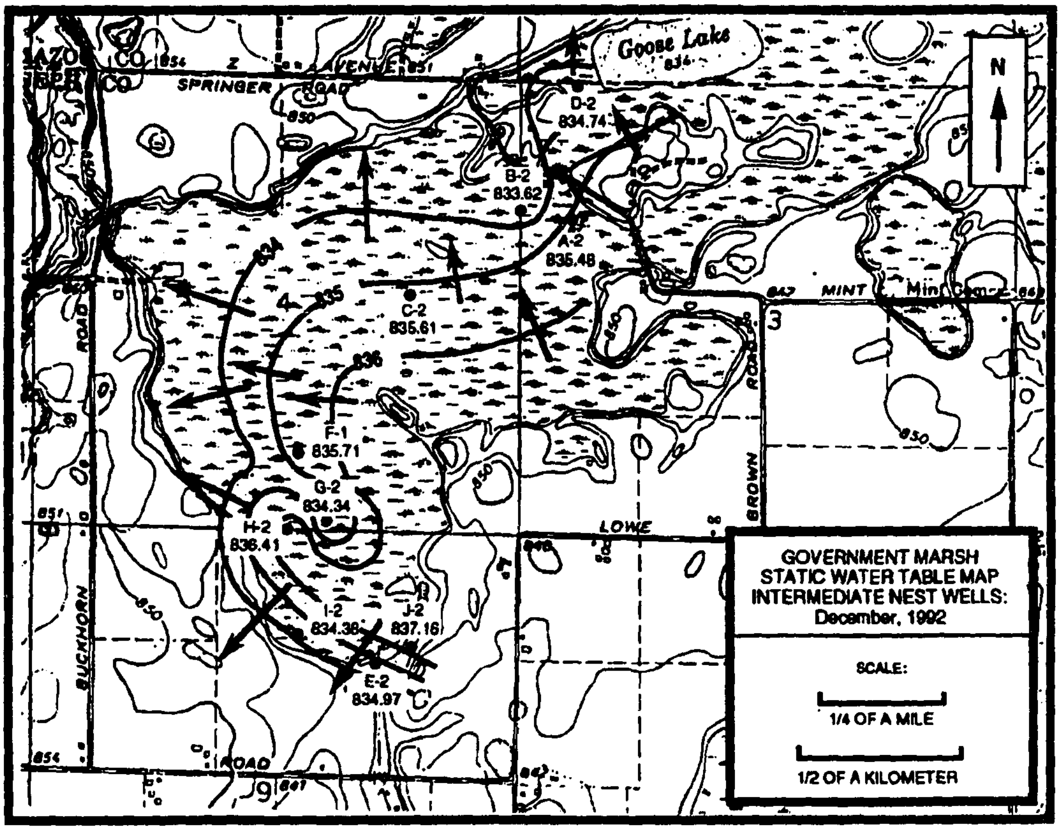
Base map taken U.S.G.S. topographic quadrangle map of Vicksburg, Michigan, 7.5 Minute Series.



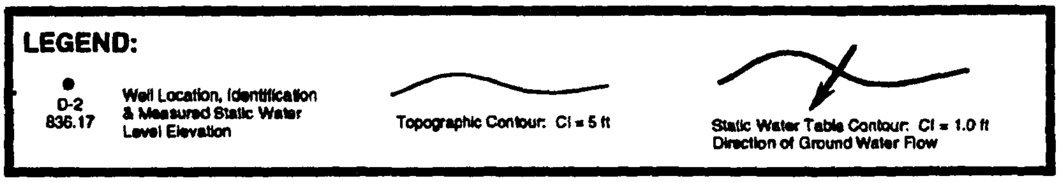


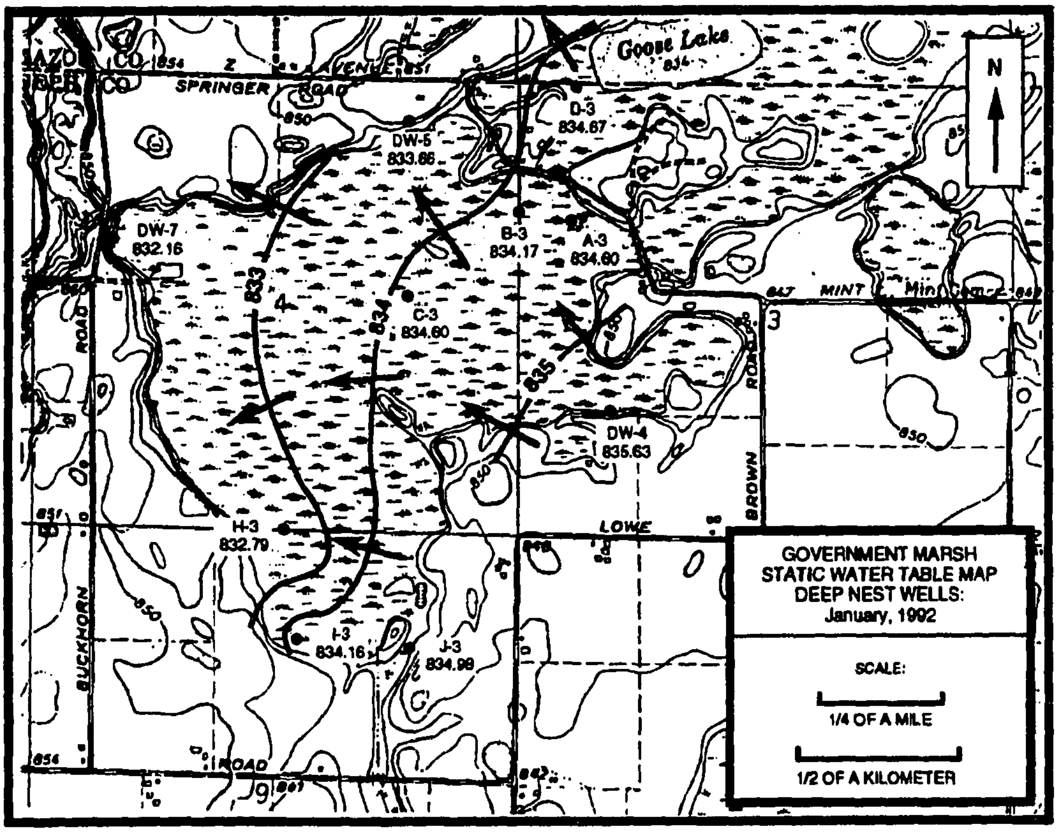
Base map taken U.S.G.S. topographic quadrangle map of Vicksburg, Michigan, 7.5 Minute Series.





Base map taken U.S.G.S. topographic quadrangle map of Vicksburg, Michigan, 7.5 Minute Series.

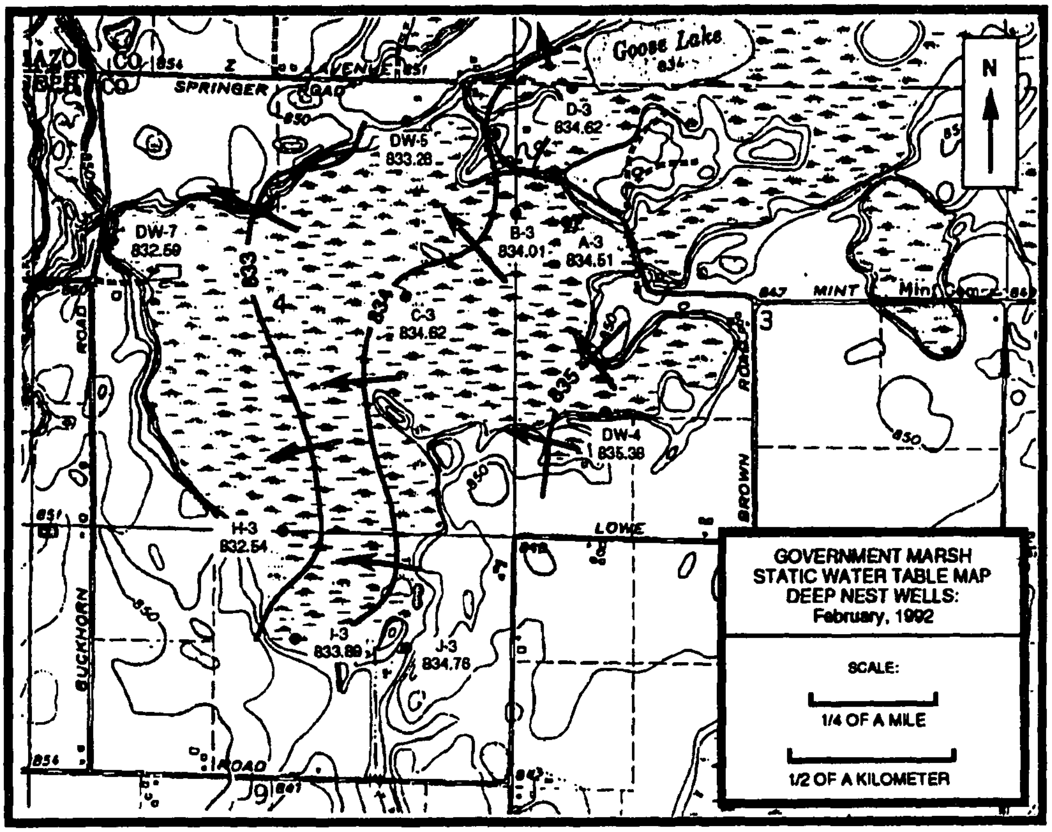




Base map taken U.S.G.S. topographic quadrangle map of Vicksburg, Michigan, 7.5 Minute Series.

LEGEND:

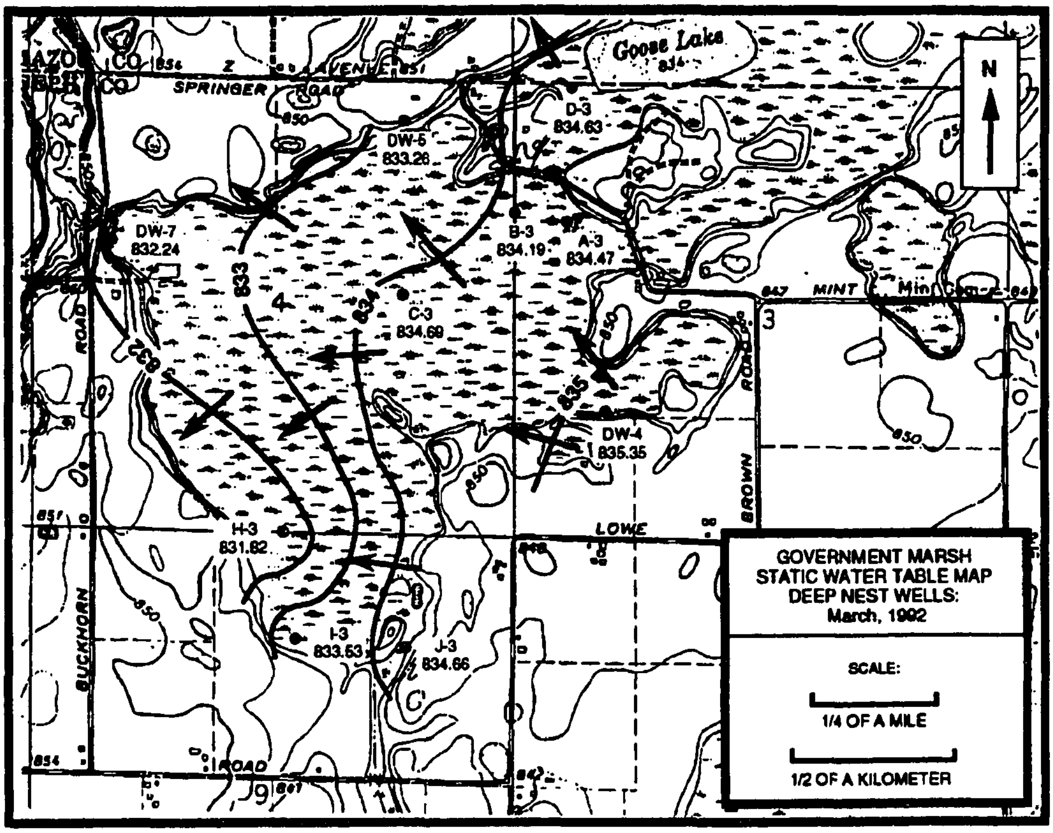
D-3 836.17 — Well Location, Identification & Measured Static Water Level Elevation	Topographic Contour: CI = 5 ft	Static Water Table Contour: CI = 1.0 ft; Direction of Ground Water Flow



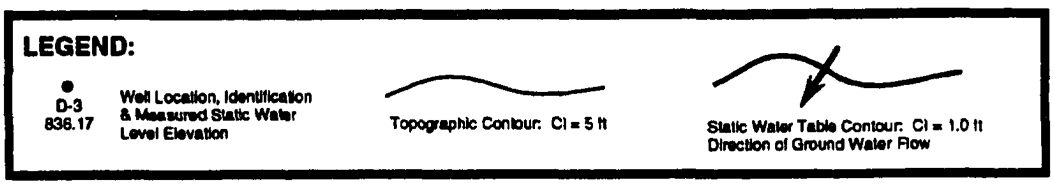
Base map taken U.S.G.S. topographic quadrangle map of Vicksburg, Michigan, 7.5 Minute Series.

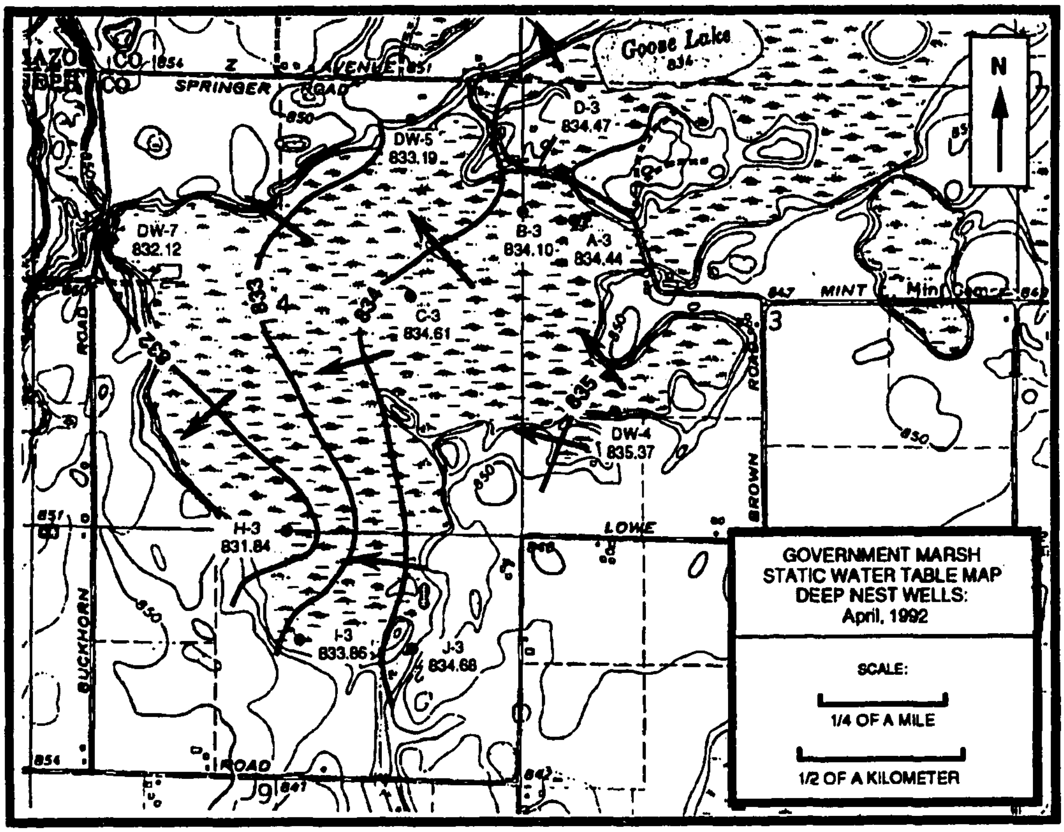
LEGEND:

D-3 836.17 — Well Location, Identification & Measured Static Water Level Elevation	Topographic Contour: CI = 5 ft	Static Water Table Contour: CI = 1.0 ft; Direction of Ground Water Flow



Base map taken U.S.G.S. topographic quadrangle map of Vicksburg, Michigan, 7.5 Minute Series.





