

TEST FOR CONTAMINATION OF WATER AT WELL 103,
SOUTH WELL FIELD, COLUMBUS, OHIO

By

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ABSTRACT

The City of Columbus, Ohio is currently developing a glacial aquifer as a source of water for municipal use. Three radial collectors well have been emplaced in the aquifer along the Scioto River; one has been emplaced in the aquifer along Big Walnut Creek. This study determines whether continuous pumping of one well, Well 103, will result in contamination of the glacial aquifer with highly mineralized water from the underlying carbonate aquifer.

Chemical analyses of water collected from the glacial aquifer indicate that contamination has not occurred at Well 103. The parameters measured varied insignificantly throughout the 113 days (October 6, 1983 to January 27, 1984) of this study. Calcium averaged 103.8 mg/l. Magnesium averaged 38.0 mg/l which is below the limit of 125 mg/l placed on drinking water by the U.S. EPA (1975). However, hydrogen sulfide appeared in the glacial aquifer in December with an average concentration of 1.15 mg/l. The sulfide concentration is above the limit of 0.05 mg/l placed on drinking water by the U.S. EPA (1975). Continued monitoring of the other parameters may show a gradual increase if the sulfide is an indication of interaction between the glacial and carbonate aquifer.

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INTRODUCTION

Continental glaciation during the Pleistocene epoch left behind a fairly complex system of glacial deposits in central Ohio. In south-central Franklin County, glacial outwash, composed of sand and gravel deposited during the Wisconsin stage of glaciation, constitutes an unconfined aquifer. Schmidt (1958) recognized the aquifer as the best source of groundwater in Franklin County. The City of Columbus is currently developing this aquifer as a source of water for municipal use. Three radial collector wells were emplaced in the outwash along the east bank of the Scioto River; one was emplaced in the outwash along the west bank of Big Walnut Creek. However, there is concern that, once continuous pumping of the wells begins, highly mineralized water will be drawn up from the underlying bedrock aquifer and mix with the water from the outwash aquifer. The presence of contaminants in the water recovered from the outwash aquifer could increase the costs of purification to such an extent that recovery of water from the new well field could become uneconomical.

PURPOSE

Garner (1983) analyzed the geochemical and hydrogeological relationship between the glacial and bedrock aquifer at the "South Well Field". In his study water samples collected for analysis came from observation wells that were pumped dry within two hours and then allowed to recharge. Garner concluded that there was upward movement of bedrock water into the glacial aquifer at Well 101 and Well 104. He did not detect bedrock water at Well 103.

This present study tests Garner's hypothesis that bedrock water is absent at Well 103.

The purpose of this study is to determine whether continuous pumping of Well 103 has caused contamination of the glacial aquifer with the bedrock water. Changes in water quality at Well 103 were used as the criteria for detecting contamination.

GEOLOGY OF WELL 103

The geology of south-central Franklin County consists of consolidated sedimentary rocks of late Silurian and Devonian age overlain by unconsolidated glacial deposits from the Wisconsinan stage of the Pleistocene epoch.

Well 103 is located along the east bank of the Scioto River in the western half of the "South Well Field" (Fig. 1). Well 103 is in an area where the surface material is made of kame and esker deposits (Fig. 2). The kame and esker deposits are well sorted and stratified, and are primarily composed of sand and coarse gravel with minor amounts of silt and clay (Garner, 1983). These deposits appear as mounds and ridges that rise above the surrounding ground moraine. Beneath the surficial deposits there is a thick sequence of glacial outwash that contains discontinuous layers of till near the base of the outwash. The glacial outwash deposits are predominately coarse sand and fine-to coarse gravel. There are also lenses of clay, silt, and silty gravel. The upper outwash at Well 103 is generally coarser and cleaner than the lower outwash (Ranney, 1981). The reason for the difference may be that the outwash was deposited by at least two substages

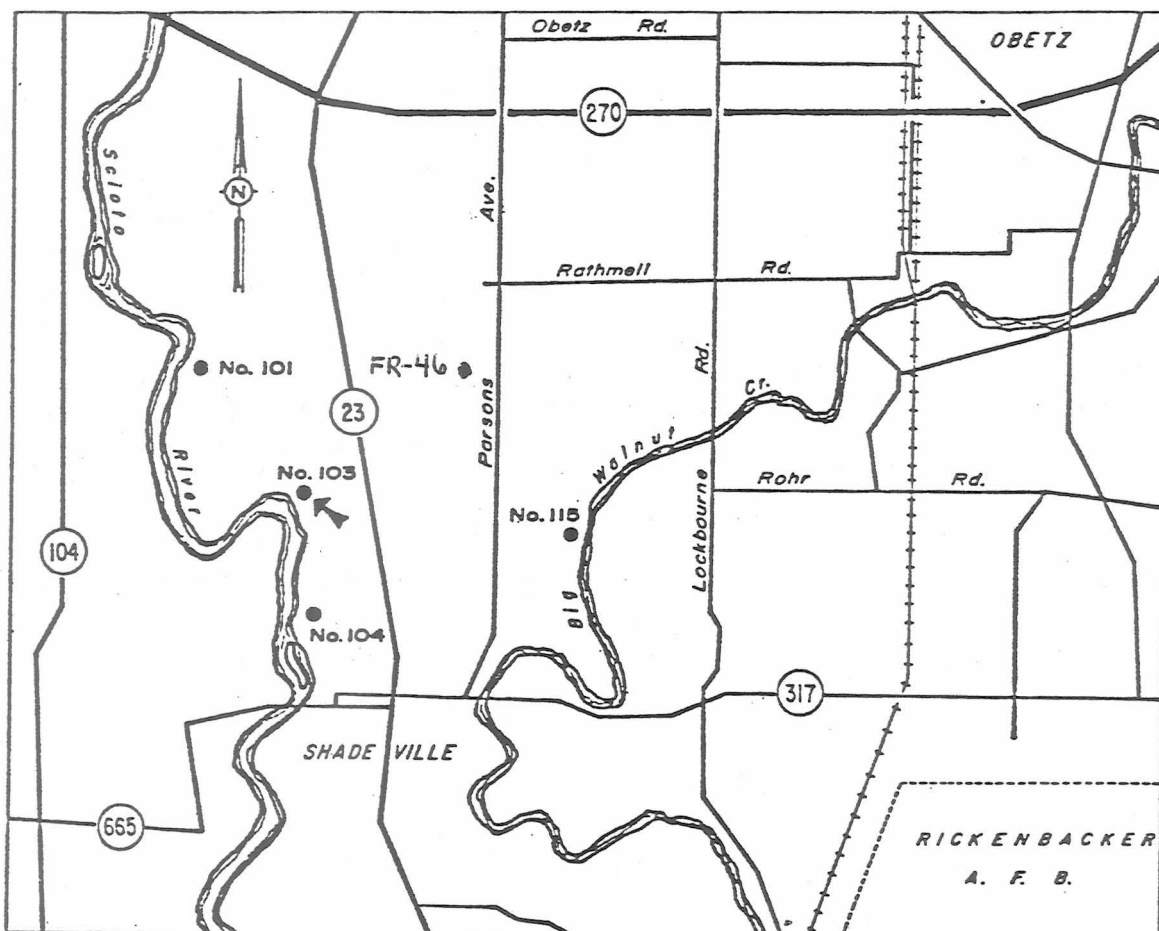


FIGURE 1. Map of "South Well Field" area showing location of Well 103. Also shows location of Well 101, Well 104, and FR-46 (Ranney, 1981)

