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Wisconsin Groundwater Management Practice Monitoring Project No. 44

GROUNDWATER
Wisconsin's
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Wisconsin Department of Natural Resources

Water Resources Center
University of Wisconsin - MSN
1975 Willow Drive
Madison, WI 53706

FINAL REPORT

ON

ASSESSMENT OF GEOLOGIC CONTROLS ON GROUNDWATER FLOW AND DISTRIBUTION IN PRECAMBRIAN BEDROCK, CENTRAL WISCONSIN, USING REMOTE SENSING AND GEOPHYSICAL ANALYSIS

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EXECUTIVE SUMMARY

Although it did not provide a quick and reliable technique for the identification of zones of abundant groundwater in covered Precambrian bedrock, this project has contributed significantly to our understanding of the geologic factors which control groundwater distribution and flow in these rocks. A potentiometric surface map based on bedrock wells by Hutasoit and Davidson (1989) shows that groundwater heads vary from 1600 to 1000 feet in elevation with locally complex subpatterns. For the area of study, which includes Wood, Portage, and Marathon Counties, the potentiometric surface is a subdued version of the bedrock topographic surface and is broadly similar to the water table for all wells (Lippelt and Hennings, 1981; Batten, 1989). The complex bedrock topography suggests that local flow systems in the Precambrian bedrock are considerably smaller (1-5km) and shallower than the broad regional systems common to unconsolidated deposits and sandstone terranes (10-50 km). There appears to be excellent interconnection between bedrock and the overlying unconsolidated materials, despite local development of up to 30 ft or more of weathered clayey residuum at the Precambrian surface. Because of this connectivity the Precambrian bedrock appears to be part of an unconfined regional aquifer system, with considerable local complexity caused by topography, degree of weathering, and structural characteristics of individual rock units.

Preliminary publications from this investigation have dealt with: 1) the limitations of the remote sensing data technique (Davidson, and others, 1989a), 2) the merged-data methodology employed here (Davidson, and others, 1989b), and 3) the application of ground resistivity to the search for groundwater (Bebel,

1989). A summary article on the project is planned, and maps of the crystalline rock water table, thickness of unconsolidated materials, and elevation of crystalline rock surface are being prepared.

High quality data has been compiled on fractures in various bedrock units, and useable, but not well understood, ground radar data has also been obtained for several test areas. Further work on analysis of TM imagery and other remote sensing data sets appears warranted as does accumulation of high quality aeromagnetic and other regional geophysical data.

I. Statement of problem:

The purpose of this two year investigation was to assess the applicability of digital remote sensing data (Landsat Thematic Mapper) integrated with geology and geophysics in identifying areas of potentially high groundwater yield from crystalline rock wells.

A. Characterization of regional geology

The area selected for this study, most of Wood, Portage, and Marathon Counties, was chosen because of the availability of modern geologic mapping at the 1:100,000 scale of both bedrock (Brown and Greenberg, 1986; Greenberg and Brown, 1986; LaBerge and Myers, 1983) and Pleistocene geology (Attig and Muldoon, in press; Clayton, in press; Clayton, 1986). A large area of central Marathon, northeastern Wood, and northwestern Portage Counties is covered by very thin (0-20 feet) and deeply weathered surficial deposits. This area has the best potential of any area in the crystalline terrane of northern Wisconsin for remote sensing techniques being able to read through the cover and identify structural features in the bedrock. Because of the thin surficial deposits and the erosional edge of the Cambrian sandstone, this region is dependent on crystalline bedrock wells for most domestic and some municipal water supplies.

B. Groundwater occurrence and movement in Precambrian bedrock

At the onset of this study groundwater occurrence and movement in the Precambrian bedrock of central Wisconsin had not been extensively investigated. Figure la illustrates groundwater infiltration and flow in a typical unconfined aquifer system where all geologic units have similar hydrogeologic characteristics. Under these circumstances, groundwater flow paths would be regional in extent, with infiltration occurring through the Pleistocene and Paleozoic cover into Precambrian bedrock. However, over comperable distances flow rates within fractured Precambrian bedrock are known to be significantly slower, requiring hundreds to thousands of years, compared to flow rates within the overlying units which would occur at faster rates (10's to 100's of years). In addition, where clay rich residuum locally occurs at the crystalline rock surface, it is uncertain whether or how well groundwater would penetrate into the fractured Precambrian rock.

The results of the present investigation indicate that the flow model depicted in Figure la is unrealistic. First, results of this study suggest that although residual clays are locally present infiltration into the Precambrian is more widespread than previously anticipated. Secondly, flow systems within Precambrian bedrock are smaller than originally thought, probably restricted to zones of less than 5km width, and locally much less than that. Regional flow systems involving crystalline basement rocks are influenced by regional Precambrian surface topography, but the circulation is shallow and subject to strong influence of local topography, rock type, and degree of weathering. Finally, in at least one instance, it was determined that paleosol layers occurring at the top of the Precambrian do not appear to influence infiltration rates.

II. Statement of approach

The intent of this study was to integrate the results of visual interpretation of remotely sensed data with available geology and geophysics as a means to locate zones of highly fractured rock or anomalous moisture content that would have high potential for groundwater within Precambrian bedrock. These zones were to be characterized within each of the data sets and additional new areas identified. This merged data procedure for the identification of zones containing high groundwater abundance is an iterative process. It is based on the construction and refinement of a model involving location and characterization of structurally-controlled zones up to 10 km width and extending 100's of kilometers in length. (see initial grant proposal).

A. Remote sensing

The use of Landsat TM data was judged to be ideal for this particular project owing to the synoptic coverage it provided at 1:250,000 scale and because it also served as an excellent mapping base with 30m resolution. Aerial photography was also available for portions of the area at 1:2400 scale.

B. Geophysical data

Potential field geophysics (gravity and magnetics) were available for the entire area. It was anticipated that these digital data sets at a useable scale could be integrated on the computer with the TM imagery, thus providing a significant, computerized data set for use in the investigation. Moreover, it was anticipated that resistivity and ground radar surveys conducted as part of this study would further delimit the zones of abundant groundwater and verify the nature of linear features identified in the remote sensing phase.

C. Geological data

One of the reasons this study area was selected was the availability of recently published 1:100,000 scale bedrock and surficial geologic maps of the counties involved (Brown and Greenberg, 1986; Greenberg and Brown, 1983; LaBerge and Myers, 1983; Attig and Muldoon, in press; Clayton, 1986 and in press). Geological field investigations of two types were also planned. The first involved collecting detailed structural data from linear fracture zones and zones having high potential for groundwater identified in the remote sensing phase. An additional priority involved collection of as much data as possible on the fracture characteristics of bedrock units by examining outcrops identified on the county geologic maps. It was also proposed to examine the nature of the interface between Precambrian bedrock and the overlying units, either Paleozoic or Pleistocene. Results of these investigations were to be incorporated into a model which could be used to delimit additional zones favorable for high groundwater yield.

III. Analysis of Anticipated and Actual Results

A. Remote sensing phase

Data acquisition and analysis

Although problems of budget implementation and data acquisition forced a thorough revision of the entire project schedule (see Figures 2a, 2b), several worthwhile results were achieved. A Landsat TM image was ordered, processed at 1:250,000 scale and delivered in February, 1987. Regrettably, that image of the study area (April, 1985) was snow covered to a great extent, and therefore arrangements had to be made to obtain a snow-free image. The second image (June, 1986) was delivered in August, 1987, too late for significant field investigation during year 1 (7/86 - 6/87)--see Figure 3.