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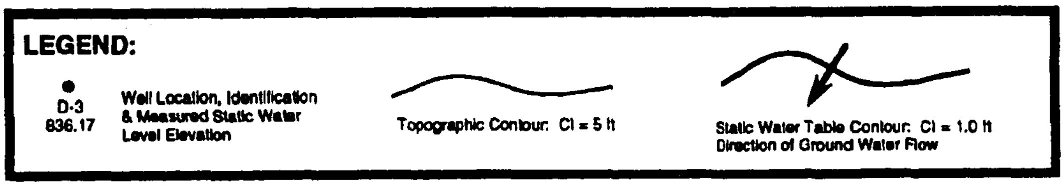
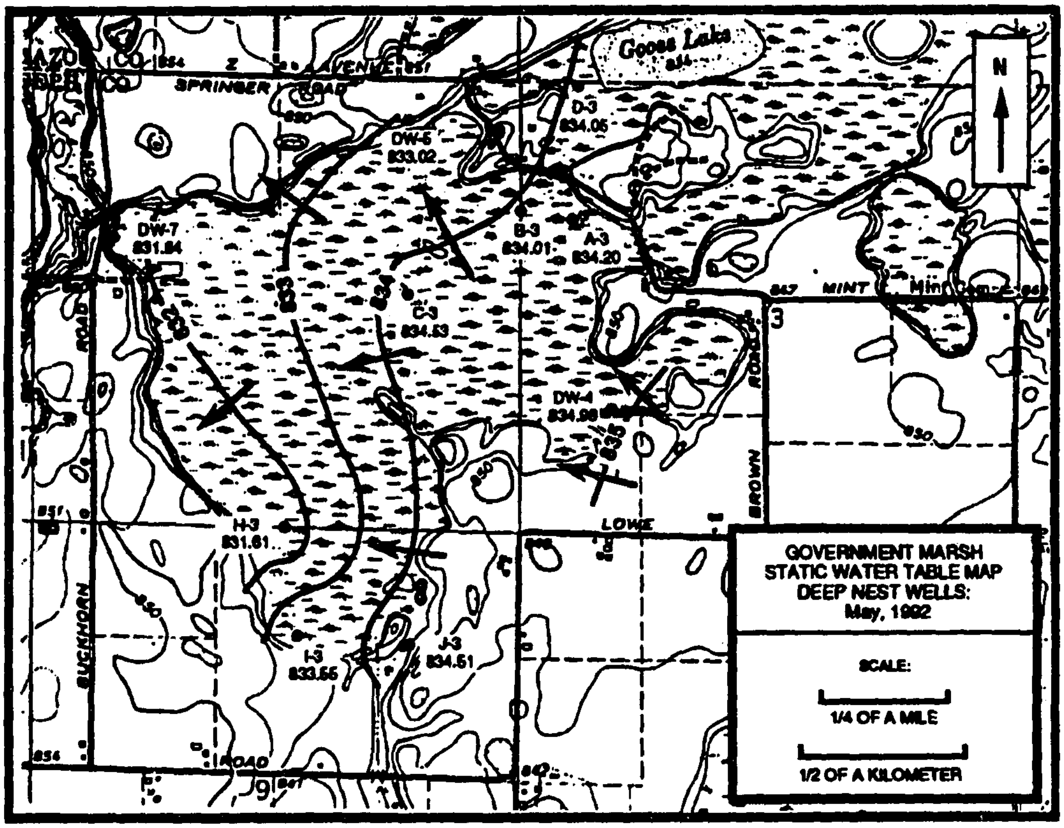
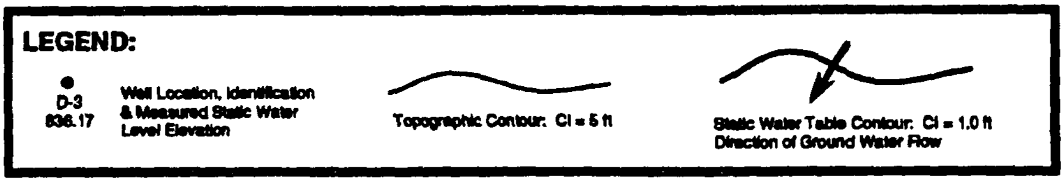
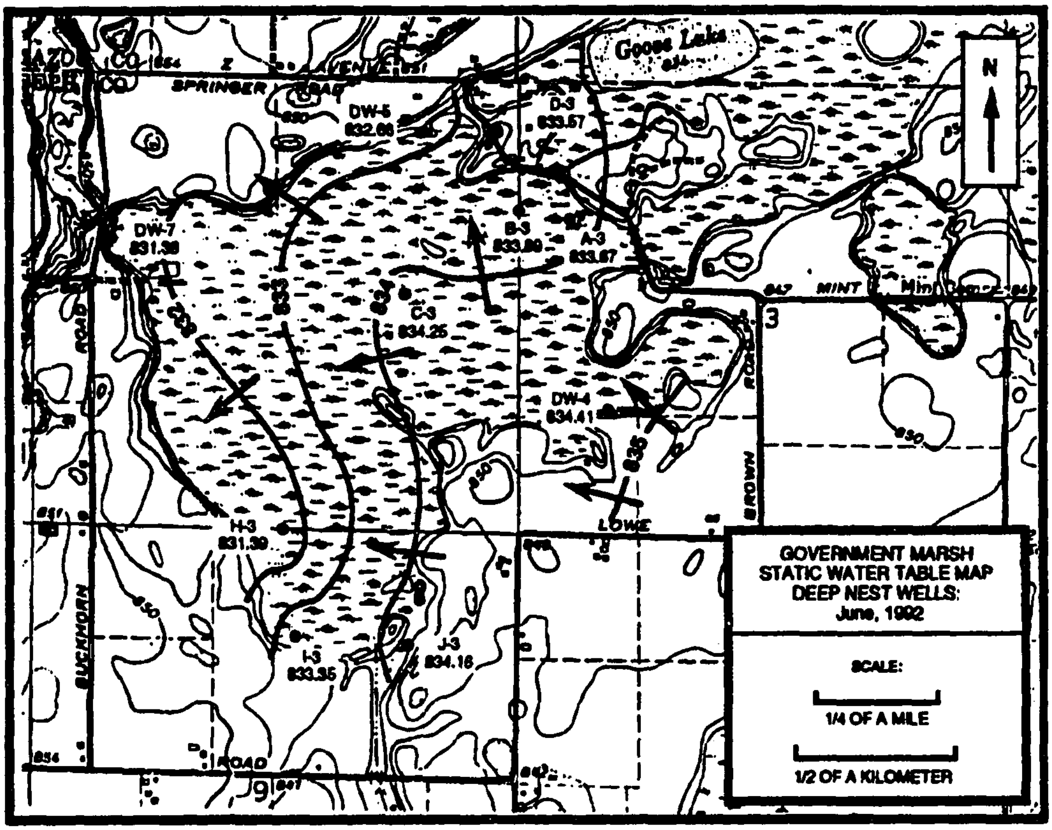




Base map taken U.S.G.S. topographic quadrangle map of Vicksburg, Michigan, 7.5 Minute Series.





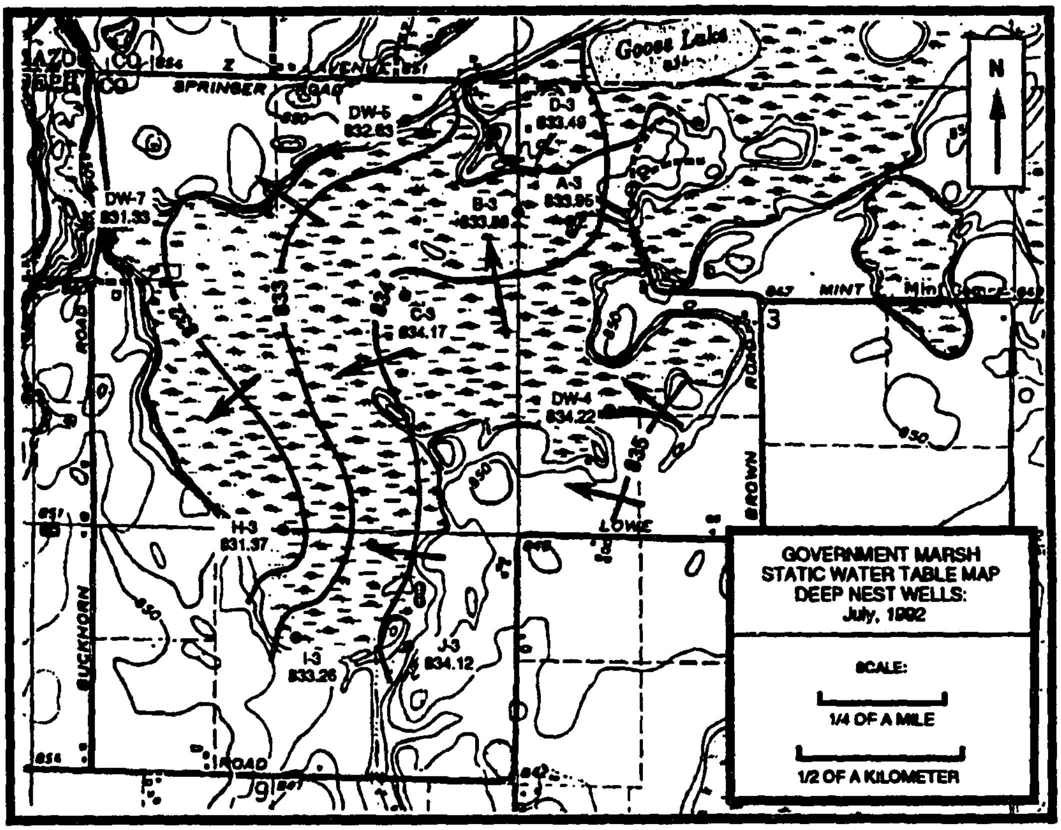
Base map taken U.S.G.S. topographic quadrangle map of Vicksburg, Michigan, 7.5 Minute Series.

LEGEND:

D-3 836.17 — Well Location, Identification & Measured Static Water Level Elevation

Topographic Contour: CI = 5 ft

Static Water Table Contour: CI = 1.0 ft
Direction of Ground Water Flow



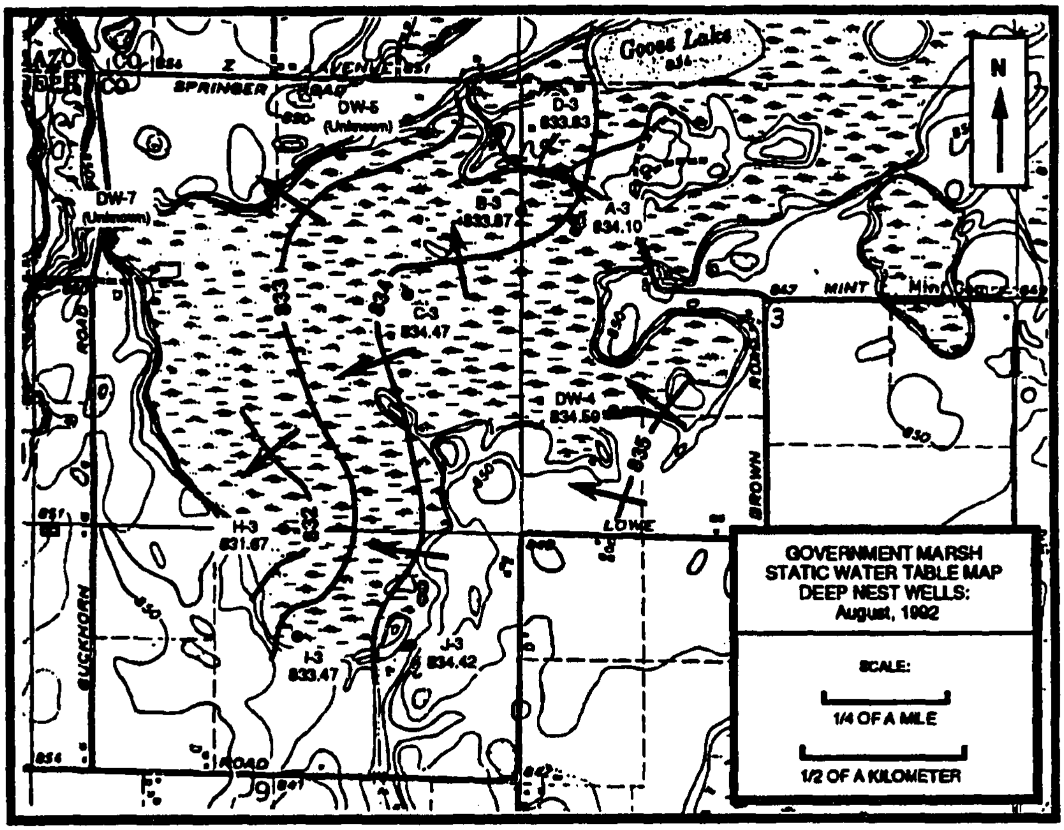
Base map taken U.S.G.S. topographic quadrangle map of Vicksburg, Michigan, 7.5 Minute Series.

LEGEND:

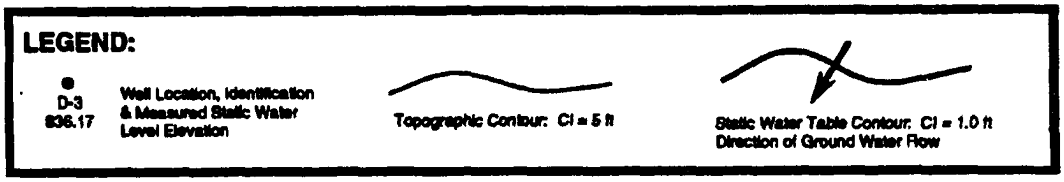
D-3 836.17 — Well Location, Identification & Measured Static Water Level Elevation

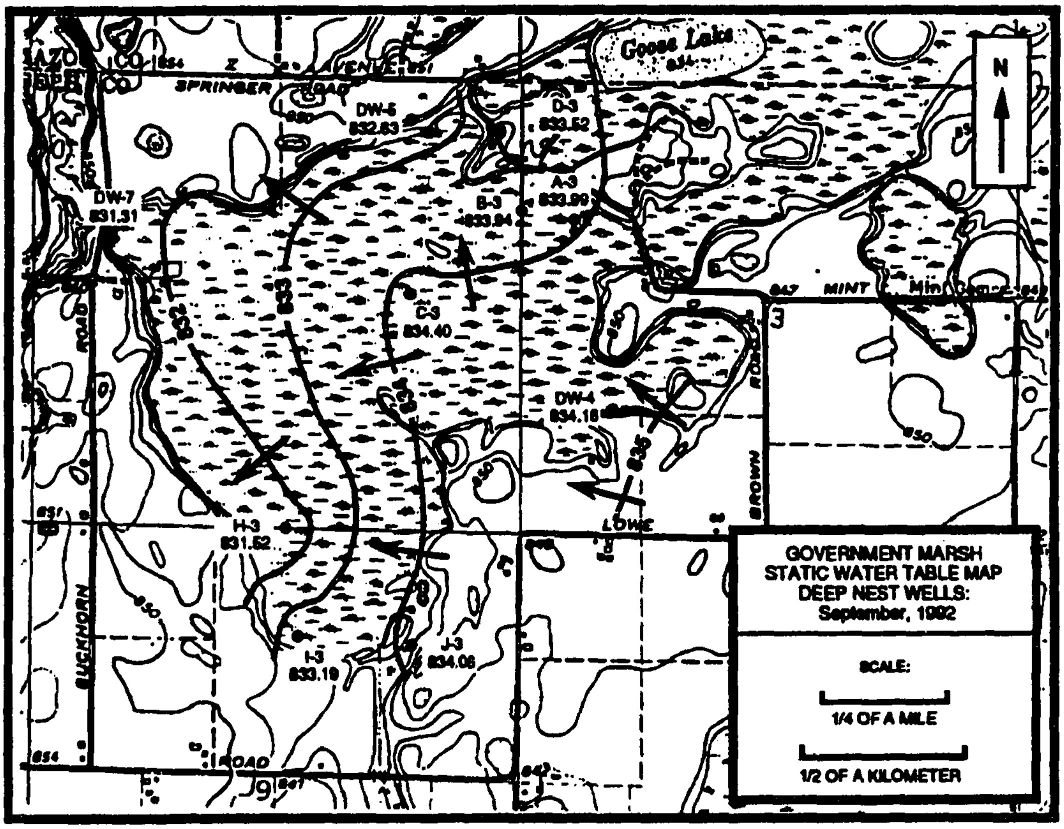
Topographic Contour: CI = 5 ft

Static Water Table Contour: CI = 1.0 ft
Direction of Ground Water Flow



Base map taken U.S.G.S. topographic quadrangle map of Vicksburg, Michigan, 7.5 Minute Series.





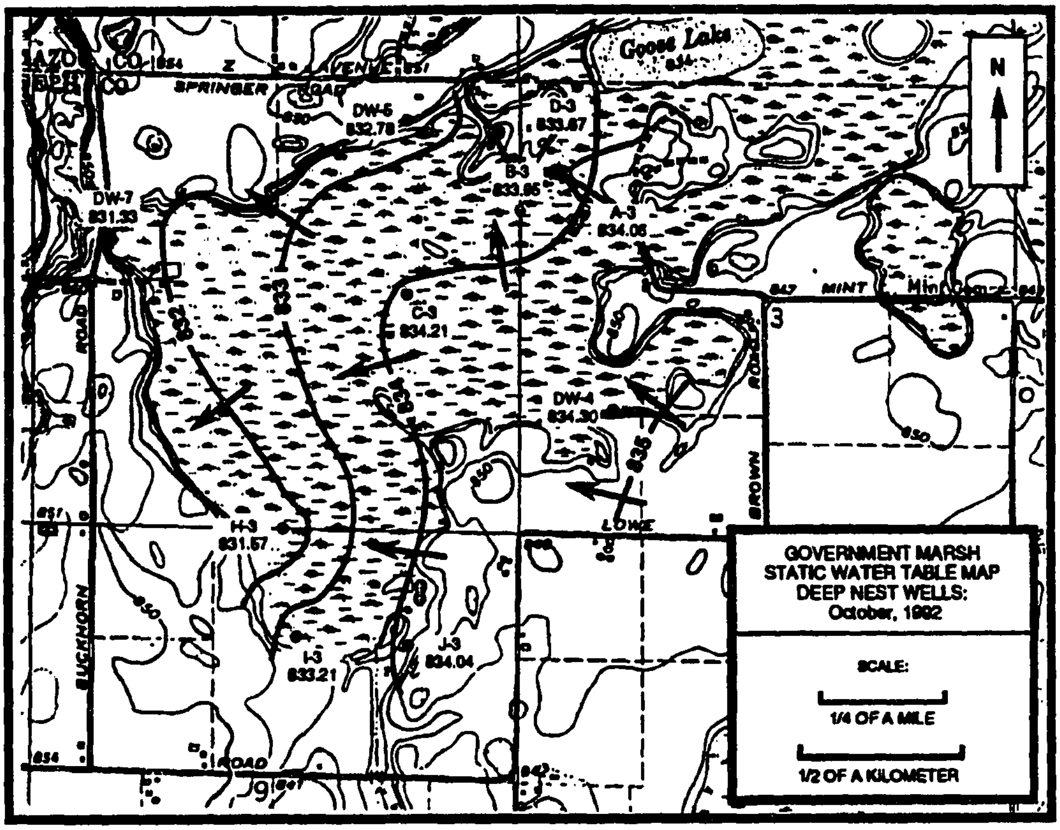
Base map taken U.S.G.S. topographic quadrangle map of Vicksburg, Michigan, 7.5 Minute Series.

LEGEND:

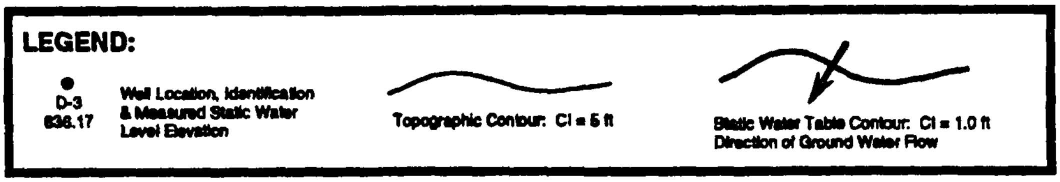
D-3 836.17 — Well Location, Identification & Measured Static Water Level Elevation

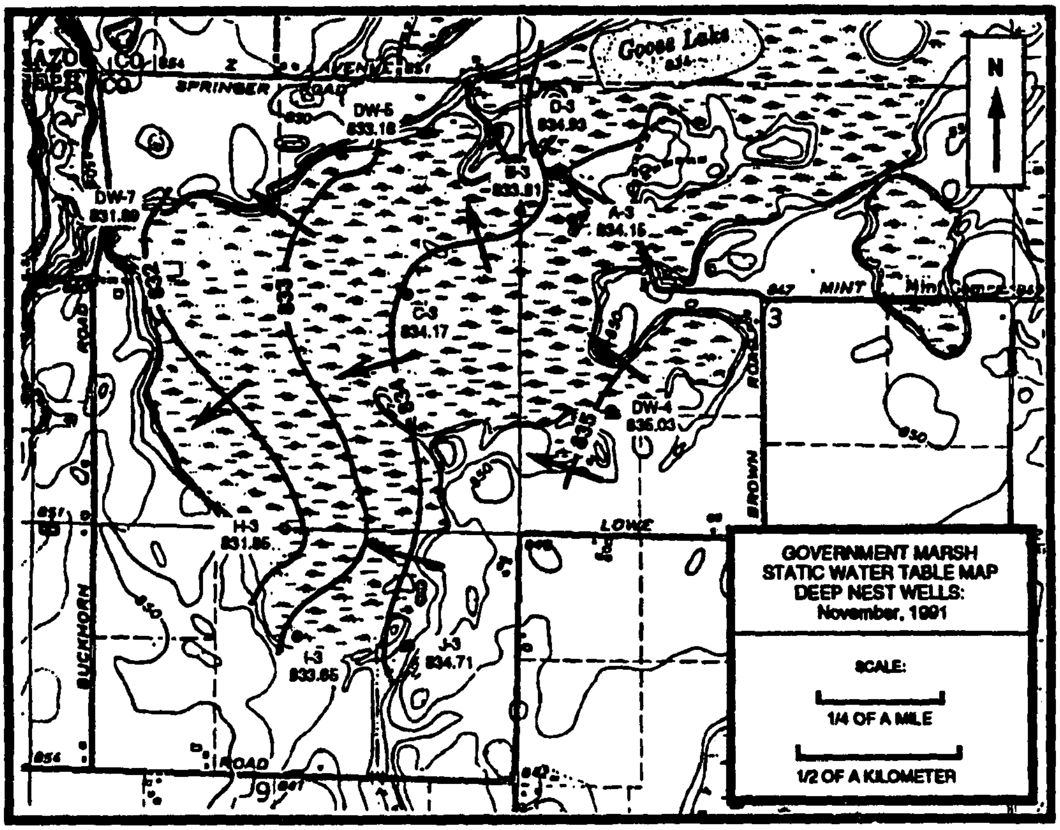
Topographic Contour: CI = 5 ft

Static Water Table Contour: CI = 1.0 ft
Direction of Ground Water Flow



Base map taken U.S.G.S. topographic quadrangle map of Vicksburg, Michigan, 7.5 Minute Series.





