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MINNESOTA
MDH
DEPARTMENT OF HEALTH

Protecting, maintaining and improving the health of all Minnesotans

April 27, 2007

Mr. Stephen Thornhill
Burns & McDonnell Engineering Company
P.O. Box 419173
Kansas City, Missouri 64141

Dear Mr. Thornhill:

This letter is in response to the request for comments on the rail line being proposed by the Itasca County Regional Rail Authority (Surface Finance Docket No. 34992) near Marble, Minnesota.

The Minnesota Department of Health (MDH) administers the state's Wellhead Protection program. Based on the information that you have provided, it appears that portions of the routes labeled Options 3 and 4 would likely fall within the Wellhead Protection Area (WHPA) and Drinking Water Supply Management Area (DWSMA) for the city of Marble. The WHPA is the surface and subsurface area surrounding a well or well field that supplies a public water system, through which contaminants are likely to move toward and reach the well or well field (Minnesota Statutes, Part 103I.005, subdivision 24). The DWSMA is the area delineated using identifiable landmarks that reflect the scientifically-calculated wellhead protection area boundaries as closely as possible (Minnesota Rules 4720.5100, subpart 13). In addition, it appears that a portion of Option 3 would pass near enough to the city of Marble well field so that it would fall within the city's proposed Emergency Response Area. This is a subset of the WHPA through which contaminants are likely to move toward and reach the well or well field within a one-year time period. In addition to the delineation of the ERA, WHPA and DWSMA, Minnesota Rules 4720.5210 and 4720.5550 require an assessment of the vulnerability of the wells and aquifer to contamination. The wells used by the city of Marble are considered highly sensitive to contamination due to a combination of the geologic setting and well construction shortcomings, whereas the Biwabik Iron Formation aquifer used by the Marble city wells is considered to be moderately to highly vulnerable to contamination within the city's DWSMA.

Figures displaying the ERA, WHPA, and DWSMA, and the report in which they appear describing how they were delineated, are enclosed. Please be advised that the report and figures are considered draft at this point. The city of Marble is in the process of reviewing these documents. After completing their review and approval, the city of Marble will formally request approval from the MDH for this portion of their Wellhead Protection plan. Upon approval by the MDH, the report and delineated areas will be considered final. It is expected that final approval will occur within the next three-four months.

Drinking water protection concerns regarding the construction and operation of a railroad within a WHPA include the potential for contaminants leaking or spilling and eventually being captured by the city wells. Of greatest concern would be those portions of Routes 3 and 4 that may be located 1) within the city's ERA or WHPA, and 2) where the aquifer is considered highly vulnerable to contamination (see Figures 1 and 12 of the enclosed report). Contaminant spills or leaks in such areas could enter the aquifer rapidly and be captured by the city wells within a relatively short time period. If either of these rail options is ultimately pursued, it is important that environmental safeguards are in-place within these critical areas, both during the construction and operation of the rail line, to prevent a potential negative impact to the city of Marble public water supply.

Thank you for the opportunity to comment on the proposed development. Please contact me at (651) 201-4654 if you have any questions on this matter.

Sincerely,

James F. Walsh, Hydrogeologist
Division of Environmental Health
P.O. Box 64975
St. Paul, Minnesota 55164-0975

JFW:kmc
Enclosure
cc: Larisa Varishovetsky, MDH Planner, Metro Office
Mike Luhrsen, MDH Engineer, Bemidji District Office
Beth Kluthe, MDH Planner, Bemidji District Office

DRAFT

Wellhead Protection Plan

Part I

Wellhead Protection Area Delineation
Drinking Water Supply Management Area Delineation
Well and Aquifer Vulnerability Assessment

For

The City of Marble

April, 2007

James F. Walsh

Minnesota Department of Health

Table of Contents

List of Tables

List of Figures

Glossary of Terms

Capture Zone. The subsurface area surrounding a well or well field that supplies a public water supply system through which water is likely to move toward and reach the well. The capture zone and the surface water contribution area, when needed, comprise the wellhead protection area (WHPA).

Drinking Water Supply Management Area (DWSMA). The area delineated using identifiable land marks, defined in this report, that reflects the scientifically calculated wellhead protection area boundaries as closely as possible (Minnesota Rules 4720.5100, subpart 13).

Source Water Protection Area (SWPA). A source water assessment includes a description of 1) the area to be protected, 2) potential contamination sources that may impact the source of drinking water, and 3) the susceptibility of the public water supply to potential contamination sources. For the purposes of this delineation report, the SWPA and the DWSMA are the same.

Wellhead Protection Area (WHPA). The surface and subsurface area surrounding a well or well field that supplies a public water system, through which contaminants are likely to move toward and reach the well or well field (Minnesota Statutes, Part 103I.005, subdivision 24).

Introduction

This report documents the technical information necessary to prepare Part I of a wellhead protection plan that will help ensure an adequate and safe drinking water supply for the city of Marble, public water supply identification number 1310023. It documents the delineation of the wellhead protection area (WHPA), the drinking water supply management area (DWSMA), and the vulnerability assessments for the public water supply wells and DWSMA. An updated source water assessment with a new protection area (SWPA) also is included. Definitions explaining the differences between the terms WHPA, DWSMA, and SWPA are provided in the "Glossary of Terms" at the beginning of this report.

The delineation was performed in accordance with Minnesota Rules 4720.5100-4720.5590 for preparing and implementing wellhead protection plans for public water supply wells. The Minnesota Department of Health (MDH) administers these rules and the results described in this report reflect those of the MDH to 1) identify the capture zones for delineation of the WHPA, and 2) prepare well and DWSMA vulnerability assessments. Also, this report presents the findings of the public water supplier to identify the boundaries of the DWSMA.

The public water supplier operates two wells, termed Well No. 1 (Unique No. 228842) and Well No. 2 (Unique No. 228846). The wells are located in Section 27 of Township 56 North, Range 24 West in Itasca County. Appendix I contains Table 1 that presents some of the key information about these wells that affect their vulnerability assessments.

The WHPA for Wells No. 1 and 2 (228842 and 228846) was determined using a modified volumetric analysis recommended by the MDH for fractured rock aquifers (MDH, 2005). The DWSMA boundaries were determined using U.S. Public Land Survey boundaries, city streets, and roads. Figure 1 shows the boundaries for the WHPA and the DWSMA.

Source Water Assessment

The MDH is required under Section 1453 of the 1996 Amendments to the federal Safe Drinking Water Act to prepare source water assessments for all public water supply systems. Congress intends that assessments should be used to educate public water suppliers and the customers they serve about the source of their drinking water and potential contaminants that may affect people's health. The following Source Water Assessment for the public water supplier contains the information specified in Minnesota's source water assessment program description.

Source Water Assessment for
The City of Marble

Public Water Supplier ID Number: 1310023

Water Supplier Contact: Mladen Simunovich
Marble Water Superintendent
218-247-7576
P.O. Box 38
Marble, MN 55764

MDH Contact: Beth Kluthe
Minnesota Department of Health
218-308-2115
705 Fifth Street, Suite A
Bemidji, MN 56601
beth.kluthe@health.state.mn.us

Status of the Source Water Protection Plan

The Minnesota Department of Health has approved the 1) delineation of the wellhead protection area, 2) delineation of the drinking water supply management area, and 3) assessments of well and aquifer vulnerability. The public water supplier is proceeding with the development of the remainder of the wellhead protection plan.

Source Water Protection Area - See Figure 1.

Description of the Source Water -The water supply for the city of Marble comes from the Biwabik Iron Formation, a bedrock aquifer that exhibits unconfined hydraulic conditions at the city wells. The aquifer is about 550 feet thick and is covered by approximately 10 feet of overlying bedrock of the Virginia Formation and approximately 130 feet of glacial sediments at the city well field. Generally, groundwater moves in a northeasterly direction in the wellhead protection area, although the flow directions are likely variable and influenced by the water levels within the Arcturus and Hill-Annex Mine Pit lakes.

Table 2
Wells Used by the Public Water Supplier

Well No.	Unique No.	Well Use	Aquifer Type	Well Depth (ft)	Well Sensitivity	Aquifer Sensitivity
1	228842	Primary	Biwabik Iron Formation	500	High	Moderate
2	228846	Primary	Biwabik Iron Formation	503	High	Moderate

Aquifer Sensitivity - The sensitivity of the aquifer used by the public water supplier ranges from moderate to high throughout the drinking water supply management area. This rating reflects that the aquifer is generally covered by low permeability bedrock and/or glacial deposits, but young water is present in the aquifer. Tritium samples taken from Wells 1 and 2 (228842 and 228846) on February 10 and June 3, 2004, showed 9.6 tritium units and 9.1 tritium units, indicating that most of the water pumped by the wells entered the ground within the last 50 years.

Well Construction Assessment - Existing construction information for the Marble city wells suggests that grout was not drawn into the annular space of the outer well casings as they were driven, as is currently required by the State Well Code. In addition, the inner well casing for Well 1 (228842) is telescoped – in other words, it does not extend above the ground surface as required by code. Finally, it is unclear whether the annular space between the outer and inner well casings is grouted. These factors could provide pathways for near-surface contamination to enter the source water. As a result, the sensitivity of the wells to contamination is considered to be high.

Susceptibility of the Source Water to Contamination - The source water used by the public water supplier is considered susceptible to potential sources of contamination principally because of the geologic setting, although the construction of the city wells may also provide an avenue for contamination. The land uses within the drinking water supply management area may potentially contribute contaminants that may present a health concern to the users of the public water supply.

Contaminants of Concern - Routine testing of water from the Marble city wells has shown that they have generally been free from contaminants and meet all potability standards of the Safe Drinking Water Act. However, the wells are considered susceptible to contamination from a variety of sources. These include contaminants that may persist in groundwater for long periods of time which are resistant to retardation or removal by movement through fine-grained sediment.

Delineation of the Wellhead Protection Area

Physical Setting

The city of Marble is located in Itasca County near the western end of the Mesabi Iron Range. The town is surrounded by features associated with a nearly 100-year old history of iron mining, which ceased in this area in the early 1980s (David Lotti, personal communication). These features include tailings ponds, waste rock stockpiles, and abandoned mine pits that have filled with water. The nearest mine pit lakes are the Arcturus, Gross-Marble, Hill-Trumbull and Hill-Annex (Figure 2). Each of these was an individual, natural ore mine pit, but the Gross-Marble, Hill-Trumbull and Hill-Annex have become a single water body due to high water levels. They are separated from the Arcturus by a narrow land bridge that is currently overflowing. The pit lakes are variable in depth, with the Arcturus ranging up to approximately 100 feet and the Gross-Marble and Hill-Annex up to 200-250 feet at current water levels (Excelsior Energy, 2006).

Assessment of Data Elements

This section documents how the data elements specified under Minnesota Rules 4720.5400 were used to describe the physical environment.

Soils: The aquifer used by the city of Marble is buried beneath younger bedrock and glacial deposits, except where exposed at the margins of the nearby mine pits. As a result, soil maps are not useful for delineating its boundaries. However, the Itasca County soils survey (Nyberg, 1987) was useful for assessing the vulnerability of the aquifer.

Precipitation: The method used to delineate the WHPA does not account for aquifer recharge. As a result, precipitation was not considered.

Geology: Figures 2, 3 and 4 show the distribution of the aquifer and its stratigraphic relationships with adjacent geologic materials. They were prepared using existing geologic maps (Jennings and Reynolds, 2005; Jirsa and others, 2005) and well record data that is contained in the County Well Index database. A complete listing of the geological maps and studies that were used to further define local hydrogeologic conditions is provided in the section of this report entitled "Selected References."

The natural landscape of the Marble area was strongly affected by late-Pleistocene glaciation. Although the town of Marble is situated on relatively flat ground, the surrounding area consists of an irregular topography of small hills and depressions (Figure 2). This distribution of landforms is attributed to rapidly shifting depositional environments commonly found near the margins of glacial ice, probably of the Koochiching lobe (Jennings and Reynolds, 2005). Dominant glacial landforms in the Marble area include lake chains that have been attributed to subglacial drainage features known as tunnel valleys (Jennings and Reynolds, 2005). These include the 1) Dunning-Big Diamond-Twin Lakes, and 2) Mud-Upper Panaca-Lower Panaca lake chains. The lake basins within these channels likely formed from late melting of remnant ice blocks. The irregular hills adjacent to these lakes are composed dominantly of coarse-grained sediment, indicative of ice contact deposits (Jennings and Reynolds, 2005).