The suitable TM image was subsequently interpreted, and several major zones were delineated as having anomalously high moisture content in Precambrian bedrock. Interestingly, some of these zones trended nearly 90° across predominant structural trends; suggesting that some of these may be related to late structural features such as joint sets at high angle to regional foliation.

By July 1988, subscene images were generated from the Landsat TM digital tape at the Laboratory for Spatial and Cartographic Analysis at Northern Illinois University. These subscenes were then enhanced, manipulated (ratioed, principle component of analysis) and interpreted relative to their full scene counterparts.

Results:

Although major linear features were identified on the regional (1:250,000 scale) TM imagery, smaller segments of these large features could not be readily distinguished on the subscene images (Davidson and others, 1989a; 1989b). The exact nature of these large scale features is presently unknown, since no obvious correlation with known geologic features could be established. They may represent broad units of slightly more sheared or foliated rocks, with greater fracture density than adjacent lithologies. In light of what was learned in the ground-based phase of this study, the inability to interpret these broad TM anomalies suggests that the 1:250,000 scale is of little value in identifying structures relevant to groundwater resource analysis in this terrane. Linear features of the type described by Socha (1983) were identified on aerial photographs, but at a local scale that could not be correlated with the imagery.

B. Geophysical-geological integration phase

Data acquisition and analysis

As TM imagery was not available during the first field season (Figures 2a, 2b), a geological investigation was undertaken to determine fracture densities and orientations in areas of exposed Precambrian bedrock. Four areas were selected on the basis of geologic criteria and studied in detail by measuring orientation and density of fractures. A reconnaissance fracture study of typical Precambrian exposures throughout the three county area was also conducted during the summer of 1987.

Analysis of the gravity and magnetic data involved obtaining tapes of the digital information from two different sources. These tapes were then programmed to be input together with the remote sensing imagery on an image processing computer system. Delays were encountered, in obtaining the data and because of the extensive programming time required to input the data into the computer system. This work was carried out during the summer of 1988.

Two types of on-ground physical investigations were also carried out during the summer of 1988. The first of these was a series of ground penetrating radar surveys conducted over areas that had undergone structural mapping the previous year and other areas of known geology. The second involved resistivity surveys, again conducted in areas of known fracture related water occurrences.

Results:

Structural analysis of the areas investigated indicate that certain types of geological units display higher fracture densities in diverse orientations per unit area than others, and are thus more suitable for groundwater infiltration and movement. Typically, units such as amphibolite (chlorite-horneblende schist) and metavolcanic rocks have extensive closely spaced (1 to 10 cm spacing) and interconnected fracture systems (Figure 3a). Intrusive igneous rocks (granites and basalts) tend to be more massive (fracture spacing .5 to 5 m) and have but a few preferred fracture orientations (Figure 3b). An example of the fracture orientation results from a detailed study along the Wisconsin River bed in Port Edwards is shown in Figure 5. Quantitative fracture data is available upon request (see also, Davidson and others, 1989a).

Computer analysis and integration of the potential field geophysical data did not prove to be practical because of limitations of the available data. Suitably detailed aeromagnetic data covered only the northern one-eighth of the study area. Although the gravity data covered the entire area, the nature of data collection points (10 km grid) was not meaningful when compared with the 30m grid provided by the TM data. Moreover, it was determined that the potential field geophysical data could not be mathematically manipulated on-line on the computer system. Thus, it was useful only as a qualitative guide to interpreting the geology.

Figures 6a and 6b provide examples of ground radar surveys. In general, this technique proved to be unsuccessful in all areas tested, mainly because of the high abundance of clay minerals in the residual soils and weathered glacial deposits (M. Lemcke, Wisconsin Geological Survey, personal communication). The survey in Port Edwards (fig 5a) appeared to delineate the top of bedrock by a strong reflection. This surface could be directly observed in the river bank, providing ideal calibration of the radar profile. However, variation in fracture density and porosity of the bedrock units which could also be observed in outcrop, could not be positively identified from the profile.

The profile shown in figure 6b was taken in an area of fractured granitic gneiss overlain by 1-2 meters of Cambrian sandstone in central Wood County. The log shows some signals which might be interpreted as the undulating surface of the gneiss, but the signal is sufficiently attenuated by clay shale layers in the sandstone, that drilling would be necessary to calibrate. Fifteen other traverses in areas of known geology produced similarly uninterpretable or very uncertain results. At this time we conclude that the ground penetrating radar is a technique that warrants further investigation but will probably only prove useful in conjunction with other techniques which will provide independent data for interpretation.

Two resistivity surveys were run in conjunction with this study. The first of these was over an area near the Junction City municipal well in Portage County. The survey was run normal to a linear topographic low containing an intermittent stream. This feature is typical of the local scale lineaments observed by Socha (1984) in adjacent Wood County. This lineament was selected for study because of the proximity of a producing well, the conclusions of Socha (1984), and the knowledge that the driller chose the site in part based on the presence of the lineament. Vertical electrical soundings along a traverse crossing the lineament showed decrease in apparent resistivity in a zone 6 to 9 m. wide which coincided with the trace of the feature (Bebel, 1989). Bedrock at this site is metamorphosed Precambrian volcanic rock, a typical lithology throughout the three county area. The resistivity decrease is interpreted to represent increased water content and therefore greater conductivity probably caused by intense local fracturing within the narrow zone underlying the axis of the lineament.

Recent work at the Junction City site by WGNHS has included drilling of a 300 ft. core and downhole logging of several nearby wells. The borehole resistivity logs taken in test wells adjacent to the lineament all show a low resistivity above 50 ft. increasing with depth. The core shows an intensely weathered and fractured zone to 50 feet, with moderately fractured and weathered bedrock to around 100 feet, with relatively fresh and unfractured rock below this point. Preliminary results from the Junction City investigation suggest that most of the water produced from the crystalline bedrock comes from the upper weathered zone where numerous open fractures exist. The resistivity anomaly is probably caused by a narrow zone where high fractures persist to a greater depth. Although the Junction City site is still under investigation as part of another WGNHS research project, we suggest that this is probably a typical example of a successful high-capacity well which takes advantage of structural conditions in the bedrock that are identifiable from a combination of aerial photo interpretation and ground geophysics.

Another resistivity survey was conducted in northeastern Marathon County near Eau Claire Dells Park. In this case the profile crossed the contact of the Wolf River Batholith with highly fractured metavolcanic rock. The volcanic rock is interpreted to be within a major shear zone (LaBerge and Myers, 1983). The resistivity survey again identified the change in rock type by a decrease in resistivity in the more fractured material. Although rocks of the Wolf River batholith and other granites abundant in the three county area are jointed (Figure 4b), they do not in general have the pervasive interconnected fractures typical of the metavolcanic rocks.

Neither of these tests used the azimuthal resistivity technique which would also identify the direction of the dominant fractures. A test of azimuthal resistivity is planned for the Junction City site.

C. Groundwater measurement phase

Analysis:

In 1988 the original research plan was modified to include a reconnaissance investigation of groundwater-flow systems within Precambrian bedrock based on Geologic Logs and well constructor's reports available at the Wisconsin Geological and Natural History Survey. This analysis was intended to provide at least a broad scale understanding of the hydrogeologic regime which could be refined by more precise and detailed studies in the future. Records for over 3000 wells cased into Precambrian bedrock within the three county area were examined, and a map of the potentiometric surface was produced (Hutasoit and Davidson, 1988). In addition, cross sections were constructed from the map to help delineate the approximate size and shape of local and regional flow patterns.

