

A GUIDE TO ON-LINE GEOLOGICAL INFORMATION AND PUBLICATIONS FOR USE IN GSHP SITE CHARACTERIZATION

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ABSTRACT

The ground-source heat pump industry has historically failed to take full advantage of the public information sources available for site characterization. Virtually every state and province in North America maintains a website (or sites) dedicated to either groundwater or geology or both. These sites vary greatly in terms of the information available, but in many cases, offer a wealth of data useful in the characterization of site geology and hydrology. Sites are typically maintained by federal and state geological surveys and water resources agencies.

Information may include various types of geological maps, publications, databases, water well completion reports, comprehensive reports on water and geology, and monitoring well water level data. From these sources, it is possible to determine site geology, depth to bed rock, water levels aquifer presence or absence, aquifer type, well yields, ground and groundwater temperatures, well design data, drilling rig types which have worked successfully in the area, and a host of other useful information. This paper outlines the types of data available, provides a tutorial on reading water well completion reports, and lists websites URLs for sites in the 12 most active GSHP states.

INTRODUCTION

One of the first steps in the consideration of a GSHP system is a characterization of the site in terms of geology and groundwater availability. Information concerning aquifer (or aquifers) available at the site, their ability to produce water, depth to water, geology, depth to bedrock and the nature of the soil and rock (hydraulic and thermal properties) are key issues. This information guides the designer in the selection of the type of GSHP system to be used and in the design of the system.

The ground-source industry has not taken full advantage of available geological information resources in the past. This document is an effort to introduce GSHP designers to some of these information sources and the nature of the data that is available. A special emphasis has been placed on Internet based resources operated by government agencies--primarily the USGS and state geological surveys. The following section provides some background information on the maps and other information sources in general. This is followed by summaries of information available for the most active GSHP states.

GEOLOGICAL TERMINOLOGY

One of the hurdles engineers encounter in the process of consulting references such as those referenced below is the terminology used in the field of geology. Contributing to the confusion is the fact that geology is something of a mix between science and history. Publications and maps often refer to materials not by their physical characteristics (the issue we as GSHP professionals are interested in) but by the period in the earth's history in which the material was deposited. For geologists, with a background in the science and a familiarity with the geographical area, the age of the material carries with it a rough idea of the physical characteristics. For engineers or those lacking this background, more information is required. To a large extent, there is no simple solution to this other than experience in reading and interpreting geological maps and data, but there are some useful references on the Internet to assist us in translating geology-speak into something we can understand. The Kentucky Geology Survey's web site (<http://www.ky.edu/KGS/home.htm>) has a comprehensive glossary of geological terms. The Indiana Geological Survey's website (<http://adamite.igs.indiana.edu/index.htm>) has a good summary of geological time with a chart and a brief explanation. It is useful to have these sites bookmarked for future reference. An extensive glossary of aquifer and hydrology terms is available on the Kansas State Geological Survey's site at: <http://www.kgs.ukans.edu/highplains/atlas/glossary/htm>.

KEY REFERENCES

USGS Groundwater Atlas of the United States
<http://sr6capp.er.usgs.gov/gwa/gwa.html>

This document may be the best regional scale (many figures readable to +/- 1 mile), groundwater and geological reference available. It is published in 13 volumes each covering a multi-state region of the country. It provides detailed descriptions of aquifer locations and physical characteristics, water quality, geology, physiography, cross sections and a host of data useful for both open loop and closed loop site characterization. All 13 volumes are accessible through the web site with full text and color illustrations and maps. They are also available as a hard copy publication. This is a document that answers the questions: Is there an aquifer accessible at the site suitable for an open loop system? What is the general geology of the site?

Water Well Completion Reports

The single best source of information for any site are water well completion reports from wells on or near the site. These are reports filed (with the state agency responsible for water well regulation) by the well driller upon completion of the construction of the well. There is a host of information (water level, well construction, pump test results, lithology, etc.) on these documents that is of use for both open and closed loop system site characterization. The availability of well completion reports varies from state to state. An increasing number of states, as detailed in the state summaries below, have these reports available on the Internet.

Anatomy of a Water Well Report

Figures 1 and 2 are examples of water well reports from the state of Oregon. This form is typical of many western states. The level of detail is somewhat less for states in the east and mid-west.

The report contains information on the owner in Section 1 and the nature of the work that was done (new well, deepening, repair etc) in Section 2. The drilling method (Section 3) is of interest since it indicates what type of rig has worked successfully in the area before. As you can see, well 1 was completed in a hard rock formation with an air rotary rig and well 2 in unconsolidated materials with a cable tool rig.