Although surficial materials in the Marble area are dominated by sediments of the Koochiching lobe, interpretations are complicated by apparent admixture with sediments of the Rainy lobe, probably owing to collapse of both units related to late melting of buried ice (Jennings and Reynolds, 2005). The total thickness of glacial sediments in the Marble area is on the order of 130 feet. Generally, glacial drift thickens to the south and thins to the north, approaching zero along the crest of the Giants Range. The Giants Range is a linear ridge, composed of Archean granitic and metasedimentary rocks, that trends northeast to southwest and is located north of the mine pits (Jones, 2002).

Winter (1971) identified three major morainal till units and associated glaciofluvial outwash deposits in this general area, only two of which appear to occur in Marble. These are the upper surficial and middle boulder till units (Jones, 2002). The surficial till is brown in color; sandy, silty, and calcareous; and is generally less than 30 feet thick in this area (Jones, 2002). The boulder till ranges widely in color from gray to yellow, and consists of sands and silts, with abundant cobbles and boulders, and is generally less than 50 feet thick (Winter, 1971). Glaciofluvial outwash deposits lie stratigraphically between the surficial and boulder tills, and often lie between the boulder till and deeper tills or bedrock (Winter, 1973a). Those that occur between the surficial and boulder tills are the thickest and most continuous outwash deposits in the Marble area, often greater than 50 feet thick and sometimes greater than 100 feet in portions of buried valleys (Winter, 1973a). These outwash deposits consist of fine-grained sands throughout much of the study area, but are highly transmissive, coarse-grained sands, gravels and boulders within buried valleys, and at other locations where the bedrock surface is low (Jones, 2002).

The bedrock geology of the Marble area is shown in Figure 3. The uppermost bedrock beneath the city of Marble consists of the Coleraine Formation, a Cretaceous package of conglomerate, hematite-cemented sandstone and blue-green shale (Jirsa and others, 2005). The thickness and distribution of this unit is poorly known. Morey (1999) indicates that it may be up to 100 feet thick in some areas of the western Mesabi Iron Range. However, the geologic records for the Marble city wells do not indicate the presence of the Coleraine Formation at those locations. The Coleraine Formation is generally not considered to be an aquifer.

The Coleraine Formation lies unconformably on Paleoproterozoic rocks of the Animikie Group, which includes the Virginia Formation, the Biwabik Iron Formation, and the Pokegama Formation. These rocks, in turn, rest unconformably on Archean granitic rocks of the Giants Range Batholith. Rocks of the Animike Group dip southward around 9-13 degrees and have been diagenetically altered, but not significantly metamorphosed (Jirsa and others, 2005).

The Virginia Formation consists of interbedded carbonaceous shale, mudstone, siltstone, and fine-grained feldspathic greywacke (Jirsa and others, 2005). A cherty siderite layer occurs within the Virginia Formation in this area, which makes it difficult to distinguish from the underlying Biwabik Iron Formation. The Virginia Formation is less than 10 feet thick at the city wells, and thins out to the north so that the uppermost bedrock present within the nearby mine pits is the Biwabik Iron Formation (Jirsa and others, 2005). The Virginia Formation is generally not considered a productive layer.

The Biwabik Iron Formation is the dominant bedrock aquifer along the Mesabi Iron Range because of the combination of fracturing and solution-weathering that have occurred locally in its subcrop area. These same factors have accounted for the development of so-called "natural ores," portions of the iron formation where magnetite has been oxidized to hematite, thereby enriching the iron content. Natural ore mines dominated production on the Mesabi Range through the 1950s, after which most natural ore inventories were depleted and mining activity focused on the relatively unaltered iron formation or "taconite." Several natural ore mines existed in the Marble area and were active until the late 1970s or early 1980s. After mining and dewatering ceased, these became the current Arcturus, Gross-Marble, Hill-Trumbull and Hill-Annex pit lakes.

The complete thickness of the Biwabik Iron Formation in the Marble area is probably on the order of 550 feet, although it thins out completely north of the mine pits. It has been subdivided into four members, based largely on mineral content and texture (Figure 4). The Upper and Lower Cherty members consist largely of thick-bedded, granular chert, iron silicates, magnetite and hematite; whereas the Upper and Lower Slaty members are predominantly thin-bedded iron silicates and carbonates, plus magnetite and hematite (Jirsa and others, 2005). A distinct carbonaceous marker horizon, known as the Intermediate Slate or "paint rock," separates the Lower Slaty and Lower Cherty members. The cherty members of the formation are probably the most hydraulically conductive because of their coarser texture. The city wells are probably open to all four members of the Biwabik Iron Formation (Cotter and others, 1965).

Down-hole chemical logging of Marble Well No. 1 (228842) was conducted on November 17, 2004, using a Hydrolab Minisonde 4a. This tool measures the temperature, specific conductance, pH, dissolved oxygen and oxidation-reduction potential (ORP) of the water column in a well. Changes in these parameters are often related to the presence of preferred flow horizons. The purpose of the logging was to identify specific horizons or fracture zones within the Biwabik Iron Formation that are responsible for controlling groundwater flow to the city wells. This information is useful for fine-tuning the delineation of the city's wellhead protection area, as well as assessing the vulnerability of the aquifer.

The results of the chemical logging suggest that the dominant productive horizons within the Biwabik Iron Formation at this location are 1) the Upper Cherty Member, and 2) portions of the Lower Cherty Member. The Upper Cherty flow zone extends from approximately 200-275 feet below the top of the well casing and is characterized by a large, positive deflection in specific conductance and dissolved oxygen (Figure 5), with a minor increase in temperature. Increases in these parameters may reflect the influx of relatively shallow, short-residence time water that has been impacted by road de-icing salt.

Two separate flow zones were identified in the Lower Cherty Member. The uppermost of these two zones extends from approximately 360-440 feet below the top of the well casing. Within this zone, the upper 40 feet are characterized by small, negative deflections in specific conductance and dissolved oxygen (Figure 5), with a minor decrease in temperature. The bottom 40 feet of this zone are characterized by large, negative deflections in specific conductance and dissolved oxygen, accompanied by a small decrease in temperature. The lowermost flow zone identified in the Lower Cherty Member was observed from approximately 470-480 feet, which was the maximum depth that the probe could be deployed. This zone is characterized by moderate, negative deflections in specific conductance and dissolved oxygen, and a moderate increase in temperature. The negative deflections in specific conductance and dissolved oxygen in the Lower Cherty horizons are presumed to reflect the influx of relatively deep-seated and longer residence-time water into the borehole.

In summary, the well profiling results suggest that the majority of the groundwater flow to the Marble city wells comes from a series of productive zones in the cherty members of the Biwabik Iron Formation. The cumulative thickness of these zones is on the order of 165-185 feet, which compares with a total aquifer thickness of approximately 550 feet. Of the productive zones, those within the Lower Cherty member below a depth of approximately 400 feet are likely dominant. This was determined by comparing the specific conductance values determined for the water column with that of a pumped sample collected from Well No. 1 (228842) shortly after the logging session. The specific conductance value for the pumped sample was 432 μmohs/cm, which is similar to the average value determined below 400 feet and much lower than that determined for intervals higher in the water column. By comparing the average specific conductance values for these zones, a simple mass balance calculation can be used to estimate their relative importance. Based on this calculation, the productive horizons below 400 feet may account for up to 83% of the flow in Well No. 1 (228842). These interpretations should be viewed with some caution because it was not possible to conduct physical measurements of flow within the borehole coincident with the chemical logging. Flow measurements are considered to be more definitive than other physical or chemical logging methods and should be taken in the future if the opportunity presents itself.

The Biwabik Iron Formation is thought to have little primary porosity, and groundwater flow through this unit is thought to be controlled by faults, joints (both high-angle and bedding-plane), zones of solution-weathering and man-made mining structures such as drifts and shafts. Natural ore bodies were likely formed by interaction between the iron formation and groundwater (meteoric or hydrothermal). As a result, it is useful to analyze the nature of these ore bodies for possible insights into current groundwater flow patterns. Natural ore bodies in the Marble area tend to be flat-lying features that follow specific stratigraphic horizons and are separated by layers of relatively unaltered slaty strata (Morey, 1999). These are often characterized by broad halos of oxidized iron formation (Bleifuss, 1964). Many such ore bodies have fissure or trough-like roots that follow fault or fold axes (Morey, 1999). In the Marble area, major faults trend northeasterly, with strikes ranging from approximately 40 to 65 degrees (Jirsa and others, 2005). Faults are of the normal variety, dip steeply and displacements are poorly known but probably minor. Jirsa and others (2005) identified three dominant jointing orientations in the Lower Cherty Member of the Biwabik Iron Formation from mapping conducted north of the Hill-Annex Mine Pit complex:

- A set that is oriented approximately 20 degrees east of north;
- A set that is oriented approximately 65 degrees east of north; and
- A set that is oriented approximately 40 degrees west of north.

All mapped joints plunge deeply, with dips ranging from 81 to 90 degrees. Some are mineralized with iron oxides.

To summarize, it is likely that groundwater flow through the Biwabik Iron Formation in the Marble area is controlled by features such as 1) bedding plane contacts, which generally dip from 9 to 13 degrees in a southeasterly direction, and 2) high-angle faults and joints that strike approximately 20-65 degrees or 320 degrees. Man-made mining structures such as shafts, drifts and adits may also affect groundwater flow, however it is not known if such features are present in the Marble area.

The Pokegama Formation conformably underlies the Biwabik Iron Formation. It consists of quartzite, quartz-rich siltstone, shale, and localized basal conglomerate. This unit is probably around 80 feet thick in the Marble area, based on the geologic mapping of Jirsa and others (2005). It is generally not considered an aquifer.

Groundwater Quantity and Quality: The Minnesota Department of Natural Resources permits high-capacity wells and documents their pumping volumes in the State Water Use Database (SWUDs). It is important to identify other high-capacity wells in the vicinity of the Marble wells because they may affect the boundary of the capture zone in the WHPA. The only high-capacity wells identified within two miles of the Marble city wells are the municipal wells for Calumet. The Calumet municipal wells are completed in the Virginia Formation and Biwabik Iron Formation. As a result, these wells may constitute a flow boundary to the Marble wells and must be considered as a factor in the WHPA delineation.

Water quality information on the Marble city wells was obtained from MDH records, as well as published data (Cotter and others, 1965). The parameters evaluated were chloride and sulfate, which can be useful indicators of general water quality. Elevated chloride is likely related to road de-icing salt, although fertilizer and wastewater are other possible sources. Elevated sulfate is generally related to naturally-occurring minerals, although wastewater is a possible source. Common mineral sources include gypsum, a soluble calcium sulfate mineral that occurs in minor amounts in some rocks, or the oxidation of sulfide-bearing minerals such as pyrite. Gypsum is not known to occur in the Biwabik Iron Formation or associated Precambrian rocks of the Marble area, although it could be present in minor amounts in glacial drift or Cretaceous sediments. Pyrite is known to occur locally within both the Biwabik Iron Formation and the Virginia Formation and may be present in the Coleraine Formation, which tends to have a greater sulfur content than the Animikie Group rocks (Morey, 1999). It is possible that some of the waste rock stockpiles in the Marble area contain pyrite or other sulfide minerals, and result in localized occurrences of sulfate-rich groundwater.

The historic data from the Marble city wells show that the chloride content of the water has remained relatively constant over time in the range of 2-13 mg/l, with the exception of a single sample from Well No. 2 (228846) taken on October 14, 2004, that yielded 38 mg/l (Figure 6). It is unclear what caused that particular sample to be elevated in chloride. Additional future monitoring should be conducted to establish whether that result was an anomaly or the beginning of a trend. The sulfate data show a similar pattern (Figure 7). Sulfate values have generally fallen in the range of 15-40 mg/l, with the exception of two samples from Well No. 2 (228846) taken on November 27, 1970, and August 23, 1976, that showed values of 140 mg/l and 230 mg/l, respectively. Again, it is unclear what caused these elevated values. Perhaps it can be attributed to changing groundwater flow patterns in the area related to fluctuating water levels at the nearby mine pits. When the Hill-Annex Mine Pit complex was completely dewatered prior to its closure around 1980, the water level would have been approximately 200 feet lower than currently observed (Figure 8). This would have created a hydraulic gradient much steeper than currently exists in the area. As a result, vertical leakage to the aquifer was likely enhanced and the capture area for the city wells likely extended much further to the south than is currently indicated.