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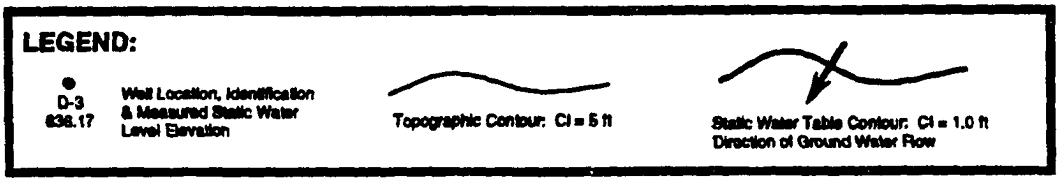

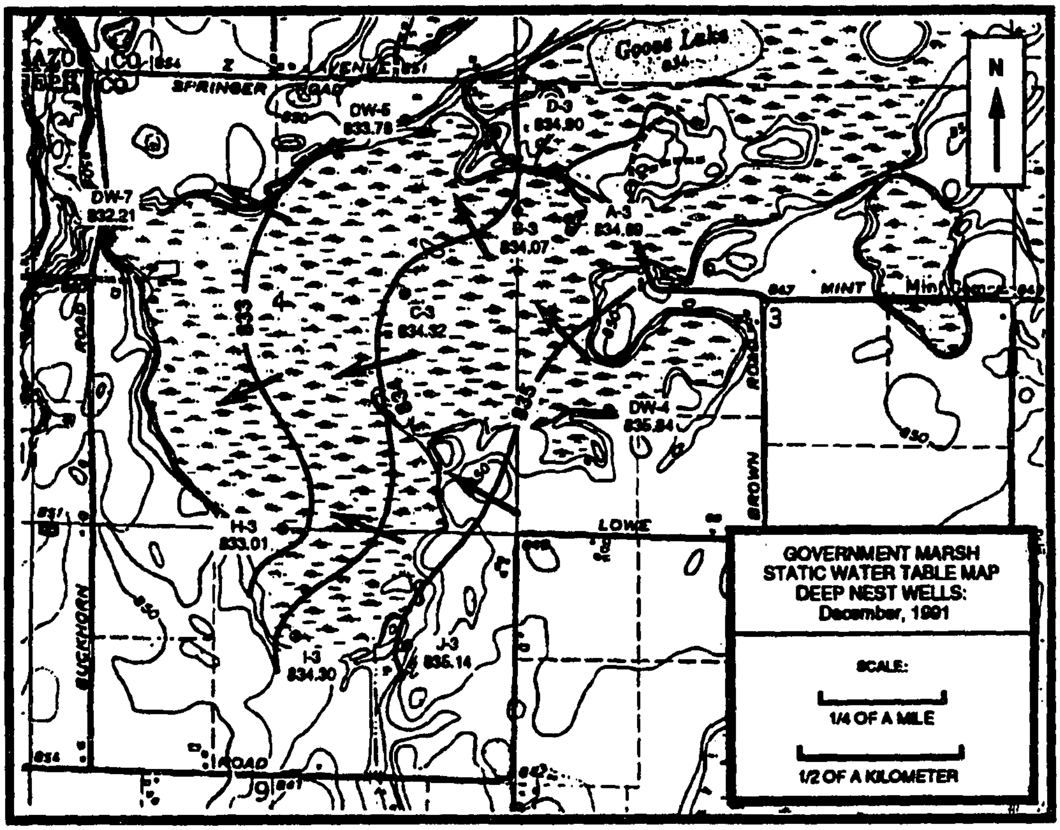

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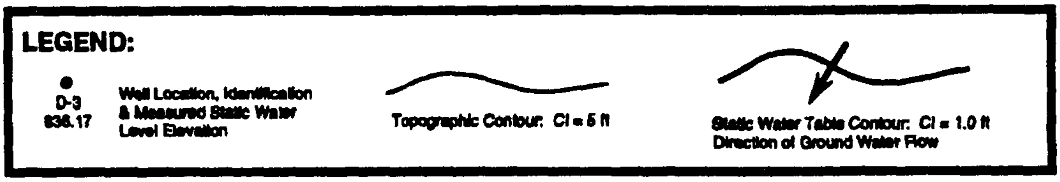

Appendix G

Slug Tests and Permeater Data

Slug Test Data

Location: Deep Well 2

Date of Test: 10 / 12 / 91

Time (min)	Drawdown (ft)
0.0133	5.924
0.0166	3.162
0.02	3.051
0.0233	2.755
0.0266	2.392
0.03	2.191
0.0333	1.935
0.05	0.365

Slug Test Data

Location: Deep Well 3

Date of Test: 10 / 12 / 91

Time (min)	Drawdown (ft)
0.0133	5.318
0.0166	3.742
0.02	2.689
0.0233	2.411
0.0266	2.169
0.03	1.856
0.0333	1.519
0.05	0.324

Slug Test Data

Location: Deep Well 4

Date of Test: 10 / 12 / 91

Time (min)	Drawdown (ft)
0.0266	1.204
0.03	1.182
0.0333	1.138
0.05	0.826
0.0666	0.605
0.0833	0.45
0.15	0.138
0.1666	0.104
0.1833	0.059
0.2	0.056
0.2166	0.037
0.2333	0.028
0.25	0.022
0.2666	0.012
0.2833	0.009
0.3	0.006
0.3166	0.003

Slug Test Data

Location: Deep Well 5

Date of Test: 10 / 12 / 91

Time (min)	Drawdown (ft)
0.03	1.207
0.0333	1.135
0.05	0.813
0.0666	0.513
0.0833	0.315
0.1	0.173
0.1166	0.097
0.1333	0.04

Slug Test Data

Location: Deep Well 7

Date of Test: 10 / 12 / 91

Time (min)	Drawdown (ft)
0.0266	1.131
0.03	1.128
0.0333	1.084
0.05	0.63
0.0666	0.337
0.08333	0.189
0.1	0.085
0.1166	0.044
0.1333	0.012

Slug Test Data

Location: Deep Well 6

Date of Test: 10 / 12 / 91

Time (min)	Drawdown (ft)
0.0266	1.324
0.03	1.258
0.0333	1.245
0.05	0.933
0.0666	0.706
0.0833	0.564
0.1	0.432
0.1166	0.331
0.1166	0.331
0.1333	0.239
0.15	0.189
0.1666	0.142
0.1833	0.129
0.2	0.085
0.2166	0.056
0.2333	0.05
0.25	0.044
0.2666	0.025
0.2833	0.022
0.3	0.015
0.3166	0.012
0.3333	0.006

Slug Test Data

Location: Deep Well 8

Date of Test: 10 / 12 / 91

Time (min)	Drawdown (ft)
0.02	3.007
0.0233	2.925
0.0266	3.014
0.03	2.604
0.0333	2.72
0.05	0.69
0.0666	0.151

Slug Test Data

Location: Nest A-1

Date of Test: 10 / 27 / 91

Time (min)	Drawdown (ft)
0.02	1.75
0.5	1.45
1	1.3
1.5	1.18
2	1.1
2.5	1.05
3	1
3.5	0.975
4	0.95
5	0.9

Slug Test Data

Location: Nest A-2

Date of Test: 10 / 27 / 91

Time (min)	Drawdown (ft)
0.02	2.425
0.5	2.325
1	2.3
1.5	2.275
2	2.265
3	2.26
3.5	2.25

Slug Test Data

Location: Nest B-1

Date of Test: 10 / 27 / 91

Time (min)	Drawdown (ft)
0.02	2.5
0.5	2.43
1	2.35
1.5	2.3
2.5	2.2
3	2.18
3.5	2.15
4	2.13
4.5	2.1
5	2.075

Slug Test Data

Location: Nest B-2

Date of Test: 10 / 27 / 91 (began on)

Time (days)	Drawdown (ft)
0.000694	21.83
0.978	19.98
2.32	18.29
3.29	17.32
5.25	15.55
6.31	14.72
6.87	14.3
8.005	13.5
9.03	12.85
12.02	11.13
12.82	10.25
15.3	9.19
16.34	8.78
18.14	8.14
21.16	7.5
21.14	6.5
24.95	6.33
27.37	5.85
30.04	5.35
32.21	5.04
35.27	4.68

Slug Test Data

Location: Nest B-3

Date of Test: 10 / 27 / 91 (began on)

Time (days)	Drawdown (ft)
0.000694	27.9
0.978	21.24
2.32	18.43
3.29	16.92
5.25	14.44
6.31	13.4
6.87	12.8
8.005	11.73
9.03	10.85
12.02	8.64
12.82	7.48
15.3	5.94
16.34	5.4
18.14	4.6
20.16	4.59
21.14	4.46
24.06	3.54

Slug Test Data

Location: Nest C-2

Date of Test: 10 / 27 / 91

Time (min)	Drawdown (ft)
0.02	2.825
0.5	2.8
1	2.775
1.5	2.75
2	2.725
2.5	2.7
4	2.675
5	2.65
6	2.625
7	2.6
8	2.58
10	2.55
15	2.5
20	2.425
25	2.375
30	2.325

Slug Test Data

Location: Nest C-3

Date of Test: 10 / 27 / 91 (began on)

Time (days)	Drawdown (ft)
0.903	16.025
3.22	11.36
5.22	9.16
6.83	7.95
7.97	7.32
8.99	6.55
10.96	5.08
12.78	4.275
14.18	3.4
15.25	2.94

Slug Test Data

Location: Nest D-1

Date of Test: 10 / 27 / 91

Time (min)	Drawdown (ft)
0.02	3.65
0.5	3.45
1	3.3
1.5	3.15
2	3.025
2.5	2.95
3	2.85
4	2.8
4.5	2.7
5	2.65
6	2.6
6.5	2.58
7	2.55
7.5	2.53
8	2.5
8.5	2.48
9.5	2.45
10.5	2.43
12	2.4
14.5	2.38
17	2.35
20.5	2.33

Slug Test Data

Location: Nest D-2

Date of Test: 10 / 27 / 91

Time (min)	Drawdown (ft)
0.002	3.83
1	3.8
2	3.75
3	3.73
5	3.7
6	3.68
7	3.65
9	3.64
10	3.63
11	3.6
13	3.59
14	3.58
15	3.56
16	3.55
23	3.5
28	3.48
33	3.45

Slug Test Data

Location: Nest D-3

Date of Test: 10 / 27 / 91

Time (min)	Drawdown (ft)
0.02	3.38
1	3.37
2	3.34

Slug Test Data

Location: Nest E-1

Date of Test: 10 / 21 / 91

Time (min)	Drawdown (ft)
0.002	4.85
0.25	4.4
0.5	4.2
0.75	4.1
1	4.05
1.15	4.03
1.3	4
3	3.98
4	3.96
7	3.98

Slug Test Data

Location: Nest E-2

Date of Test: 10 / 21 / 91

Time (min)	Drawdown (ft)
0.0233	0.967
0.0266	0.923
0.03	0.838
0.0333	0.728
0.0666	0.16
0.833	0.088
0.1	0.044
0.1166	0.015
0.1333	0.012
0.15	0.012
0.1833	0.006
0.2	0.009
0.2166	0.006
0.2333	0.003
0.25	0.006

Slug Test Data

Location: Nest F-2

Date of Test: 10 / 27 / 91

Time (min)	Drawdown (ft)
0.02	3.4
0.5	2.6
0.75	2.58

Slug Test Data

Location: Nest G-1

Date of Test: 10 / 21 / 91

Time (min)	Drawdown (ft)
31.54	10.98
55.29	9.78
101.22	7.83
126.4	6.96
170.01	5.68
192.51	5.08
266.02	3.47
310.37	2.7
343.12	1.84
368.55	1.52
411.11	1.08
460.24	0.6
484.05	0.42

Slug Test Data

Location: Nest G-2

Date of Test: 10 / 21 / 91

Time (min)	Drawdown (ft)
1.33	10.98
2.31	9.78
4.22	7.83
5.28	6.96
7.08	5.68
8.04	5.08
11.08	3.47
12.94	2.7
14.3	1.84
15.37	1.52
17.13	1.08
19.18	0.6
20.17	0.42

Slug Test Data

Location: Nest H-2

Date of Test: 10 / 27 / 91

Time (min)	Drawdown (ft)
0.02	3.953
0.0233	2.377
0.0266	1.053
0.03	1.144
0.0333	1.116
0.05	0.958
0.0666	0.967
0.0833	0.955
0.1166	0.92
0.1333	0.904
0.15	0.895
0.1666	0.885
0.1833	0.87
0.2	0.863
0.2166	0.848
0.2333	0.844
0.25	0.829
0.2666	0.826
0.2833	0.813
0.3	0.8
0.3166	0.797
0.3333	0.785
0.4166	0.74
0.5	0.703
0.75	0.592
0.8333	0.554

0.9166	0.517
1	0.488
1.0833	0.46
1.1666	0.425
1.25	0.4
1.3333	0.365
1.4166	0.337
1.5	0.305
1.5833	0.277
1.6666	0.249
1.75	0.23
1.8333	0.198

Slug Test Data

Location: Nest H-3

Date of Test: 10 / 27 / 91

Time (min)	Drawdown (ft)
0.0233	4.975
0.0266	2.887
0.03	2.616
0.0333	2.85
0.05	2.635
0.0666	2.594
0.0833	2.563
0.1	2.541
0.1166	2.528
0.1333	2.509
0.15	2.497
0.1666	2.481
0.1833	2.468
0.2	2.495
0.2166	2.452
0.2333	2.446
0.25	2.433
0.2666	2.427
0.2833	2.418
0.3	2.405
0.3166	2.402
0.3333	2.396
0.4166	2.37
0.5	2.323
0.5833	2.304
0.6666	2.273
0.75	2.247

0.8333	2.219
0.9166	2.197
1	2.181
1.0833	2.156
1.1666	2.124
1.25	2.102
1.3333	2.08
1.4166	2.058
1.5	2.036
1.5833	2.011
1.6666	1.995
1.75	1.983
1.8333	1.957
1.9166	1.945
2	1.923
2.5	1.815
3	1.715
3.5	1.617
4	1.541
4.5	1.459
5	1.393

Slug Test Data

Location: Nest I-1

Date of Test: 10 / 27 / 91

Time (min)	Drawdown (ft)
0.0233	1.642
0.0266	1.56
0.03	1.522
0.0333	1.522
0.05	1.456
0.0666	1.412
0.0833	1.384
0.1	1.346
0.1666	1.317
0.1333	1.295
0.15	1.267
0.1666	1.245
0.1833	1.223
0.2	1.194
0.2166	1.179
0.2333	1.153
0.25	1.135
0.2666	1.106
0.2833	1.097
0.3	1.068
0.3166	1.053
0.3333	1.034
0.4166	0.939
0.5	0.867
0.5833	0.797
0.6666	0.725
0.75	0.671

0.8333	0.63
0.9166	0.58
1	0.523
1.0833	0.491
1.1666	0.466
1.25	0.428
1.3333	0.394
1.4166	0.372
1.5	0.346
1.5833	0.318
1.6666	0.299
1.75	0.286
1.8333	0.261
1.9166	0.252
2	0.242
2.5	0.182
3	0.138
3.5	0.107

Slug Test Data

Location: Nest I-2

Date of Test: 10 / 27 / 91

Time (min)	Drawdown (ft)
0.0166	5.224
0.02	5.388
0.0233	3.499
0.0266	3.777
0.03	3.578
0.0333	3.591
0.05	3.354
0.0666	3.178
0.0833	3.026
0.1	2.894
0.1166	2.774
0.1333	2.657
0.15	2.538
0.1666	2.437
0.1833	2.336
0.2	2.232
0.2166	2.147
0.2333	2.052
0.25	1.973
0.2666	1.87
0.2833	1.825
0.3	1.746
0.3166	1.617
0.3333	1.614
0.4166	1.311
0.5	1.059
0.5833	0.879

0.6666	0.715
0.75	0.602
0.8333	0.498
0.9166	0.412
1	0.353
1.0833	0.302
1.1666	0.255
1.25	0.217
1.3333	0.201
1.4166	0.17
1.5	0.151
1.5833	0.141
1.6666	0.122
1.75	0.126
1.8333	0.1
1.9166	0.097
2	0.091
2.5	0.072
3	0.069
3.5	0.069
4	0.063
4.5	0.056

Slug Test Data

Location: Nest I-3

Date of Test: 10 / 27 / 91

Time (min)	Drawdown (ft)
0.02	4.571
0.0233	3.657
0.0266	3.155
0.03	2.648
0.0333	2.746
0.05	1.973
0.0666	1.469
0.0833	1.09
0.1	0.807
0.1166	0.614
0.1333	0.453
0.15	0.353
0.1666	0.271
0.1833	0.195
0.2	0.154
0.2166	0.129
0.2333	0.094
0.25	0.088
0.2666	0.072
0.2833	0.063
0.3	0.037
0.3166	0.037
0.4166	0.018

Slug Test Data

Location: Nest J1

Date of Test: 10 / 27 / 91

Time (min)	Drawdown (ft)
0.02	2.679
0.0266	1.935
0.03	1.683
0.333	1.62
0.05	1.544
0.0666	1.513
0.0833	1.481
0.1	1.459
0.1166	1.434
0.1333	1.415
0.15	1.403
0.1666	1.371
0.1833	1.358
0.2	1.343
0.2166	1.317
0.2333	1.311
0.25	1.295
0.2666	1.276
0.2833	1.257
0.3	1.251
0.3166	1.229
0.3333	1.213
0.4166	1.153
0.5	1.1
0.5833	1.037
0.6666	0.993