Section 3 details the hole diameter or diameters used and this information along with the casing description (Section 6) and screen (Section 7) provide a very clear picture of the well construction. The screen information is very useful for design of new wells. If the screen/gravel pack described has been successful in terms of minimizing sand production, it is an effective guide for future wells in the same area. As you can see, well 1 was completed in a rock formation with no screen or casing in the lower portion of the well (called open hole completion). Well 2 was completed with a stainless steel "V slot" screen with 0.50 slot size (openings) between 167 and 182 ft. The lower portion of the well drilled to 246 ft was backfilled and plugged to 202 ft due to the lack of water production in that zone. The 8" casing was cemented from 2 ft to 152 ft.

Section 8 is especially important for open loop design. As it presents information concerning the well's ability to produce water is presented along with the water temperature. The temperature is also important for closed loop design since it's temperature is the same as the "undisturbed soil/rock temperature" in the same area. Of the two examples, well 1's data is less useful than well 2. For well 1, the driller indicates that the well produced 100 gpm but does not show the drawdown information. Instead he shows that the drill stem was at 145 ft. This does not tell us what the water level was in the well at this flow (although it is clear that it was above 145 ft). Well 2's data indicates both the flow rate and the drawdown. This allows us to calculate a specific capacity for this well of approximately 2.4 gpm/ft of drawdown (200 gpm/85 ft)--a useful value in making well pump head and system design calculations.

Sections 10 and 11 information permits additional conclusions to be drawn as to the type of aquifer in which the well is completed. The static water level has an impact on pumping for open loop systems and may influence the type of rig used for drilling (wells or boreholes). Beyond that, the static water level when considered in the context of the depth at which water was encountered, suggests the type of aquifer present. This is most clear in the well 2 report. This well was constructed in such a way that all the water bearing zones were cased off except the one between 167 and 182 ft. The static water level in this well is at 11 ft. It is clear that this is an artesian (confined) aquifer since the water bearing zone starts at 167 ft but the water level is 156 ft higher. This 156 ft difference represents the pressure in that aquifer.

Section 12, the well log is valuable information for closed loop systems since it indicates the type of materials encountered in the subsurface. From this information, some idea of the heat transfer characteristics of the material can be determined. For well 1, most of the hole is rock (the black rock indicated is the reference this driller uses for basalt) and would likely have a fairly high thermal conductivity. In addition, the time to complete the well may offer some information concerning the drilling difficulty encountered. Well number 1 was completed in a single day in rock. On the other hand, well 2 required a month and a half to complete in soft drilling conditions. It is likely, however, that the difference in construction period is related more to the rig type since well 2 was constructed with a cable tool machine--a very slow process relative to a rotary rig.

Useful Maps

One very good source of information on the geology of an area is a "geological quadrangle" map. These maps, of which there are over 1700, show bedrock, surficial or engineering geology of selected 7.5 and 15 minute quadrangles of the U.S. Each map is accompanied by an explanatory text printed on the map margin or sometimes as a separate pamphlet. Some maps include cross sections and columnar sections illustrating stratigraphy. These maps are typically published in 1:24,000 scale and use the topographical map (a map which shows surface elevations) of the same area as the base. As a result, they bear the same name as the topo map for the area. These names are often related not to a town or city but to a local geological feature making the process of identifying the correct map difficult. Most of the map lists on the sites described below are indexed by the name of the map. Unless the name is known, it is not possible to easily locate the map you need. The USGS maintains a site to simplify the search process. At: <http://mapping.usgs.gov/mac/findmaps.html>, click on the **Map Finder (through GLIS)** link. The next page allows you to locate the correct map by entering the zip code for the area or by clicking on an interactive map of the U.S. In either case, a map of the general area will come up showing the quadrangles for that area.