Results:

A generalized potentiometric map based on all available Precambrian well data (through 1987) in the three county area is shown in Figure 8, (Hutasoit and Davidson, 1989). A more detailed map at the scale of 1:100,000 was produced and will be made available. This map clearly demonstrates that the regional hydrologic gradient slopes to the south and toward the Wisconsin River, but with complex sub-patterns. Within the central part of the area overburden thickness appears to have minimal effect on this gradient. The close relationship to bedrock topography and consequently to bedrock lithology and structure suggests that groundwater flow within Precambrian bedrock probably occurs in small isolated systems, often as narrow as 1-2km (Figure 8, 9). These local systems appear to be lithologically or structurally controlled, and discharge in topographic lows.

Finally, from the available data it appears that there is excellent connectivity between the Precambrian bedrock and overlying units, even in areas where weathering profiles exist. The Junction City drill core and numerous cores throughout the three county area also suggest that abundant open fractures are restricted to the upper few tens of feet of the Precambrian rock. Thus, flow patterns typical of deep unconfined aquifers do not appear to be applicable in Precambrian bedrock. Rather, a model incorporating a multi layer unconfined aquifer appears to be more realistic. Water movement takes place in a complex aquifer made up of highly variable residuum overlying a variably fractured upper zone of bedrock. The potential for developing a good water supply depends on rock type, depth of weathering, intensity and orientation of fracturing, and most importantly on local topography on the solid bedrock surface.

IV. Keys and constraints in the successful application of investigated technologies

Although this investigation has not yielded a simple "quick-fix" methodology for assessing groundwater potential in areas of near surface Precambrian bedrock, it has determined that several techniques are <u>not</u> effective. Ground penetrating radar may be useful in rare cases where dry sandy soil overlies bedrock, but it is generally not effective in a geologic environment dominated by clay rich residual soils and weathered glacial till.

Gravity and magnetic data collected at the density normally used for regional geologic studies is useful only as a guide to regional structural analysis. Detailed magnetometer and gravimeter surveys of small areas have been used to locate fault zones based on density contrast or magnetic expression, but these are site specific techniques not widely used. They may have potential use in site specific investigations when combined with other geophysical techniques. Obtaining regional potential field data of sufficient quality to merge with TM data would be desirable but very expensive and probably not cost effective for this type of study. Although subscene analysis of Landsat imagery works well in some geologic environments, particularly arid regions, it does not appear to be a feasible method for identifying water bearing structural zones in highly vegetated, glaciated terrains such as northern and central Wisconsin.

What works? Ground resistivity appears to be an effective tool for water exploration in fractured Precambrian bedrock. One disadvantage is that resistivity surveys are time and labor intensive and can be costly. It is therefore recommended that resistivity surveys should be used following appraisal of all geologic data available (geologic maps and borehole information) and an analysis of topographic lows on both the land and bedrock surfaces throughout the area. The acquisition of additional detailed structural information such as fracture geometry and fracture abundance in various geologic units would also be extremely helpful.

It is suggested that future research involve further analysis of remote sensing data (aerial photographs and infrared photographs) at scales of approximately 1:24,000-1:60,000. Preliminary examination of high attitude black and white and color infrared photos at the 1:40,000 scale has shown promise. At these scales linear features can be observed which are certainly geologically meaningful but too local to be identified on TM imagery and invisible on regional geophysical surveys.

A thorough testing of the azimuthal resistivity technique also appears warranted. This technique has proven successful in other areas in identifying preferred directions of fracture porosity, and holds great potential for identifying the small scale fracture systems which control local flow systems. It is, perhaps, too early to completely write off ground radar as a water prospecting tool. Additional testing should be done using this method in conjunction with drilling and resistivity techniques in site-specific investigations. In areas of sandy overburden and a low water table, radar should be useful to delineate the bedrock surface if properly calibrated. A computerized methodology for the determination of topographically low features from either digital data or digitized map data could prove extremely helpful in determining potential zones of groundwater yield within Precambrian bedrock. A definitive investigation of the nature of the crystalline bedrock surface at the contact with the overlying Paleozoic or Pleistocene units should be done. The distribution of weathered material at this interface should be more thoroughly studied with respect to influence on infiltration rates and hydraulic conductivity of this critical and apparently highly variable layer.

V. Application to resource definition and management:

This study represents a first effort at defining the geologic factors which control the occurrence and movement of groundwater in the near surface crystalline bedrock of central Wisconsin. Wood, Portage, and Marathon Counties are the largest area of the state where the crystalline rock aquifer is an important and often the only source of potable water. Batten (1989) concluded that 85% of the water wells in Wood County use the Precambrian aquifer. Similar geologic conditions exist in parts of northern Clark County and eastern Eau Claire County, as well as in scattered areas of the northern counties where surficial materials are thin. The three central counties along the Wisconsin River are, however, the most populous and consequently subject to the most intense development and agricultural activity.

Much progress has been made in understanding groundwater movement and contaminant transport in the sand and gravel aquifer of the central sands region and the Wisconsin River Valley. It should be obvious from the preceding discussion that we are now looking at a much more complex situation. Although the principal problem up to this point has been obtaining adequate water supply, contamination of the crystalline rock aquifer could present serious problems. Movement of contaminants is now predictable and in most cases manageable in the more homogeneous sand and gravel aquifer, but given the inherent complexity and the primitive state of knowledge regarding the details of local flow systems and contaminant transport in the crystalline rock, we suggest that contamination problems would be difficult and costly to define and remedy.

From a management perspective we consider that this study is only a beginning, and that much more research needs to be done. Intelligent land-use planning and water resource management in this and all other areas of the state underlain by near-surface crystalline bedrock will depend on our development of effective methodologies for evaluating and modeling local flow systems and movement of pollutants in this geologically complex aquifer system.