0.75	0.926
0.8333	0.882
0.9166	0.841
1	0.797
1.0833	0.759
1.1666	0.721
1.25	0.681
1.3333	0.649
1.4166	0.624
1.5	0.586
1.5833	0.554
1.6666	0.523
1.75	0.504
1.8333	0.479
1.9166	0.454
2	0.428
2.5	0.334
3	0.252
3.5	0.182
4	0.135
4.5	0.119
5	0.094
5.5	0.075

Slug Test Data

Location: Nest J-2

Date of Test: 10 / 27 / 91

Time (min)	Drawdown (ft)
0.0133	4.297
0.0166	3.912
0.02	3.278
0.0233	3.07
0.0333	2.323
0.05	1.22
0.0666	0.627
0.0833	0.309
0.1166	0.1
0.1333	0.072
0.15	0.05
0.1666	0.041
0.1833	0.037
0.2166	0.028

Slug Test Data

Location: Nest J-3

Date of Test: 10 / 27 / 91

Time (min)	Drawdown (ft)
0.02	3.449
0.0233	3.001
0.0266	2.531
0.03	2.528
0.0333	2.323
0.05	1.22
0.0666	0.627
0.0833	0.309
0.1166	0.1
0.1333	0.072
0.15	0.05
0.1666	0.041
0.1833	0.037
0.2	0.037
0.2166	0.028

Permeameter: constant head
Location: DW's 1 and 2 Depth: 23 to 28 ft
Date: 10 / 15 / 92

Test No.	t, sec	q, cm^3	L, cm	A, cm^2	h, cm
1	41.89	250	12.3	31.65	65
2	44.01	250	12.3	31.65	65
3	44.47	250	12.3	31.65	65

Test No.	K, cm/s	T, °C	Correction Factor	K_{corr}, cm/s
1	.03568	20.0	1.00	.03568
2	.03396	19.9	1.0025	.03405
3	.03149	19.9	1.0025	.03157
			mean =	.03379

Permeameter: constant head
Location: DW's 1 and 2 Depth: 38 to 43 ft
Date: 10 / 15 / 92

Test No.	t, sec	q, cm^3	L, cm	A, cm^2	h, cm
1	38.33	250	12.1	31.65	65
2	40.81	250	12.1	31.65	65
3	43.01	250	12.1	31.65	65

Test No.	K, cm/s	T, °C	Correction Factor	K_{corr}, cm/s
1	.03836	20.6	.9857	.03781
2	.03603	20.4	.9904	.03568
3	.03419	20.3	.9928	.03394
			mean =	.03584

Permeameter: constant head
Location: DW 3 Depth: 20 to 30 ft
Date: 10 / 15 / 92

Test No.	t, sec	q, cm^3	L, cm	A, cm^2	h, cm
1	54	300	12.7	31.65	56.0
2	53	300	12.7	31.65	56.0
3	56	300	12.7	31.65	56.0

Test No.	K, cm/s	T, °C	Correction Factor	K_{corr}, cm/s
1	.0329	25.0	.8893	.0293
2	.0335	25.0	.8893	.0298
3	.0317	24.8	.8934	.0284
			mean =	.0292

Permeameter: constant head
Location: DW 4 Depth: 15 to 30 ft
Date: 10 / 15 / 92

Test No.	t, sec	q, cm^3	L, cm	A, cm^2	h, cm
1	57	300	12.4	31.65	56.0
2	56	300	12.4	31.65	56.0
3	53	300	12.4	31.65	56.0

Test No.	K, cm/s	T, °C	Correction Factor	K_{corr}, cm/s
1	.0368	18.5	1.0377	.0382
2	.0375	18.5	1.0377	.0389
3	.0396	18.5	1.0377	.0411
			mean =	.0394

Permeameter: constant head
Location: DW 5 Depth: 30 to 33 ft
Date: 10 / 15 / 92

Test No.	t, sec	q, cm^3	L, cm	A, cm^2	h, cm
1	46	300	13.0	36.65	56.0
2	46	300	13.0	36.65	56.0
3	45	300	13.0	36.65	56.0

Test No.	K, cm/s	T, °C	Correction Factor	K_{corr}, cm/s
1	.0413	22.7	.9377	.0387
2	.0413	22.6	.9399	.0388
3	.0422	21.9	.9554	.0403
			mean =	.0393

Permeameter: constant head
Location: DW 6 Depth: 20 to 30 ft
Date: 10 / 18 / 92

Test No.	t, sec	q, cm^3	L, cm	A, cm^2	h, cm
1	56	300	12.8	36.65	56.0
2	53	300	12.8	36.65	56.0
3	55	300	12.8	36.65	56.0

Test No.	K, cm/s	T, °C	Correction Factor	K_{corr}, cm/s
1	.0344	24.2	.9056	.0303
2	.0353	25.2	.8853	.0312
3	.0340	25.0	.8893	.0303
			mean =	.0306

Permeameter: constant head
Location: DW 7 Depth: 30 to 40 ft
Date: 10 / 18 / 92

Test No.	t, sec	q, cm^3	L, cm	A, cm^2	h, cm
1	45	300	13.0	36.65	56.0
2	48	300	13.0	36.65	56.0
3	46	300	13.0	36.65	56.0

Test No.	K, cm/s	T, °C	Correction Factor	K_{corr}, cm/s
1	.0422	24.7	.8954	.0378
2	.0396	25.1	.8873	.0351
3	.0413	25.5	.8794	.0363
			mean =	.0364

Permeameter: constant head
Location: DW 8 Depth: 40 to 43 ft
Date: 10 / 18 / 92

Test No.	t, sec	q, cm^3	L, cm	A, cm^2	h, cm
1	60	300	13.0	36.65	56.0
2	61	300	13.0	36.65	56.0
3	61	300	13.0	36.65	56.0

Test No.	K, cm/s	T, °C	Correction Factor	K_{corr}, cm/s
1	.0318	25.2	.8853	.0280
2	.0312	25.3	.8833	.0275
3	.0312	25.5	.8794	.0274
			mean =	.0276

Permeameter: falling head

Location: B-3 Depth: 20-25 feet, sapro peat

Date: 9 / 10 / 93

Test No.	h_1, cm	h_2, cm	t, sec	q (in), cm^3	q (in), cm^3	L, cm
1	35.5	17.6	40129	17.9	17.9	6.4
2	43.6	36.6	47786	7.0	7.0	6.4
3	48.9	43.7	36394	5.2	5.2	6.4

Test No.	A, cm^2	a, cm^2	T, °C	K, cm/s	Correction factor
1	6.35	1.13	18.1	3.5 E-6	1.051
2	6.35	1.13	18.2	7.4 E-7	1.048
3	6.35	1.13	19.8	6.3 E-7	1.005

1	K corrected =	3.7 E-6
2		7.8 E-7
3		6.3 E-7

K corrected mean = 1.7 E-6

Permeameter: falling head

Location: C-3 Depth: 12-17 feet, sapro peat

Date: 9 / 11 / 93

Test No.	h_1, cm	h_2, cm	t, sec	q (in), cm^3	q (in), cm^3	L, cm
1	35.1	23.8	81961	11.3	11.3	5.5
2	44.0	38.8	55395	5.2	5.2	5.5
3	38.8	35.1	49981	3.7	3.7	5.5

Test No.	A, cm^2	a, cm^2	T, °C	K, cm/s	Correction factor
1	6.35	1.13	16.0	8.3E-7	1.106
2	6.35	1.13	17.9	4.0E-7	1.053
3	6.35	1.13	21.6	3.5E-7	.962

1	K corrected =	9.1E-7
2		4.2E-7
3		3.4E-7

K corrected mean = 5.6E-7

Permeameter: falling head

Location: F-3 Depth: 15-18 feet, sapro peat

Date: 9 / 12 / 93

Test No.	h_1, cm	h_2, cm	t, sec	q (in), cm^3	q (in), cm^3	L, cm
1	57.2	30.0	14995	27.2	27.2	5.2
2	54.6	38.2	19253	16.4	16.4	4.7
3	46.5	31.6	34788	14.9	14.9	4.7

Test No.	A, cm^2	a, cm^2	T, °C	K, cm/s	Correction factor
1	6.35	1.13	25.0	7.0E-6	.889
2	6.35	1.13	21.4	2.8E-6	.967
3	6.35	1.13	19.5	1.7E-6	1.012

1	K corrected =	6.3E-6
2		2.7E-6
3		1.7E-6

K corrected mean = 3.6E-6

Permeameter: falling head
Location: C Depth: 16-18 feet, marl
Date: 9 /13 / 93

Test No.	h_1, cm	h_2, cm	t, sec	q (in), cm^3	q (in), cm^3	L, cm
1	33.8	23.3	12548	10.5	10.5	6.40
2	41.8	33.9	23941	7.9	7.9	6.40
3	51.8	41.9	45903	9.9	9.9	6.40

Test No.	A, cm^2	a, cm^2	T, °C	K, cm/s	Correction factor
1	6.35	1.13	21.6	6.0E-6	.962
2	6.35	1.13	21.4	1.6E-6	.967
3	6.35	1.13	20.7	9.4E-7	.983
1			K corrected =	5.8E-6	
2				1.5E-6	
3				9.2E-7	

K corrected mean = 2.7E-6

Permeameter: falling head

Location: DW's 1 and 2 Depth: 15-20 feet, marl

Date: 9 / 14 / 93

Test No.	h_1, cm	h_2, cm	t, sec	q (in), cm^3	q (in), cm^3	L, cm
1	54.2	36.6	10726	17.6	17.6	5.9
2	37.6	22.4	13857	15.2	15.2	5.9
3	34.9	23.6	11850	11.3	11.3	5.9

Test No.	A, cm^2	a, cm^2	T, °C	K, cm/s	Correction factor
1	6.35	1.13	18.4	6.8E-6	1.040
2	6.35	1.13	18.1	7.0E-6	1.051
3	6.35	1.13	18.3	6.2E-6	1.043

Test No.		
1	K corrected =	7.1E-6
2		7.3E-6
3		6.4E-6

K corrected mean = 6.9E-6

Permeameter: falling head
Location: F Depth: 18-22 feet, marl
Date: 9 /15 / 93

Test No.	h_1, cm	h_2, cm	t, sec	q (in), cm^3	q (in), cm^3	L, cm
1	42.0	26.6	46497	15.4	15.4	5.8
2	54.6	43.0	83186	11.6	11.6	5.8
3	58.3	29.6	44252	28.7	28.7	5.8

Test No.	A, cm^2	a, cm^2	T, °C	K, cm/s	Correction factor
1	6.35	1.13	20.3	1.8E-6	.993
2	6.35	1.13	19.4	5.3E-7	1.015
3	6.35	1.13	20.8	2.8E-6	.981

1	K corrected =	1.8E-6
2		5.4E-7
3		2.8E-6

K corrected mean = 1.7E-6

Permeameter: falling head
Location: H Depth: surface, peat
Date: 1 / 6 / 94

Test No.	h_1, cm	h_2, cm	t, sec	q (in), cm^3	q (in), cm^3	L, cm
1	41	52	231	11.0	11.0	5.9
2	57	67	249	10.0	10.0	5.9
3	42	53	232	11.0	11.0	5.9

Test No.	A, cm^2	a, cm^2	T, °C	K, cm/s	Correction factor
1	6.35	1.13	13.4	1.9E-4	1.184
2	6.35	1.13	13.6	1.2E-4	1.178
3	6.35	1.13	13.8	1.9E-4	1.171

Test No.	K corrected
1	K corrected = 2.3E-4
2	1.4E-4
3	2.2E-4

K corrected mean = 2.0E-4

Appendix H

WATEQ4F Solubility Index Values

Southern Flow System

	Phase	Log IAP/KT	Log IAP
17	Anhydrite	-2.445	-6.780
21	Aragonite	-.253	-8.514
150	Artinite	-7.089	3.531
144	Barite	-.195	-10.415
19	Brucite	-6.158	11.643
12	Calcite	-.099	-8.514
11	Dolomite (d)	-1.284	-17.431
401	Dolomite (c)	-.675	-17.431
340	Epsomite	-4.942	-7.182
18	Gypsum	-2.191	-6.780
64	Halite	-9.379	-7.830
117	Huntite	-6.209	-35.263
38	Hydrmagnesit	-17.113	-24.022
10	Magnesite	-1.106	-8.916
339	Melanterite	-6.252	-8.644
66	Mirabilite	-9.990	-11.777
191	MnCl2, 4H2O	-15.623	-13.529
182	MnSO4	-12.864	-9.646
58	Nahcolite	-5.883	-6.563
60	Natron	-11.642	-13.511
149	Nesquehonite	-3.501	-8.916
539	Portlandite	-11.854	12.045
188	Pyrocroite	-6.020	9.180
190	Rhodochrs(d)	-.990	-11.380
564	Rhodochrs(c)	-.301	-11.380
9	Siderite (d)	.072	-10.378
94	Siderite (c)	.424	-10.378
65	Thenardite	-11.618	-11.777
61	Thermonatrit	-13.735	-13.511
59	Trona	-19.917	-20.074
145	Witherite	-3.527	-12.149

Canal Water

	Phase	Log IAP/KT	Log IAP
17	Anhydrite	-2.737	-7.098
21	Aragonite	.014	-8.322
150	Artinite	-5.796	3.804
144	Barite	-.976	-10.947
19	Brucite	-5.137	11.703
12	Calcite	.158	-8.322
11	Dolomite (d)	-.526	-17.066
401	Dolomite (c)	.024	-17.066
340	Epsomite	-5.380	-7.520
18	Gypsum	-2.517	-7.098
64	Halite	-9.691	-8.109
117	Huntite	-4.587	-34.555
38	Hydrmagnesit	-14.512	-23.274
10	Magnesite	-.715	-8.744
339	Melanterite	-6.619	-8.828
66	Mirabilite	-10.850	-11.964
191	MnCl2, 4H20	-17.133	-14.423
182	MnSO4	-12.837	-10.168
58	Nahcolite	-5.941	-6.489
60	Natron	-11.878	-13.189
149	Nesquehonite	-3.123	-8.744
539	Portlandite	-10.674	12.126
188	Pyrocroite	-6.145	9.055
190	Rhodochrs(d)	-1.002	-11.392
564	Rhodochrs(c)	-.262	-11.392
9	Siderite (d)	.398	-10.052
94	Siderite (c)	.838	-10.052
65	Thenardite	-11.785	-11.964
61	Thermonatrit	-13.313	-13.188
59	Trona	-18.883	-19.678
145	Witherite	-3.609	-12.171

Mean Bog Surface Water

	Phase	Log IAP/KT	Log IAP
195	a-Cryptomeln		-383.511
17	Anhydrite	-4.581	-8.922
21	Aragonite	-6.785	-15.086
150	Artinite	-21.310	-11.277
144	Barite	-1.867	-11.937
184	Birnessite	-39.815	3.786
186	Bixbyite	-45.959	-46.340
19	Brucite	-13.695	3.553
12	Calcite	-6.637	-15.086
97	Chalcedony	-.635	-4.257
20	Chrysotile	-30.813	2.145
29	Clinoenstite	-12.348	-.704
99	Cristobalite	-.588	-4.257
28	Diopside	-21.534	-1.153
11	Dolomite (d)	-14.054	-30.427
401	Dolomite (c)	-13.479	-30.427
340	Epsomite	-6.996	-9.179
119	FeS ppt	-5.345	-9.260
27	Forsterite	-26.188	2.849
111	Greenalite	-19.434	1.376
18	Gypsum	-4.341	-8.923
64	Halite	-9.715	-8.147
187	Hausmannite	-55.418	7.127
196	Hollandite		-332.402
117	Huntite	-31.529	-61.109
38	Hydrmagnesit	-49.836	-57.812
67	Mackinawite	-4.612	-9.260
98	Magadiite	-16.033	-30.333
10	Magnesite	-7.405	-15.341
189	Manganite	-22.612	2.728
339	Melanterite	-7.150	-9.435
66	Mirabilite	-11.787	-13.187
134	Mn2(SO4)3	-79.412	-84.535
191	MnCl2, 4H2O	-16.616	-14.168
192	MnS green	-14.773	-10.886
182	MnSO4	-13.963	-11.061
58	Nahcolite	-8.132	-8.736
60	Natron	-17.802	-19.350
149	Nesquehonite	-9.808	-15.341
185	Nsutite	-38.778	3.786
539	Portlandite	-19.458	3.809
197	Psilomelane		-333.080
114	Pyrite	-1.053	-19.702
188	Pyrocroite	-13.529	1.671
183	Pyrolusite	-38.574	3.786
101	Quartz	-.187	-4.257
200	Rancieite		-189.433
190	Rhodochrs(d)	-6.834	-17.224
564	Rhodochrs(c)	-6.115	-17.224
153	Sepiolite(d)	-24.326	-5.666
36	Sepiolite(c)	-21.587	-5.666
9	Siderite (d)	-5.148	-15.598
94	Siderite (c)	-4.745	-15.598

A-1

	Phase	Log IAP/KT	Log IAP
195	a-Cryptomeln		-136.715
17	Anhydrite	-2.409	-6.754
21	Aragonite	-.349	-8.658
150	Artinite	-7.707	2.216
144	Barite	-.542	-10.586
184	Birnessite	-9.944	33.657
186	Bixbyite	-9.360	-9.800
19	Brucite	-7.267	9.877
12	Calcite	-.202	-8.658
97	Chalcedony	-.209	-3.813
20	Chrysotile	-10.761	22.004
29	Clinoenstite	-5.503	6.064
99	Cristobalite	-.165	-3.813
28	Diopside	-7.133	13.125
11	Dolomite (d)	-1.898	-18.313
401	Dolomite (c)	-1.329	-18.313
340	Epsomite	-5.581	-7.752
27	Forsterite	-12.911	15.941
111	Greenalite	-1.649	19.161
18	Gypsum	-2.173	-6.754
64	Halite	-10.585	-9.014
187	Hausmannite	-12.217	49.943
196	Hollandite		-109.661
117	Huntite	-7.945	-37.623
38	Hydrmagnesit	-20.569	-28.744
98	Magadiite	-9.967	-24.267
10	Magnesite	-1.695	-9.655
189	Manganite	-4.440	20.900
339	Melanterite	-6.435	-8.700
66	Mirabilite	-12.230	-13.557
134	Mn2(SO4)3	-57.413	-62.685
191	MnCl2, 4H2O	-16.472	-13.957
182	MnSO4	-12.328	-9.485
58	Nahcolite	-6.536	-7.125
60	Natron	-13.973	-15.461
149	Nesquehonite	-4.100	-9.656
185	Nsutite	-8.907	33.657
539	Portlandite	-12.274	10.874
197	Psilomelane		-109.825
188	Pyrocroite	-7.057	8.143
183	Pyrolusite	-8.455	33.657
101	Quartz	.234	-3.813
200	Rancieite		-62.427
190	Rhodochrs(d)	-.999	-11.389
564	Rhodochrs(c)	-.275	-11.389
153	Sepiolite(d)	-10.346	8.314
36	Sepiolite(c)	-7.567	8.314
9	Siderite (d)	-.153	-10.603
94	Siderite (c)	.259	-10.603