RECEIVED

LININ 52570

STATE OF OREGON WATER SUPPLY WELL REPORT JUL 27 1989

WELL I.D.# 0000226

WATER SUPPLY WELL REPORT PAGE 1 OF 3 (START CARD) 85423

OWNER: [Redacted] Well Number 0000226

ADDRESS: [Redacted] City [Redacted] State OR Zip 97321

TYPE OF WELL: [Redacted] Well Description: [Redacted]

LOCATION OF WELL: [Redacted] County [Redacted] Township [Redacted] Range [Redacted] Section [Redacted]

WELL METHOD: [Redacted] Well Depth: [Redacted]

WELL BEARING ZONES: [Redacted]

STATIC WATER LEVEL: [Redacted]

WELL LOG: [Redacted]

WELL TESTS: [Redacted]

WELL TESTS: [Redacted]

WELL TESTS: [Redacted]

WELL TESTS: [Redacted]

WELL TESTS: [Redacted]

WELL TESTS: [Redacted]

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WELL TESTS: [Redacted]

WELL TESTS: [Redacted]

WELL TESTS: [Redacted]

RECEIVED

KLAM 51702

STATE OF OREGON WATER SUPPLY WELL REPORT APR 6 1999

WELL I.D.# L268856

WATER SUPPLY WELL REPORT START CARD # 10847A

OWNER: [Redacted] Well Number [Redacted]

ADDRESS: [Redacted] County Klamath State OR Zip 97623

TYPE OF WELL: [Redacted] Well Description: [Redacted]

LOCATION OF WELL: [Redacted] County [Redacted] Township [Redacted] Range [Redacted] Section [Redacted]

WELL METHOD: [Redacted] Well Depth: [Redacted]

WELL BEARING ZONES: [Redacted]

STATIC WATER LEVEL: [Redacted]

WELL LOG: [Redacted]

WELL TESTS: [Redacted]

WELL TESTS: [Redacted]

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Figure 1.

Figure 2.

Other maps that may be of interest for GSHP site characterization include bedrock topography maps, surficial geology maps and Quaternary geology maps. Bedrock Topography maps indicate the depth to the top of the local bedrock or stating it another way, the thickness of the overburden materials. This information is useful in determining the drilling conditions and in making decisions as to the depth of the boreholes at the site.

Surficial Geology maps, in areas in which there is a thick sequence of unconsolidated material above the bedrock, may be the only maps necessary for characterization of site materials. For sites with less than 100 ft of unconsolidated materials, these maps would be used in conjunction with bedrock geology maps. As the name implies, these maps focus on the materials close to the surface, normally the unconsolidated materials deposited in recent geological time (what geologists refer to as Quaternary (the last 2 million years) or Tertiary (from 65 million to 2 million years ago).

SUMMARIES OF INFORMATION AVAILABLE IN SELECTED STATES

The following section presents summaries of information available for the states with the most active commercial GSHP markets. Similar information for other states can be accessed through two very useful sites. The American Association of State Geologists site <http://www.kgs.ukans.edu:80/AASG/AASG.html#STATES> includes an interactive map of the U.S. Clicking on any state brings up the website for that particular states Geological Survey (or equivalent state agency). The USGS site <http://search.usgs.gov/> contains a similar interactive map of the U.S. (click on the **USGS by state link** to access it). Clicking on a state brings up the USGS information resources for that state including groundwater, surface water and geology. These two websites provided the starting point for all of the information presented below.

TEXAS

Texas Bureau of Economic Geology (<http://www.utexas.edu/research/beg/>) no online maps, list of geological quadrangle maps (but no online index map), list of hydro-geological reports, recommended publications (click on Publications, Best Sellers): **The Geology of Texas, Vol 1, Stratigraphy**, by Sellards, Adkins and Plummer, 1007 pages, \$18 #BL3232, **Geologic Atlas of Texas**, published as individual sheets (listed on the web site), color, scale 1:250,000, \$6 ea.

Texas Water Research Institute (<http://twri.tamu.edu/index.html>) appears to be primarily a surface water group but has a good general report in downloadable format **Groundwater in the Great Basin** (click on icon on first page) also a good links page including links to many Water Research institutes in other states.

Texas Water Development Board (<http://www.twdb.state.tx.us/>). Online publication **Aquifers of Texas** (click on Publications on first page) has maps of nine major and 20 minor aquifers in the state along with descriptions of typical well yields and aquifer geology.

Online water well completion reports database is accessible by clicking on the Well Information icon on the first page (at the bottom of the page). This database takes a little time to get into and it appears to be well construction and water quality focused. No driller's logs (lithology log).

USGS Texas information Site (<http://usgs.tx.gov/>) online data for water levels at about 25 locations in Texas. Data is in real time. Access by clicking on Groundwater under the **Online Data** heading.

