Preliminary maps of shallow buried sand and gravel aquifer systems of Stearns County, Minnesota, and adjoining areas

James A. Berg, Minnesota DNR Waters
August 2007

Purpose and Introduction

Five shallow buried sand and gravel aquifer systems were mapped using located well log data from the Minnesota Geological Survey (MGS)/Minnesota Department of Health (MDH) County Well Index (CWI) database (low-resolution map Stearns07_page_raster_100dpi.pdf ; high-resolution map Stearns07sec_vector_200dpi.pdf). The project was initiated in response to increasing residential and industrial development along the Mississippi River valley in eastern Stearns County and western Benton and Sherburne counties and associated increases in ground water appropriation in these areas. These increases raised some concerns about the recharge characteristics of buried sand and gravel aquifers in this area of the Mississippi River valley in response to this increased ground water pumping. In addition, a general understanding of the distribution of buried sand and gravel aquifers for the remainder of Stearns County was needed for resource management planning.

This area was a good candidate for this subsurface mapping since the Stearns County Geologic Atlas, Part A (geologic mapping), and Part B (hydrogeologic mapping), and associated database development had been completed in 1995 and 1998, respectively (Meyer, 1995; Falteisek, 1998). Also, surficial sand and gravel mapping had been completed for adjoining areas of Benton County (Ellingson, 2002), Sherburne County (Eng, 1987), and Wright County (Lehr, 1990). Chemistry data to estimate ground-water residence time were also available based on many ground-water samples collected in this area by the DNR, Minnesota Pollution Control Agency (MPCA), and MDH. A few data sets from key DNR observation wells and water level lake gages were also available and useful for assessing probable buried aquifer recharge characteristics.

Quaternary Geologic History

By understanding the depositional setting and history of the buried aquifers that we attempted to map we hoped to make the best possible estimates of aquifer distribution based on limited data from well logs. Therefore, the presumed depositional setting from each aquifer system is included in the descriptions of aquifers mapped for this study.

The Quaternary is the last geologic period that includes the glacial age (Pleistocene) and geologic events since the end of the last ice age (Holocene). In Minnesota, the Pleistocene is generally divided into the late Wisconsinan, the most recent ice advance events along with their associated formation names that are understood relatively well due to abundant surface exposures and geomorphic features, and older pre-late

Wisconsinan formations and deposits that are mostly known from core and well log information. The sediments of these formations are further classified by a bedrock source area, or provenance locations in Canada: Riding Mountain, Winnipeg, Rainy, and Superior source areas in the far northwest, northwest, north, and northeast, respectively. Sediment, especially till, deposited by ice advances from each of these source areas tend to have distinct compositions of rock fragment types and similar proportions of sand, silt, clay and gravel.

Data density and hole depth in the Stearns County area was only sufficient to map five of the relatively shallow aquifer systems (low-resolution map Stearns07_page_raster_100dpi.pdf ; high-resolution map Stearns07sec_vector_200dpi.pdf). Some information is available regarding the depositional history for three of the associated till formations: till deposited prior to the Hewitt formation, and the late Wisconsinan Hewitt and Cromwell Formations (Meyer and Swanson, 1996; Harris and Berg, 2006; Meyer, G.N. and Knaeble A. R., personal communication).

The land surface of the Stearns County area prior to the deposition of the Hewitt formation probably consisted of glacial sediment from a northwest source (Winnipeg provenance) and includes deposits of the Browerville and Lake Henry formations. During the retreat of these ice lobes to the northwest much of aquifer 1 was deposited. An ice advance from the Rainy provenance entered the county from the north and covered aquifer 1 with Hewitt formation materials. Most of the hewtop aquifer was deposited during retreat of the ice lobe to the north. The eastern portion of the hewtop aquifer was covered by Cromwell Formation till deposited by the next ice advance from the northeast (Superior provenance), the Superior lobe. Most of the cromtop aquifer was deposited during the recession of the Superior lobe to the northeast. Finally, Des Moines-lobe ice, advancing from the northwest covered the western portion of the hewtop aquifer and all of the cromtop aquifer with the New Ulm Formation deposits.

No research is available regarding the glacial history of buried sediments and aquifers in the Mississippi River of eastern Stearns and western Benton and Sherburne counties, which includes the area where aquifers 2 and 3 were mapped. The distribution and hydrogeology of these aquifers is discussed below in the section “Buried sand and gravel aquifer systems 2 and 3, eastern Stearns and western Benton/Sherburne counties”.