Data on the chloride, sulfate, and oxygen and hydrogen stable isotope content of the Arcturus and Hill-Annex Mine pit lake water was obtained from samples collected at several locations in the summer and fall of 2004. These results were compared with data obtained from the Marble city wells to estimate whether water from the mine pit lakes was being captured by the city wells. The chloride data show that similar values are seen at both the city wells and the pit lake (Figure 6), except for the elevated sample from Well No. 2 (228846). The sulfate data show that water from the pit lakes was somewhat elevated relative to that from the city wells (Figure 7). The stable isotope data show that little, if any, pit lake water was being captured by the city wells as of the latest sampling episode, which was October 14, 2004 (Figure 9). The samples from the Arcturus and Hill-Annex Mine pit lakes showed values that were consistently far removed from the meteoric water line, suggesting that these lakes have undergone a high degree of evaporation. However, each of the well samples plot within the limits of analytical uncertainty of the global meteoric water line. This indicates that these samples consisted primarily of groundwater that has not been exposed to evaporation at the land surface. In light of the stable isotope data, the similarities noted between the chloride and sulfate values for the city wells and the Canisteo Mine pit lake probably reflect that the recharge areas for both have comparable water quality.

In addition to the chemical and isotopic data noted above, the Marble city wells have been sampled for tritium to determine the residence time or "age" of the water. Well No. 1 (228842) was sampled on February 10, 2004, with results of 9.6 tritium units (TU). Well No. 2 (228846) was sampled on June 3, 2004, and that result showed 9.1 TU. These results show that the Biwabik Iron Formation aquifer at this location is dominated by relatively young water that entered the ground since 1954. A water sample was also obtained from the Arcturus Mine pit lake on June 3, 2004, and analyzed for tritium. That result showed 13.3 TU and is probably reflective of the tritium concentration of recent recharge in the Marble area combined with that of inflowing groundwater.

Hydrogeological Setting

In the geographic area that includes the WHPA, the aquifer from which the city wells pump has the following characteristics:

- It is composed of chert and iron minerals and is approximately 550 feet thick;
- It exhibits a porosity that is estimated to be in the range of 1-10%;
- It exhibits a base elevation of approximately 700 feet above sea level at the city wells and rises to the north at approximately 9 to 13 degrees;
- It exhibits a stratigraphic top elevation of approximately 1,250 feet above sea level at the city wells and rises to the north at approximately 9 to 13 degrees;
- It is bounded stratigraphically by relatively impermeable bedrock units in addition to a significant thickness of till.

The aquifer exhibited unconfined hydraulic conditions at the city wells when last measured in 2004. This was determined by comparing the static water level measurements from Well No. 1 (228842) with the stratigraphic top of the Biwabik Iron Formation aquifer (Figure 4). The static water level occurred in the iron formation. However, the aquifer is probably confined a short distance to the south of the city well field (Figures 4 and 10).

The Minnesota Department of Natural Resources (DNR) has developed a procedure for determining geologic sensitivity at well sites (DNR, 1991). The Marble city wells exhibit a geologic sensitivity rating of moderate using the DNR criteria.

The groundwater flow field for the Biwabik Iron Formation is not known with certainty because of the lack of wells with water level data in this area. In addition, the potentiometric surface has probably been strongly altered by mine dewatering. Nothing is known of pre-mining groundwater conditions, but it is certain that mining activities have significantly altered groundwater flow patterns in the area. It is likely that, under pre-mining groundwater conditions, the direction of groundwater flow in both the glacial deposits and the Biwabik Iron Formation was generally to the south or southeast, down-dip from the Giants Range.

Current data suggest that the Hill-Annex Mine Pit complex represents the low point on the local potentiometric surface, and that the dominant groundwater flow direction is northeasterly in the Marble area (Figure 10). This is based on a comparison between 1) static water level measurements for Well No. 1 (228242) taken on November 17, 2004, and 2) current water levels in the Arcturus and Hill-Annex Mine Pit lakes (Excelsior Energy, 2006). Groundwater movement upgradient of the Marble city wells is presumed to be in a northeasterly direction (approximately 22 degrees). The horizontal hydraulic gradient is unknown upgradient of the city wells because no data points exist. However, if it is similar to that observed between the city wells and the Hill-Annex Mine Pit lakes, then it is approximately 0.008. Current data on vertical hydraulic gradients is not available. However, historical data suggest that an upward gradient existed within the Biwabik Iron Formation when Well No. 1 (228842) was reconstructed in 1964. The static water level rose 11 feet after the well was deepened from 385 feet to 500 feet.

Criteria Used to Delineate the Wellhead Protection Area

The criteria for delineating the WHPA, as required in Minnesota Rules 4720.5510, were addressed as follows.

Time of Travel - A time of travel criterion is difficult to apply to an aquifer such as the Biwabik Iron Formation, where flow occurs through well-developed secondary porosity features. As a result, the WHPA is based on a cylinder calculated using a 10-year pumping volume to account for the ambiguity of flow directions caused by secondary porosity. Also, an emergency response area was defined, as specified under Minnesota Rules 4720.5250, using the one-year pumping volume.

Daily Volume of Water Pumped – Information provided by the city of Marble was used to determine the maximum discharge from their wells. The results are presented in the following table. The daily volume of discharge used as an input parameter in the model was calculated by dividing the greatest annual pumping volume by 365 days.

Table 3
Annual Volume of Water Discharged From Marble Water Supply Wells

Well No.	Unique No.	2001	2002	2003	2004	2005	Future Pumping
1	228842	**38,592,000**	32,861,000	26,844,500	12,800,000	11,400,000	No Increase Expected
2	228846	----------	------------	3,173,500	12,800,000	11,400,000	No Increase Expected

(Expressed as gallons. Bolding indicates greatest annual pumping volume.)

The values shown in Table 3 are the total number of gallons pumped annually by the Marble city wells and reported to the Minnesota Department of Natural Resources under Groundwater Appropriations Permit No. 752176. The city of Marble indicates that it intends to pump approximately the same amounts of water during the next five years. As a result, the maximum amount of annual pumping, shown in bold above, was used to express the daily volume of water pumped from the city wells.

The maximum annual volume pumped by Marble Well Nos. 1 and 2 (228842 and 228846) over the 2001-2005 time period was incorporated as a daily volume in the calculations used to designate the capture zone for the wells. For delineation purposes, the pumping rate shown in Table 4 was applied only to Well No. 1 (228842). This allowed for simplification of the fixed radius calculation because the complicating effects of interfering wells could be avoided. This delineation method is appropriate because 1) the wells are closely spaced (approximately 125 feet apart), and 2) Well No. 1 (228842) has been used predominantly in the past. The rate selected is consistent with WHP rule requirements because the maximum volume is used.

Table 4
Pumping Rate Used for WHPA Delineation

Well Number	Equivalent Annual Volume (gallons)	Input Value (cubic meters/day)
1	38,592,000	400.2

Groundwater Flow Field - The groundwater flow field was determined by compiling static water level elevations from 1) wells that are completed in the aquifer used by the city of Marble, and 2) fully-penetrating surface water features such as the Arcturus and Hill-Annex Mine Pit lakes (Figure 10). The ambient flow field in the aquifer upgradient of the city wells is oriented in a northeasterly direction (approximately 22 degrees) with a horizontal gradient of approximately 0.008.

Aquifer Transmissivity - Because of the fractured nature of the Biwabik Iron Formation aquifer, transmissivity was not used to delineate the WHPA, consistent with "Guidance for Delineating Wellhead Protection Areas in Fractured and Solution-Weathered Bedrock in Minnesota" (MDH, 2005).

Flow Boundaries - The following conditions define the extent to which flow boundaries must be considered:

- Geologic boundaries that must be considered include 1) the stratigraphic top and bottom of the Biwabik Iron Formation, and 2) the orientation of dominant geologic structures such as faults and joints.
- Hydrologic boundaries that must be considered include surface water features that at least partially penetrate the aquifer, including the Arcturus and Hill-Annex Mine Pit lakes. In addition, other high-capacity wells that pump from the Biwabik Iron Formation also need to be accounted for in the delineation. The only such wells identified within two miles of the Marble city wells belong to the city of Calumet. Those wells have been accounted for in the Marble WHPA delineation, as described below.

Method Used to Delineate the Wellhead Protection Area - In aquifers influenced by flow through secondary porosity, groundwater may move a much greater distance to supply a pumping well than in porous media aquifers. In addition, flow directions are considerably more variable in aquifer settings influenced by fractures or conduit flow. Therefore, numerical and analytical methods that traditionally are used to designate capture zones for wells completed in porous media aquifers may not apply to fractured and solution-weathered bedrock aquifers. To account for this, MDH has developed the document entitled, "Guidance for Delineating Wellhead Protection Areas in Fractured and Solution-Weathered Bedrock in Minnesota" (MDH, 2005).

According to the guidance, a fracture flow analysis is required when the aquifer exhibits flow through secondary porosity features, as is presumed for the Biwabik Iron Formation. Of the various delineation methods specified in the guidance document, Delineation Technique 2 is most appropriate. This technique is specific to fractured or solution-weathered aquifers that 1) are hydraulically unconfined, or 2) have a horizontal hydraulic gradient of greater than 0.001, and 3) possess a well discharge to discharge vector ratio of less than 3,000 (MDH, 2005).

The formula and values used for calculating the ratio of the well discharge to the discharge vector are presented below:

$$Q/Q_s = \frac{(Q \ \ in \ \ gpm)(\frac{1 ft^3}{7.48\, gal})(\frac{1440 \min}{1\, day})(\frac{0.0283 m^3}{1 ft^3})}{(thickness\ in\ ft)(0.3048\, m/ft)(hydraulic\ conductivity\ in\ m/d)(hydraulic\ gradient)}$$

Q = Well Discharge (L^3/T)
Q_s = Discharge Vector (L^2/T) = (H) (K) i

Where: H = aquifer thickness (L)
K = hydraulic conductivity (L/T)
i = hydraulic gradient

For the Marble city wells, 1) the well discharge was determined from the annual water use figures; 2) the aquifer thickness was determined to be 185 feet, which represents the maximum cumulative thickness of likely hydraulically conductive horizons based on down-hole logging; 3) the hydraulic conductivity was estimated to be 5 ft/day, based on specific capacity data for the city wells using the method described in Appendix III; and 4) the hydraulic gradient was estimated to be 0.008. The resulting well discharge to discharge vector ratio is 582.

Delineation Technique 2 uses a calculated fixed radius to represent the volume of aquifer material needed to supply water to the city wells over a 10-year time period. The calculated fixed radius was then modified to account for 1) upgradient groundwater flow, 2) ambiguity of the groundwater flow direction, and 3) the effects of the orientations of secondary porosity features, such as fractures and faults. Details of this approach are presented below.

The calculated fixed radius (CFR) is a simple volumetric calculation for a cylinder that would supply the discharge amount for the well, based on 1) the highest pumping rate in the last five years, 2) the cumulative thickness of the productive aquifer horizons open to the well, and 3) the effective porosity of the aquifer.

$$R = \sqrt{\frac{Q}{nL\pi}}$$

Where: R = radius of the capture area

Q = well discharge = (well pumping rate)(pumping time period)

n = effective porosity

L = cumulative thickness of productive aquifer horizons

π = 3.14159

The CFR calculation for the city of Marble was based on the following:

- 10 years of pumping.
- Q = 385,920,000 gallons, which is the annual pumping rate multiplied by the number of years of pumping. Table 4 lists the maximum annual pumping rate for the city wells. This value represents the combined pumping of both city wells and was applied to Well No. 1 (228842) to represent the cumulative discharge from both city wells. This approach is considered appropriate given that the wells are located within approximately 125 feet of each other.
- n = 0.10. This value represents the upper end of the estimated range shown in the MDH guidance document (2005) for dolomite and limestone. No specific category exists for iron formation, and limestone is considered to be a reasonable equivalent given that both are marine chemical sediments. The high-end value was used because it is being applied to only the hydraulically conductive portions of the aquifer, as determined from borehole logging described earlier in this report.
- L = 185 feet. This is the cumulative thickness of productive aquifer horizons identified using borehole logging techniques. Using this value rather than the entire thickness of the Biwabik Iron Formation (approximately 550 feet) results in a more conservative well capture zone.

Using the values noted above, the CFR for the Marble city wells is 941 feet (Figure 11). In order to account for upgradient groundwater flow, the CFR noted above was projected in the dominant upgradient flow direction for an additional 10-year pumping volume. This projection was then adjusted plus and minus 10 degrees from the dominant flow direction to account for uncertainty in the groundwater flow field (Figure 11). Finally, the CFR was projected an additional 10-year pumping volume upgradient along the dominant trend of linear bedrock structural features, such as faults and joint axes (Figure 11). The resulting WHPA for the city of Marble is a composite of these delineation methods.