PENNSYLVANIA

Pennsylvania Topographic and Geologic Survey (Dept of Conservation and Natural Resources) (<http://www.dcnr.state.pa.us/topogeo/indexbig.htm>). A map and listing of libraries which serve as repositories for Geological Survey maps and Publications can be accessed on the Publications page. Geological quadrangle maps in black and white online and downloadable. These maps are of limited value for GSHP applications since they typically do not contain cross sections. They can be accessed by clicking on **Publications** on the first page and then **Atlas of Preliminary Geological Quadrangle Maps of Pennsylvania**. A useful feature of this online publication is that clicking on the List of Quadrangles link brings up a alphabetical listing of the Quadrangle maps with a summary of other publications available in that same quadrangle.

Recommended Publications:

PA Ground Water Information System CD - this is a database of water well completion reports for the entire state \$35. Information about the database is available on the site. Click on the Pub title on the first page of the site.

The Geology of Pennsylvania - 888 pages, \$24, description can be found under Publications.

Map #7 - Geology of Pennsylvania (Free upon request)

Map #15 - Limestone and Dolomite (Free upon request)

Map #64 - Surficial Materials (Free upon request)

Map #59 - Glacial Deposits (Free upon request)

USGS PA Water Information Site (<http://pa.water.usgs.gov/>). Online, real time depth to water for approximately 25 sites in PA. Click on **Statewide Groundwater Conditions** on the first page of the site.

NEW YORK

New York State Geological Survey (<http://www.nysm.nysed.gov/geology.html>). Online maps of both bedrock and surficial geology accessible by clicking on **Maps and Digital Data** on the first page of the site. User must have ArcView/ArcInfo software to access the maps. List of geological quadrangle maps (but no online index map) by clicking on **Publications** and then **Geology**.

Recommended Publications:

Geology of New York: A simplified Account, Isachsen and others, 1991, \$18.95

Geology of New York: A Short Account, \$5

USGS New York Groundwater Information Site (<http://ny.water.usgs.gov>). Online, realtime depth-to-water information for 15 sites in the state. Also historical information on another 40 sites which are now discontinued. For access, click on the **Groundwater** under the **Data** heading on the first page.

Water table Altitudes in Kings and Queens Counties NY in PDF format under **News and Features**. It has map of water levels.

Evidently, water well driller registration and the filing of water well completion reports was not required in New York state (except in a few counties on Long Island) until 1 Jan 2000. As a result there is no database of this information as there is in other states. Water well regulatory functions are the responsibility of the Department of Environmental Conservation, Division of Water.

TENNESSEE

Department of Environment and Conservation, Geology Division (<http://www.state.tn.us/environment/tdg/index.html>). Good generalized geologic map of the entire state (no cross sections) online. Click on the **Big Map** link for the best scale.

List of geologic quadrangle maps. Click on **Publications** on first page then click on **Geologic Quadrangle Maps** on menu on left of page. \$3 ea

Recommended Publications:

State Geologic Map - in 4 sheets (West, W Central, E Central and East). 1:250,000 scale (1" = 4 miles), color, formation descriptions. \$4 per sheet.

Department of Environment and Conservation, Division of Water Supply (<http://www.state.tn.us/environment/dws/index.html>). List of Licensed Water Well Drillers in TN - click on **Water Well Drillers List** link on first page of site. Lists drillers by name, Lic. number and phone number.

USGS TN Water Information Site (<http://tn.water.usgs.gov/>). It appears that USGS, as of 1995, was monitoring water level in 48 wells in the state. Online information is not available for these wells as it is in other states. However, this information would be available by contacting the state USGS office (email link on site).

Online publication **Public Water Supply Systems and Associated Water Use in TN, 1995** contains good information about production from public water system wells throughout the state. This data is attached as appendices to the report in table form. Access report by clicking on **Publications and Product Information** on the first page of the site and then **Selected Tennessee Publications** and then the report title.

KENTUCKY

Kentucky Geological Survey (Univ of Kentucky) (<http://www.ky.edu/KGS/home.htm>). This is the only state for which there is 100 % coverage in geological quadrangle maps. List available on site

Hydrologic atlas maps list. These maps include information about water wells, aquifers, availability, chemistry, depth to water etc. Click on **Mapping** icon at top of first page, then **Maps for sale by Commodity**. Maps available by county, groups of counties and in some cases by quadrangle (1:24,000 scale). \$4.50 to \$12.

Simplified map of Geology of Kentucky online. Click on the **Geology of Kentucky** icon at the top of the first page. Includes cross section and explanatory text. Good summary of geological time scale.