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LIST OF FIGURES

Figure 1a

Idealized Cross-Section of Study Area
Central Wisconsin

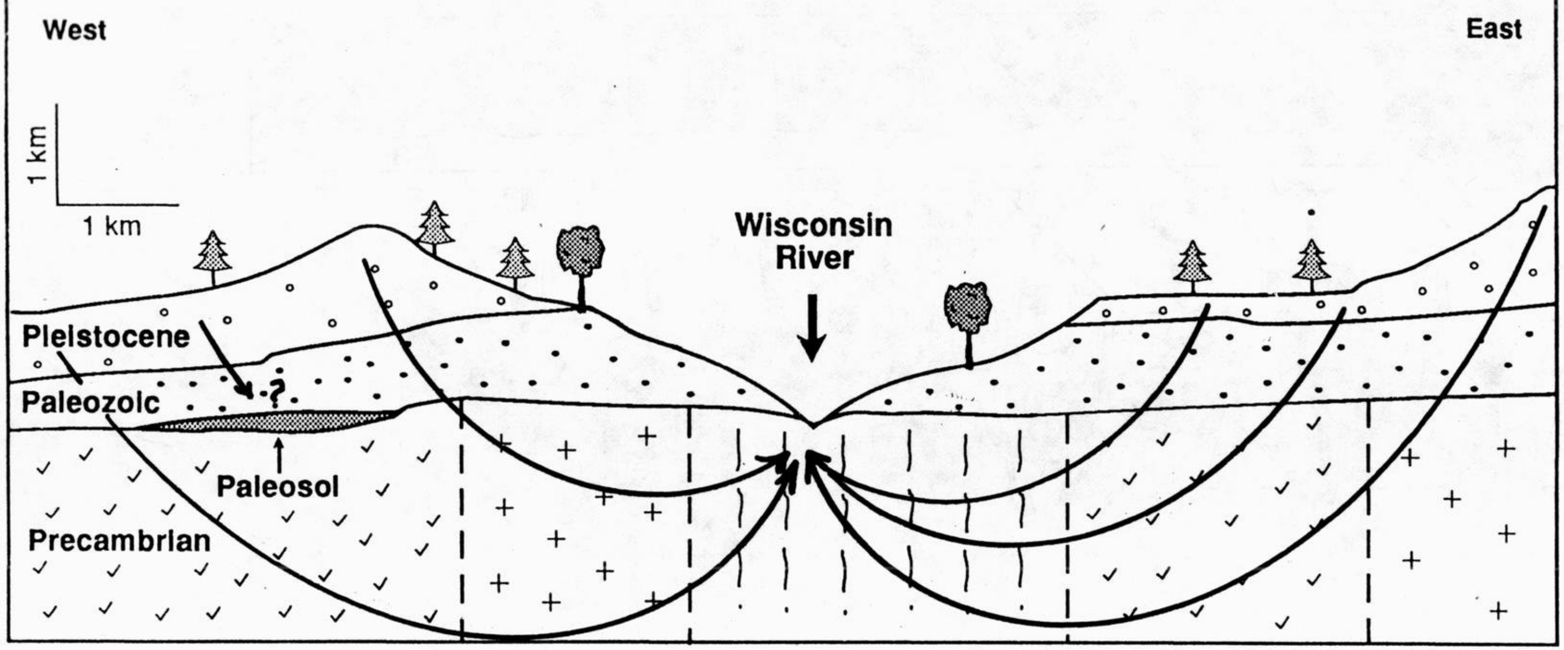
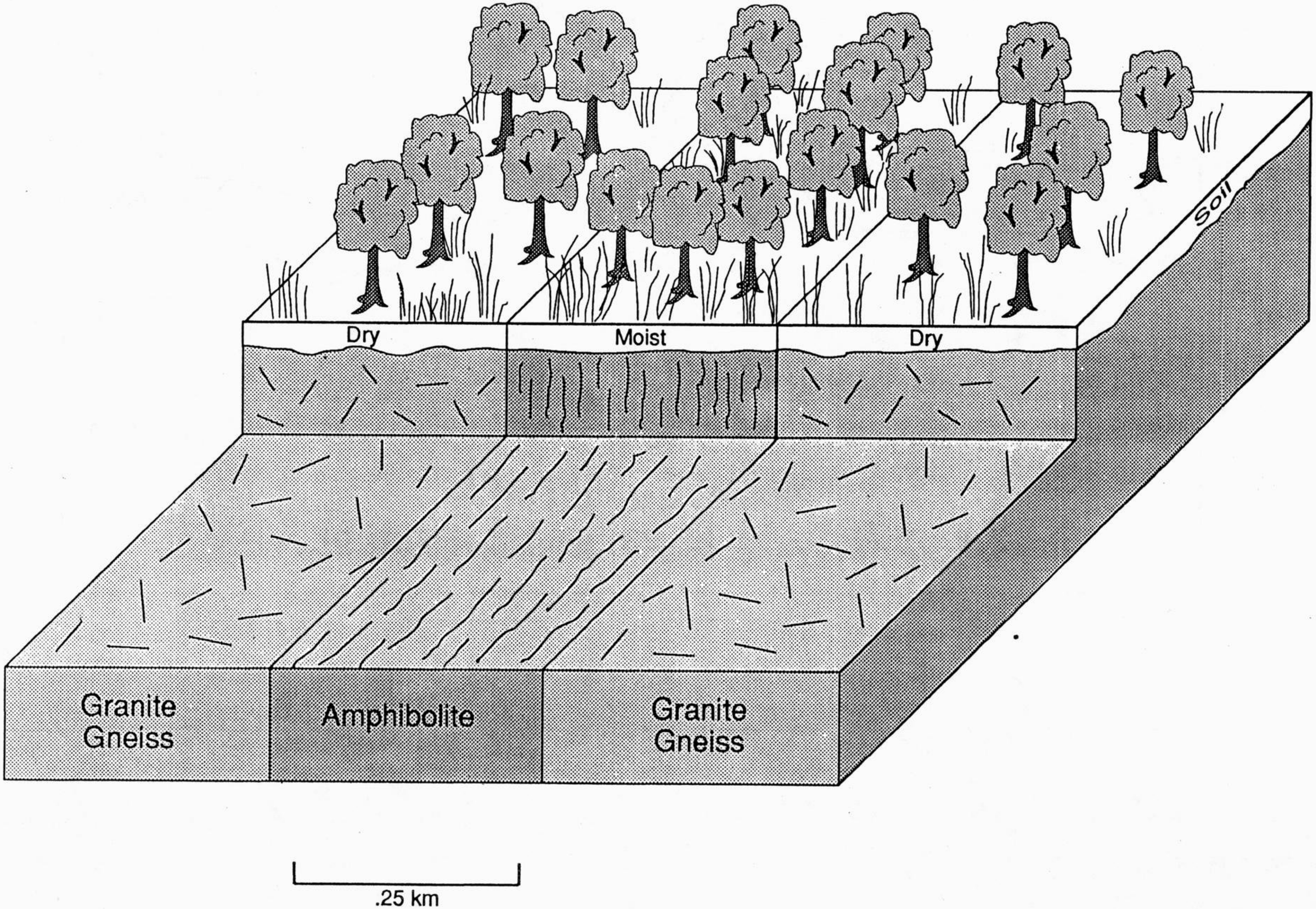