In order to estimate whether pumping of the Calumet city wells has any impact on the WHPA for Marble, an updated source water protection area (SWPA) was delineated for the Calumet city wells using the method described above. Contrary to the Marble delineation, the entire open-hole interval was used as the aquifer thickness because no borehole logging data exist for the Calumet wells. As a result, the lowest estimated porosity value (0.01) was used in the CFR calculation in order to make it as conservative as possible. The SWPA was based on a 10-year pumping volume using the maximum pumping value for the previous 5 years, and was extrapolated both upgradient and along geologic structure for an additional 10-year pumping volume (Figure 11). The resulting composite area was terminated along the Hill-Annex fault, a major structural feature that separates the relatively unoxidized iron formation east of the fault from the strongly oxidized iron formation to the west. The Calumet SWPA is separated from the Marble WHPA by approximately 2,600 feet at their closest point, suggesting that the wells are not close enough to constitute hydrologic boundaries at their current pumping rates.

Results of Model Calibration and Sensitivity Analysis - The fracture flow delineation procedure cannot be calibrated because it is a simple calculation of an aquifer volume based on well discharge, aquifer thickness, and effective porosity.

Model Sensitivity - Model sensitivity refers to the amount of change in model results caused by the variation of a particular input parameter. Because of the fractured nature of the Biwabik Iron Formation aquifer, a porous-media groundwater flow model was not used to delineate the WHPA. As a result, no model sensitivity analysis was performed. However, an effort was made to assess the sensitivity of the WHPA to the input parameters used in the CFR calculation and extrapolation.

The CFR calculation is sensitive to the pumping rate of the well, in addition to aquifer thickness and porosity. The well pumping rate used in the CFR calculation is prescribed in the state's wellhead protection rule ((Minnesota Rules 4720.5510, subpart 4) and is a conservative value because it is based on the highest recorded value for the wells. The use of any smaller value in the CFR calculation would result in a reduced CFR and WHPA.

Aquifer thickness and porosity are indirectly proportional to the resulting CFR; larger values result in smaller CFRs and vice-versa. The 185-foot aquifer thickness used in the CFR calculation is based on the cumulative thickness of productive aquifer horizons identified using borehole logging techniques. Using this value rather than the entire thickness of the Biwabik Iron Formation (approximately 550 feet) results in a more conservative well capture zone. The porosity of the Biwabik Iron Formation is unknown. A relatively high value of 0.10 was used in the calculation because it is being applied to only the hydraulically conductive portions of the aquifer based on borehole logging. For comparison, a porosity value of 0.05 would yield a CFR of 1,332 feet.

The extrapolation of the CFR is sensitive to the 1) ambient groundwater flow direction, and 2) orientation of dominant geologic structural features. Uncertainty in the groundwater flow field was accounted for by creating a composite of capture zones from angles of flow that are 10 degrees greater and 10 degrees lesser than the representative angle of ambient flow (Minnesota Rule 4720.5510, subpart 5, B(2). The orientation of dominant geologic structural features was based on the geologic mapping of Jirsa and others (2005). The variation in the strike of dominant structural features was accounted for by utilizing the range of observed values.

Uncertainty Analysis - As noted above, the WHPA for the city of Marble is sensitive to a variety of input parameters. The least well known of these parameters are aquifer thickness, porosity, and groundwater flow field. The following section describes steps that could be taken to provide a greater degree of certainty in the calculated capture zone.

Recommendations for Future Data Collection

1) Enhancing the understanding of local hydrogeologic conditions.

Aquifer Thickness and Porosity -

- The borehole logging conducted on Well No. 1 (228842) yielded important information regarding likely productive horizons within the Biwabik Iron Formation aquifer. However, the aquifer thickness estimates provided by this logging method should be considered preliminary in the absence of physical measurements of flow within the borehole. Borehole flow measurements are considered to be more definitive than other physical or chemical logging methods and should be taken in the future if the opportunity presents itself. The Minnesota Geological Survey possesses such equipment and may consent to its use at the Marble city wells under appropriate conditions. The minimum conditions required for successful deployment of this equipment include 1) the well(s) must be accessible and open (no pumps or related equipment in the well); and 2) adequate notice must be provided so the equipment can be mobilized. If the city of Marble plans to conduct maintenance or repair on either of their wells, that would involve short-term removal of the well pump(s), they should contact the MDH to arrange for this type of borehole investigation. The results should allow for a more accurate determination of the thickness of the water-producing horizons penetrated by the wells. With that information in hand, the CFR and resulting WHPA could be refined using the appropriate aquifer thickness and porosity.

Groundwater Flow Field -

- The city of Marble should work with the MDH so that every 5 years, the locations of new wells that are constructed within one mile of your well field can be verified and accurate elevations obtained. This information may help address uncertainties related to the distribution of hydraulic head in the Biwabik Iron Formation aquifer.

- The city of Marble should continue to measure the static water level at the city wells on an annual basis. This information can be used in conjunction with water level data from the nearby mine pit lakes to verify the local horizontal hydraulic gradient. If the horizontal hydraulic gradient were to change such that it became 0.001 or less, then a different delineation technique may be indicated for the city's WHPA.

- Hydraulic Conductivity - Although this parameter is not used directly in the calculation of the city of Marble's WHPA, it does factor into determining the appropriate delineation technique because of its impact on the well discharge to discharge vector calculation (MDH, 2005). For this delineation, hydraulic conductivity was estimated using specific capacity data from the city wells, based on records provided by the city. This method of estimating specific capacity is less accurate than an aquifer test conducted for determining aquifer transmissivity. It may be beneficial for the city of Marble to conduct an aquifer test in the future so that hydraulic conductivity of the Biwabik Iron Formation aquifer can be more accurately determined. The MDH can assist the city with planning and conducting such a test.

2) Surface water/groundwater exchange.

Chemical and Isotopic Data -

- Existing isotopic data suggest that the Marble city wells were not capturing an identifiable component of pit lake water as of October, 2004. It is possible that this relationship could change through time, either because of increases in water use by the city, or an increase in water level elevation within the nearby mine pit lakes. In order to track whether such changes may be occurring and verify the accuracy of the currently delineated WHPA, the MDH recommends that one of the city wells be sampled for the stable isotopes of water, chloride, and sulfate on an annual basis. The city will be responsible for most of the sampling, but the MDH will pay for the analyses using funding that it has dedicated for this work. There would be no cost to the city for the analyses and MDH staff time. If it became apparent that the city wells were capturing a significant component of pit lake water, then that feature and its surface watershed area would need to be added to the WHPA for the city of Marble.

3) Water use considerations.

Revisions to the WHPA -

- The following water use factors should be monitored to determine if a revision of the WHPA or DWSMA is required: 1) the installation of any new high-capacity wells within 1.5 miles of the city well field, and 2) increased discharge from the city wells over the values used in this report.

Delineation of the Drinking Water Supply Management Area

Method Used to Designate the Drinking Water Supply Management Area - The Drinking Water Supply Management Area (DWSMA) was determined by overlaying the WHPA on a map of area roads, railroads, and public land survey boundaries and using a geographic information system to select the closest such feature. This area was then reviewed and modified by staff from the city of Marble and the MDH.

Assessment of Well Vulnerability

This part documents the vulnerability of the wells used by the public water supplier and is required under Minnesota Rules 4720.5210. The protocol for determining well vulnerability is defined in the MDH document entitled Methodology for Phasing Wells into Minnesota's Wellhead Protection Program (1993), which was approved by the U.S. Environmental Protection Agency as part of its review of Minnesota's wellhead protection program description. The MDH uses the protocol to maintain a database defining the potential vulnerability of community and noncommunity public water supply wells. A score is calculated for each well using 1) construction criteria defined in the State Well Code, 2) geologic sensitivity, and 3) the results of water quality monitoring conducted by the MDH. A numeric score is assigned to each well based on the results of the three areas of evaluation. A cutoff score is used to define wells that are most likely to be vulnerable based on their construction, geologic setting, and sampling history. The printouts of the vulnerability ratings for each well are presented in Appendix I.

The results of the well vulnerability assessments suggest that the wells used by the city of Marble are vulnerable to contamination. This conclusion is based primarily on the fact that water samples collected from the city wells on February 10 and June 3, 2004, contained tritium at 9.6 and 9.1 tritium units, indicating the predominance of young (post-1954) water in the samples. An additional factor is that the city wells do not meet current standards for construction.

Vulnerability Assessment for the Drinking Water Supply Management Area

The aquifer used by the Marble city well was evaluated for its vulnerability to contamination throughout the extent of the DWSMA on the basis of 1) geologic and soils maps, 2) geologic logs from wells in the area, and 3) the chemical and isotopic data noted above.

The Itasca County Soil Survey includes an assessment of the geologic sensitivity at the water table based on the criteria of the DNR (1991). The geologic sensitivity ratings within the Marble DWSMA range from very high to low. These ratings correlate well with the surficial geologic mapping of Jennings and Reynolds (2005). Geologic sensitivity ratings of very high correspond to areas where bedrock is within 50 feet of the land surface and/or the overlying glacial sediment is relatively coarse. This condition was noted only along the northern margins of the DWSMA near the Arcturus and Gross-Marble mine pits where the Biwabik Iron Formation is exposed or covered by only a thin veneer of glacial sediment (Jennings and Reynolds, 2005). Geologic sensitivity ratings of moderate and low are assigned where the soil has a relatively high clay or loam content, suggesting that till was the parent material. Again, these areas are well correlated with those areas mapped as Koochiching lobe till by Jennings and Reynolds (2005).

The geologic sensitivity ratings described above were compared with that from Marble Well No. 2 (228846), which is the only well with a complete stratigraphic record that is completed in the Biwabik Iron Formation and located within the city's DWSMA. The geologic sensitivity rating for that well is moderate, which is consistent with the rating suggested by surficial geologic mapping (Figure 12). Geologic protection at the city well field consists of clay-rich till and the Virginia Formation. Although the Virginia Formation thins to a feather-edge a short distance north of the Marble city wells, based on the mapping of Jirsa and others (2005), till cover continues almost to the edge of the Arcturus and Gross-Marble mine pits. At that point, the Biwabik Iron Formation is exposed.

The chemical and isotopic data for the Marble city wells suggest that the Biwabik Iron Formation is characterized by the presence of young water. As a result, the overlying geologic protection provided by the Virginia Formation and till cover is considered to be leaky. This is consistent with a moderate vulnerability rating. Those areas determined to exhibit a geologic sensitivity rating of low, based on surficial geologic mapping, were increased to a vulnerability rating of moderate to reflect the leaky nature of the till. Finally, mapped areas smaller than a few acres in size were incorporated within the surrounding mapped area so as to avoid small slivers of land that would be difficult to identify and manage.

In summary, the vulnerability of the Biwabik Iron Formation aquifer ranges from high to moderate throughout the city of Marble DWSMA. Within areas rated as high, the time required for water moving vertically from the land surface to reach the aquifer is probably on the order of days to months. Within areas rated as moderate, the time required for water moving vertically from the land surface to reach the aquifer is probably on the order of several years to decades.

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Appendix I

Municipal Well Information

Table 1
Municipal Water Supply Well Information
Marble, Minnesota

Local Well Name	Unique Number	Use/ Status[1]	Casing Diameter (inches)	Casing Depth (feet)	Well Depth (feet)	Date Constructed/ Reconstructed	Well Vulnerability	Aquifer
1	228842	P	12	200	500	1926/1964	Vulnerable	PEBI
2	228846	P	20	176	503	1955	Vulnerable	PEBI

Note: 1. Primary (P) or Emergency backup (E) well

625 Robert St. N. St. Paul MN 55155
P.O. Box 64975 St. Paul MN 55164 - 0975

MINNESOTA DEPARTMENT OF HEALTH
SECTION OF DRINKING WATER PROTECTION
SWP Vulnerability Rating

PWSID: 1310023
SYSTEM NAME: Marble
WELL NAME: Well #1

TIER: 3
WHP RANK:
UNIQUE WELL #: 00228842

COUNTY: Itasca | TOWNSHIP NUMBER: 56 | RANGE: 23 W | SECTION: 19 | QUARTERS: ACA

CRITERIA		DESCRIPTION	POINTS
Aquifer Name(s)	:	Biwabik Iron-Formation	
DNR Geologic Sensitivity Rating	:	Medium	25
L Score	:	0	
Geologic Data From	:	Data Inferred From Nearby Wells	
Year Constructed	:	1926	
Construction Method	:	Cable Tool/Bored	0
Casing Depth	:	200	10
Well Depth	:	500	
Casing grouted into borehole?		Unknown	0
Cement grout between casings?		Unknown	5
All casings extend to land surface?		Yes	0
Gravel - packed casings?		No	0
Wood or masonry casing?		No	0
Holes or cracks in casing?		Unknown	0
Isolation distance violations?			0
Pumping Rate	:	240	5
Pathogen Detected?			0
Surface Water Characteristics?			0
Maximum nitrate detected	:	<1 09/01/1975	0
Maximum tritium detected	:	9.6 02/10/2004	VULNERABLE
Non-THMS VOCs detected?			0
Pesticides detected?			0
Carbon 14 age	:	Unknown	0
Wellhead Protection Score	:		45
Wellhead Protection Vulnerability Rating	:		VULNERABLE
Vulnerability Overridden	:		

COMMENTS

QWTA-PEBI, DRIFT STRATIGRAPHY INFERRED FROM WELL #2. Well was deepened in 1964 from original depth of 385 to 500 feet. A 12-inch inner casing was installed from top to bottom, with the bottom 300-feet perforated. The original casing depth was 130 feet.