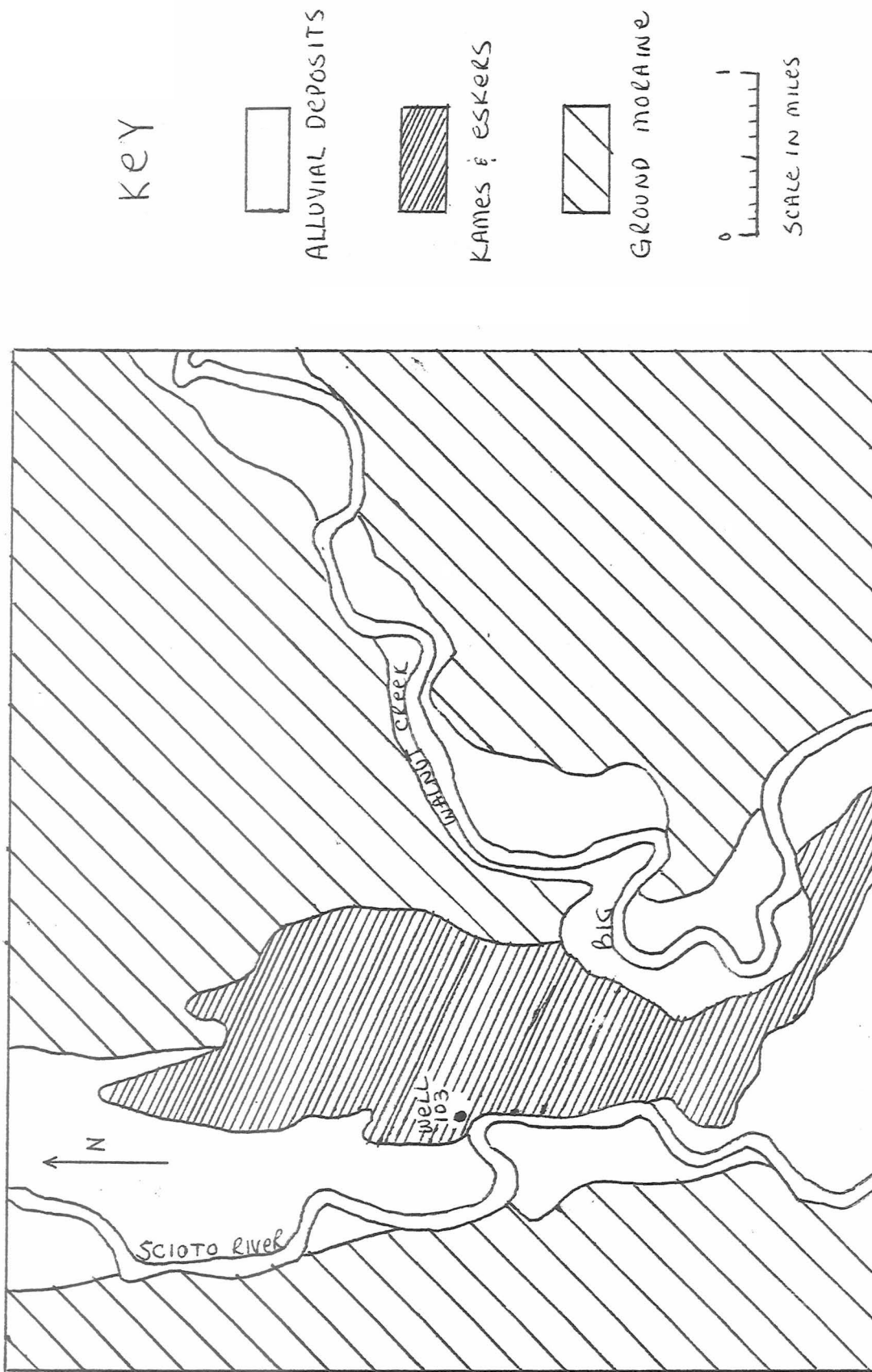


FIG. 2. Area distribution of unconsolidated deposits at the "South Well Field" (Schmidt, 1958)

of Wisconsinan glaciation (Kempton and Goldthwait, 1959). The thickness of the unconsolidated deposits at Well 103 range from 100 to 113 feet (Ranney, 1981). The results of a test hole drilled by Ranney in 1974 at the site of the main caisson of Well 103 is shown in Figure 3.

The bedrock at Well 103 is composed of Silurian limestones and dolomites and Devonian limestones. The clay encountered by Ranney (Fig. 3) may be from Devonian shale or from a glacial till first deposited over the limestones. Stauffer et al. (1911) suggested that the bedrock was originally deposited as sediment in a shallow inland sea during the Mid-Paleozoic Era, and was later uplifted and tilted by the tectonic activity that formed the Cincinnati arch.

The clay encountered by Ranney at Well 103 is gray-to blue-gray and has fine gravel and coarse sand intermixed (Ranney, 1981). The unit underlying the clay is the Delaware Limestone of Middle Devonian age. The Delaware Limestone grades upward from a thin-bedded, blue-gray limestone with thin shaly layers into a fairly dense and massive limestone. The Delaware Limestone is only a fair to poor source of groundwater because of the low porosity caused by its small grain size and argillaceous composition (Schmidt, 1958). The Columbus Limestone of Early Devonian age, which underlies the Delaware Limestone, consists of a massive, light bluish-gray limestone containing 81 to 93 percent calcium carbonate. The Columbus Limestone is recognized as a fairly good source of groundwater because of its high intergranular porosity and multiple joint systems (Schmidt, 1958).

FIGURE 3

(From Ranney, 1981)

RESULT OF TEST HOLE DRILLED AT SITE OF WELL 103

Depth Below Land Surface (feet)	Formation
0 - 5	Sandy soil
5 - 20	Medium to coarse sand 30%, fine gravel
20 - 36	Medium to coarse sand 30%, fine to med. gravel, scattered cobbles > 10%
36 - 65	Coarse sand > 20%, fine to med. gravel, cobbles > 10%
65 - 69	Fine sand 30%, med. to coarse sand, fine gravel 20% scattered boulders
69 - 76	Fine to med. gravel, coarse sand > 10%
76 - 82	Medium to coarse sand 20%, fine gravel, cobbles > 10%
82 - 90	Medium to coarse sand 20%, fine to med. gravel
90 - 97	Medium to coarse sand 30%, fine gravel
97 - 113	Medium to coarse sand 30%, fine to med. gravel
113	Gray clay - coarse sand intermixed

The Columbus Limestone disconformably overlies the Bass Island Group of Late Silurian age. The Bass Island Group is a brown, crystalline-to granular, argillaceous dolomite (Norris and Fidler, 1971). The Bass Island Group is the best source of groundwater within the carbonate aquifer because of its extremely well developed secondary porosity resulting from mineral dissolution along joints, fractures, bedding planes, and intergranular openings (Norris and Fidler, 1973). The next oldest unit at Well 103 is the Lockport Dolomite of Middle Silurian age. This formation is a light gray-to white coarsely crystalline dolomite (Norris and Fidler, 1973). The upper portion of the Lockport Dolomite provides good groundwater supplies. The areal distribution of the bedrock at the "South Well Field" is shown in Figure 4. This figure indicates that the Devonian Shales are absent at Well 103. Thus, the clay encountered above the bedrock is a till deposited on the limestones.