A detailed treatment of the geology on a county by county basis is ongoing. Only Fayette County is currently online.

Possibly the most useful information for GSHP would be searches of the **Kentucky Hydrologic Data Base** and **The KGS Oil and Gas Data Base**. The hydrologic information includes results from 39,000 water wells and 18,000 water chemistry analyses. Information on water well construction, yields, depth, static level and water quality data, etc. Database is not searchable online. Contact is Bart Davidson (bdavidson@kgs.mm.uky.edu) or 606-257-5500. Oil and gas data includes driller logs, wireline logs (geophysical data) etc. Contact is Brandon Nuttall at KGS (bnuttall@kgs.mm.uky.edu) or 606-257-5500. Minimum fees for these services appear to be \$30 to \$40.

Downloadable geologic and hydrologic GIS maps available on the site. ArcView/ArcInfo software required for viewing. Click on **Mapping** icon at top of first page then, **GIS Coverages**. Under **State Hydrology Series**, the **Water Wells** map appears to be the most useful (data on depth, depth to water, date, use, depth to bedrock, etc.). Using the same approach but clicking on **Geology Series**, the **Oil and Gas wells** and **Generalized Geology** maps should provide good information on the subsurface.

Kentucky Groundwater Development Commission (<http://dlgnt1.state.ky.us/wrdc/>). This organization is working on a Digital Atlas of Groundwater in Kentucky in conjunction with the KY Geological Survey. Based on the hydrologic atlas series published in the 1960's, new information will be added and corrections made. Water well, groundwater availability and quality and aquifer descriptions will be included. Data not yet available.

VIRGINIA

Virginia Department of Mines, Minerals and Energy, Div of Mineral Resources (<http://www.mme.state.va.us/dmr/home.dmr.html>). General **Geology of Virginia** (access by clicking on the phrase at the top of the first page) explains the general geology and physiographic provinces of the state. Text describes the rock types and faulting etc.

Geological quadrangle maps listed. Click on **maps and publications, geological** and then geological quadrangle maps.

Oil and Gas Database--includes well location, status and stratigraphy. Not available online. Contact Dave Spears 804-951-6361

The state is working on the digitizing of both 1:100,000 and 1:24,000 geological maps but this work is in progress. Some maps may soon be available on CD-ROM. Inquire.

Recommended Publications:

Geologic Map of Virginia and expanded explanation (1993). 1:500,000, 80 pages, \$9.50 .

Geological map and generalized cross sections of the Coastal Plain and adjacent parts of the Piedmont, VA, R B Mixon, 1:250,000 1989, \$6.75.

USGS VA Water Information Site (<http://va.water.us.gov>). Online water level information for 11 sites in VA. Click on **Groundwater Levels** under VA Drought Conditions.

INDIANA

Indiana Geological Survey (<http://adamite.igs.indiana.edu/index.htm>). This is one of the most comprehensive and useful state geological sites.

Excellent glossary of geological terms. Click on **Reference Library** on the first page and then **Glossary of Geological Terms**.

Glossary and descriptions of stratigraphic units in inches. Click on **Reference Library** and the **Compendium of Paleozoic Rocks**. Detailed descriptions on rock units.

Online maps of both bedrock and surficial geology for the entire state. Click on **Reference Library** then **Maps and Charts**. Bedrock geology shows the types of bedrock units and their location along with a brief explanation of the material (point to the material on map and description is displayed). Surficial Materials shows the type and depth of these materials on a state map. This allows the determination of the depth of the “overburden” materials and the type.

Databases of core and well samples are “Coming Soon.”

Recommended Publications:

Regional geological maps 1°x2°. These maps show both bedrock and unconsolidated deposits. Scale 1:250,000. \$2.50 ea. To access list, use publications search engine and select “regional geological maps.”

IN Dept of Natural Resources, Division of Water (<http://www.state.in.us/dnr/water>). Online water well completion reports. Click on **databases** then search **water well records**. Full well report info available—depth, flow test, construction details, lith log, etc.

Several excellent publications on groundwater availability on river basin (regional) and county by county basis. See publications list.

MARYLAND

Maryland Geological Survey (<http://mgs.dnr.md.gov>). Online publication **A Brief Description of Maryland Geology**. Click on Earth Science Information Center on the first page, then the document title. Contains a map of the Physiographic provinces of the state

and a general geological map with formation descriptions and explanatory text. Publication also includes a downloadable file of the geological map.