625 Robert St. N. St. Paul MN 55155
P.O. Box 64975 St. Paul MN 55164 - 0975

MINNESOTA DEPARTMENT OF HEALTH
SECTION OF DRINKING WATER PROTECTION
SWP Vulnerability Rating

PWSID: 1310023
SYSTEM NAME: Marble
WELL NAME: Well #2

TIER: 3
WHP RANK:
UNIQUE WELL #: 00228846

COUNTY: Itasca   TOWNSHIP NUMBER: 56   RANGE: 23 W   SECTION: 19   QUARTERS: ACAA

CRITERIA		DESCRIPTION	POINTS
Aquifer Name(s)	:	Biwabik Iron-Formation	
DNR Geologic Sensitivity Rating	:	Medium	25
L Score	:	0	
Geologic Data From	:	Well Record	
Year Constructed	:	1955	
Construction Method	:	Cable Tool/Bored	0
Casing Depth	:	176	10
Well Depth	:	503	
Casing grouted into borehole?		Unknown	0
Cement grout between casings?		Unknown	5
All casings extend to land surface?		Yes	0
Gravel - packed casings?		No	0
Wood or masonry casing?		No	0
Holes or cracks in casing?		Unknown	0
Isolation distance violations?			0
Pumping Rate	:	510	10
Pathogen Detected?			0
Surface Water Characteristics?			0
Maximum nitrate detected	:	<1 09/01/1975	0
Maximum tritium detected	:	9.1 06/03/2004	VULNERABLE
Non-THMS VOCs detected?			0
Pesticides detected?			0
Carbon 14 age	:	M	0
Wellhead Protection Score	:		50
Wellhead Protection Vulnerability Rating	:		VULNERABLE
Vulnerability Overridden	:		

COMMENTS

Appendix II

Figures Used In This Report

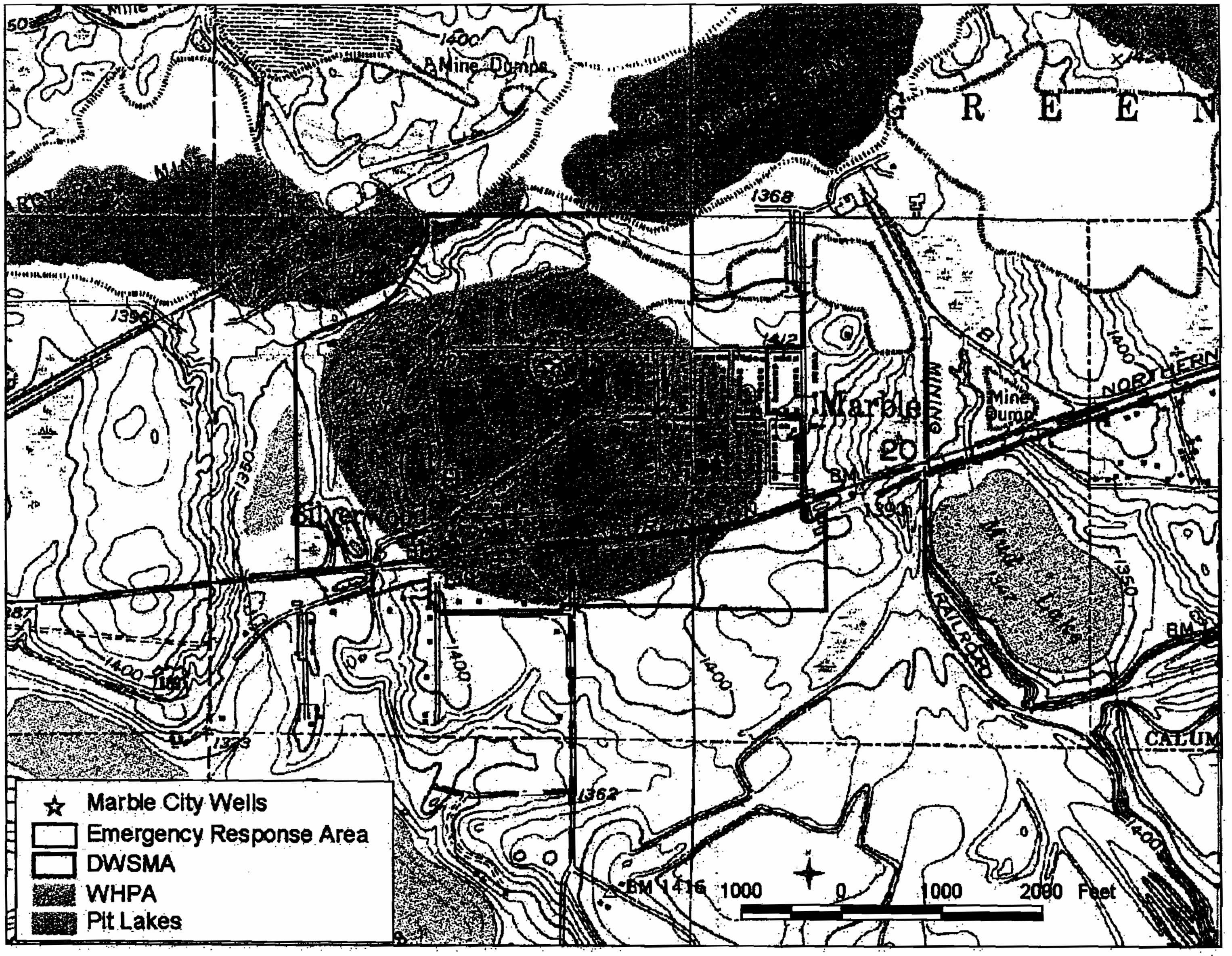

Figure 1. **Wellhead protection area (WHPA), drinking water supply management area (DWSMA) and emergency response area (ERA) for the city of Marble.**

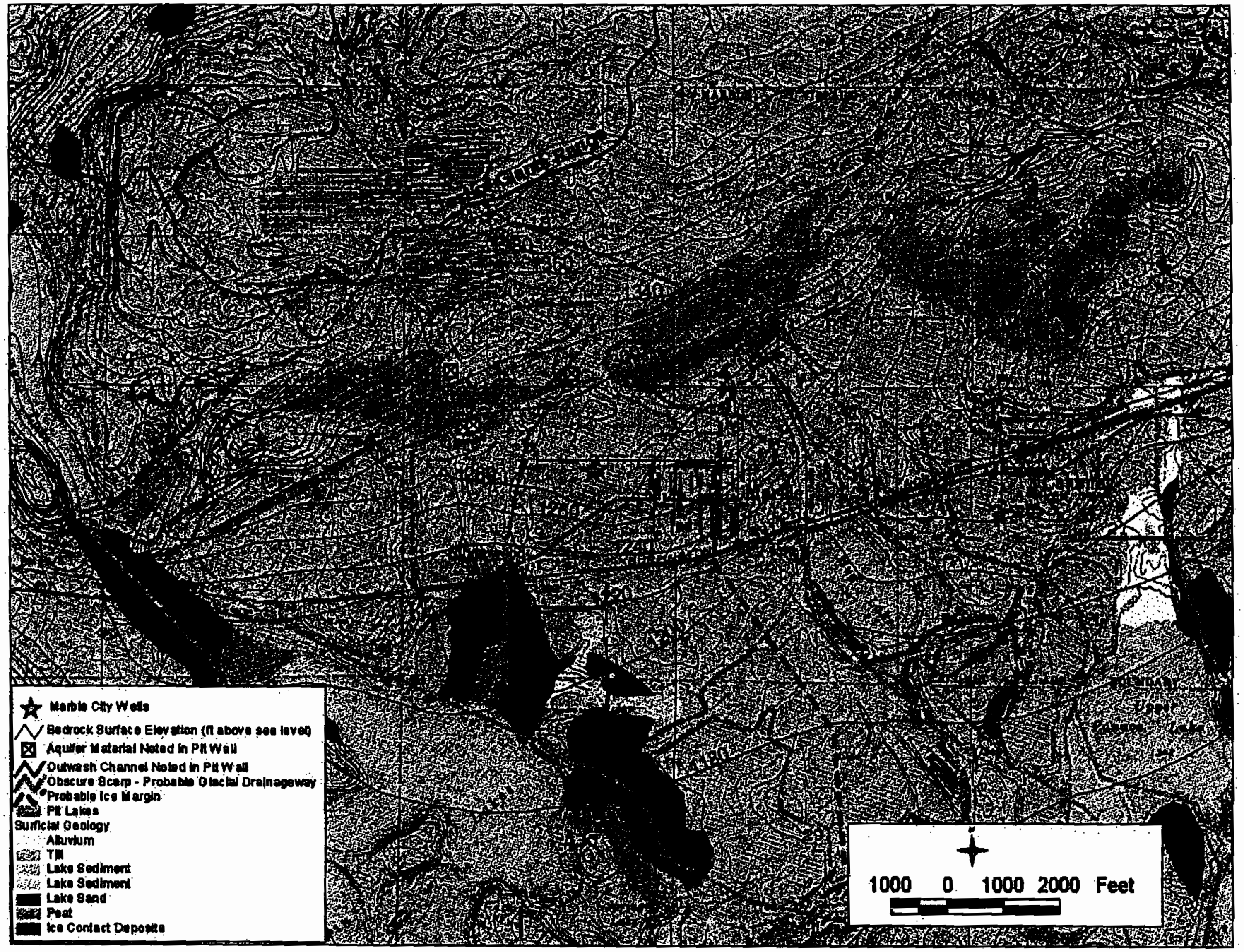

Figure 2. Surficial geology of the Marble area (after Jennings and Reynolds, 2005).

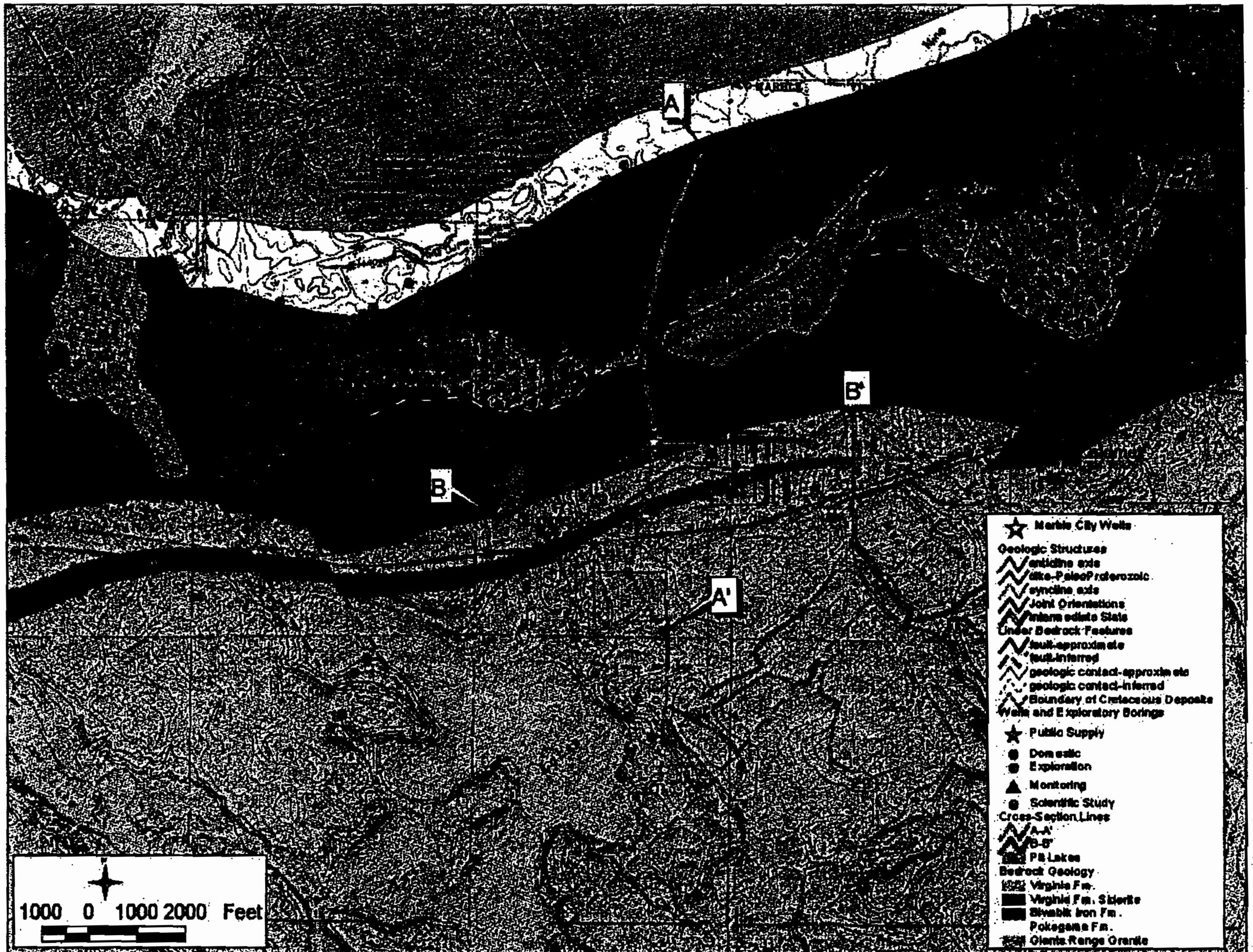

Figure 3. Bedrock geology of the Marble area (Jirsa and others, 2005).