SAMPLING PROCEDURES

The sampling of groundwater at Well 103 began on October 6, 1983 and continued until January 27, 1984. Pumping of the well was conducted once a week, eight hours each time, until December 23, 1983. Samples were taken only after the well was pumped for a considerable time (usually after three hours) because the water was then representative of the aquifer. The quality of water standing in an unused well generally does not reflect the quality of water in the aquifer (Wood, 1976). Changes in temperature and

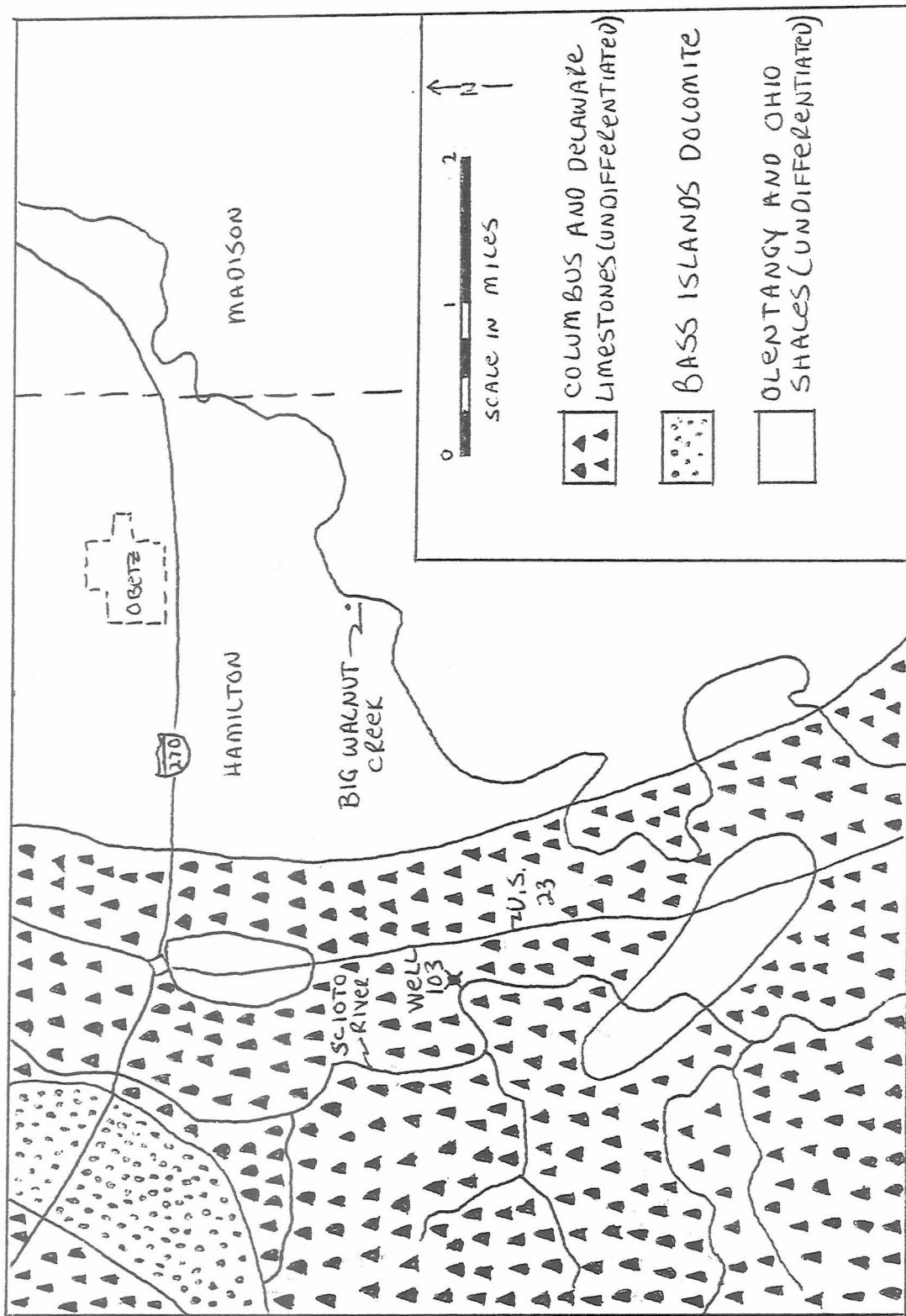


FIG. 4. The areal distribution of the bedrock at the "South Well Field". (Schmidt, 1958)

pH, along with changes in rates of oxidation and volatilization occur in standing water which alter its composition. From December 23, 1983 until January 27, 1984, Well 103 was pumped continuously. Recognition of bedrock water entering the glacial aquifer will be indicated by changes in the chemical composition of water when the well was pumped continuously. Sampling of the water on January 27, 1984 was done at three fifteen minute intervals one hour after pumping was stopped. This procedure allowed collection of representative samples of water as the aquifer recharged. Water samples were collected directly from the caisson. Sampling was done at a depth of 80 feet because the collector bottle would have been sucked into the pumps at a lower depth. A cross section of the caisson is shown in Figure 5. Once collected, the water samples were analyzed at the facilities of the Dublin Road Water Plant, in Columbus.