Mapping and Correlation Methods

The maps (low-resolution map Stearns07_page_raster_100dpi.pdf ; high-resolution map Stearns07sec_vector_200dpi.pdf) show the extent of the five shallow buried aquifer systems in the area. These aquifer systems were mapped by constructing 50 west-east geologic cross sections with a 1-kilometer north-south spacing across the Stearns County area (cross sections for Stearns County). Well information was projected to the line of the cross section at distances no greater than 500 meters. The cross sections were constructed by first creating “stick diagrams” using a custom ArcGIS extension. Each stick diagram consists of a colored representation of the driller’s log of geologic materials encountered during drilling plotted at the correct elevation. Sand is generally shown as yellow, and clay (usually glacial till) is generally shown as gray or brown. A complete legend is shown on XSEC_Legend.pdf. This basic diagram before interpretation also included black lines representing the land surface and the bedrock surface. The surface geologic boundaries, from the above-referenced surface geologic maps, were added to all the cross sections. In addition, special stratigraphic logs interpreted by MGS from rotosonic cores and drill cuttings were also added to the cross sections. These stratigraphic logs were very useful for correlating geologic units and mapping subsurface unit boundaries in the western and southwestern portions of the county.

The correlation process mostly consisted of drawing stratigraphic boundaries (including aquifer boundaries) as line shapefiles in ArcView and ArcGIS primarily based on all sand occurrences within similar elevation ranges. These occurrences were assumed to be indicators of boundaries between successive glacial events. Correlations were first completed from west to east within each cross section, and then these lines were compared north to south by superimposing adjacent sets of cross-section line shapefiles within the same ArcView “view” or ArcGIS “dataframe”. The bottom stratigraphic boundaries of eight geologic units or formations were approximated in this manner using the nomenclature from adjoining Todd County (Setterholm, 2007).

The uppermost subsurface boundary is the base of the surficial sand (indicated by the line surfsdbot), which is underlain by a Des Moines lobe till in the western portion of the area called the New Ulm Formation (line nubot). In the eastern portion of the area, the exposed till is a Superior lobe deposit called the Cromwell Formation (line crombot). Across much of the area, both the New Ulm and Cromwell Formations may be underlain by a Rainy lobe deposit called the Hewitt Formation (line hewbot). Since most of the subsurface stratigraphic information was concentrated in the southwestern portion of the county some stratigraphic boundaries of the Lake Henry formation were identified in that portion of the study area. Otherwise, the bottom stratigraphic boundaries of units below the Hewitt formation top were given nonspecific number designations (indicated by lines 1bot, 2bot, etc.) to identify correlative boundaries.

Once the bottoms of these units and formations were drawn and correlated, each line was copied and given a “top” designation (lines cromtop, hewtop, etc) for the appropriate underlying units or formations. Where enough well log information was available to map sand and gravel occurrences between till formations the “top” stratigraphic line was edited to match the bottom of the sand deposit or some reasonable estimation. Therefore, gaps between otherwise coincident and similarly colored lines represent sand and gravel deposits and were identified as buried aquifers cromtop, hewtop, 1, 2, and 3. The sand boundaries for each aquifer system and each cross section were matched to a sketch map of the aquifer system boundaries to ensure that aquifer boundaries were consistent in map and cross-section views.

Buried aquifer distribution and characteristics

Cromtop aquifer

All of the mapped buried aquifer systems are shown together in a layered* PDF image (high-resolution map Stearns07sec_vector_200dpi.pdf). The uppermost-buried aquifer system consists of sand and gravel that was deposited as the Superior lobe ice retreated to the northeast. Meltwater carrying sand and gravel drained from the northwest-southeast oriented ice margin toward the location of the present-day Sauk River valley (Meyer and Swanson, 1996). The till deposit in this region created by this advance of the Superior lobe is called the Cromwell Formation; therefore, the aquifer on top of this formation was given the informal name of cromtop aquifer (shown above the thick gray line on cross sections and by gray shapes on the maps). In the western two-thirds of Stearns County, the Cromwell Formation and the cromtop aquifer are overlain by Des Moines lobe till deposits called the New Ulm Formation. This aquifer system is bounded on the west by the buried western extent of the Cromwell Formation and on the east by the eastern edge of the New Ulm Formation. Higher elevation occurrences of this sand layer may be unsaturated. The typical thickness range appears to be approximately 20–40 feet. The thickest occurrences appear to be north of St. Rosa in north-central Stearns County (see cross-section 010) where the aquifer is approximately 60 to 70 feet thick. Uses of this aquifer system include domestic, industrial, and non-municipal public supply.