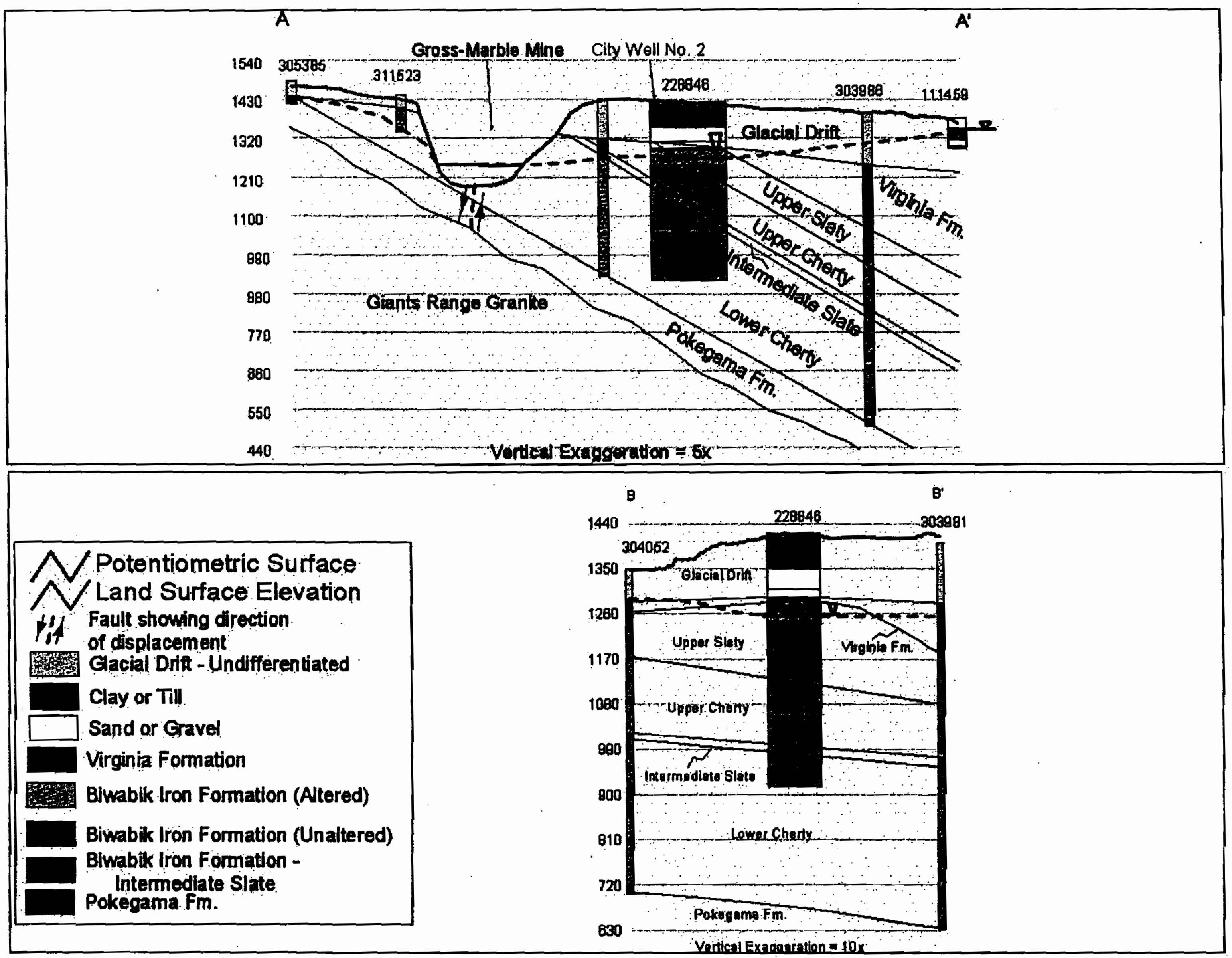

Figure 4. Geologic cross-sections through the Marble area.

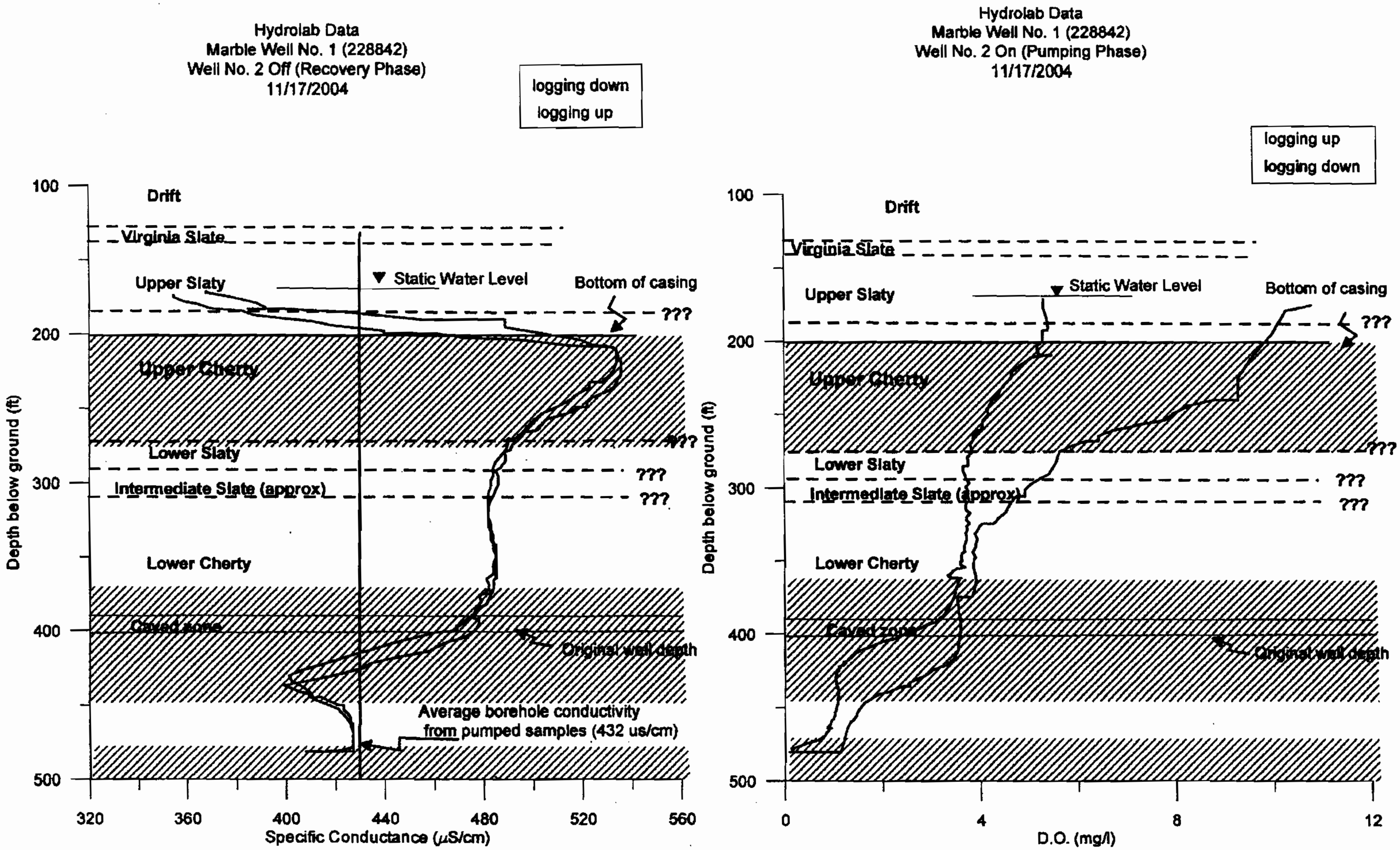

Figure 5. Specific conductance and dissolved oxygen profiles of the water column for Marble Well No. 1 (228842). Hachures indicate possible preferred flow zones.

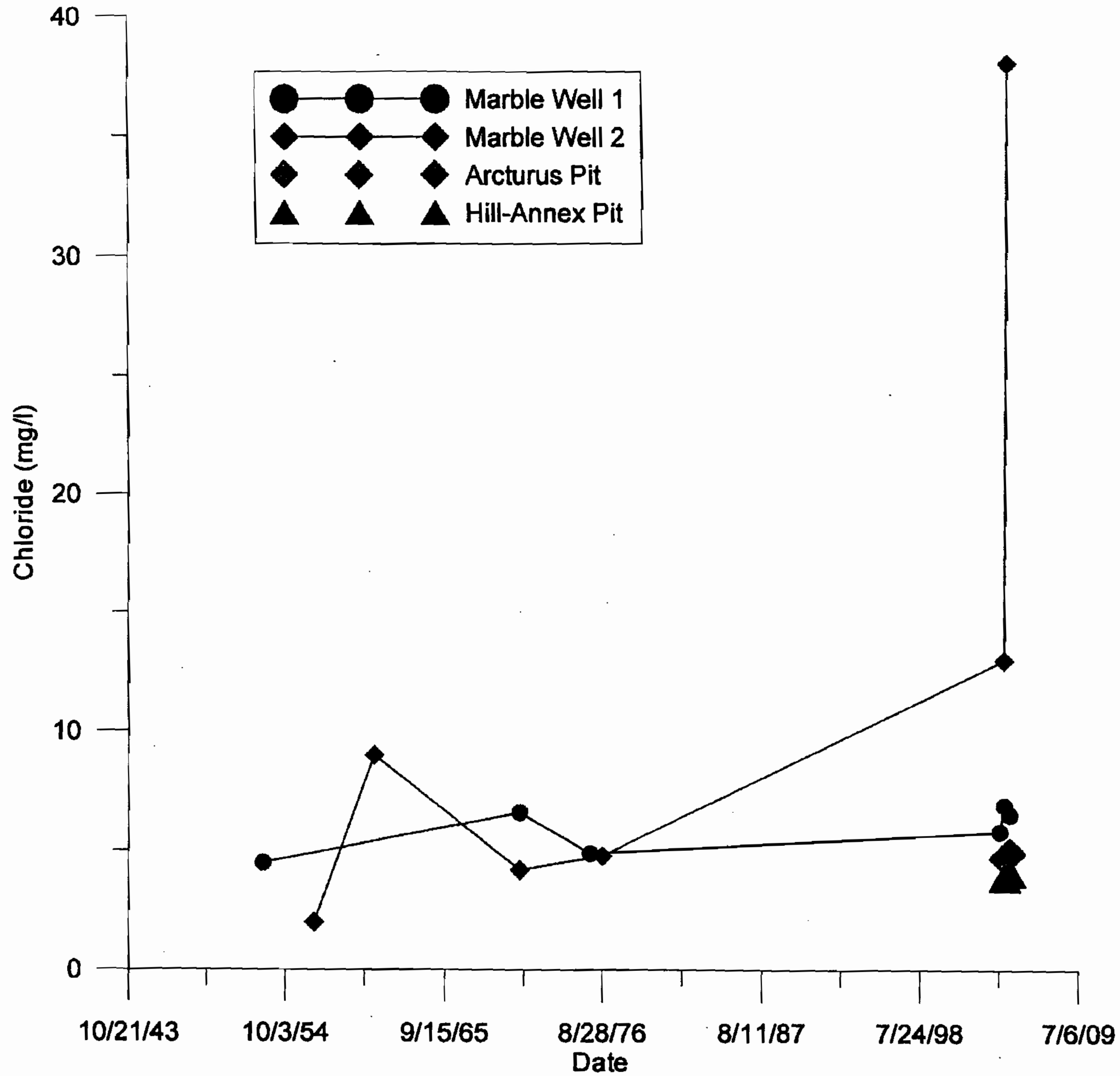

Figure 6. Chloride data through time.