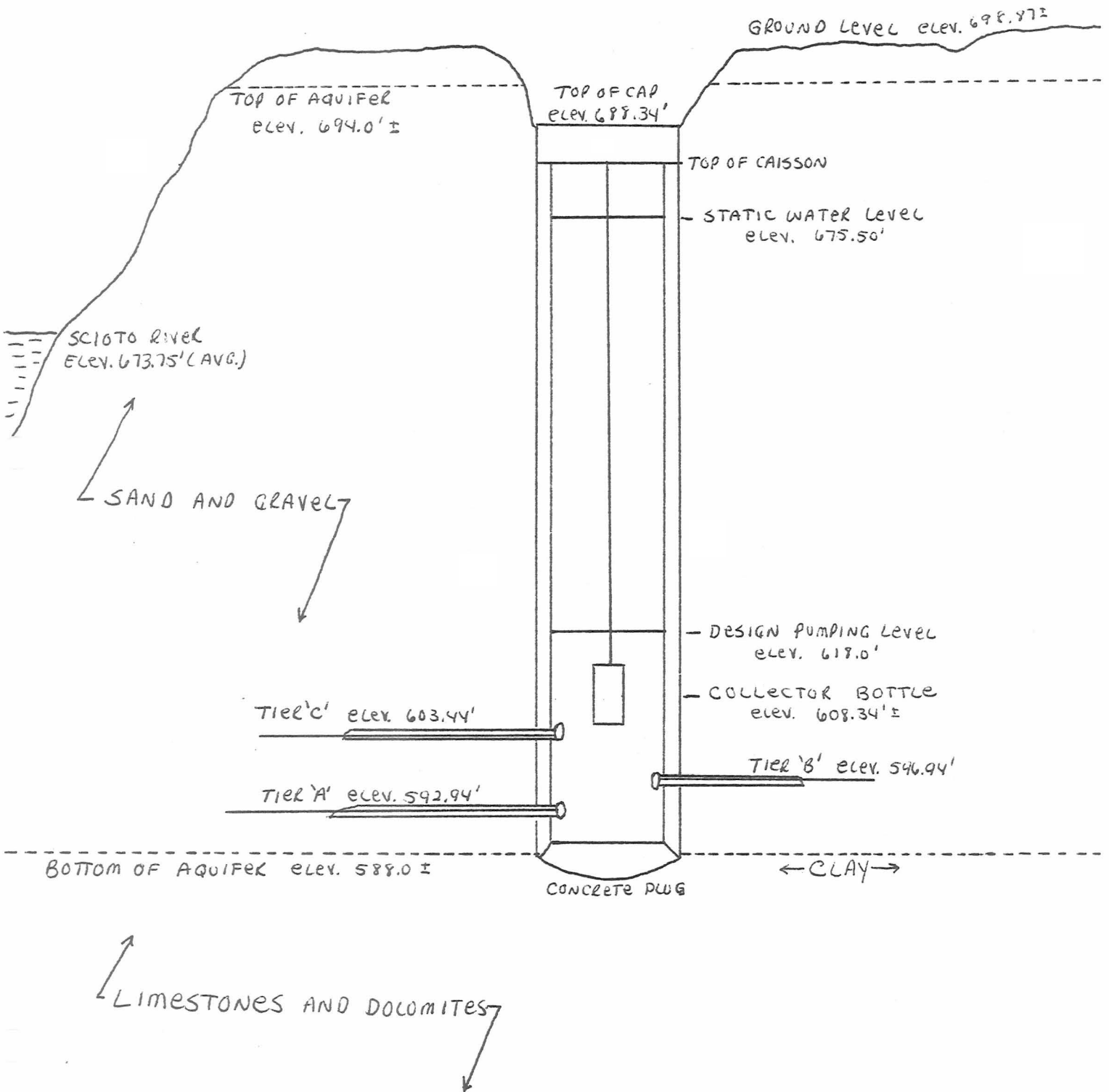
ANALYTICAL METHODS

Two different samples of water were collected at each sampling. Each sample was tested for the same parameters and the average value was taken as the result. The parameters measured were the concentrations of calcium, magnesium, chloride, sulfide, alkalinity, total hardness, noncarbonate hardness, pH, and specific conductivity.

Calcium and Magnesium

Calcium and magnesium concentrations are the two most important parameters for this study because they occur abundantly in water

FIG. 5. Section view of radial collector well at Site 103 (Ranney, 1981)



from the limestone aquifer. An increase in the concentrations of calcium and magnesium in the water recovered in the well would indicate mixing of the glacial aquifer with water from the bedrock aquifer. Calcium concentration was determined by EDTA titration. All groundwater samples were prepared for calcium titration by diluting a 10 ml aliquot with 40 ml of deionized water. The dilution was necessary to suppress the precipitation of calcium carbonate after the addition of a base raised the pH of the solution to above 12. The endpoint was identified by a change in color from red to blue. Murexide was used as the indicator. The concentration of calcium in milligrams per liter was calculated using the following equation:

$$\text{Calcium (mg/l)} = \frac{(A) (400.8 \text{ mg/l})}{B}$$

A = milliliters of titrant

B = milliliters of sample

400.8 mg(Ca)/l = 0.0100 M EDTA

The concentration of magnesium in milligrams per liter was calculated at a pH above 12 by using the following equation:

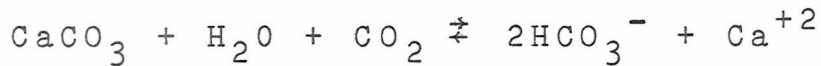
$$\text{Magnesium (mg/l)} = \frac{(A)(243 \text{ mg/l})}{(B)}$$

A = difference between volume of titrant used in Total Hardness titration and that used in the Calcium titration

B = milliliters of sample

Alkalinity

Alkalinity is primarily a measurement of carbonate, bicarbonate, and hydroxide content in the water (Standard Methods, 1981). Since the pH of the water samples ranged from 7.14 to 7.20, the bicarbonate ion (HCO_3^-) predominated in the water. The bicarbonate ion occurs in solutions in contact with limestone by the following reaction:



Thus an increase in the alkalinity of the samples (represented by the bicarbonate ion) may also indicate the presence of water from the limestone aquifer. The alkalinity of the samples was determined by titration with EDTA. The samples were prepared for titration by diluting a 10 ml aliquot with 90 ml of deionized water. A pH of 4.5 indicated endpoint by a change in color from a greenish blue to a clear pink. A mixed bromcresol green-methyl red indicator was used. The alkalinity in milligrams per liter was calculated using the following equation:

$$\text{Alkalinity (mg/l)} = \frac{(A)(1000 \text{ mg/l})}{(B)}$$

A = milliliters of titrant

B = milliliters of sample

Specific Conductivity

Conductivity is a numerical expression of the ability of an aqueous solution to carry an electric current (Standard Methods, 1981). This property depends on the total and relative concentrations of ions along with the mobility and the valence of the ions. Solutions of most inorganic acids, bases, and salts

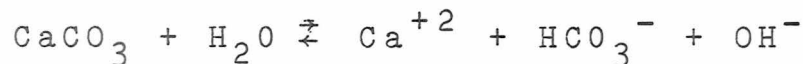
are relatively good electrical conductors. Conductivity is expressed in micromhos per centimeter ($\mu\text{mhos/cm}$). An increase in conductivity of the samples may indicate mixing because the bedrock aquifer contains a higher concentration of ions. The conductivity was measured directly by means of a conductivity probe.

pH

The pH is a very important parameter in water chemistry. The pH indicates the intensity of the acidic or basic character of a solution. Many chemical reactions that take place in groundwater are dependent on pH. The pH is expressed by the following equation:

$$\text{pH} = -\log (\text{H}^+)$$

where (H^+) is the hydrogen ion activity in moles/liter. An increase in the pH of the samples may indicate contamination because the bedrock aquifer has a higher concentration of the hydroxyl ion (OH^-) which makes the solution more basic. The following equation expresses the reaction that produces the hydroxyl ion:



The pH was determined by means of a pH meter using an electrode sensitive to H^+ .

Total Hardness

Hardness is a direct measure of the concentrations of calcium and magnesium salts in solution: bicarbonates, carbonates, sulfates,

chlorides, and infrequently nitrates (Schmidt, 1958). Hardness is also a measure of the concentrations of iron, manganese, and aluminum salts in solution (Schmidt, 1958). Bedrock water in a limestone aquifer can contain high levels of bicarbonates, carbonates, and sulfates in solution. Thus, an increase in total hardness in the water of the glacial aquifer may indicate that mixing with bedrock water is occurring. Total hardness was determined by EDTA titration. The samples were prepared for titration by diluting a 10 ml aliquot with 40 ml of deionized water. The endpoint was indicated by a change in color from a purple to a clear blue. Eriochrome Black T was used as the indicator. Total hardness in milligrams per liter was calculated using the following equation:

$$\text{Total Hardness (mg/l)} = \frac{(A) (1000 \text{ mg/l})}{(B)}$$

A = milliliters of titrant

B = milliliters of sample

Noncarbonate Hardness

Noncarbonate hardness occurs in groundwater as calcium sulfate or calcium chloride, which remains soluble when the water is heated and must be precipitated as carbonates by treatment with anhydrous sodium carbonate (Schmidt, 1958). High levels of noncarbonate hardness require higher costs in treatment. Also, noncarbonate hardness is highly corrosive to metal pipes and pumps. Noncarbonate hardness in milligrams per liter was calculated using the following equation:

$$\text{Noncarbonate Hardness (mg/l)} = \frac{(A) (1000 \text{ mg/l})}{(B)}$$

A = difference between volume of titrant used in Total Hardness titration and that used in the Alkalinity titration in milliliters