A-2

	Phase	Log IAP/KT	Log IAP
195	a-Cryptomeln		-336.775
17	Anhydrite	-2.805	-7.139
21	Aragonite	-2.503	-10.769
150	Artinite	-13.480	-2.951
144	Barite	-.227	-10.422
184	Birnessite	-33.505	10.096
186	Bixbyite	-37.239	-37.357
19	Brucite	-10.730	6.987
12	Calcite	-2.350	-10.769
97	Chalcedony	-.096	-3.800
20	Chrysotile	-20.468	13.360
29	Clinoenstite	-8.804	3.187
99	Cristobalite	-.035	-3.800
28	Diopside	-13.734	7.206
11	Dolomite (d)	-6.190	-22.371
401	Dolomite (c)	-5.587	-22.371
340	Epsomite	-5.742	-7.973
119	FeS ppt	-2.488	-6.403
27	Forsterite	-19.704	10.173
111	Greenalite	-9.618	11.192
18	Gypsum	-2.552	-7.140
64	Halite	-10.270	-8.718
187	Hausmannite	-43.717	20.568
196	Hollandite		-287.556
117	Huntite	-16.440	-45.575
38	Hydrmagnesit	-32.350	-39.422
67	Mackinawite	-1.755	-6.403
98	Magadiite	-11.265	-25.565
10	Magnesite	-3.772	-11.602
189	Manganite	-17.674	7.666
339	Melanterite	-6.321	-8.696
66	Mirabilite	-11.249	-12.977
134	Mn2(SO4)3	-77.785	-82.233
191	MnCl2, 4H2O	-16.331	-14.183
192	MnS green	-11.418	-7.431
182	MnSO4	-12.892	-9.722
58	Nahcolite	-6.470	-7.139
60	Natron	-14.787	-16.607
149	Nesquehonite	-6.169	-11.603
185	Nsutite	-32.468	10.096
539	Portlandite	-15.984	7.819
197	Psilomelane		-287.862
114	Pyrite	4.634	-14.211
188	Pyrocroite	-9.364	5.236
183	Pyrolusite	-33.390	10.096
101	Quartz	.374	-3.800
200	Rancieite		-164.001
190	Rhodochrs(d)	-2.962	-13.352
564	Rhodochrs(c)	-2.269	-13.352
153	Sepiolite(d)	-16.088	2.572
36	Sepiolite(c)	-13.534	2.572
9	Siderite (d)	-1.874	-12.324
94	Siderite (c)	-1.515	-12.324

A-3

	Phase	Log IAP/KT	Log IAP
17	Anhydrite	-3.246	-7.580
21	Aragonite	-.213	-8.481
150	Artinite	-7.562	2.929
19	Brucite	-7.213	10.468
12	Calcite	-.060	-8.481
97	Chalcedony	.016	-3.681
20	Chrysotile	-9.720	24.040
29	Clinoenstite	-5.177	6.786
99	Cristobalite	.076	-3.681
28	Diopside	-6.381	14.516
11	Dolomite (d)	-1.710	-17.906
401	Dolomite (c)	-1.108	-17.906
340	Epsomite	-6.296	-8.524
27	Forsterite	-12.558	17.254
18	Gypsum	-2.994	-7.581
64	Halite	-10.245	-8.692
117	Huntite	-7.585	-36.754
38	Hydrmagnesit	-20.087	-27.230
98	Magadiite	-8.747	-23.047
10	Magnesite	-1.586	-9.424
66	Mirabilite	-11.894	-13.596
58	Nahcolite	-6.079	-6.742
60	Natron	-12.698	-14.497
149	Nesquehonite	-3.983	-9.424
539	Portlandite	-12.351	11.410
101	Quartz	.485	-3.681
153	Sepiolite(d)	-8.769	9.891
36	Sepiolite(c)	-6.200	9.891
100	Silica gel	-.526	-3.681
395	SiO2 (a)	-.866	-3.681
37	Talc	-6.158	16.678
65	Thenardite	-13.435	-13.596
61	Thermonatrit	-14.709	-14.497
31	Tremolite	-13.868	45.709
59	Trona	-21.002	-21.239

B-1

	Phase	Log IAP/KT	Log IAP
195	a-Cryptomeln		-392.851
17	Anhydrite	-4.243	-8.581
144	Barite	-1.063	-11.164
184	Birnessite	-40.706	2.895
186	Bixbyite	-48.159	-48.473
19	Brucite	-14.182	3.184
97	Chalcedony	-1.721	-5.364
20	Chrysotile	-34.353	-1.175
29	Clinoenstite	-13.911	-2.179
99	Cristobalite	-1.670	-5.364
28	Diopside	-24.233	-3.711
340	Epsomite	-7.034	-9.229
119	FeS ppt	-5.280	-9.195
27	Forsterite	-28.245	1.005
111	Greenalite	-21.375	-.565
18	Gypsum	-3.998	-8.581
64	Halite	-10.407	-8.843
187	Hausmannite	-58.782	4.204
196	Hollandite		-340.389
67	Mackinawite	-4.547	-9.195
98	Magadiite	-23.524	-37.824
189	Manganite	-23.565	1.775
339	Melanterite	-6.719	-9.026
66	Mirabilite	-11.979	-13.462
134	Mn2(SO4)3	-80.761	-85.713
191	MnCl2, 4H2O	-18.356	-15.983
192	MnS green	-15.840	-11.928
182	MnSO4	-14.729	-11.759
185	Nsutite	-39.669	2.895
539	Portlandite	-19.570	3.832
197	Psilomelane		-341.545
114	Pyrite	-.838	-19.536
188	Pyrocroite	-14.546	.654
183	Pyrolusite	-39.750	2.895
101	Quartz	-1.267	-5.364
200	Rancieite		-194.458
153	Sepiolite(d)	-28.383	-9.723
36	Sepiolite(c)	-25.690	-9.723
100	Silica gel	-2.259	-5.364
395	SiO2 (a)	-2.587	-5.364
402	Sulfur	-8.315	-23.495
37	Talc	-34.202	-11.902
65	Thenardite	-13.294	-13.462
198	Todorokite		-241.884
31	Tremolite	-77.779	-19.323

B-2

	Phase	Log IAP/KT	Log IAP
195	a-Cryptomeln		-308.662
21	Aragonite	-1.442	-9.715
150	Artinite	-10.811	-.396
184	Birnessite	-30.395	13.206
186	Bixbyite	-32.363	-32.542
19	Brucite	-8.693	8.915
12	Calcite	-1.290	-9.715
97	Chalcedony	-.712	-4.398
20	Chrysotile	-15.678	17.949
29	Clinoenstite	-7.393	4.517
99	Cristobalite	-.655	-4.398
28	Diopside	-11.372	9.439
11	Dolomite (d)	-3.609	-19.835
401	Dolomite (c)	-3.012	-19.835
119	FeS ppt	-.463	-4.378
27	Forsterite	-16.251	13.432
111	Greenalite	-4.658	16.152
64	Halite	-10.096	-8.540
187	Hausmannite	-37.207	26.675
196	Hollandite		-260.977
117	Huntite	-10.837	-40.074
38	Hydrmagnesit	-24.283	-31.565
67	Mackinawite	.270	-4.378
98	Magadiite	-14.592	-28.892
10	Magnesite	-2.266	-10.120
189	Manganite	-15.370	9.970
191	MnCl2, 4H2O	-16.496	-14.279
192	MnS green	-9.923	-5.959
58	Nahcolite	-5.974	-6.627
60	Natron	-13.346	-15.103
149	Nesquehonite	-4.663	-10.120
185	Nsutite	-29.358	13.206
539	Portlandite	-14.359	9.319
197	Psilomelane		-261.622
114	Pyrite	8.198	-10.601
188	Pyrocroite	-8.465	6.735
183	Pyrolusite	-30.020	13.206
101	Quartz	-.247	-4.398
200	Rancieite		-149.236
190	Rhodochrs(d)	-1.910	-12.300
564	Rhodochrs(c)	-1.210	-12.300
153	Sepiolite(d)	-14.023	4.637
36	Sepiolite(c)	-11.427	4.637
9	Siderite (d)	-.269	-10.719
94	Siderite (c)	.101	-10.719
100	Silica gel	-1.254	-4.398
395	SiO2 (a)	-1.591	-4.398

B-3

	Phase	Log IAP/KT	Log IAP
195	a-Cryptomeln		-302.865
17	Anhydrite	-3.485	-7.820
21	Aragonite	-.708	-8.976
150	Artinite	-9.421	1.078
144	Barite	-.811	-10.999
184	Birnessite	-29.568	14.033
186	Bixbyite	-31.361	-31.496
19	Brucite	-13.362	4.325
12	Calcite	-.555	-8.976
97	Chalcedony	.453	-3.245
20	Chrysotile	-27.289	6.485
29	Clinoenstite	-10.889	1.080
99	Cristobalite	.514	-3.245
28	Diopside	-13.017	7.889
11	Dolomite (d)	-7.488	-23.681
401	Dolomite (c)	-6.886	-23.681
340	Epsomite	-11.322	-13.550
119	FeS ppt	.306	-3.609
27	Forsterite	-24.420	5.405
111	Greenalite	.142	20.952
18	Gypsum	-3.233	-7.820
64	Halite	-8.805	-7.252
187	Hausmannite	-35.934	28.243
196	Hollandite		-254.903
117	Huntite	-23.929	-53.091
38	Hydrmagnesit	-47.368	-54.496
67	Mackinawite	1.039	-3.609
98	Magadiite	-6.321	-20.621
10	Magnesite	-6.869	-14.705
189	Manganite	-14.771	10.569
339	Melanterite	-6.358	-8.727
66	Mirabilite	-9.315	-11.023
134	Mn2(SO4)3	-80.628	-85.117
191	MnCl2, 4H2O	-16.418	-14.251
192	MnS green	-9.633	-5.652
182	MnSO4	-13.922	-10.769
58	Nahcolite	-4.486	-5.151
60	Natron	-10.376	-12.180
149	Nesquehonite	-9.266	-14.706
185	Nsutite	-28.531	14.033
539	Portlandite	-13.715	10.054
197	Psilomelane		-255.765
114	Pyrite	9.393	-9.439
188	Pyrocroite	-8.095	7.105
183	Pyrolusite	-29.383	14.033
101	Quartz	.922	-3.245
200	Rancieite		-146.001
190	Rhodochrs(d)	-1.535	-11.925
564	Rhodochrs(c)	-.840	-11.925
153	Sepiolite(d)	-19.746	-1.086
36	Sepiolite(c)	-17.181	-1.086
9	Siderite (d)	.567	-9.883
94	Siderite (c)	.930	-9.883
100	Silica gel	-.089	-3.245

C-1

	Phase	Log IAP/KT	Log IAP
195	a-Cryptomeln		-374.411
17	Anhydrite	-4.428	-8.763
21	Aragonite	-6.235	-14.511
150	Artinite	-20.234	-9.849
144	Barite	-1.688	-11.846
184	Birnessite	-38.149	5.452
186	Bixbyite	-44.227	-44.422
19	Brucite	-13.847	3.733
12	Calcite	-6.084	-14.511
97	Chalcedony	-.350	-4.030
20	Chrysotile	-30.436	3.138
29	Clinoenstite	-12.187	-.298
99	Cristobalite	-.293	-4.030
28	Diopside	-20.443	.334
11	Dolomite (d)	-13.713	-29.951
401	Dolomite (c)	-13.118	-29.951
340	Epsomite	-7.475	-9.692
119	FeS ppt	-4.198	-8.113
27	Forsterite	-26.196	3.435
111	Greenalite	-15.323	5.487
18	Gypsum	-4.178	-8.763
64	Halite	-10.146	-8.589
187	Hausmannite	-53.217	10.559
196	Hollandite		-323.277
117	Huntite	-31.565	-60.830
38	Hydrmagnesit	-50.690	-58.027
67	Mackinawite	-3.465	-8.113
98	Magadiite	-14.086	-28.386
10	Magnesite	-7.579	-15.440
189	Manganite	-21.337	4.003
339	Melanterite	-6.561	-8.909
66	Mirabilite	-11.594	-13.226
134	Mn2(SO4)3	-80.052	-84.697
191	MnCl2, 4H2O	-17.060	-14.825
192	MnS green	-14.034	-10.076
182	MnSO4	-13.963	-10.872
58	Nahcolite	-7.387	-8.637
60	Natron	-17.233	-18.974
149	Nesquenonite	-9.977	-15.440
185	Nsutite	-37.112	5.452
539	Portlandite	-18.984	4.662
197	Psilomelane		-324.164
114	Pyrite	.944	-17.843
198	Pyrocroite	-12.647	2.553
183	Pyrolusite	-37.704	5.452
101	Quartz	.113	-4.030
200	Rancieite		-184.422

C-2

	Phase	Log IAP/KT	Log IAP
195	a-Cryptomeln		-298.024
21	Aragonite	-1.599	-9.874
150	Artinite	-10.349	.050
184	Birnessite	-29.165	14.436
186	Bixbyite	-30.431	-30.618
19	Brucite	-8.363	9.230
12	Calcite	-1.447	-9.874
97	Chalcedony	.050	-3.632
20	Chrysotile	-13.173	20.427
29	Clinoenstite	-6.301	5.598
99	Cristobalite	.108	-3.632
28	Diopside	-8.904	11.890
11	Dolomite (d)	-4.209	-20.440
401	Dolomite (c)	-3.613	-20.440
119	FeS ppt	.144	-3.771
27	Forsterite	-14.828	14.829
111	Greenalite	-1.160	19.650
64	Halite	-10.270	-8.713
187	Hausmannite	-34.590	29.239
196	Hollandite		-250.941
117	Huntite	-12.323	-41.574
38	Hydrmagnesit	-25.728	-33.037
67	Mackinawite	.877	-3.771
98	Magadiite	-9.016	-23.316
10	Magnesite	-2.709	-10.567
189	Manganite	-14.421	10.919
191	MnCl2, 4H2O	-16.380	-14.154
192	MnS green	-9.302	-5.341
58	Nahcolite	-6.643	-7.295
60	Natron	-13.920	-15.669
149	Nesquehonite	-5.107	-10.567
185	Nsutite	-28.128	14.436
539	Portlandite	-13.739	9.924
197	Psilomelane		-251.598
114	Pyrite	9.315	-9.479
188	Pyrocroite	-7.799	7.401
183	Pyrolusite	-28.755	14.436
101	Quartz	.515	-3.632
200	Rancieite		-143.565
190	Rhodochrs(d)	-2.006	-12.396
564	Rhodochrs(c)	-1.306	-12.396
153	Sepiolite(d)	-11.096	7.564
36	Sepiolite(c)	-8.494	7.564
9	Siderite (d)	-.376	-10.826
94	Siderite (c)	-.005	-10.826
100	Silica gel	-.491	-3.632
395	SiO2 (a)	-.828	-3.632

C-3

	Phase	Log IAP/KT	Log IAP
195	a-Cryptomeln		-298.364
17	Anhydrite	-3.366	-7.701
21	Aragonite	-1.181	-9.446
150	Artinite	-9.801	.759
144	Barite	-6.823	-17.027
184	Birnessite	-28.941	14.660
186	Bixbyite	-30.473	-30.575
19	Brucite	-8.209	9.537
12	Calcite	-1.028	-9.446
97	Chalcedony	-.525	-4.234
20	Chrysotile	-13.739	20.143
29	Clinoenstite	-6.709	5.303
99	Cristobalite	-.463	-4.234
28	Diopside	-9.701	11.274
11	Dolomite (d)	-3.390	-19.560
401	Dolomite (c)	-2.785	-19.560
340	Epsomite	-6.135	-8.369
119	FeS ppt	.170	-3.745
27	Forsterite	-15.089	14.840
111	Greenalite	-2.150	18.660
18	Gypsum	-3.113	-7.701
64	Halite	-10.229	-8.678
187	Hausmannite	-34.715	29.678
196	Hollandite		-256.020
117	Huntite	-10.681	-39.788
38	Hydrmagnesit	-23.903	-30.919
67	Mackinawite	[illegible].903	-3.745
98	Magadiite	-13.084	-27.384
10	Magnesite	-2.291	-10.114
189	Manganite	-14.255	11.085
339	Melanterite	-6.483	-8.863
66	Mirabilite	-11.789	-13.537
134	Mn2(SO4)3	-79.887	-84.293
191	MnCl2, 4H2O	-16.346	-14.216
192	MnS green	-9.272	-5.278
182	MnSO4	-13.583	-10.397
58	Nahcolite	-6.331	-7.003
60	Natron	-13.445	-15.282
149	Nesquehonite	-4.687	-10.114
185	Nsutite	-27.904	14.660
539	Portlandite	-13.631	10.205
197	Psilomelane		-256.388
114	Pyrite	9.476	-9.381
188	Pyrocroite	-7.691	7.509
183	Pyrolusite	-28.896	14.660
101	Quartz	-.054	-4.234
200	Rancieite		-143.641
190	Rhodochrs(d)	-1.752	-12.142
564	Rhodochrs(c)	-1.060	-12.142
153	Sepiolite(d)	-12.288	6.372
36	Sepiolite(c)	-9.746	6.372
9	Siderite (d)	-.158	-10.608
94	Siderite (c)	.199	-10.608
100	Silica gel	-1.068	-4.234

D-1

	Phase	Log IAP/KT	Log IAP
195	a-Cryptomeln		-356.403
17	Anhydrite	-4.086	-8.424
144	Barite	-6.780	-16.881
184	Birnessite	-36.417	7.184
186	Bixbyite	-40.881	-41.196
19	Brucite	-16.369	.998
97	Chalcedony	-.502	-4.145
20	Chrysotile	-38.476	-5.298
29	Clinoenstite	-14.879	-3.148
99	Cristobalite	-.451	-4.145
28	Diopside	-22.116	-1.593
340	Epsomite	-10.931	-13.126
119	FeS ppt	-3.188	-7.103
27	Forsterite	-31.400	-2.150
111	Greenalite	-12.658	8.152
18	Gypsum	-3.842	-8.424
64	Halite	-11.357	-9.793
187	Hausmannite	-48.516	14.469
196	Hollandite		-310.673
67	Mackinawite	-2.455	-7.103
98	Magadiite	-14.561	-28.861
189	Manganite	-19.927	5.413
339	Melanterite	-6.336	-8.643
66	Mirabilite	-13.952	-15.435
134	Mn2(SO4)3	-78.615	-83.567
191	MnCl2, 4H2O	-17.005	-14.632
192	MnS green	-12.853	-8.941
182	MnSO4	-13.451	-10.481
185	Nsutite	-35.380	7.184
539	Portlandite	-17.703	5.699
197	Psilomelane		-311.294
114	Pyrite	2.552	-16.146
188	Pyrocroite	-11.557	3.643
183	Pyrolusite	-35.462	7.184
101	Quartz	-.049	-4.145
200	Rancieite		-174.809
153	Sepiolite(d)	-29.100	-10.440
36	Sepiolite(c)	-26.408	-10.440
100	Silica gel	-1.041	-4.145
395	SiO2 (a)	-1.368	-4.145
402	Sulfur	-7.017	-22.136
37	Talc	-35.388	-13.588
65	Thenardite	-15.267	-15.435
198	Todorokite		-217.353
31	Tremolite	-75.231	[illegible]