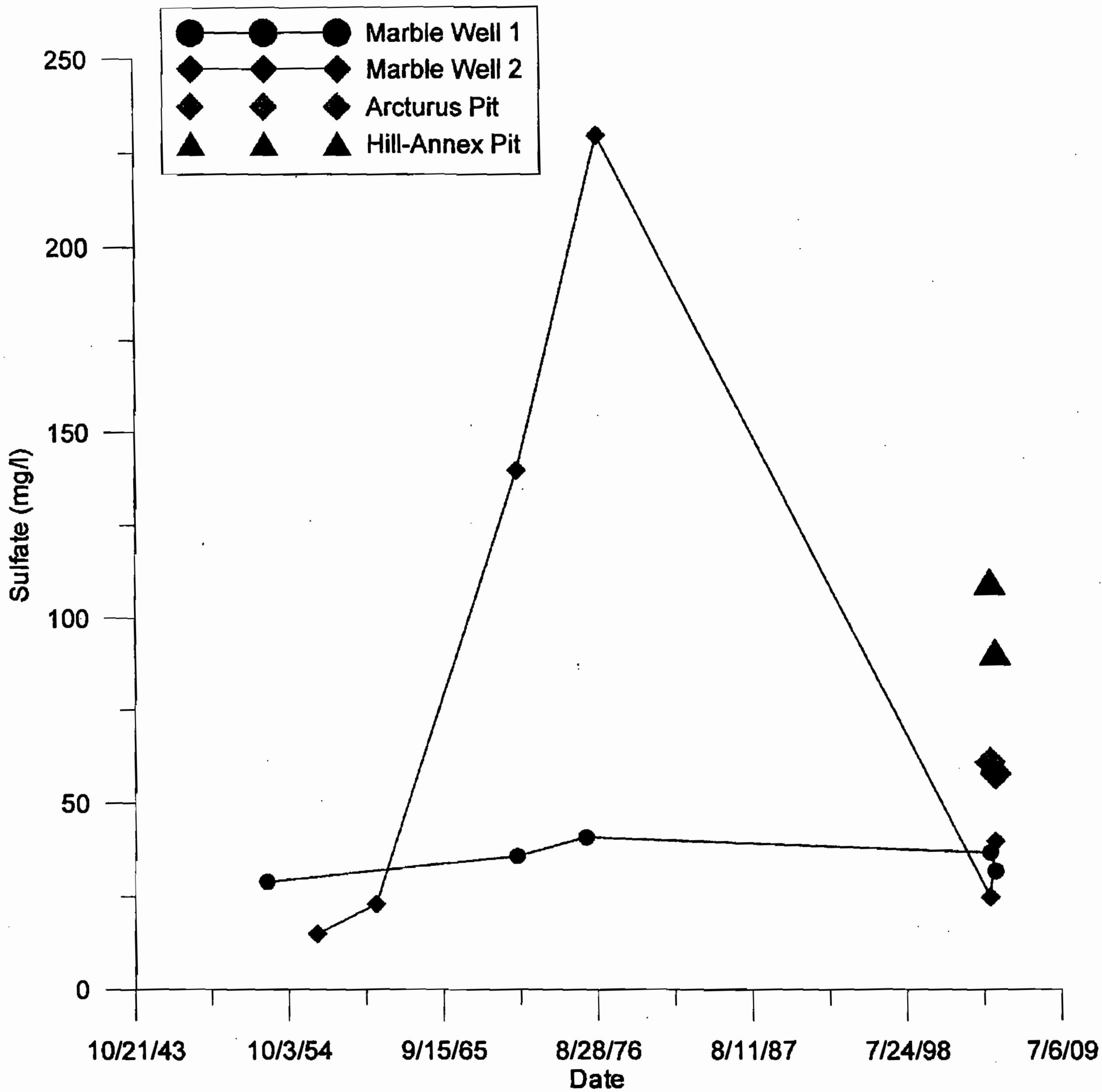

Figure 7. Sulfate data through time.

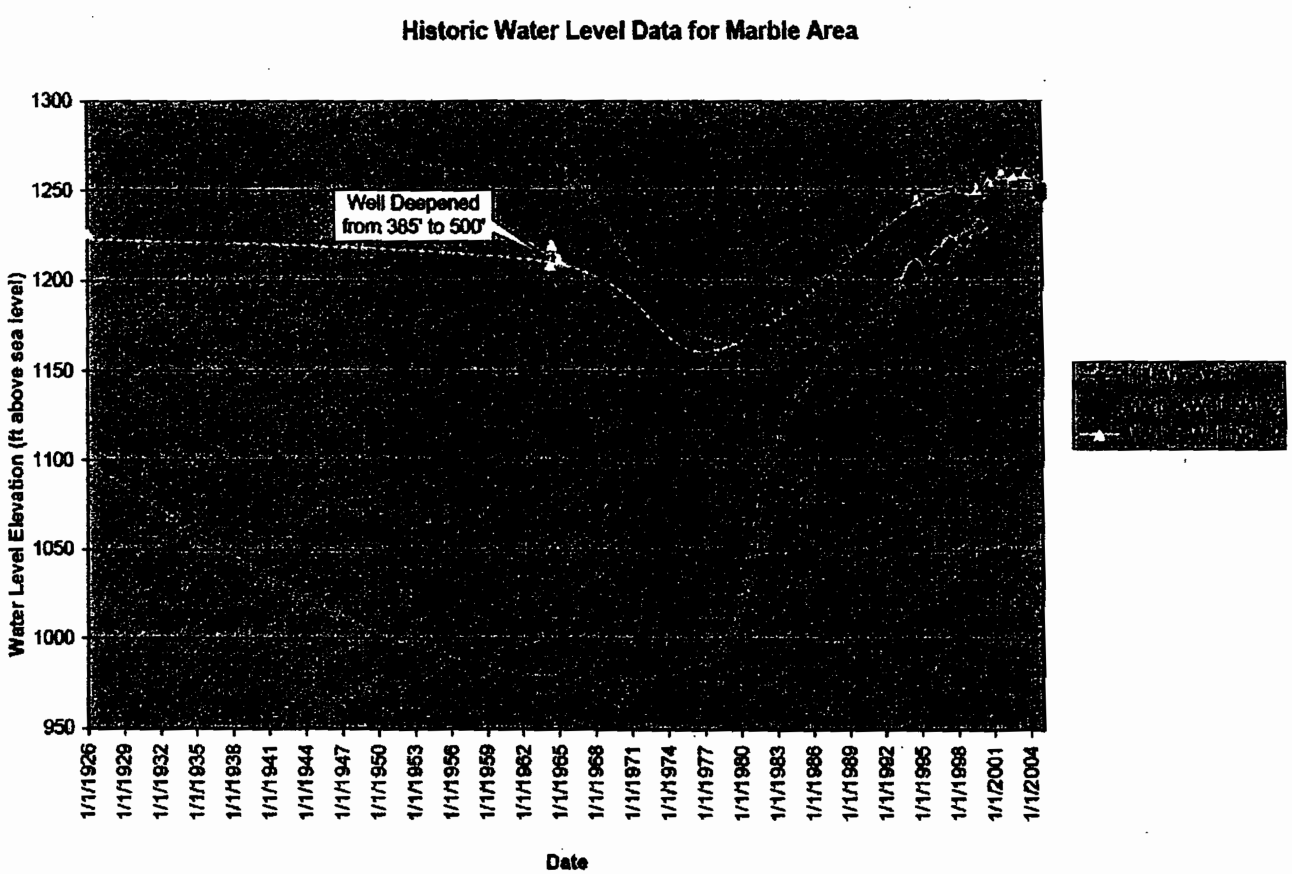

Figure 8. Graph of historic water level data for the Marble area. Historic pit water level data is estimated based on information from the city of Marble and pit bathymetry data. Well water level data is from 1) well construction records, 2) city maintenance records, and 3) Cotter and others (1965). Points represent actual data, whereas dashed lines represent the author's estimates.

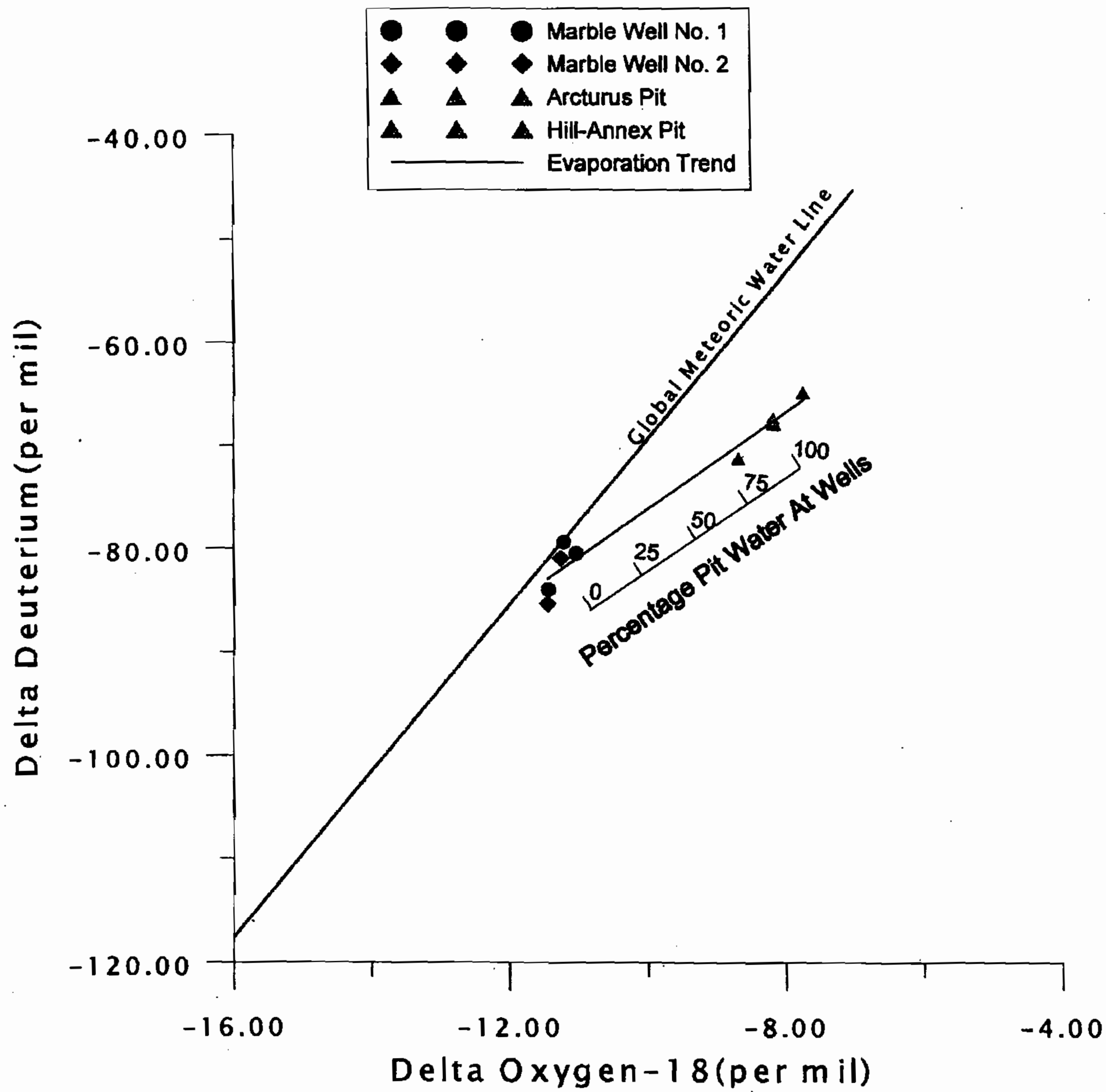

Figure 9. Stable isotopes of water.