B = milliliters of sample

Chloride

The chloride concentration has little effect on the suitability of water for ordinary use, unless present in such high concentrations as to make the water impotable (Schmidt, 1958). Excessive amounts of chloride in water along with calcium, magnesium, and iron add to the noncarbonate hardness and are highly corrosive. Chloride concentration was determined by EDTA titration. The amount of sample titrated was 50 ml. The endpoint was indicated by a change in color from a clear yellow to a pinkish yellow. Potassium chromate was used as the indicator. Prior to titration, a blank consisting of 50 ml of deionized water was analyzed to determine the necessary blank correction. Chloride concentration in milligrams per liter was calculated using the following equation:

$$\text{Chloride (mg/l)} = \frac{(A - C) (500 \text{ mg/l})}{(B)}$$

A = milliliters of titrant

B = milliliters of sample

C = milliliters of titration for blank

Sulfide

Sulfur can exist in groundwater as sulfide, originating from

contact with pyrite and other sulfur-bearing minerals, or from the reduction of sulfate in the water by bacterial action (Schmidt, 1958). Thus, sulfides can only exist in low-oxygen reducing environments. The bedrock aquifer at the "South Well Field" represents a reducing environment because of the lack of water circulation. Sulfide probably does not exist in the glacial aquifer because of the highly oxygenating conditions there. Sulfide in the bedrock aquifer at Well 103 exists as hydrogen sulfide gas (H_2S). Any detection of hydrogen sulfide in the glacial aquifer would indicate some kind of interaction with the bedrock aquifer. Sulfide levels were not originally considered an important parameter for this study because Garner (1983) stated that he detected no sulfide in the water at Well 103. The decision to measure sulfide levels came after a "rotten egg" odor of hydrogen sulfide was noticed at the well site in December of 1983. Sulfide levels were determined colorimetrically with a La Mott Sulfide Test Kit. Basically, the principle of the method involves a reaction between paramindimethylani-line, ferric chloride, and sulfide ion, which results in the formation of methylene blue. Sulfide concentration is expressed in milligrams per liter.

RESULTS

The results of the water analyses at Well 103 are presented in Table 1. The only significant change observed in the water over the testing period was the appearance of hydrogen sulfide in the water.

TABLE 1

CHEMICAL RESULTS FROM ANALYSES OF WATER SAMPLES FROM WELL 103

Date	pH	Conductivity (Mhos/cm)	Total Hardness (mg/l)	Alkalinity (mg/l)	Noncarbonate Hardness (mg/l)	Calcium (mg/l)	Magnesium (mg/l)	Chloride (mg/l)	Sulfide (mg/l)
10/6/83	7.15	695	410	335	75	104	36.5	33.5	--
10/12/83	7.14	740	415	330	85	103	38.3	34	--
11/3/83	7.15	--	420	320	100	104	38.9	34	--
11/18/83	7.20	--	415	310	105	106	35	34	--
1/13/84	7.15	677.5	412	316.5	95.5	100	39.4	39.3	1.4
1/20/84	7.15	667.5	417.5	328	89.5	105.2	37.5	40	0.9
1/27/84 2:00 pm	7.18	715	420	330	90	108	36.5	39	--
2:15 pm	7.18	710	420	337.5	82.5	104	38.9	37.5	--
2:30 pm	7.17	720	420	335	85	100	41.3	37.5	--

The sulfide level ranged from 0.9-1.4 mg/l with an average of 1.15 mg/l. This average is above the limit of 0.05 mg/l placed on drinking water by the U.S. EPA (1975). The concentration of calcium ranged from 100-108 mg/l with an average of 103.8 mg/l. The magnesium concentration ranged from 35-41.3 mg/l with an average of 36.5 mg/l. This average is well below the limit of 125 mg/l placed on drinking water by the U.S. EPA (1975). The results of the three previous parameters are graphed versus time in Figure 6.

The total hardness ranged from 410-420 mg/l with an average of 416.6 mg/l. The noncarbonate hardness ranged from 75-105 mg/l with an average of 89.7 mg/l. The chloride concentration ranged from 33.5-40 mg/l with an average of 36.5 mg/l. This average is also well below the limit of 125 mg/l placed on drinking water by the U.S. EPA (1975). The results of the total and noncarbonate hardness along with the chloride concentration are graphed versus time in Figure 7.

The conductivity of the water ranged from 667.5-740 μ mhos/cm with an average of 703.5 μ mhos/cm. The pH ranged from 7.14-7.20 with an average of 7.16. The alkalinity ranged from 310-337.5 mg/l with an average of 326.8 mg/l. The results of the alkalinity, conductivity, and the pH are graphed versus time in Figure 8.

DISCUSSION OF RESULTS

All of the parameters, except for sulfide, varied insignificantly during the study. The slight variations in water quality could be attributed to natural inhomogeneities in the composition

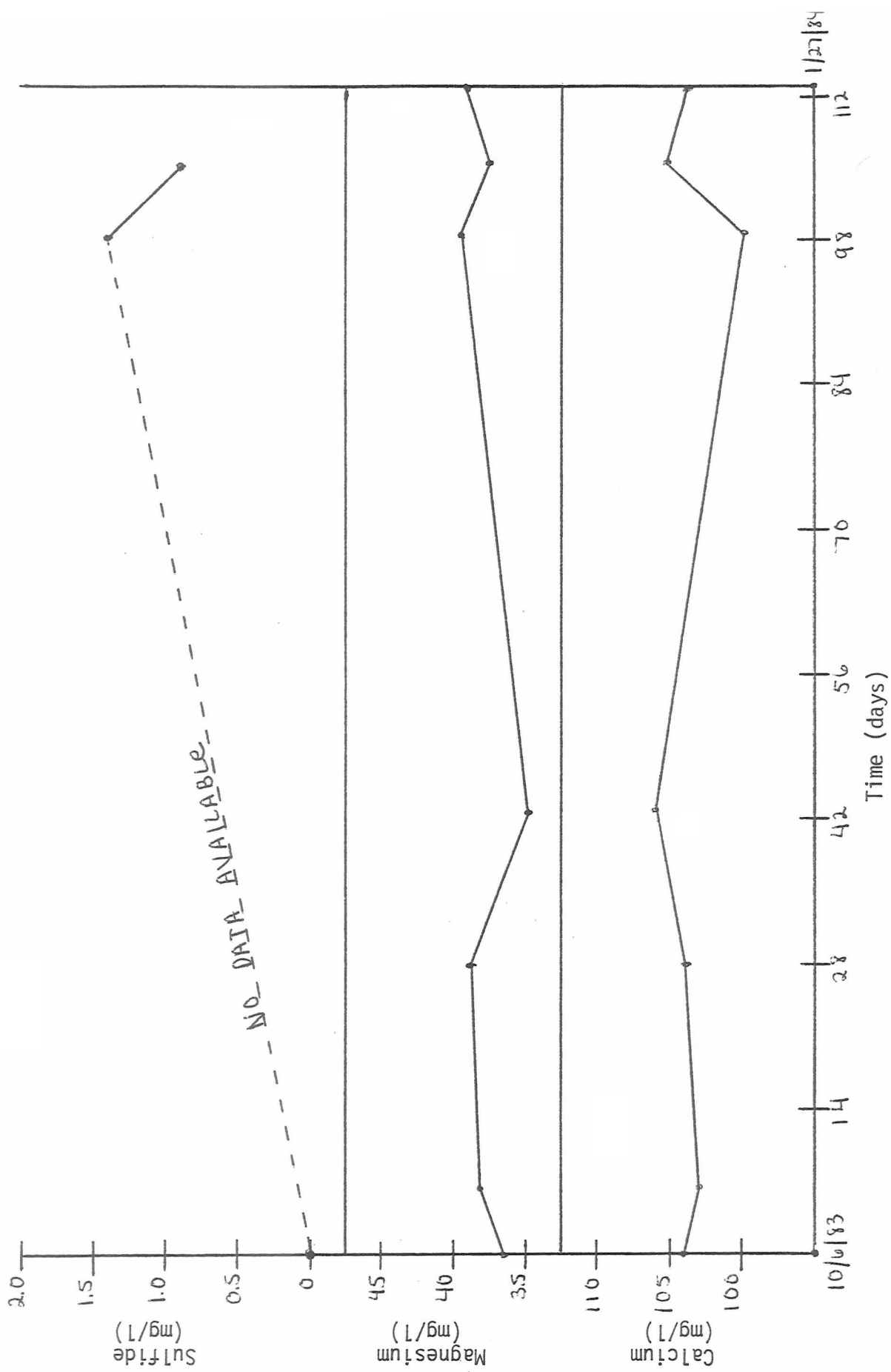


FIGURE 6. Plot of variations with time of the calcium, magnesium, and sulfide concentrations of water from Well 103 using the data from Table 1.