D-2

	Phase	Log IAP/KT	Log IAP
195	a-Cryptomeln		-333.068
21	Aragonite	-3.842	-12.115
150	Artinite	-15.307	-4.892
184	Birnessite	-33.306	10.295
186	Bixbyite	-36.505	-36.684
19	Brucite	-10.287	7.321
12	Calcite	-3.690	-12.115
97	Chalcedony	-.164	-3.849
20	Chrysotile	-19.362	14.265
29	Clinoenstite	-8.438	3.472
99	Cristobalite	-.106	-3.849
28	Diopside	-13.965	6.846
11	Dolomite (d)	-7.907	-24.132
401	Dolomite (c)	-7.310	-24.132
119	FeS ppt	-1.289	-5.204
27	Forsterite	-18.890	10.793
111	Greenalite	-6.190	14.620
64	Halite	-9.817	-8.262
187	Hausmannite	-42.579	21.303
196	Hollandite		-283.519
117	Huntite	-18.929	-48.167
38	Hydrmagnesit	-33.467	-40.748
67	Mackinawite	-.556	-5.204
98	Magadiite	-11.229	-25.529
10	Magnesite	-4.163	-12.017
189	Manganite	-17.441	7.899
191	MnCl2, 4H2O	-15.943	-13.726
192	MnS green	-11.103	-7.139
58	Nahcolite	-6.891	-7.544
60	Natron	-14.875	-16.632
149	Nesquehonite	-6.560	-12.017
185	Nsutite	-32.269	10.295
539	Portlandite	-16.456	7.223
197	Psilomelane		-284.503
114	Pyrite	5.743	-13.056
188	Pyrocroite	-9.696	5.504
183	Pyrolusite	-32.931	10.295
101	Quartz	.301	-3.849
200	Rancieite		-162.490
190	Rhodochrs(d)	-3.444	-13.834
564	Rhodochrs(c)	-2.745	-13.834
153	Sepiolite(d)	-15.565	3.095
36	Sepiolite(c)	-12.968	3.095
9	Siderite (d)	-1.449	-11.899
94	Siderite (c)	-1.079	-11.899
100	Silica gel	-.705	-3.849
395	SiO2 (a)	-1.042	-3.849

D-3

	Phase	Log IAP/KT	Log IAP
195	a-Cryptomeln		-286.414
21	Aragonite	-.922	-9.189
150	Artinite	-8.984	1.530
184	Birnessite	-27.636	15.965
186	Bixbyite	-28.269	-28.395
19	Brucite	-7.453	10.249
12	Calcite	-.769	-9.189
97	Chalcedony	-.284	-3.986
20	Chrysotile	-11.027	22.774
29	Clinoenstite	-5.717	6.263
99	Cristobalite	-.224	-3.986
28	Diopside	-7.926	12.997
11	Dolomite (d)	-2.662	-18.849
401	Dolomite (c)	-2.060	-18.849
119	FeS ppt	.888	-3.027
27	Forsterite	-13.340	16.511
111	Greenalite	.780	21.590
64	Halite	-9.979	-8.427
187	Hausmannite	-31.664	32.567
196	Hollandite		-239.793
117	Huntite	-9.021	-38.170
38	Hydrmagnesit	-21.292	-28.392
67	Mackinawite	1.621	-3.027
98	Magadiite	-10.881	-25.181
10	Magnesite	-1.827	-9.660
189	Manganite	-13.207	12.133
191	MnCl2, 4H2O	-16.086	-13.928
192	MnS green	-8.563	-4.579
58	Nahcolite	-6.099	-6.765
60	Natron	-12.722	-14.533
149	Nesquehonite	-4.223	-9.660
185	Nsutite	-26.599	15.965
539	Portlandite	-13.066	10.720
197	Psilomelane		-240.469
114	Pyrite	10.595	-8.243
188	Pyrocroite	-6.899	8.301
183	Pyrolusite	-27.486	15.965
101	Quartz	.185	-3.986
200	Rancieite		-137.421
190	Rhodochrs(d)	-1.218	-11.608
564	Rhodochrs(c)	-.523	-11.608
153	Sepiolite(d)	-10.120	8.540
36	Sepiolite(c)	-7.561	8.540
9	Siderite (d)	.395	-10.055
94	Siderite (c)	.756	-10.055
100	Silica gel	-.827	-3.986
395	SiO2 (a)	-1.168	-3.986
402	Sulfur	-3.242	-18.520

E-1

	Phase	Log IAP/KT	Log IAP
195	a-Cryptomeln		-161.898
17	Anhydrite	-3.641	-7.980
21	Aragonite	-2.681	-10.975
150	Artinite	-12.561	-2.432
144	Barite	-.126	-10.220
184	Birnessite	-12.607	30.994
186	Bixbyite	-13.659	-13.990
19	Brucite	-8.674	8.665
12	Calcite	-2.532	-10.975
97	Chalcedony	-.622	-4.260
20	Chrysotile	-15.651	17.475
29	Clinoenstite	-7.306	4.405
99	Cristobalite	-.571	-4.260
28	Diopside	-11.801	8.688
11	Dolomite (d)	-5.491	-21.827
401	Dolomite (c)	-4.911	-21.827
340	Epsomite	-5.666	-7.858
27	Forsterite	-16.129	13.070
111	Greenalite	-3.278	17.532
18	Gypsum	-3.397	-7.980
64	Halite	-9.633	-8.068
187	Hausmannite	-17.917	44.964
196	Hollandite		-132.350
117	Huntite	-14.038	-43.532
38	Hydrmagnesit	-26.945	-34.745
98	Magadiite	-13.377	-27.677
10	Magnesite	-2.937	-10.853
189	Manganite	-6.350	18.990
339	Melanterite	-5.537	-7.839
66	Mirabilite	-11.139	-12.602
134	Mn2(SO4)3	-58.565	-63.557
191	MnCl2, 4H2O	-15.462	-13.071
182	MnSO4	-12.491	-9.537
58	Nahcolite	-6.542	-7.158
60	Natron	-13.997	-15.597
149	Nesquehonite	-5.338	-10.853
185	Nsutite	-11.570	30.994
539	Portlandite	-14.828	8.543
197	Psilomelane		-133.238
188	Pyrocroite	-8.215	6.985
183	Pyrolusite	-11.584	30.994
101	Quartz	-.169	-4.260
200	Rancieite		-76.230
190	Rhodochrs(d)	-2.142	-12.532
564	Rhodochrs(c)	-1.429	-12.532
153	Sepiolite(d)	-14.109	4.551
36	Sepiolite(c)	-11.406	4.551
9	Siderite (d)	-.384	-10.834
94	Siderite (c)	.011	-10.834
100	Silica gel	-1.160	-4.260

F-1

	Phase	Log IAP/KT	Log IAP
195	a-Cryptomeln		-368.930
21	Aragonite	-4.838	-13.144
150	Artinite	-18.226	-8.267
184	Birnessite	-38.228	5.373
186	Bixbyite	-43.433	-43.854
19	Brucite	-12.369	4.810
12	Calcite	-4.691	-13.144
97	Chalcedony	-.310	-3.920
20	Chrysotile	-26.242	6.588
29	Clinoenstite	-10.703	.889
99	Cristobalite	-.265	-3.920
28	Diopside	-18.451	1.848
11	Dolomite (d)	-9.956	-26.357
401	Dolomite (c)	-9.385	-26.357
119	FeS ppt	-4.676	-8.591
27	Forsterite	-23.214	5.699
111	Greenalite	-16.796	4.014
187	Hausmannite	-52.038	10.250
196	Hollandite		-318.634
117	Huntite	-23.137	-52.783
38	Hydrmagnesit	-39.935	-48.044
67	Mackinawite	-3.943	-8.591
98	Magadiite	-13.217	-27.517
10	Magnesite	-5.261	-13.213
189	Manganite	-21.434	3.906
192	MnS green	-13.977	-10.104
58	Nahcolite	-6.926	-7.520
60	Natron	-16.265	-17.772
149	Nesquehonite	-7.666	-13.214
185	Nsutite	-37.191	5.373
539	Portlandite	-18.309	4.878
197	Psilomelane		-319.214
114	Pyrite	[redacted]	-18.199
188	Pyrocroite	-12.762	2.438
183	Pyrolusite	-36.821	5.373
101	Quartz	[redacted]	-3.920
200	Rancieite		-181.637
190	Rhodochrs(d)	-5.194	-15.584
564	Rhodochrs(c)	-4.472	-15.584
153	Sepiolite(d)	-20.803	-2.143
36	Sepiolite(c)	-18.037	-2.140
9	Siderite (d)	-3.621	-14.071
94	Siderite (c)	-3.212	-14.071
100	Silica gel	-.847	-3.920
395	SiO2 (a)	-1.167	-3.920
402	Sulfur	-7.553	-22.678

F-2

	Phase	Log IAP/KT	Log IAP
195	a-Cryptomeln		-357.306
17	Anhydrite	-3.826	-8.161
21	Aragonite	-4.203	-12.481
150	Artinite	-16.774	-6.435
144	Barite	-1.177	-11.323
184	Birnessite	-36.233	7.368
186	Bixbyite	-41.062	-41.282
19	Brucite	-12.227	5.310
12	Calcite	-4.051	-12.481
97	Chalcedony	-.248	-3.921
20	Chrysotile	-25.407	8.087
29	Clinoenstite	-10.468	1.389
99	Cristobalite	-.193	-3.921
28	Diopside	-17.211	3.515
11	Dolomite (d)	-9.444	-25.699
401	Dolomite (c)	-8.852	-25.699
340	Epsomite	-6.687	-8.899
119	FeS ppt	-3.745	-7.660
27	Forsterite	-22.856	6.699
111	Greenalite	-13.771	7.039
18	Gypsum	-3.577	-8.162
64	Halite	-10.089	-8.530
187	Hausmannite	-48.855	14.761
196	Hollandite		-307.280
117	Huntite	-22.830	-52.136
38	Hydrmagnesit	-40.144	-47.563
67	Mackinawite	-3.012	-7.660
98	Magadiite	-12.771	-27.071
10	Magnesite	-5.348	-13.218
189	Manganite	-19.808	5.532
339	Melanterite	-6.909	-9.249
66	Mirabilite	-11.517	-13.119
134	Mn2(SO4)3	-79.199	-83.906
191	MnCl2, 4H2O	-16.718	-14.455
192	MnS green	-12.873	-8.924
182	MnSO4	-13.578	-10.511
58	Nahcolite	-6.910	-7.553
60	Natron	-15.723	-17.439
149	Nesquehonite	-7.746	-13.219
185	Nsutite	-35.196	7.368
539	Portlandite	-17.550	6.047
197	Psilomelane		-307.740
114	Pyrite	2.160	-16.610
188	Pyrocroite	-11.504	3.696
183	Pyrolusite	-35.685	7.368
101	Quartz	.213	-3.921
200	Rancieite	[illegible]	-175.183
190	Rhodochrs(d)	-4.441	-14.831

F-3

	Phase	Log IAP/KT	Log IAP
195	a-Cryptomeln		-301.334
21	Aragonite	-.678	-8.956
150	Artinite	-9.119	1.219
184	Birnessite	-29.679	13.922
186	Bixbyite	-30.994	-31.213
19	Brucite	-8.515	9.021
12	Calcite	-.526	-8.956
97	Chalcedony	-.004	-3.677
20	Chrysotile	-13.784	19.710
29	Clinoenstite	-6.513	5.345
99	Cristobalite	.052	-3.677
28	Diopside	-8.881	11.844
11	Dolomite (d)	-2.812	-19.067
401	Dolomite (c)	-2.220	-19.067
119	FeS ppt	-.396	-4.311
27	Forsterite	-15.189	14.366
111	Greenalite	-3.002	17.808
64	Halite	-10.271	-8.713
187	Hausmannite	-35.272	28.344
196	Hollandite		-254.505
117	Huntite	-9.984	-39.290
38	Hydrmagnesit	-24.004	-31.424
67	Mackinawite	.337	-4.311
98	Magadiite	-9.274	-23.574
10	Magnesite	-2.241	-10.111
189	Manganite	-14.773	10.567
191	MnCl2, 4H2O	-16.314	-14.050
192	MnS green	-9.436	-5.487
58	Nahcolite	-6.142	-6.785
60	Natron	-13.583	-15.299
149	Nesquehonite	-4.639	-10.111
185	Nsutite	-28.642	13.922
539	Portlandite	-13.421	10.176
197	Psilomelane		-254.836
114	Pyrite	8.472	-10.297
188	Pyrocroite	-7.989	7.211
183	Pyrolusite	-29.131	13.922
101	Quartz	.458	-3.677
200	Rancieite		-145.180
190	Rhodochrs(d)	-1.531	-11.921
564	Rhodochrs(c)	-.828	-11.921
153	Sepiolite(d)	-11.648	7.012
36	Sepiolite(c)	-9.023	7.012
9	Siderite (d)	-.295	-10.745
94	Siderite (c)	.081	-10.745
100	Silica gel	-.545	-3.677
395	SiO2 (a)	-.879	-3.677
402	Sulfur	-3.986	-19.215

H-1

	Phase	Log IAP/KT	Log IAP
195	a-Cryptomeln		-131.448
17	Anhydrite	-3.541	-7.884
21	Aragonite	-.730	-9.034
150	Artinite	-8.301	1.680
144	Barite	-1.433	-11.491
184	Birnessite	-9.228	34.373
186	Bixbyite	-8.276	-8.684
19	Brucite	-6.110	11.090
12	Calcite	-.582	-9.034
97	Chalcedony	-.181	-3.795
20	Chrysotile	-7.189	25.679
29	Clinoenstite	-4.313	7.295
99	Cristobalite	-.135	-3.795
28	Diopside	-6.109	14.214
11	Dolomite (d)	-1.300	-17.693
401	Dolomite (c)	-.728	-17.693
340	Epsomite	-5.332	-7.510
27	Forsterite	-10.566	18.385
111	Greenalite	-.140	20.670
18	Gypsum	-3.303	-7.884
64	Halite	-9.198	-7.628
187	Hausmannite	-10.698	51.667
196	Hollandite		-104.747
117	Huntite	-5.384	-35.010
38	Hydrmagnesit	-15.477	-23.546
98	Magadiite	-9.749	-24.049
10	Magnesite	-.712	-8.659
189	Manganite	-3.830	21.510
339	Melanterite	-6.904	-9.179
66	Mirabilite	-10.068	-11.434
134	Mn2(SO4)3	-59.288	-64.481
191	MnCl2, 4H2O	-16.255	-13.775
182	MnSO4	-12.826	-9.952
58	Nahcolite	-5.190	-5.787
60	Natron	-11.064	-12.584
149	Nesquehonite	-3.115	-8.659
185	Nsutite	-8.191	34.373
539	Portlandite	-12.497	10.715
197	Psilomelane		-105.018
188	Pyrocroite	-6.553	8.647
183	Pyrolusite	-7.871	34.373
101	Quartz	.265	-3.795
200	Rancieite	[illegible]	-59.769
190	Rhodochrs(d)	-.712	-11.102
564	Rhodochrs(c)	.009	-11.102
153	Sepiolite(d)	-7.866	10.794
36	Sepiolite(c)	-5.108	10.794
9	Siderite (d)	.121	-10.329
94	Siderite (c)	.529	-10.329
100	Silica gel	-.718	-3.795

H-2

	Phase	Log IAP/KT	Log IAP
195	a-Cryptomeln		-168.314
17	Anhydrite	-3.337	-7.676
21	Aragonite	-1.783	-10.077
150	Artinite	-11.509	-1.388
144	Barite	-6.926	-17.017
184	Birnessite	-13.316	30.285
186	Bixbyite	-14.815	-15.150
19	Brucite	-9.070	8.262
12	Calcite	-1.634	-10.077
97	Chalcedony	-.172	-3.809
20	Chrysotile	-15.946	17.167
29	Clinoenstite	-7.253	4.453
99	Cristobalite	-.123	-3.809
28	Diopside	-11.148	9.333
11	Dolomite (d)	-4.242	-20.581
401	Dolomite (c)	-3.662	-20.581
340	Epsomite	-5.913	-8.104
27	Forsterite	-16.472	12.715
111	Greenalite	-5.910	14.900
18	Gypsum	-3.094	-7.677
64	Halite	-9.701	-8.136
187	Hausmannite	-19.528	43.327
196	Hollandite		-143.870
117	Huntite	-12.088	-41.588
38	Hydrmagnesit	-25.940	-33.754
98	Magadiite	-10.944	-25.244
10	Magnesite	-2.587	-10.504
189	Manganite	-6.937	18.403
339	Melanterite	-6.560	-8.860
66	Mirabilite	-11.268	-12.726
134	Mn2(SO4)3	-59.244	-64.246
191	MnCl2, 4H2O	-15.786	-13.391
182	MnSO4	-12.794	-9.845
58	Nahcolite	-5.932	-6.548
60	Natron	-13.530	-15.127
149	Nesquehonite	-4.988	-10.504
185	Nsutite	-12.279	30.285
539	Portlandite	-14.673	8.689
197	Psilomelane		-143.988
188	Pyrocroite	-8.679	6.521
183	Pyrolusite	-12.276	30.285
101	Quartz	.280	-3.809
200	Rancieite	[illegible]	-79.208
190	Rhodochrs(d)	-1.855	-12.245
564	Rhodochrs(c)	-1.141	-12.245
153	Sepiolite(d)	-13.564	5.096
36	Sepiolite(c)	-10.858	5.096
9	Siderite (d)	-.810	-11.260
94	Siderite (c)	-.415	-11.260
100	Silica gel	-.711	-3.809
395	SiO2 (a)	-1.037	-3.809