Recommended Publications:

Most useful appear to be the **county geological maps** (some of which are out of print). Click on County Topographical and Geological Maps \$7.50 ea. Also publication #69-02-1 **Groundwater Aquifers and Mineral Commodities of Maryland** (also out of print but should be available at MGS repositories a list of which is on the websites).

USGS Maryland Water Information Site (<http://md.water.usgs.gov/groundwater/county>).

Site has historic water level data for at least one well in each county in both MD and DE. Includes a graph of past levels and a description of well construction and location.

MISSOURI

Missouri Department of Natural Resources - Division of Geology and Land Survey (<http://www.dnr.state.mo.us/dgls/homedgls.htm>). Nothing of help for the GSHP designer on this web site. This organization is also responsible for administering the states water well industry but no online data is available.

Email address for questions regarding geology, stratigraphy and surficial materials: gspgdam@mail.dnr.state.mo.us

OHIO

Ohio Geological Survey (http://www.dnr.state.oh.us/odnr/geo_survey/). Online maps of bedrock, surficial geology and Physiographic provinces in the state. Click on Geology of Ohio on the first page, then map title.

Online “Geo Facts” publications - #1 Bedrock Topography of OH. Explains the topic and includes map ordering info.

#20 Geology of OH - The Cambrian Useful maps available from the Survey: Bedrock Topography Maps, by county. Shows the depth to bedrock as contours. Scale is 1:24,000 and cost is \$4 ea; Geologic Map of Ohio 1:500,000, \$5, order #M1; Quaternary Geologic Map of OH, 1:500,000, \$10, order #M2

Department of Natural Resources - Division of Water (<http://www.dnr.state.oh.us/odnr/water/>). Online searching of water well completion reports. Click on **Online searching of water well logs** under New Items on the first page. Can locate wells by county and road or well number. Information on water level, production, construction, lithology etc.

Online map of generalized water well production (in gpm) for entire state. Click on **Publications, then Groundwater Publications, Maps, Generalized State Groundwater Map of Well Yields**.

Online index map to individual county groundwater availability maps. Navigate to same location described immediately above for well yield map. Click on **Ground-**

water Resources Map Availability. Includes state map indicating status of individual county maps and ordering information.

NEW JERSEY

New Jersey Geological Survey (Dept of Environmental Protection) (<http://www.state.nj.us/dep/njgs/index.html>). Online map Geology of New Jersey on first page of site. Link at bottom of map for download of Adobe file with map and text providing a description of the geology in each of the major physiographic provinces of the state. Also a link to ordering info for the newest three map set on New Jersey Geology.

Online map of major aquifers in the state with well yields indicated. Click on **GEODATA, Groundwater icon, Aquifers of NJ (1:250,000)**. Map and data are downloadable but requires ARC/INFO software. Click on **image** for online display of map.

Publications search engine online. Best strategy is to use the county name as a key word to locate publication for the site you are interested in.

USGS NJ Water Information Site (<http://nj.water.usgs.gov/>). Online geologic map of NJ click on **Groundwater, Geologic Map**. Also at same location, Aquifers of NJ with maps, text and tables describing aquifers of the state. Groundwater levels for 172 wells in the state including both current and past water level data.

MINNESOTA

Minnesota Geological Survey (<http://www.geo.umn.edu/mgs/index.html>). Online map of bedrock geology of MN with descriptions. Click on **more information on MN geology** on the first page of the site, **state maps** then map title. Same location also has map of Quaternary geology and cross section of the state.

More detailed information on both the bedrock and Quaternary geology of the state are available in two online (and downloadable publications). Click on **more information on MN geology** on the first page and then **Minnesota at a glance** and then the title of the publication (in Adobe Acrobat). Documents have maps and descriptions of the geology of the entire state.

Geology of central MN presented in some detail in the online document of the same name including text maps and formation descriptions. Click on more information on MN geology, regional information then the title of the document.

Water well information is contained in the County Well Index (CWI). Not available online. Database is available on disks (typically 1 disk per county) for \$5 ea. User manual available for \$6. Ordering and general information by clicking on the CWI link on the first page of the site. Database contains well construction, production, lithology, static water level information, etc.

Recommended Map Publications:

County Geologic Atlases. Order numbers C-1 thru C-12 Regional Hydrologic Assesments Order numbers RHA-2 thru RHA-5 Geologic and Surficial maps, typically 1:24,000 scale. Most recent are available online. Order numbers M-1 thru M102. M-83 thru M102 are online.