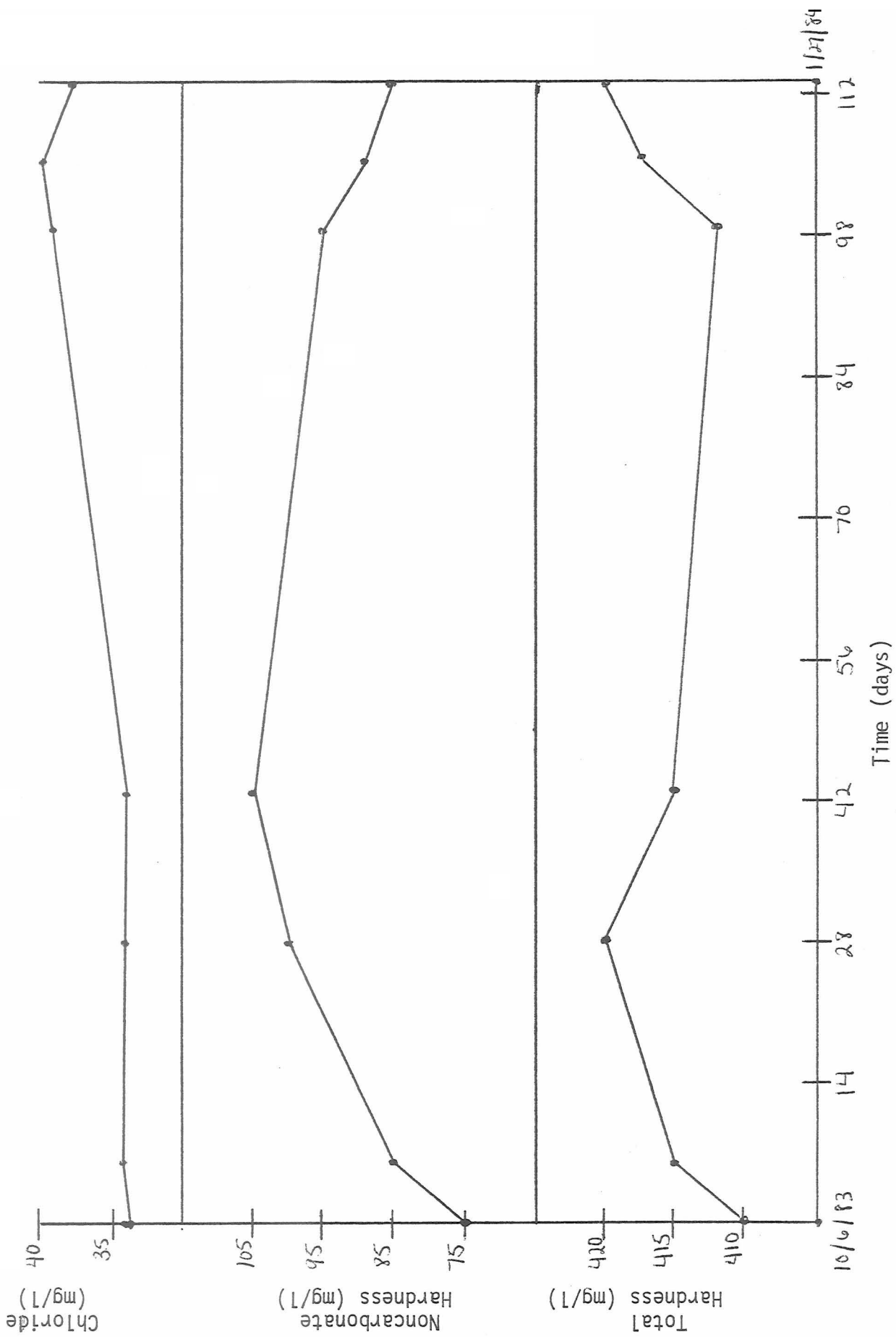


FIGURE 7. Plot of variations with time of the total hardness, the noncarbonate hardness, and the chloride concentration of water from Well 103 using the data from Table 1.