H-3

	Phase	Log IAP/KT	Log IAP
195	a-Cryptomeln		-157.344
17	Anhydrite	-3.561	-7.897
21	Aragonite	-1.903	-10.184
150	Artinite	-11.250	-.949
144	Barite	-6.770	-16.907
184	Birnessite	-11.719	31.882
186	Bixbyite	-12.980	-13.220
19	Brucite	-8.676	8.825
12	Calcite	-1.752	-10.184
97	Chalcedony	-.356	-4.022
20	Chrysotile	-14.997	18.431
29	Clinoenstite	-7.028	4.803
99	Cristobalite	-.301	-4.022
28	Diopside	-10.667	10.015
11	Dolomite (d)	-4.508	-20.778
401	Dolomite (c)	-3.918	-20.778
340	Epsomite	-6.099	-8.307
27	Forsterite	-15.863	13.628
111	Greenalite	-3.630	17.180
18	Gypsum	-3.313	-7.897
64	Halite	-9.810	-8.250
187	Hausmannite	-17.249	46.235
196	Hollandite		-133.312
117	Huntite	-12.626	-41.966
38	Hydrmagnesit	-26.063	-33.551
98	Magadiite	-11.958	-26.258
10	Magnesite	-2.715	-10.594
189	Manganite	-5.811	19.529
339	Melanterite	-6.391	-8.724
66	Mirabilite	-11.024	-12.601
134	Mn2(SO4)3	-59.857	-64.616
191	MnCl2, 4H2O	-16.142	-13.856
182	MnSO4	-13.002	-9.956
58	Nahcolite	-6.091	-6.729
60	Natron	-13.193	-14.888
149	Nesquehonite	-5.114	-10.594
185	Nsutite	-10.682	31.882
539	Portlandite	-14.321	9.235
197	Psilomelane		-133.609
188	Pyrocroite	-8.023	7.177
183	Pyrolusite	-11.086	31.882
101	Quartz	.104	-4.022
200	Rancieite		-73.502
190	Rhodochrs(d)	-1.853	-12.243
564	Rhodochrs(c)	-1.147	-12.243
153	Sepiolite(d)	-13.077	5.583
36	Sepiolite(c)	-10.438	5.583
9	Siderite (d)	-.561	-11.011
94	Siderite (c)	-.181	-11.011
100	Silica gel	-.896	-4.022
395	SiO2 (a)	-1.229	-4.022

I-1

	Phase	Log IAP/KT	Log IAP
195	a-Cryptomeln		-300.711
17	Anhydrite	-3.562	-7.903
21	Aragonite	-1.813	-10.112
150	Artinite	-11.171	-1.124
144	Barite	-.223	-10.297
184	Birnessite	-30.096	13.505
186	Bixbyite	-30.571	-30.945
19	Brucite	-7.859	9.403
12	Calcite	-1.664	-10.112
97	Chalcedony	-.489	-4.114
20	Chrysotile	-13.003	19.981
29	Clinoenstite	-6.365	5.289
99	Cristobalite	-.441	-4.114
28	Diopside	-10.234	10.164
11	Dolomite (d)	-3.442	-19.809
401	Dolomite (c)	-2.866	-19.809
340	Epsomite	-5.305	-7.489
119	FeS ppt	.129	-3.786
27	Forsterite	-14.370*	14.692
111	Greenalite	-2.558	18.252
18	Gypsum	-3.321	-7.903
64	Halite	-8.292	-6.724
187	Hausmannite	-34.345	28.252
196	Hollandite		-253.201
117	Huntite	-9.638	-39.205
38	Hydrmagnesit	-21.439	-29.388
67	Mackinawite	.862	-3.786
98	Magadiite	-12.731	-27.031
10	Magnesite	-1.765	-9.698
189	Manganite	-14.901	10.439
339	Melanterite	-5.778	-8.065
66	Mirabilite	-9.248	-10.657
134	Mn2(SO4)3	-76.516	-81.619
191	MnCl2, 4H2O	-14.750	-12.310
192	MnS green	-9.129	-5.239
182	MnSO4	-12.428	-9.518
58	Nahcolite	-4.990	-5.595
60	Natron	-11.310	-12.867
149	Nesquehonite	-4.167	-9.698
185	Nsutite	-29.059	13.505
539	Portlandite	-14.294	8.989
197	Psilomelane		-253.953
114	Pyrite	8.388	-10.267
188	Pyrocroite	-7.826	7.374
183	Pyrolusite	-28.889	13.505
101	Quartz	-.041	-4.114
200	Rancieite		-145.191
190	Rhodochrs(d)	-1.337	-11.727
564	Rhodochrs(c)	-.619	-11.727
153	Sepiolite(d)	-12.197	6.463
36	Sepiolite(c)	-9.463	6.463
9	Siderite (d)	.176	-10.274
94	Siderite (c)	.578	-10.274
100	Silica gel	-1.027	-4.114

I-2

	Phase	Log IAP/KT	Log IAP
195	a-Cryptomeln		-182.489
17	Anhydrite	-3.215	-7.550
21	Aragonite	-2.885	-11.163
150	Artinite	-13.710	-3.364
144	Barite	[illegible].440	-9.708
184	Birnessite	-14.664	28.937
186	Bixbyite	-17.282	-17.497
19	Brucite	-9.717	7.827
12	Calcite	-2.734	-11.163
97	Chalcedony	-.356	-4.030
20	Chrysotile	-18.087	15.420
29	Clinoenstite	-8.066	3.797
99	Cristobalite	-.300	-4.030
28	Diopside	-13.167	7.567
11	Dolomite (d)	-6.047	-22.299
401	Dolomite (c)	-5.454	-22.299
340	Epsomite	-5.310	-7.523
27	Forsterite	-17.944	11.624
18	Gypsum	-2.965	-7.550
64	Halite	-9.580	-8.022
187	Hausmannite	-22.855	40.788
117	Huntite	-15.272	-44.571
38	Hydrmagnesit	-29.312	-36.718
98	Magadiite	-12.234	-26.534
10	Magnesite	-3.267	-11.136
189	Manganite	-7.909	17.431
66	Mirabilite	-10.887	-12.494
134	Mn2(SO4)3	-58.848	-63.545
191	MnCl2, 4H2O	-15.232	-12.974
182	MnSO4	-12.494	-9.424
58	Nahcolite	-6.460	-7.104
60	Natron	-14.388	-16.108
149	Nesquehonite	-5.666	-11.136
185	Nsutite	-13.627	28.937
539	Portlandite	-15.806	7.799
197	Psilomelane		-152.103
188	Pyrocroite	-9.274	5.926
183	Pyrolusite	-14.134	28.937
101	Quartz	[illegible].106	-4.030
200	Rancieite		-86.942
190	Rhodochrs(d)	-2.647	-13.037
564	Rhodochrs(c)	-1.944	-13.037
153	Sepiolite(d)	-15.096	3.564
36	Sepiolite(c)	-12.474	3.564
100	Silica gel	-.896	-4.030
395	SiO2 (a)	-1.231	-4.030

I-3

	Phase	Log IAP/KT	Log IAP
195	a-Cryptomeln		-142.371
17	Anhydrite	-3.208	-7.542
21	Aragonite	-.790	-9.054
150	Artinite	-8.848	1.728
144	Barite	-1.089	-11.296
184	Birnessite	-9.495	34.106
186	Bixbyite	-10.246	-10.339
19	Brucite	-7.111	10.649
12	Calcite	-.637	-9.054
97	Chalcedony	-.333	-4.044
20	Chrysotile	-10.049	23.859
29	Clinoenstite	-5.418	6.605
99	Cristobalite	-.271	-4.044
28	Diopside	-7.649	13.343
11	Dolomite (d)	-2.077	-18.241
401	Dolomite (c)	-1.471	-18.241
340	Epsomite	-5.440	-7.676
27	Forsterite	-12.701	17.254
111	Greenalite	.832	21.642
18	Gypsum	-2.954	-7.542
64	Halite	-7.745	-6.194
187	Hausmannite	-13.688	50.759
196	Hollandite		-114.066
117	Huntite	-7.521	-36.614
38	Hydrmagnesit	-19.111	-26.099
98	Magadiite	-11.563	-25.863
10	Magnesite	-1.367	-9.187
189	Manganite	-4.124	21.216
339	Melanterite	-6.032	-8.415
66	Mirabilite	-8.004	-9.762
134	Mn2(SO4)3	-60.928	-65.313
191	MnCl2, 4H2O	-14.745	-12.625
182	MnSO4	-13.193	-9.998
58	Nahcolite	-4.415	-5.089
60	Natron	-9.428	-11.274
149	Nesquehonite	-3.763	-9.187
185	Nsutite	-8.458	34.106
539	Portlandite	-13.070	10.782
197	Psilomelane		-114.729
188	Pyrocroite	-6.874	8.326
183	Pyrolusite	-9.484	34.106
101	Quartz	.139	-4.044
200	Rancieite		-65.255
190	Rhodochrs(d)	-1.120	-11.510
564	Rhodochrs(c)	-.428	-11.510
153	Sepiolite(d)	-9.494	9.166
36	Sepiolite(c)	-6.958	9.166
9	Siderite (d)	.524	-9.926
94	Siderite (c)	.880	-9.926
100	Silica gel	-.875	-4.044
395	SiO2 (a)	-1.219	-4.044

J-1

	Phase	Log IAP/KT	Log IAP
195	a-Cryptomeln		-287.201
21	Aragonite	-1.031	-9.339
150	Artinite	-9.196	.741
184	Birnessite	-28.717	14.884
186	Bixbyite	-28.587	-29.019
19	Brucite	-7.472	9.686
12	Calcite	-.884	-9.339
97	Chalcedony	-.666	-4.273
20	Chrysotile	-12.278	20.513
29	Clinoenstite	-6.164	5.414
99	Cristobalite	-.621	-4.273
28	Diopside	-9.053	11.220
11	Dolomite (d)	-2.661	-19.070
401	Dolomite (c)	-2.091	-19.070
119	FeS ppt	.260	-3.655
27	Forsterite	-13.776	15.100
111	Greenalite	-2.290	18.520
64	Halite	-9.581	-8.010
187	Hausmannite	-31.882	30.330
196	Hollandite		-241.490
117	Huntite	-8.869	-38.534
38	Hydrmagnesit	-21.093	-29.242
67	Mackinawite	.993	-3.655
98	Magadiite	-12.985	-27.285
10	Magnesite	-1.775	-9.732
189	Manganite	-14.037	11.303
191	MnCl2, 4H2O	-16.068	-13.562
192	MnS green	-8.822	-4.954
58	Nahcolite	-5.822	-6.414
60	Natron	-12.659	-14.155
149	Nesquehonite	-4.179	-9.732
185	Nsutite	-27.680	14.884
539	Portlandite	-13.084	10.080
197	Psilomelane		-242.013
114	Pyrite	9.440	-9.171
188	Pyrocroite	-7.477	7.723
183	Pyrolusite	-27.260	14.884
101	Quartz	-.222	-4.273
200	Rancieite		-138.208
190	Rhodochrs(d)	-1.305	-11.695
564	Rhodochrs(c)	-.582	-11.695
153	Sepiolite(d)	-12.106	6.554
36	Sepiolite(c)	-9.332	6.554
9	Siderite (d)	.054	-10.396
94	Siderite (c)	.465	-10.396
100	Silica gel	-1.203	-4.273
395	SiO2 (a)	-1.522	-4.273
402	Sulfur	-3.458	-18.576

J-2

	Phase	Log IAP/KT	Log IAP
195	a-Cryptomeln		-307.444
21	Aragonite	-1.299	-9.590
150	Artinite	-10.309	-.158
184	Birnessite	-30.732	12.869
186	Bixbyite	-32.056	-32.374
19	Brucite	-8.265	9.094
12	Calcite	-1.150	-9.590
97	Chalcedony	-.387	-4.029
20	Chrysotile	-13.940	19.226
29	Clinoenstite	-6.661	5.066
99	Cristobalite	-.336	-4.029
28	Diopside	-10.044	10.470
11	Dolomite (d)	-3.192	-19.520
401	Dolomite (c)	-2.611	-19.520
119	FeS ppt	-.361	-4.276
27	Forsterite	-15.077	14.160
111	Greenalite	-3.823	16.987
64	Halite	-9.682	-8.118
187	Hausmannite	-36.559	26.401
196	Hollandite		-260.364
117	Huntite	-9.904	-39.378
38	Hydrmagnesit	-22.862	-30.623
67	Mackinawite	.372	-4.276
98	Magadiite	-11.875	-26.175
10	Magnesite	-2.018	-9.929
189	Manganite	-15.523	9.817
191	MnCl2, 4H2O	-16.029	-13.652
192	MnS green	-9.769	-5.858
58	Nahcolite	-5.911	-6.530
60	Natron	-13.229	-14.842
149	Nesquehonite	-4.420	-9.930
185	Nsutite	-29.695	12.869
539	Portlandite	-13.961	9.433
197	Psilomelane		-260.961
114	Pyrite	[illegible]7.899	-10.797
188	Pyrocroite	-8.434	6.766
183	Pyrolusite	-29.760	12.869
101	Quartz	[illegible].066	-4.029
200	Rancieite		-148.623
190	Rhodochrs(d)	-1.868	-12.258
564	Rhodochrs(c)	-1.155	-12.258
153	Sepiolite(d)	-12.558	6.102
36	Sepiolite(c)	-9.863	6.102
9	Siderite (d)	-.226	-10.676
94	Siderite (c)	.167	-10.676
100	Silica gel	-.926	-4.029
395	SiO2 (a)	-1.253	-4.029

J-3

	Phase	Log IAP/KT	Log IAP
195	a-Cryptomeln		-140.615
17	Anhydrite	-3.146	-7.481
21	Aragonite	-.431	-8.710
150	Artinite	-8.222	2.116
144	Barite	-1.147	-11.293
184	Birnessite	-9.712	33.889
186	Bixbyite	-10.056	-10.275
19	Brucite	-7.113	10.423
12	Calcite	-.280	-8.710
97	Chalcedony	-.461	-4.134
20	Chrysotile	-10.491	23.003
29	Clinoenstite	-5.568	6.290
99	Cristobalite	-.405	-4.134
28	Diopside	-7.743	12.982
11	Dolomite (d)	-1.568	-17.823
401	Dolomite (c)	-.975	-17.823
340	Epsomite	-5.672	-7.885
27	Forsterite	-12.841	16.713
111	Greenalite	-.027	20.783
18	Gypsum	-2.897	-7.481
64	Halite	-9.649	-8.090
187	Hausmannite	-13.363	50.253
196	Hollandite		-112.832
117	Huntite	-6.742	-36.048
38	Hydrmagnesit	-18.608	-26.028
98	Magadiite	-11.970	-26.270
10	Magnesite	-1.242	-9.113
189	Manganite	-4.305	21.035
339	Melanterite	-6.285	-8.625
66	Mirabilite	-11.060	-12.662
134	Mn2(SO4)3	-60.491	-65.198
191	MnCl2, 4H2O	-15.909	-13.646
182	MnSO4	-13.192	-10.126
58	Nahcolite	-5.640	-6.283
60	Natron	-12.174	-13.890
149	Nesquehonite	-3.641	-9.113
185	Nsutite	-8.675	33.889
539	Portlandite	-12.770	10.826
197	Psilomelane		-113.410
188	Pyrocroite	-7.018	8.182
183	Pyrolusite	-9.164	33.889
101	Quartz	[illegible].000	-4.134
200	Rancieite		-64.484
190	Rhodochrs(d)	-.964	-11.354
564	Rhodochrs(c)	-.261	-11.354
153	Sepiolite(d)	-10.215	8.445
36	Sepiolite(c)	-7.590	8.445
9	Siderite (d)	[illegible].597	-9.853
94	Siderite (c)	[illegible].973	-9.853
100	Silica gel	-1.002	-4.134
395	SiO2 (a)	-1.336	-4.134

Appendix I

Geochemical Data

Spring Chemical Data for Deep Wells 1 - 5 (mg/L)
Date Sampled: Spring 1989

Well	Temp[1] C	pH	Cond.	TDS[2]	Total[3] Hardness
1	10.9	7.39	400	216	208
2	11.3	7.75	413	232	313
3	12.3	7.41	374	224	190
4	11.4	7.75	353	224	176
5	11.4	7.56	440	232	228

					Anions
Well	Cl^-	*HCO_3^-	NO_3^-/N	SiO_2	SO_4^{-2}
1	3.02	194	0.30	5.15	3.67
2	7.68	154	0.26	5.93	38.0
3	4.39	170	0.22	0.55	19.1
4	2.29	149	0.16	4.28	27.3
5	5.90	187	0.60	1.81	34.2

					Cations			
Well	Ba^{+2}	Ca^{+2}	Fe^{+2}	K^+	Mg^{+2}	Mn^{+2}	Na^+	NH_4^+
1	0.06	69.0	1.76	0.38	8.80	0.18	4.63	N/A
2	0.09	57.2	0.41	0.76	16.4	0.14	3.34	N/A
3	0.05	56.0	0.99	0.55	12.3	0.14	2.62	N/A
4	0.02	48.0	0.38	0.74	13.6	0.26	3.04	N/A
5	0.02	61.2	0.51	0.82	18.4	0.32	2.74	N/A

N/A = Not applicable
[1]Degrees Celcius
[2]Total dissolved solids
[3]Total hardness, mg/L as $CaCO_3$
*Alkalinity

Spring Chemical Data for Deep Wells 6-8 (mg/L)
Date Sampled: Spring 1989

Well	Temp[1] C	pH	Cond.	TDS[2]	Total[3] Hardness
6	10.0	7.82	353	222	177
7	11.4	7.61	422	228	211
8	11.8	7.57	431	204	208

Anions

Well	Cl^-	*HCO_3^-	NO_3^-/N	SiO_2	SO_4^{-2}
6	1.74	160	0.19	2.38	17.8
7	6.58	184	0.18	6.22	40.2
8	9.15	176	0.16	3.38	31.1

Cations

Well	Ba^{+2}	Ca^{+2}	Fe^{+2}	K^+	Mg^{+2}	Mn^{+2}	Na^+	NH_4^+
6	0.04	47.8	3.30	0.25	14.0	0.08	1.76	N/A
7	0.08	61.3	2.29	0.64	14.0	0.09	3.10	N/A
8	0.05	62.6	2.27	0.45	12.5	0.12	2.54	N/A

N/A = Not applicable
[1]Degrees Celcius
[2]Total dissolved solids
[3]Total hardness, mg/L as $CaCO_3$
*Alkalinity

Summer Chemical Data for Deep Wells 1-5 (mg/L)
Date Sampled: Summer 1989

Well	Temp[1] C	pH	Cond.	TDS[2]	Total[3] Hardness
1	11.7	7.39	400	240	213
2	10.9	7.73	408	196	215
3	12.0	7.48	380	176	198
4	11.4	7.85	355	172	181
5	12.2	7.48	436	280	226

Anions

Well	Cl^-	*HCO_3^-	NO_3^-/N	SiO_2	SO_4^{-2}
1	2.95	208	0.21	5.28	7.83
2	6.46	159	0.24	5.20	43.4
3	4.28	178	1.68	5.44	18.6
4	2.76	155	0.34	6.18	26.0
5	5.90	194	0.45	4.81	32.0

Cations

Well	Ba^{+2}	Ca^{+2}	Fe^{+2}	K^+	Mg^{+2}	Mn^{+2}	Na^+	NH_4^+
1	0.01	70.2	1.87	0.29	9.10	0.18	1.80	0.78
2	0.02	57.6	0.32	0.68	17.1	0.15	2.82	0.16
3	0.07	56.4	1.01	0.50	14.0	0.12	1.87	0.03
4	0.02	48.8	0.09	0.65	14.4	0.20	3.17	0.02
5	0.05	59.6	0.47	0.74	18.8	0.27	2.55	0.02

N/A = Not applicable
[1]Degrees Celcius
[2]Total dissolved solids
[3]Total hardness, mg/L as $CaCO_3$
*Alkalinity