Figure 1b

Lithologic Control of Infiltration



Original Plan

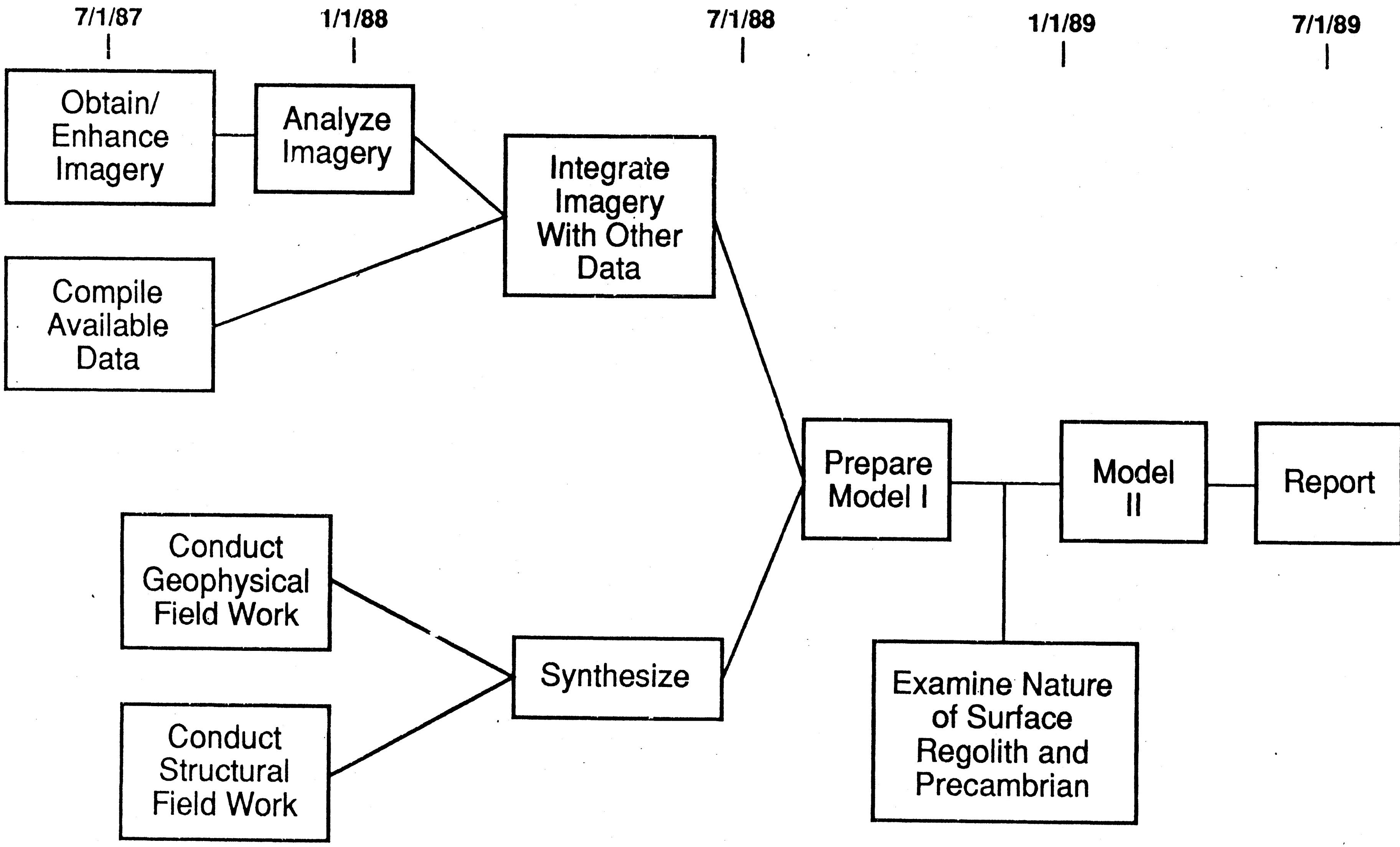


Figure 2a

Actual Plan to Date

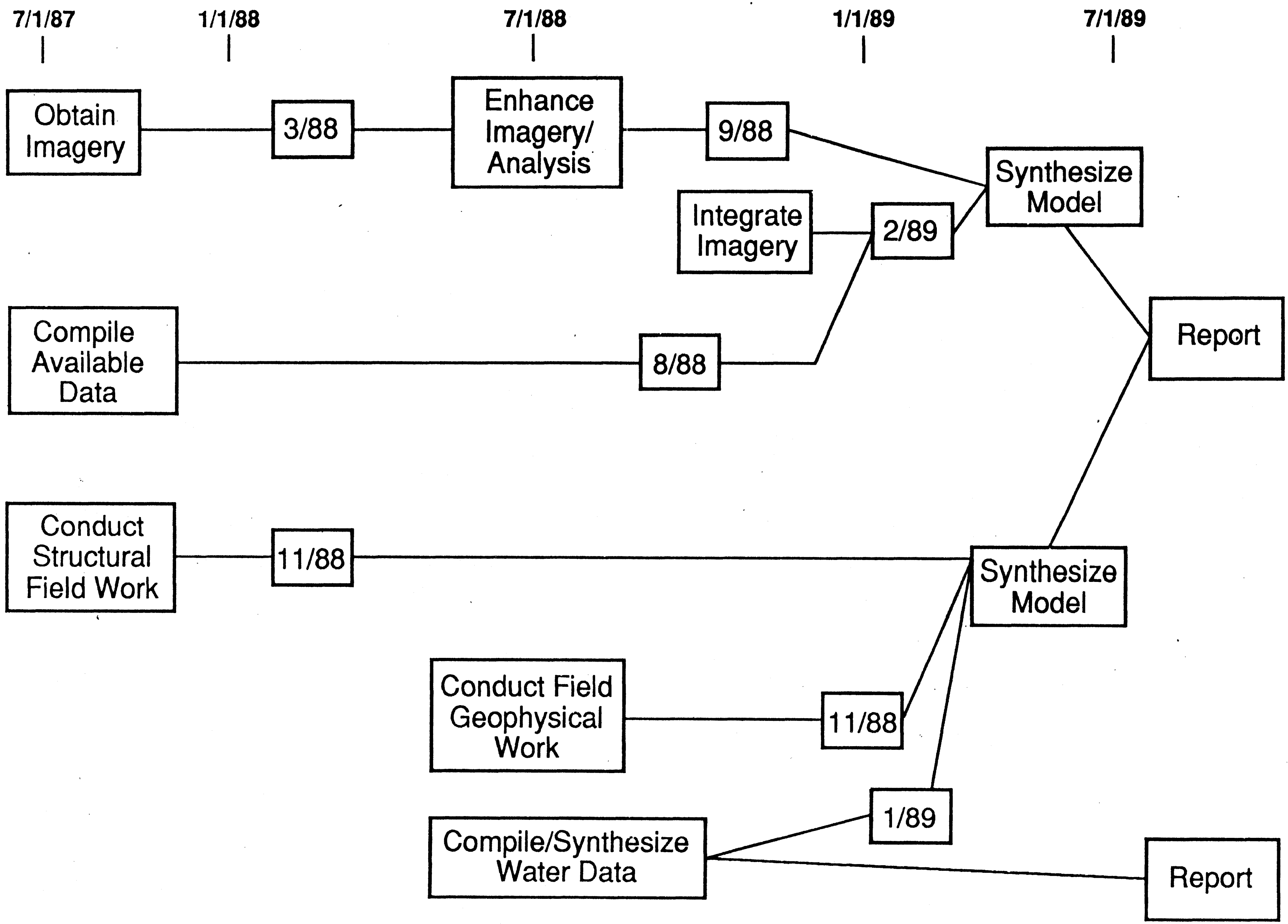


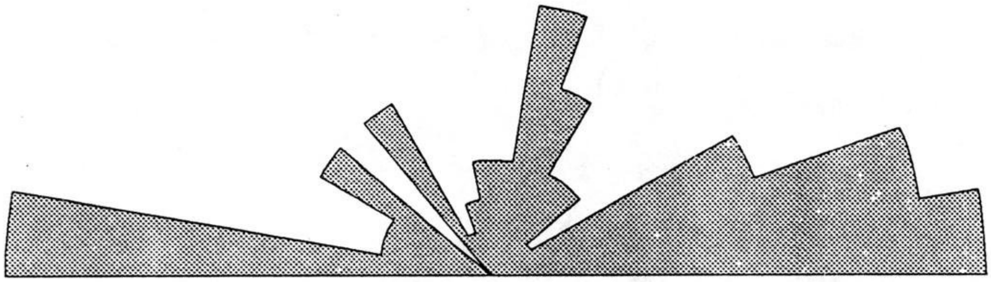
Figure 2b

Figure 4a. Typical highly fractured and jointed Precambrian metavolcanic rock, Marathon County.

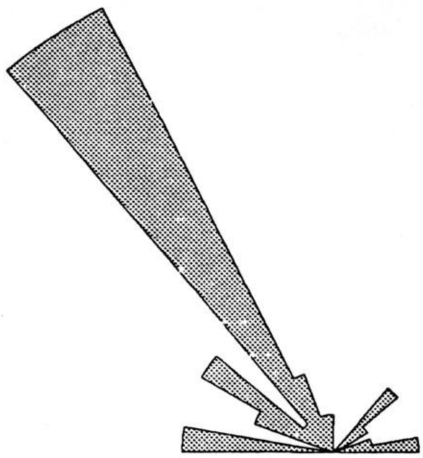
Figure 4b. Typical Massive jointed granite of Wolf River Batholith at Jordan Pond east of Stevens Point, Portage County.