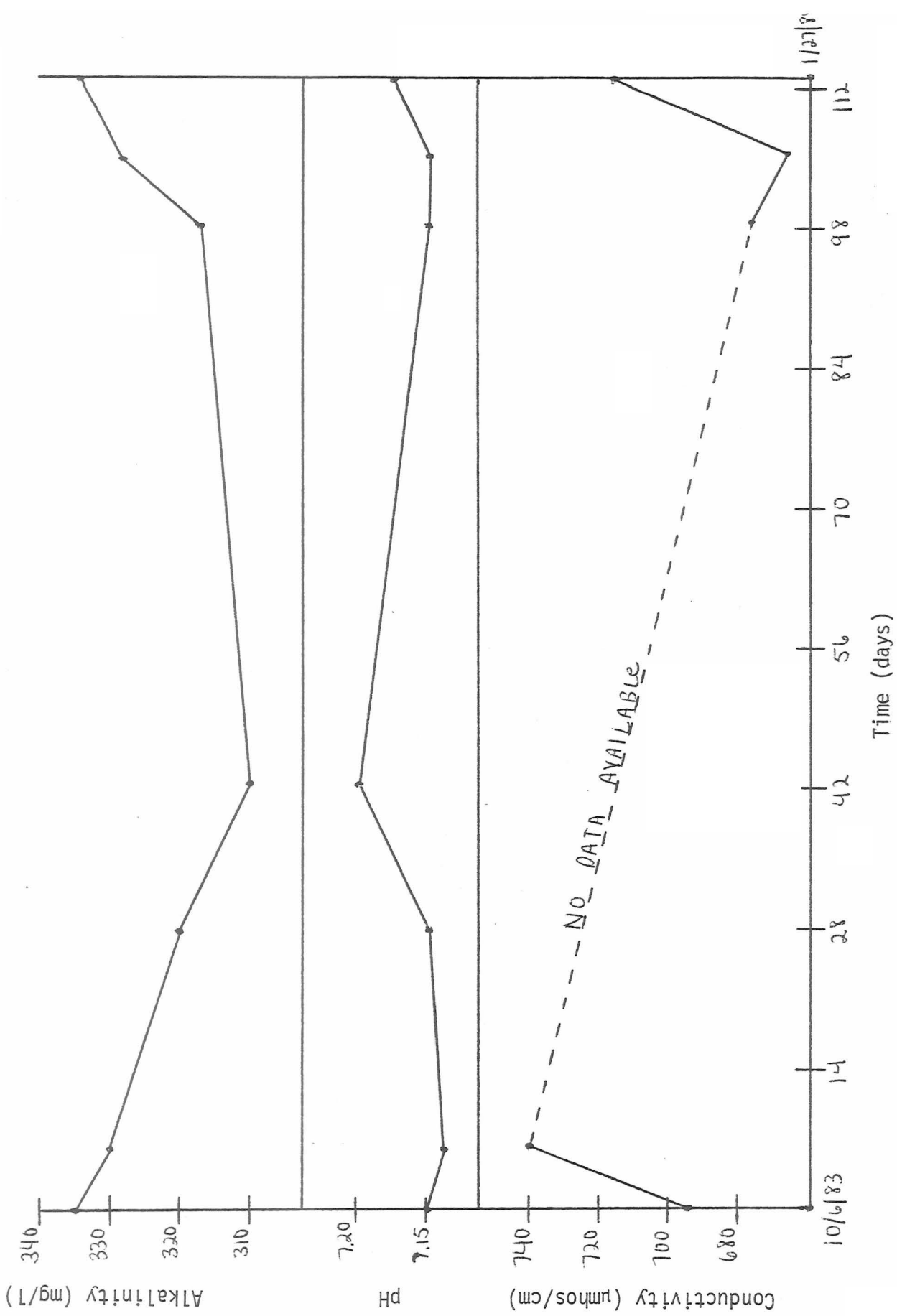


FIGURE 8. Plot of variations with time of the conductivity, the pH, and the alkalinity of water from Well 103 using the data from Table 1.

of the groundwater and to analytical uncertainties. The only significant change observed after continuous pumping began was the appearance of sulfide.

The presence of sulfide is not conclusive evidence of mixing between the glacial and bedrock aquifers because the sulfide concentrations were measured only for the last few weeks of this study. The hydrogen sulfide gas may have been trapped in a fracture zone in the limestone and was outgassed into the glacial aquifer as the overlying pressure of the glacial aquifer was lessened when continuous pumping began. Although the presence of sulfide may be temporary, the problem may reoccur because new fracture zones containing trapped hydrogen sulfide may be unsealed after additional pumping of the glacial aquifer. Therefore, a definite conclusion about the recurrence of hydrogen sulfide in the glacial water after full-scale pumping begins cannot be made at this time.

Garner (1983) constructed correlation diagrams in order to determine whether the water from the glacial aquifer at Well 101 (Fig. 1) and Well 104 (Fig. 1) was mixing with bedrock water. He constructed a mixing line by plotting concentrations of different ions in bedrock water versus water from the glacial aquifer. He chose Well FR-46 (Fig. 1) to represent uncontaminated water from the glacial aquifer because it is separated from the bedrock aquifer by the Ohio and Olentangy Shales at that locality. In addition, the well only extends into the upper part of the glacial aquifer where mixing is less likely. He chose Well BR-101 to represent the bedrock water because it extends into the bedrock and the water had the

highest concentrations of ions of any he sampled. A scale has been drawn on the mixing line of each diagram to indicate the volume percent of bedrock water that is present in a particular mixture. If mixing has occurred in a given water mass, the mixing proportions should be the same on each diagram regardless of which two constituents are plotted.

Two element-element correlation diagrams were constructed for Well 103. The mixing line determined by Garner was used in the diagrams. Data from this study were plotted on the diagrams to determine what percentage of bedrock water was present in the glacial aquifer. . A calcium-magnesium correlation diagram is presented in Figure 9. According to the distribution of data points from this study, the water at Well 103 is typical of water from the glacial aquifer and mixing with the bedrock water has not occurred. The points all plot within a small area around the endpoint of the glacial water (FR-46). Since a water mass is not necessarily homogeneous in its chemical composition, the average concentration can be used to represent it on the mixing diagram. The results of this correlation indicate that the composition of water at Well 103 is similar to the uncontaminated water at Well FR-46.

A calcium-chloride correlation diagram is shown in Figure 10. The data from this study plot above the mixing line drawn by Garner (1983). This distribution indicates slight contamination of the water from the glacial aquifer with chloride ions. Since these points form a vertical line if connected, the presence of a third mixing component containing higher concentrations of chloride

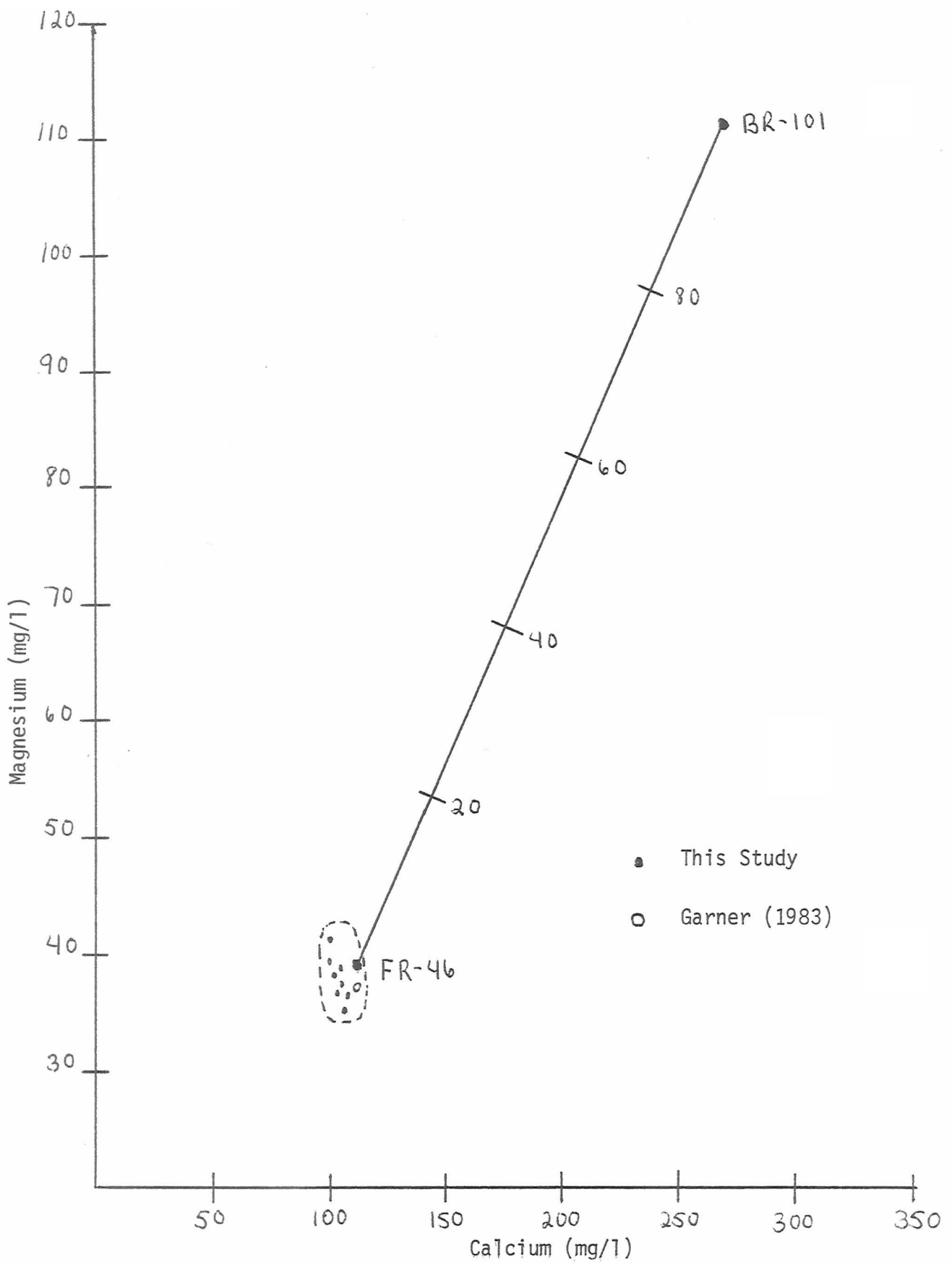


FIGURE 9. Calcium-magnesium correlation diagram for Well 103 using the data from Table 1. All points plot around Well FR-46 which indicates that water composition at Well 103 is similar to uncontaminated water at Well FR-46. Well BR-101 represents the contaminated bedrock water.