Summer Chemical Data for Deep Wells 6-8 (mg/L)
Date Sampled: Summer 1989

Well	Temp[1] C	pH	Cond.	TDS[2]	Total[3] Hardness
6	10.5	7.70	357	236	182
7	11.6	7.49	430	256	215
8	12.8	7.54	433	192	222

			Anions		
Well	Cl^-	*HCO_3^-	NO_3^-/N	SiO_2	SO_4^{-2}
6	2.66	162	0.40	5.82	22.7
7	6.56	199	0.35	7.62	17.6
8	10.3	177	0.34	6.56	32.5

				Cations				
Well	Ba^{+2}	Ca^{+2}	Fe^{+2}	K^+	Mg^{+2}	Mn^{+2}	Na^+	NH_4^+
6	0.10	48.6	3.49	0.30	14.7	0.07	1.52	0.02
7	0.09	61.2	2.30	0.51	15.2	0.09	3.03	0.51
8	0.04	64.2	2.14	0.42	14.9	0.10	2.48	1.24

N/A = Not applicable
[1]Degrees Celcius
[2]Total dissolved solids
[3]Total hardness, mg/L as $CaCO_3$
*Alkalinity

Fall Chemical Data for Deep Wells 1-5 (mg/L)
Date Sampled: Fall 1989

Well	Temp[1] C	pH	Cond.	TDS[2]	Total[3] Hardness
1	11.0	7.40	350	332	206
2	10.8	7.45	362	284	208
3	11.8	7.05	367	208	241
4	11.5	7.74	366	196	229
5	12.7	7.61	427	258	299

Anions

Well	Cl^-	*HCO_3^-	NO_3^-/N	SiO_2	SO_4^{-2}
1	3.99	206	0.36	3.94	2.50
2	7.51	161	0.35	5.41	34.9
3	3.80	174	0.37	5.19	19.8
4	2.66	164	0.33	5.33	17.4
5	5.22	182	0.49	4.51	45.8

Cations

Well	Ba^{+2}	Ca^{+2}	Fe^{+2}	K^+	Mg^{+2}	Mn^{+2}	Na^+	NH_4^+
1	0.01	68.8	2.15	0.46	8.40	0.18	2.08	1.04
2	0.02	57.4	0.37	0.87	15.6	0.15	2.76	0.17
3	<0.01	75.6	0.91	0.34	12.8	0.12	1.54	0.20
4	0.04	66.6	0.08	0.57	15.2	0.20	2.76	0.64
5	0.06	90.6	0.40	0.58	17.6	0.26	2.16	0.16

N/A = Not applicable
[1]Degrees Celcius
[2]Total dissolved solids
[3]Total hardness, mg/L as $CaCO_3$
*Alkalinity

Fall Chemical Data for Deep Wells 6-8 (mg/L)
Date Sampled: Fall 1989

Well	Temp[1] C	pH	Cond.	TDS[2]	Total[3] Hardness
6	10.9	7.50	369	236	192
7	10.9	7.58	462	260	236
8	11.0	7.58	423	300	222

					Anions
Well	Cl^-	*HCO_3^-	NO_3^-/N	SiO_2	SO_4^{-2}
6	2.28	170	0.36	5.09	23.1
7	6.84	214	0.34	6.67	18.5
8	9.02	172	0.34	5.96	34.4

					Cations			
Well	Ba^{+2}	Ca^{+2}	Fe^{+2}	K^+	Mg^{+2}	Mn^{+2}	Na^+	NH_4^+
6	0.02	50.4	3.37	0.21	14.8	0.08	1.36	3.67
7	<0.01	68.2	2.34	0.50	16.0	0.09	3.06	4.03
8	0.02	65.0	2.02	0.27	14.4	0.10	2.38	9.92

N/A = Not applicable
[1]Degrees Celcius
[2]Total dissolved solids
[3]Total hardness, mg/L as $CaCO_3$
*Alkalinity

Winter Chemical Data for Deep Wells 1-5 (mg/L)
Date Sampled: Winter 1990

Well	Temp[1] C	pH	Cond.	TDS[2]	Total[3] Hardness
1	10.5	7.05	424	272	224
2	10.3	7.39	404	228	206
3	11.5	7.40	372	228	194
4	11.1	7.70	367	236	189
5	11.6	7.58	430	216	220

			Anions		
Well	Cl^-	*HCO_3^-	NO_3^-/N	SiO_2	SO_4^{-2}
1	2.94	219	0.31	4.37	2.91
2	22.6	169	0.34	4.25	30.2
3	2.76	175	0.27	5.58	18.4
4	3.04	165	0.25	6.08	21.3
5	5.89	180	0.52	4.19	31.0

				Cations				
Well	Ba^{+2}	Ca^{+2}	Fe^{+2}	K^+	Mg^{+2}	Mn^{+2}	Na^+	NH_4^+
1	0.02	72.5	2.12	0.21	10.4	0.17	3.08	0.86
2	<0.01	55.5	0.37	0.24	16.4	0.14	3.66	0.05
3	0.04	55.8	0.47	3.96	13.4	0.12	1.80	2.14
4	0.07	50.0	<0.01	0.58	15.6	0.20	2.80	0.20
5	0.09	58.4	0.36	0.83	18.0	0.24	2.40	0.16

N/A = Not applicable
[1]Degrees Celcius
[2]Total dissolved solids
[3]Total hardness, mg/L as $CaCO_3$
*Alkalinity

Winter Chemical Data for Deep Wells 6 - 8 (mg/L)
Date Sampled: Winter 1990

Well	Temp[1] C	pH	Cond.	TDS[2]	Total[3] Hardness
6	10.4	7.37	373	222	190
7	10.1	7.15	490	272	254
8	10.1	7.19	414	238	208

					Anions
Well	Cl^-	*HCO_3^-	NO_3^-/N	SiO_2	SO_4^{-2}
6	1.52	161	0.21	5.11	25.3
7	6.51	237	0.20	6.02	14.8
8	7.12	174	0.21	6.10	32.8

					Cations			
Well	Ba^{+2}	Ca^{+2}	Fe^{+2}	K^+	Mg^{+2}	Mn^{+2}	Na^+	NH_4^+
6	0.03	51.0	3.22	0.20	15.2	0.08	1.54	4.43
7	0.08	71.5	2.14	0.84	18.4	0.09	3.76	3.86
8	0.14	57.7	1.70	0.66	15.6	0.08	2.44	6.23

N/A = Not applicable
[1]Degrees Celcius
[2]Total dissolved solids
[3]Total hardness, mg/L as $CaCO_3$
*Alkalinity

Chemical Data for Nest A (mg/L)
Date Sampled: August 28, 1991

Well	Depth of screen	Total Hardness	Temp[2] C	pH	Cond[3]	TDS[4]
A-1	5.0	427	20.5	6.75	720	570
A-2	12.5	142	12.4	5.43	315	245
A-3	22.5	271	12.9	7.10	598	430

Anions

Well	Cl^-	*HCO_3^-	NO_3^-/N	SiO_2	SO_4^{-2}
A-1	< 2	374	0.093	9.2	15.4
A-2	< 2	132	< 0.04	9.5	11.6
A-3	< 2	312	0.21	12.5	2.75

Cations

Well	Ba^{+2}	Ca^{+2}	Fe^{+2}	K^+	Mg^{+2}	Mn^{+2}	Na^+	NH_4^+
A-1	0.08	155.3	3.1	2.1	9.4	0.5	0.5	2.4
A-2	0.09	49.4	2.2	1.7	4.4	0.2	0.9	11.0
A-3	0.07	97.6	8.2	1.8	6.7	0.2	1.0	14.4

[1]Total hardness as $CaCO_3$
[2]Degrees Celcius
[3]Units = uS
[4]Total dissolved solids
*Alkalinity

Chemical Data for Nest B (mg/L)
Date Sampled: August 16, 1991

Well	Depth of screen	Total[1] Hardness	Temp[2] C	pH	Con[3]	TDS[4]
B-1	5.0	7.48	17.3	4.07	80.0	185
B-2	12.5	153	13.9	6.22	625.0	265
B-3	30.0	319	12.8	6.46	1100.0	410

Anions

Well	Cl^-	*HCO_3^-	NO_3^-/N	SiO_2	SO_4^{-2}
B-1	2.05	0	<0.04	0.26	5.78
B-2	<2	286	<0.04	2.4	0
B-3	<2	535	<0.04	34.0	0

Cations

Well	Ba^{+2}	Ca^{+2}	Fe^{+2}	K^+	Mg^{+2}	Mn^{+2}	Na^+	NH_4^+
B-1	0.02	2.2	1.1	1.8	0.3	0.002	0.6	3.5
B-2	0.09	44.0	7.9	2.0	10.5	0.2	1.4	52.1
B-3	0.20	88.4	22.9	2.4	23.8	0.2	1.9	90.3

[1]Total hardness as $CaCO_3$
[2]Degrees Celcius
[3]Units = uS
[4]Total dissolved solids
*Alkalinity

Chemical Data for Nest C (mg/L)
Date Sampled: August 21, 1991

Well	Depth of screen	Total[1] Hardness	Temp[2] C	pH	Cond[3]	TDS[4]
C-1	7.0	7.82	14,3	4.43	36	130
C-2	12.5	132	14.1	6.50	207	180
C-3	17.0	187	12.0	6.58	345	275

Anions

Well	Cl^-	*HCO_3^-	NO_3^-/N	SiO_2	SO_4^{-2}
C-1	< 2	3.1	< 0.04	5.6	2.93
C-2	< 2	92	0.74	14.0	0.00
C-3	< 2	166	0.088	3.5	2.77

Cations

Well	Ba^{+2}	Ca^{+2}	Fe^{+2}	K^+	Mg^{+2}	Mn^{+2}	Na^+	NH_4^+
C-1	0.008	2.8	1.4	1.0	0.2	0.03	1.1	0.33
C-2	0.08	44.0	7.6	1.7	5.4	0.2	0.9	4.5
C-3	0.07	61.5	6.6	2.0	8.0	0.2	1.0	6.4

[1]Total hardness as $CaCO_3$
[2]Degrees Celcius
[3]Units = uS
[4]Total dissolved solids
*Alkalinity

Chemical Data for Nest D (mg/L)
Date Sampled: August 15, 1991

Well	Depth of screen	Total[1] Hardness	Temp[2] C	pH	Cond[3]	TDS[4]
D-1	5.0	26.1	17.3	4.72	75	215
D-2	12.5	84	13.9	5.38	88	210
D-3	21.0	215	12.6	6.83	344	170

Anions

Well	Cl^-	*HCO_3^-	NO_3^-/N	SiO_2	SO_4^{-2}
D-1	2.37	0.0	< 0.04	4.3	3.20
D-2	2.20	20.8	0.16	8.5	0.00
D-3	< 2	163.0	0.13	6.2	0.00

Cations

Well	Ba^{+2}	Ca^{+2}	Fe^{+2}	K^+	Mg^{+2}	Mn^{+2}	Na^+	NH_4^+
D-1	0.07	8.3	1.8	1.4	1.3	0.1	1.1	2.7
D-2	0.3	14.9	35.1	4.5	11.3	0.4	2.3	6.5
D-3	0.2	64.5	14.5	3.3	13.2	0.4	1.8	4.3

[1]Total hardness as $CaCO_3$
[2]Degrees Celcius
[3]Units = uS
[4]Total dissolved solids
*Alkalinity

Chemical Data for Nest E (mg/L)
Date Sampled: August 27, 1991

Well	Depth of screen	Total[1] Hardness	Temp[2] C	pH	Cond[3]	TDS[4]
E-1	5.0	145	17.7	5.94	137	305
E-2	12.5	2260	14.6	6.50	374	275

			Anions		
Well	Cl^-	*HCO_3^-	NO_3^-/N	SiO_2	SO_4^{-2}
E-1	3.13	46.6	0.13	3.3	3.63
E-2	2.76	173	0.088	5.5	18.4

				Cations				
Well	Ba^{+2}	Ca^{+2}	Fe^{+2}	K^+	Mg^{+2}	Mn^{+2}	Na^+	NH_4^+
E-1	0.5	25.1	51.0	6.7	20.1	1.0	2.6	0.30
E-2	0.2	750.2	103.3	9.1	93.8	3.4	3.2	0.40

[1]Total hardness as $CaCO_3$
[2]Degrees Celcius
[3]Units = uS
[4]Total dissolved solids
*Alkalinity

Chemical Data for Nest F (mg/L)
Date Sampled: August 21, 1991

Well	Depth of screen	Total[1] Hardness	Temp[2] C	pH	Cond[3]	TDS[4]
F-1	5.0	27	20.0	4.39	66	165
F-2	12.5	37	18.0	4.81	95	160
F-3	21.5	545	14.9	6.33	579	370

Anions

Well	Cl^-	*HCO_3^-	NO_3^-/N	SiO_2	SO_4^{-2}
F-1	< 2	35.0	0.13	7.2	0.00
F-2	< 2	32.8	0.00	7.2	3.05
F-3	< 2	302	0.21	12.6	0.00

Cations

Well	Ba^{+2}	Ca^{+2}	Fe^{+2}	K^+	Mg^{+2}	Mn^{+2}	Na^+	NH_4^+
F-1	0.02	5.8	1.0	1.4	3.0	0.03	1.3	0.55
F-2	0.03	12.6	1.5	1.5	1.4	0.08	1.3	1.60
F-3	0.10	213.2	6.2	3.0	9.0	0.40	1.0	6.20

[1]Total hardness as $CaCO_3$
[2]Degrees Celcius
[3]Units = uS
[4]Total dissolved solids
*Alkalinity

Chemical Data for Nest G (mg/L)
Date Sampled: August 21, 1991

Well	TOC[1] (ft)	Depth of Sample(ft)	Temp[2] C	pH	Cond[3]	TDS[4]
G-1	837.78	7.5	20.5	6.04	228	235

					Anions
Well	Cl^-	*HCO_3^-	NO_3^-/N	SiO_2	SO_4^{-2}
G-1	< 2	99.6	0.088	2.9	4.02

						Cations		
Well	Ba^{+2}	Ca^{+2}	Fe^{+2}	K^+	Mg^{+2}	Mn^{+2}	Na^+	NH_4^+
G-1	0.1	46.0	23.6	3.4	10.3	2.0	2.1	0.27

[1]Total hardness as $CaCO_3$
[2]Degrees Celcius
[3]Units = uS
[4]Total dissolved solids
*Alkalinity

Chemical Data for Nest H (mg/L)
Date Sampled: August 20, 1991

Well	Depth of screen	Total[1] Hardness	Temp[2] C	pH	Cond[3]	TDS[4]
H-1	2.5	234	19.7	6.84	438	320
H-2	8.3	218	17.8	5.82	393	285
H-3	16.5	103	15.4	6.24	240	190

			Anions		
Well	Cl^-	*HCO_3^-	NO_3^-/N	SiO_2	SO_4^{-2}
H-1	2.69	212	0.18	9.6	3.61
H-2	2.82	192	0.088	9.3	3.05
H-3	< 2	116	0.075	5.7	3.08

				Cations				
Well	Ba^{+2}	Ca^{+2}	Fe^{+2}	K^+	Mg^{+2}	Mn^{+2}	Na^+	NH_4^+
H-1	0.06	70.1	6.0	1.7	14.3	1.0	2.1	0.62
H-2	0.07	63.7	3.5	1.7	14.4	0.7	2.5	0.84
H-3	0.06	29.7	8.1	1.9	7.0	0.4	2.6	2.20

[1]Total hardness as $CaCO_3$
[2]Degrees Celcius
[3]Units = uS
[4]Total dissolved solids
*Alkalinity

Chemical Data for Nest H (mg/L)
Date Sampled: August 20, 1991

Well	Depth of screen	Total[1] Hardness	Temp[2] C	pH	Cond[3]	TDS[4]
H-1	2.5	234	19.7	6.84	438	320
H-2	8.3	218	17.8	5.82	393	285
H-3	16.5	103	15.4	6.24	240	190

Anions

Well	Cl^-	*HCO_3^-	NO_3^-/N	SiO_2	SO_4^{-2}
H-1	2.69	212	0.18	9.6	3.61
H-2	2.82	192	0.088	9.3	3.05
H-3	< 2	116	0.075	5.7	3.08

Cations

Well	Ba^{+2}	Ca^{+2}	Fe^{+2}	K^+	Mg^{+2}	Mn^{+2}	Na^+	NH_4^+
H-1	0.06	70.1	6.0	1.7	14.3	1.0	2.1	0.62
H-2	0.07	63.7	3.5	1.7	14.4	0.7	2.5	0.84
H-3	0.06	29.7	8.1	1.9	7.0	0.4	2.6	2.20

[1]Total hardness as $CaCO_3$
[2]Degrees Celcius
[3]Units = uS
[4]Total dissolved solids
*Alkalinity

Chemical Data for Nest I (mg/L)
Date Sampled: August 21, 1991

Well	Depth of screen	Total Hardness	Temp[2] C	pH	Cond[3]	TDS[4]
I-1	5.0	300	18.8	6.00	327	250
I-2	10.0	320	14.8	5.38	157	390
I-3	20.0	703	11.8	6.70	353	240

			Anions		
Well	Cl^-	*HCO_3^-	NO_3^-/N	SiO_2	SO_4^{-2}
I-1	3.0	148	0.088	4.6	0.00
I-2	3.3	48	0.058	5.6	4.51
I-3	2.8	160	0.000	5.4	7.20

				Cations				
Well	Ba^{+2}	Ca^{+2}	Fe^{+2}	K^+	Mg^{+2}	Mn^{+2}	Na^+	NH_4^+
I-1	0.9	64.1	70.0	5.8	34.1	2.4	2.6	4.8
I-2	1.5	62.2	95.4	8.4	40.0	1.2	2.8	1.6
I-3	0.1	162.9	35.2	6.8	72.1	0.9	2.5	1.3

[1]Total hardness as $CaCO_3$
[2]Degrees Celcius
[3]Units = uS
[4]Total dissolved solids
*Alkalinity

Chemical Data for Nest J (mg/L)
Date Sampled: August 27, 1991

Well	Depth of screen	Total[1] Hardness	Temp[2] C	pH	Cond[3]	TDS[4]
J-1	6.5	242	20.3	6.50	402	295
J-2	10.0	641	17.4	6.00	366	335
J-3	16.0	522	14.9	6.73	600	370

Anions

Well	Cl^-	*HCO_3^-	NO_3^-/N	SiO_2	SO_4^{-2}
J-1	2.79	195	0.14	3.2	0.00
J-2	2.48	175	0.18	5.6	0.00
J-3	2.61	302	0.075	4.4	2.97

Cations

Well	Ba^{+2}	Ca^{+2}	Fe^{+2}	K^+	Mg^{+2}	Mn^{+2}	Na^+	NH_4^+
J-1	0.20	69.3	10.2	5.7	16.9	0.5	3.4	2.8
J-2	0.10	176.6	23.6	4.7	48.7	0.4	2.9	2.4
J-3	0.08	150.1	19.4	3.8	35.8	0.6	3.2	1.1

[1]Total hardness as $CaCO_3$
[2]Degrees Celcius
[3]Units = uS
[4]Total dissolved solids
*Alkalinity

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