Figure 5.

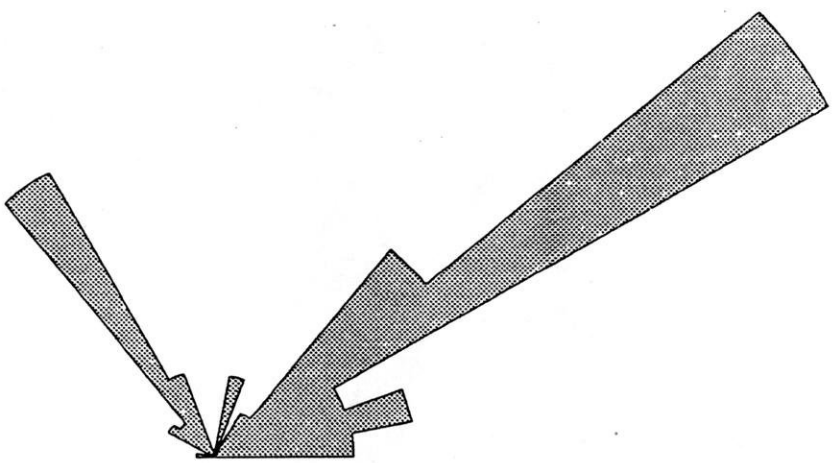
Joint Analysis
Wisconsin Rapids



4 units Chlorite Schist n = 86



4 units Tonalite Gneiss n = 33



4 units Granite Gneiss n = 109

Resistivity
Junction City, Wisconsin

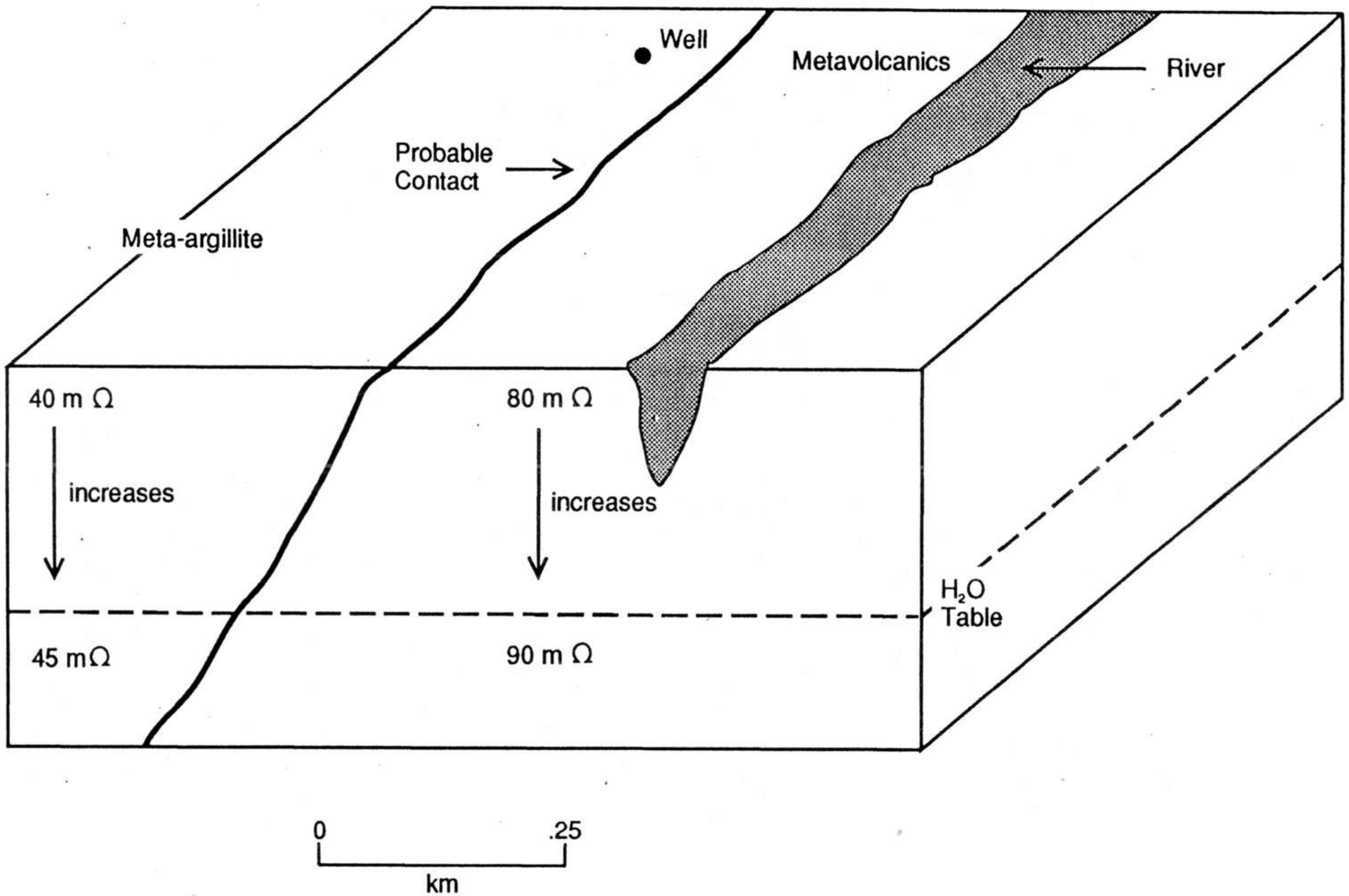


Figure 7.

Figure 8.