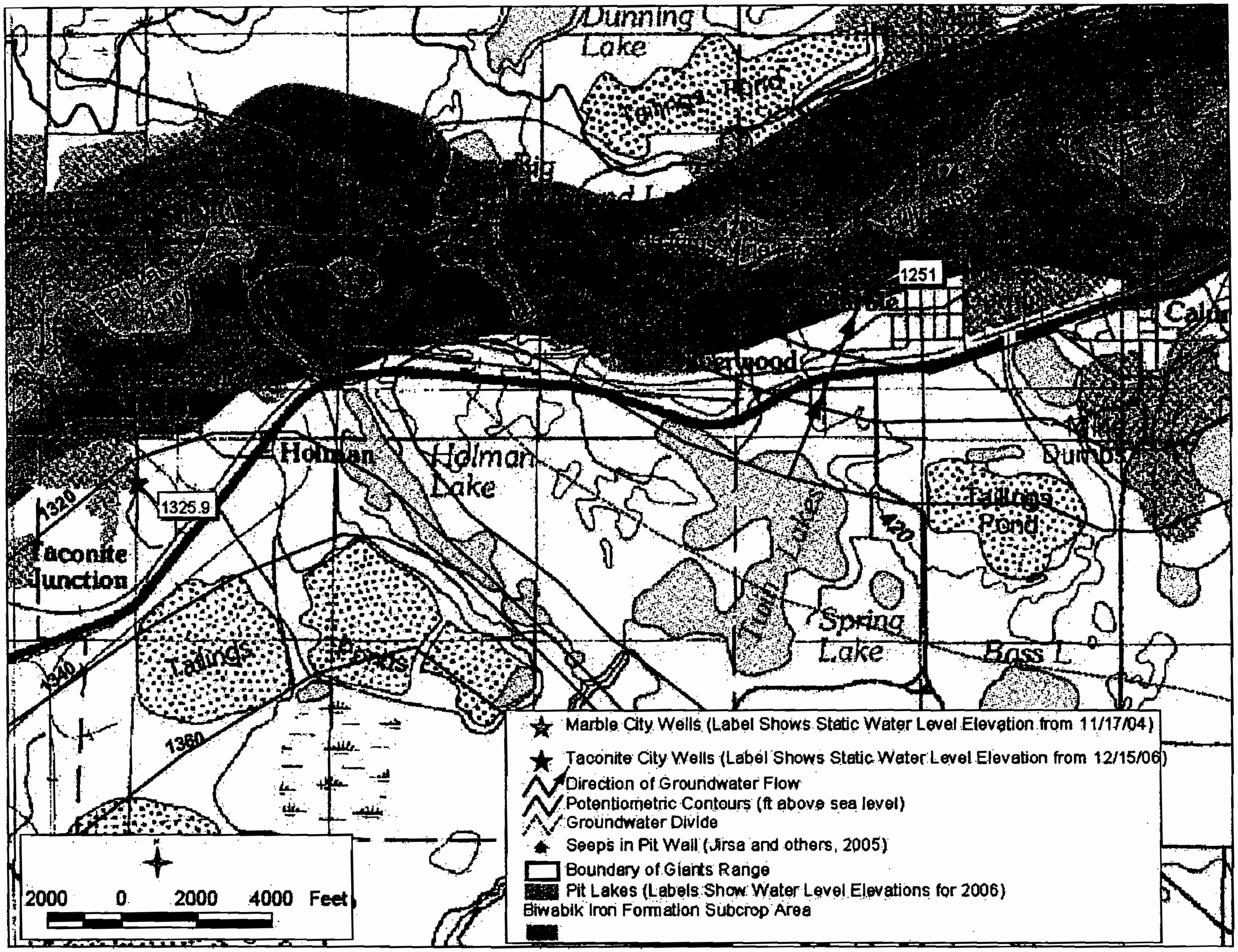

Figure 10. Groundwater flow direction in the Marble area.

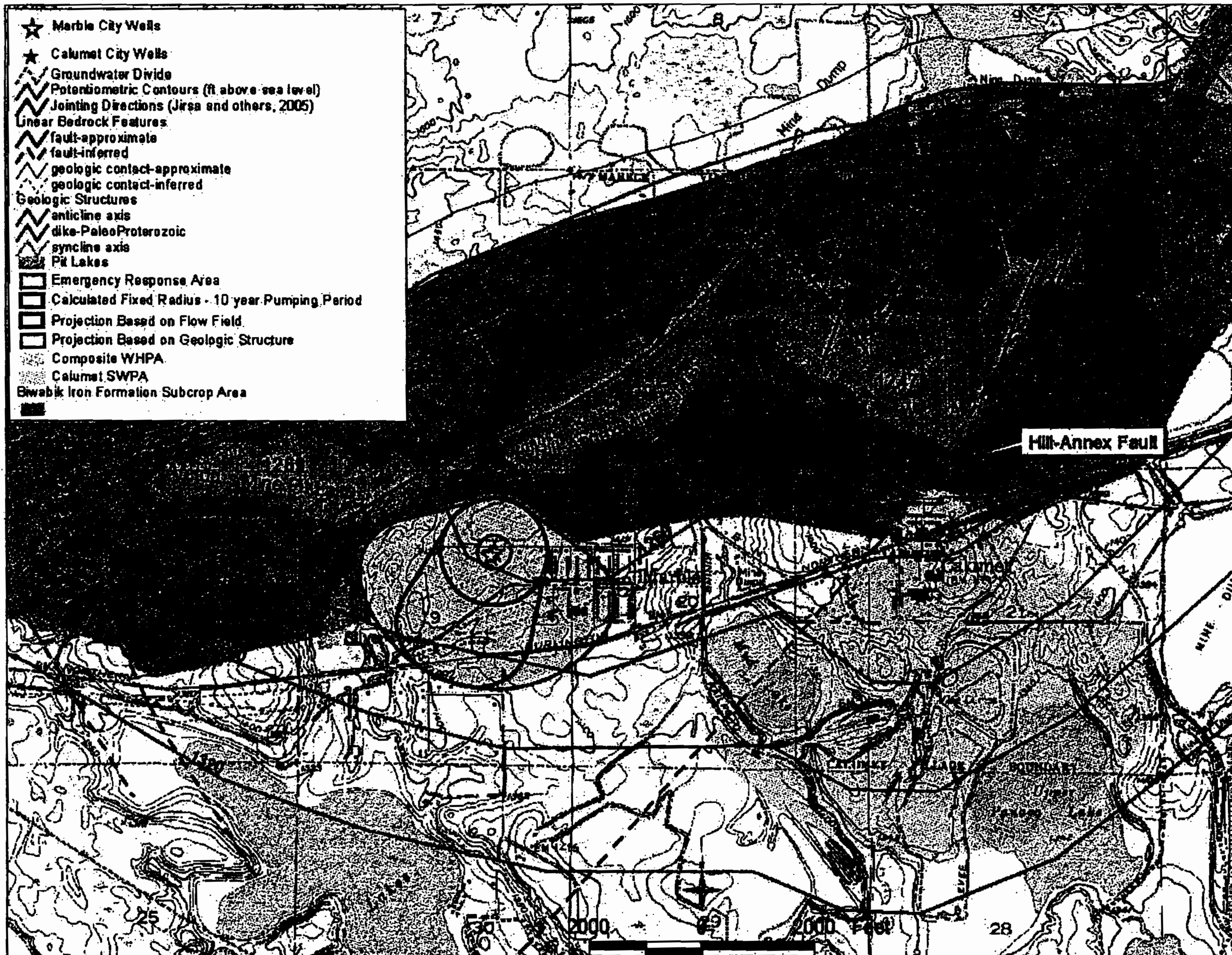

Figure 11. WHPA delineation procedure.

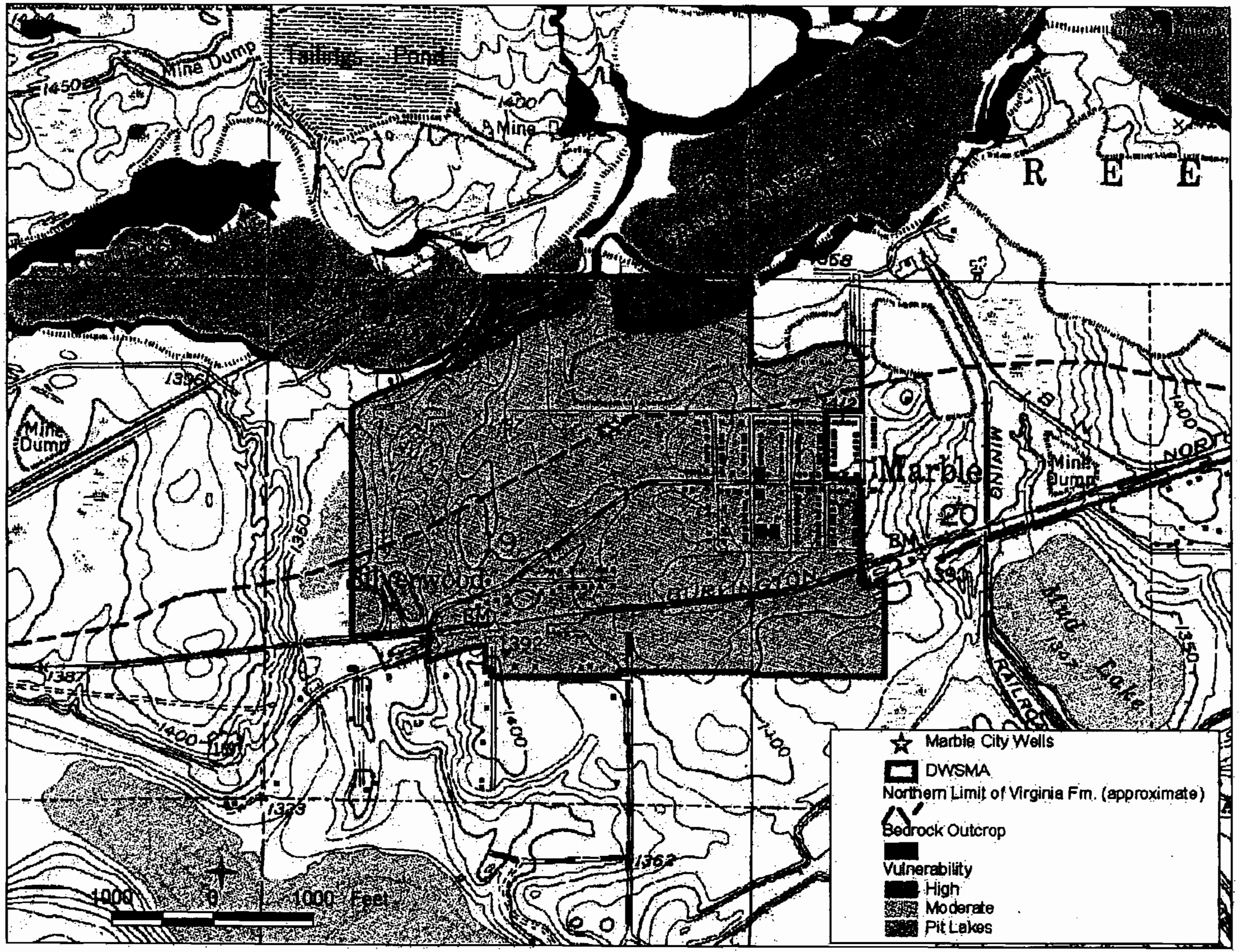

Figure 12. Vulnerability of the aquifer throughout the DWSMA.

Appendix III

Method Used to Estimate Transmissivity from Specific Capacity

Method used to Estimate Transmissivity

The method used to estimate transmissivity from specific capacity data is similar to that of Bradbury and Rotheschild, 1985, and Mace (2000) but with some differences. The method is described in some detail here.

Starting with a rearrangement of Sternberg's (1973) equation that relates specific capacity (Sc) to transmissivity (T), the duration of pumping (t) the well radius (r_w)and storativity (S) for a partially penetrating well:

$$Sc = \frac{4\pi T}{\left[\ln\left(\frac{2.25\,T\,t}{r_w^2\,S}\right) + 2 s_p\right]} \quad 1$$

Where s_p is the partial penetration factor defined base on the physical properties of the well and aquifer, L is the length of the screen portion of the aquifer and H is the aquifer thickness Brons and Marting (1961):

$$s_p = \frac{1-(L/H)}{(L/H)} \left[\ln\left(H/r_w\right) - G(L/H)\right] \quad 2$$

Where the function G is approximated by Bradbury and Rothschild (1985) using the following polynomial with 0.992 correlation coefficient:

$$G(L/H) = 2.948 - 7.363(L/H) + 11.447(L/H)^2 - 4.675(L/H)^3 \quad 3$$

Rearranging Equation 1 to solve for transmissivity and substituting for Sc in terms of the discharge of the well (Q) and the observed draw down at time t (s), Sc=Q/s:

$$T = \frac{Q}{4\pi s}\left[\ln\left(\frac{2.25\,T\,t}{r_w^2\,S}\right)\right] + \frac{Q s_p}{2\pi s} \quad 4$$

The second term in Equation 4 was solved directly from the draw down, discharge ,and the well construction and aquifer thickness information. The first term was solved iteratively with assumed values of storativity for confined (0.001) and unconfined (0.075) conditions.

References

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Sternberg, Y.M. (1973), *Efficiency of partially penetrating wells,* Ground Water, v. 11, No. 3, pp. 5-7.