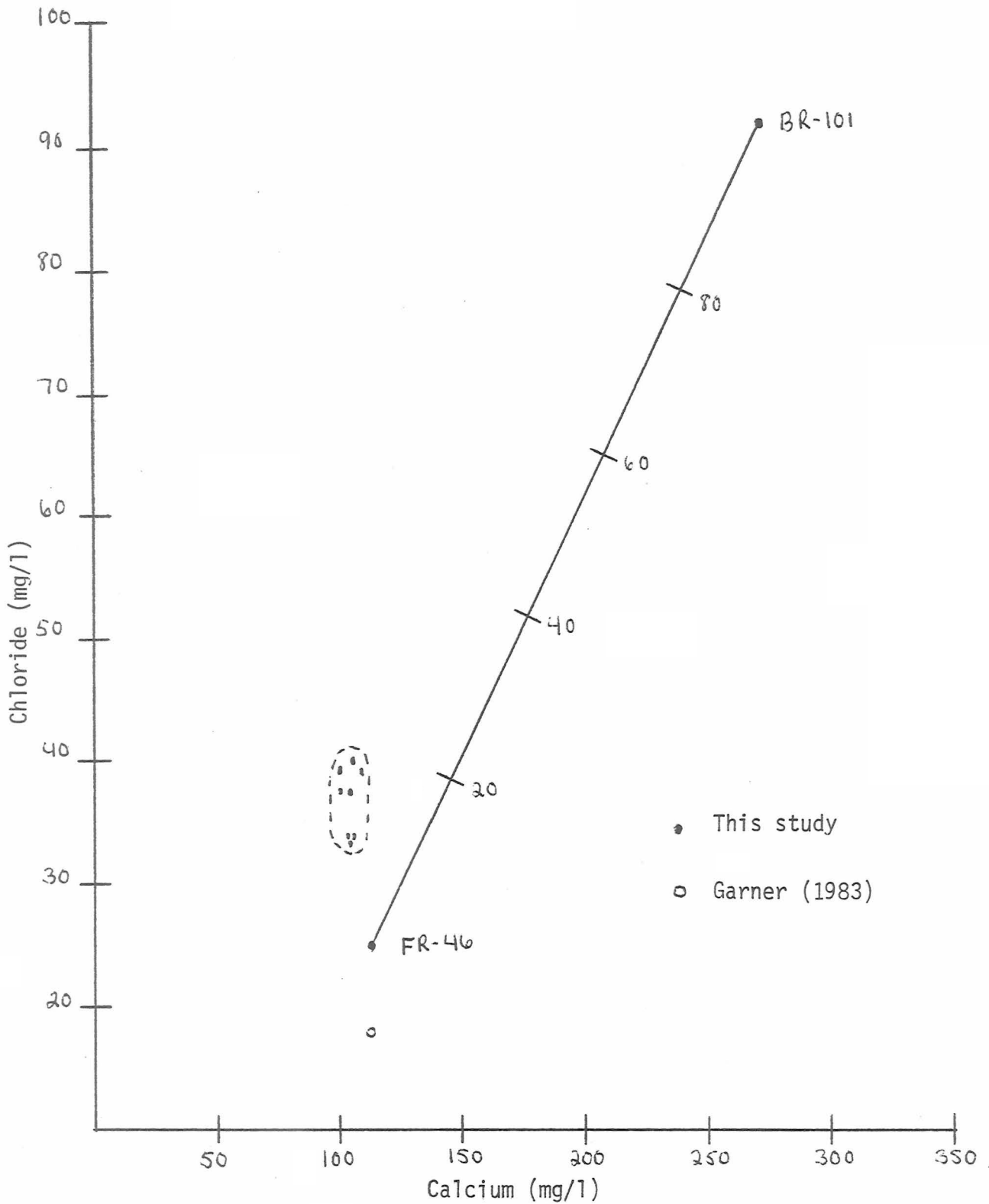


FIGURE 10. Calcium-chloride correlation diagram for Well 103 using the data from Table 1. The plot of the points indicate the presence of a third mixing component introduced from the surface containing higher concentrations of chloride. The points project back to the mixing line around Well FR-46 representing uncontaminated water and no bedrock water. Well BR-101 represents the contaminated bedrock water.

is strongly suggested. The contaminant was most likely introduced into the glacial aquifer from the surface because the increase of the chloride concentration cannot be explained in terms of mixing between the two aquifers. Possible sources of the chloride ion are: 1) salting of streets suggested by a slight increase in chloride concentration after November; 2) sewage effluent which is possible since there is a sewage treatment plant located about two miles up river from the "South Well Field". By identifying the chloride as a contaminant, the points from this study can be projected back to the mixing line. The points still would be concentrated around the endpoint of FR-46 representing water from the glacial aquifer.


A final result to be mentioned was the discovery of a yellow, hydrophobic powdery material that floated on top of the water at an observation well near Well 103. The material is some kind of an organic acid because it dissolves in a base and in ethanol. The composition of the material could not be determined from an x-ray diffraction pattern using Cu x-radiation or by ultra-violet spectrometry. The 2θ values and their corresponding "d" values of the peaks from the x-ray diffraction pattern are shown in Table 2. The material bears a physical resemblance to cellulose. If the material is some kind of cellulose, its origin may be from the breakdown of paper in the landfills located upstream from Well 103. Nothing else is known about the material at this time.

CONCLUSION

Although hydrogen sulfide has appeared in the water at Well

TABLE 2

The 2θ values of the peaks from the x-ray diffraction pattern of an unknown material that floated on top of the water at an observation well near Well 103. The corresponding "d" values are also given

Intensity of Peak	2θ	"d" Value
Highest	26.8	3.33
	11.75	7.52
	8.8	10.05
	17.8	4.98
	35.9	2.50
	Lowest	42.1

103 the conclusion of this report is that contamination of the glacial aquifer with the the bedrock water is not presently occurring at Well 103. The conclusion is based on the low concentrations of calcium and magnesium in the water and the relative stability of the parameters measured from the 113 days of this study (October 6, 1983 to January 27, 1984).

RECOMMENDATION

Although this report concluded that contamination is not occurring at the present time, the parameters in this study should be continuously monitored in the future. The 35 day period of continuous pumping that occurred during this study is not long enough to detect significant changes in the parameters that were measured. The appearance of hydrogen sulfide in the water would be the first indication that contamination may be starting because hydrogen sulfide is mobile in water. The hydrogen sulfide may be a temporary outgassing of an unsealed fracture zone. If it continues, the quality of the water in Well 103 may be adversely affected. In this case the other parameters may later show increases in concentration as the water is pumped a considerable length of time.

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