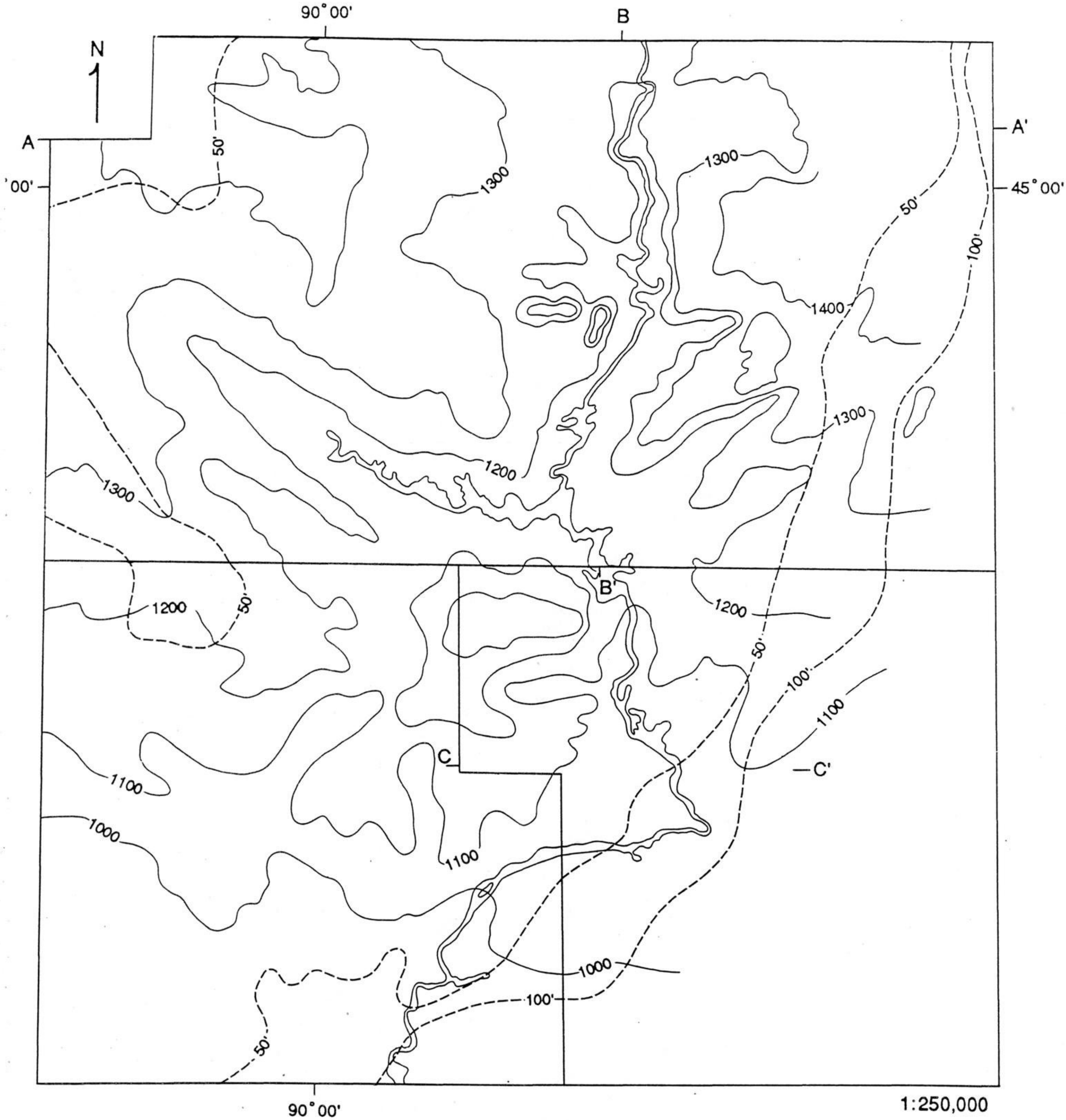


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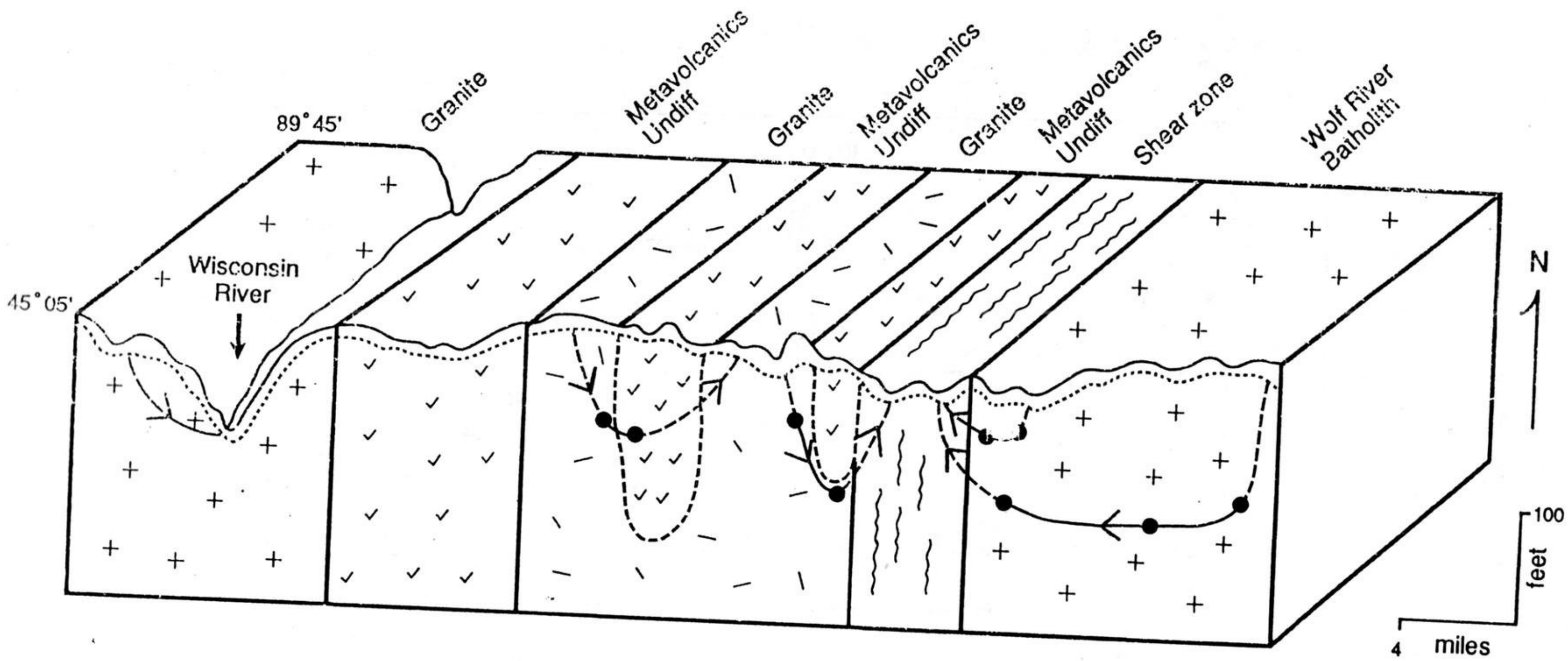
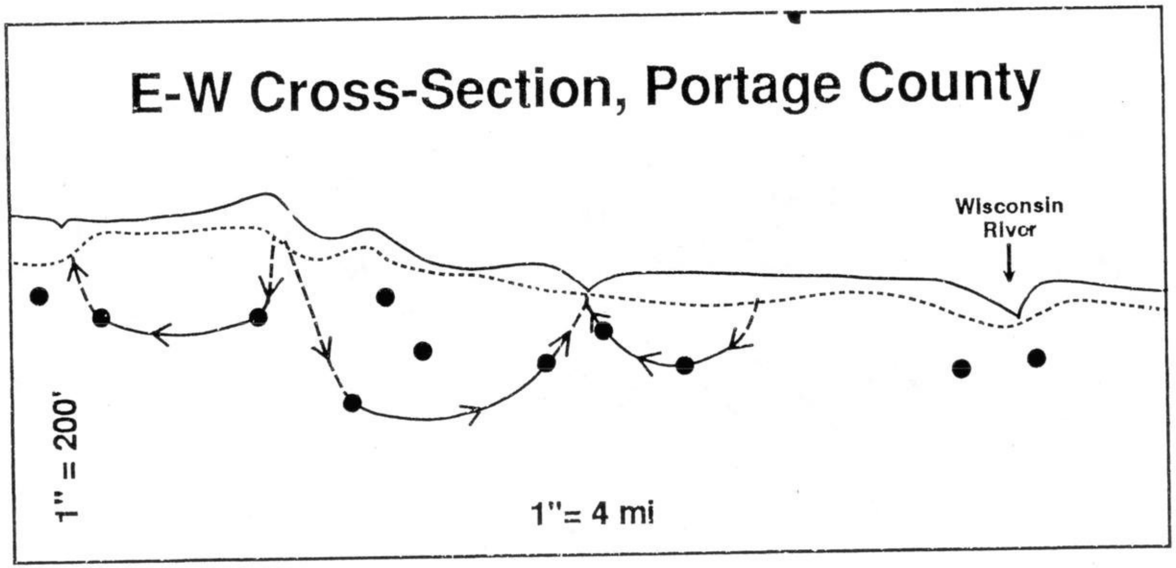
Figure 9.



E-W Cross-Section, Marathon County

Figure 10.



ASSESSMENT OF MERGED REMOTE SENSING AND GEOPHYSICAL TECHNIQUES USED IN GLACIATED PRECAMBRIAN BEDROCK, WOOD, PORTAGE, AND MARATHON COUNTIES, WISCONSIN

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SUMMARY

This project was designed to predict significant groundwater sources within Precambrian crystalline bedrock for an area in central Wisconsin covered by up to 100m of Paleozoic sedimentary and Pleistocene glacial units. The identification of thoroughgoing zones (up to 10km wide) from Landsat TM imagery at 1:250,000 scale. These zones are believed to result from a variety of bedrock structures, including shear zones, foliated units and fold structures, thought to be favorable groundwater hosts.

The zones were to be defined further by merging and analyzing available potential field geophysical data with landsat imagery, as well as field checking for the presence and nature of geologic structures associated with the lineaments. Resistivity and ground radar surveys were attempted in order to better determine the scale of the zones. Finally, results of the study were to be correlated with known well production in order to build a quantified, iterative exploration model.

To date, Landsat TM imagery has been processed, enhanced and interpreted. However, it is difficult to interpret linear zones exhibiting high moisture content from three band (1G, 2R, 3B) color composite, ratio, or principle component images. Nevertheless, field studies of bedrock fractures and foliation clearly discriminate major differences in trends, lengths, and densities among rock units (e.g. granite gneiss-amphibolite) or between sheared and unsheared phases of the same unit (e.g. metavolcanics). The widths of structurally favorable zones having high infiltration potential are on the order of 1-2km wide.

Of the potential field data available, only gravity provided complete coverage of the area. Unfortunately, survey station spacings were sufficiently large (1-1.5km) so that interpretation results were meaningful only at the regional and not prospect scale. Additionally, ground radar surveys proved useless owing to the high component of clay minerals in either the glacial cover or local bedrock paleosols. Resistivity measurements show promise in predicting zones of high water content in Precambrian bedrock, again from 1-2km wide zones.

Analysis of data from over 2,000 wells in Precambrian bedrock from the 18,000km^2 study area has confirmed the presence of relatively narrow (1-2km) cells having high groundwater flow as well as recognition of effective groundwater infiltration between Precambrian bedrock and the overlying units, despite local paleosols in the former. The hydraulic potential of the area has been determined and the flow within the "cells" has been correlated with mapped geologic and structural units.

Owing to the scale of identified zones of high groundwater flow in bedrock, it is anticipated that other remote sensing data may be more appropriate for exploration, particularly near IR photographs or radar imagery. In addition, it will be necessary to further investigate the relationship between regional drainage patterns and bedrock structures in order to establish drainage controls in areas of limited (<20m) glacial cover. If successful, automated methods for the detection of linear/planar features from digital elevation models may provide a fruitful approach for the identification of groundwater-rich zones in areas of glaciated Precambrian bedrock.

MERGED-DATA REMOTE SENSING ANALYSIS IN THE DETERMINATION OF GROUNDWATER AVAILABILITY IN PRECAMBRIAN BEDROCK, CENTRAL WISCONSIN: A LESSON IN FLEXIBILITY

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A research methodology was developed for the determination of groundwater abundance in Precambrian bedrock in an area of central Wisconsin including parts of Marathon, Wood, and Portage Counties. The exploration model was based on the assumption that groundwater flow occurs primarily in structural zones of up to 10km width which would be detectable on remotely sensed (Landsat) imagery.

Our initial plan was to follow the sequence of: 1) obtaining and enhancing Landsat imagery at 1:250,000-scale; 2) merging the imagery with available geology and geophysics; 3) interpreting the imagery for groundwater-rich zones; 4) field checking interpretation results; and 5) performing follow up ground-based geophysics (radar, resistivity) to verify the remote sensing.

As a result of delays in obtaining and processing imagery, it became necessary to modify our research procedure to: 1) field examination of fracture densities in Precambrian bedrock based on ground geology; 2) conduct an assessment of the hydrogeologic regime in the area; 3) conduct Landsat imagery enhancement and interpretation; 4) implement ground geophysical studies; and 5) merge imagery with these other data sets and reinterpret for zones with high groundwater availability.

Thus far it has been difficult to directly identify large scale zones on 1:250,000-scale imagery. The results from the supporting hydrogeologic investigation suggests that the important groundwater bearing zones may in fact be an order of magnitude narrower than anticipated. It is suggested that synoptic imagery be analyzed for such zones using computer-identified lineament techniques which assess the geomorphic expression of such features.

Groundwater, Remote Sensing

A GROUND RESISTIVITY TECHNIQUE FOR LOCATING FRACTURE AQUIFERS IN BURIED PRECAMBRIAN BASEMENT, CENTRAL WISCONSIN

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Decreases in apparent resistivity have been recognized through comparative measurements of ground resistivity taken above and below the water table located within buried crystalline basement. These decreases have been interpreted to indicate zones of high fracture porosity and therefore increased water volume allowing for greater electrical conductivity. The survey method might provide a tool for locating water well drilling sites in crystalline basement.

A Lee array was utilized during trial surveys. Vertical electrical soundings were conducted at points along the survey traverses to adjust for surface and basement topography in establishing the depths to basement and the water table. Electrode a-spacings within the range of 4.6 - 18.3 meters were determined to provide investigation depths above and below the water table along the length of the traverses. Trial surveys were conducted near Dells of Eau Claire Park (Marathon Co.), WI and at Junction City (Portage Co.), WI.

The Dells of Eau Claire traverse crossed the contact between the Wolf River Granite and a "shear zone" in felsic volcanics. Exposures of the volcanics in the Eau Claire River display an intense fracture system. The apparent resistivity decreased below the water table within the volcanics but not the granite.

The Junction City traverse was at a water well site. Basement rock at this location is early Proterozoic argillite. An apparent resistivity decrease was noted in a narrow zone (6 - 9 meters wide) north of the wellsite and on strike with the local basement structure.

It is currently planned to further test this technique during the Spring, 1989 in conjunction with a Wisconsin Geological and Natural History Survey drilling program at Junction City, WI.

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HYDROGEOLOGY OF THE PRECAMBRIAN BEDROCK, WOOD, PORTAGE AND MARATHON COUNTIES, CENTRAL WISCONSIN

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The hydrogeologic regime has been determined from available well data for Precambrian bedrock within an area of 1800 km^2 in central Wisconsin. Two major results of this study are: 1) there is apparently a high degree of connectivity between Precambrian bedrock and overlying Paleozoic and Pleistocene units. This relationship holds even within areas having a Precambrian residual paleosol up to 25m thick; and 2) groundwater flow cells in Precambrian bedrock are spatially restricted (1 - 3 km wide) with upward flow consistently coincident with topographic lows and proximal to formational contacts.

The data used in this study (from over 2000 wells) were taken from an unpublished report of the Wisconsin Geological Survey. The report contains lithologic logs, depths of wells, elevations and depths to the water table for each well in the area. Wells were located on 1:2400-scale maps. Cross-sections showing groundwater flow and a hydraulic potential map were constructed using this data.

Computation of specific capacity and plunge for the flow cells remains to be carried out. However, the implications for water prospecting in Precambrian bedrock are obvious if our interpretation is correct.

Groundwater, Precambrian