Hewtop aquifer

This aquifer system is shown in pink on the maps and between the nubot (thin gray), crombot (thin pink), and hewtop (thick pink) lines on the cross sections. The aquifer system was deposited on top of the Hewitt formation, which is a till unit deposited by a Rainy ice lobe advance from the north-northeast. This formation (formerly called the Wadena till) is the stratigraphic equivalent of the Crow Wing group to the west (Harris and Berg, 2006). As the Rainy lobe ice lobe retreated to the north, sediment transport in western Stearns County appears to have been divided along a broad northwest-southeast trending paleo-topographic high. This broad, high area is evident on Plate 6 of the Stearns County Atlas, Part A (Meyer, 1995), and on cross-sections 032 to 080. Outwash sediment transport west of this paleo-topographic high appears to have been generally southwest, whereas east of the high, sediment transport was generally southeast.

The hewtop aquifer system in Stearns County is probably equivalent to the CW aquifer system of Pope County (Berg, 2006); therefore, the western boundary of this system is west of this study area. The eastern boundary of the hewtop aquifer system may be mostly erosional due to the highly dissected and eroded nature of eastern Stearns County. An aquifer thickness of 20 to 40 feet appears common with several occurrences more

* Layers may be turned on and off if using Adobe Acrobat Reader 7.

than 50 feet thick scattered across the county. Aquifer uses include domestic, industrial, public, and municipal at Meire Grove in west-central Stearns County.

Aquifer 1

The remaining aquifer systems beneath the Hewitt formation were not given any stratigraphic names because of a general lack of stratigraphic data at these greater depths and in the eastern portion of the county. The aquifer 1 system shown in orange beneath the salmon-colored hewtop aquifer on the map was assumed to have been deposited on a similar paleo-topographic surface as the overlying hewtop aquifer system with sediment transport west of the paleo-topographic high to the southwest and transport east of the high to the southeast. This aquifer system may be equivalent to the BROW aquifer system of Pope County (Berg, 2006). An aquifer thickness of 20 to 30 feet may be typical in this system. Also similar to the hewtop aquifer system, the western boundary may be west of the study area and the eastern boundary may be erosional. Aquifer uses include domestic, industrial, public, and municipal at the City of Brooten in western Stearns County.

Buried sand and gravel aquifer systems 2 and 3, eastern Stearns County and western Benton/Sherburne counties

The remaining two buried aquifer systems mapped for this project (aquifers 2 and 3) are mainly shown as deposits within the broad paleo-topographic depression of the Mississippi River valley. Consequently, most of the sand bodies in these systems have an elongated north-south orientation. One of the main questions that initiated this study concerns the general recharge characteristics of these buried systems. For instance, some buried sand and gravel aquifers in the upper Midwest are so hydraulically isolated from surface recharge by very low-impermeability confining layers that intensive long-term pumping, in effect, removes ground water that is not replaced at human time scales (Ripley, 2000). This type of ground water usage is sometimes called ground water mining and is not a sustainable use of the resource.

Existing information from DNR, MDH, and MPCA data files was acquired and compared to the three-dimensional aquifer boundaries established by this study to determine whether any conclusions could be made regarding recharge sources and ground-water flow paths. Existing data included hydrographs of lakes and ground-water monitoring wells in the area (DNR ground-water monitoring and lake-level monitoring programs), and geochemical data such as tritium indicating ground-water residence time (DNR county atlas, MDH source-water protection, and MPCA ambient ground-water monitoring programs).

Available tritium data and chloride/bromide ratios for the project area are shown on the cross sections. Where two chemistry values are shown, the top value is tritium and chloride/bromide is the bottom value. Where only one chemistry value is shown the value represents tritium data. A high Cl/Br ratio is often a good indication that some of the chloride in the sample is from human sources such as road salt or fertilizer (Berg, 2006). A high Cl/Br is also an indication that the sampled aquifer has a good hydraulic connection to the surface.

Tritium is a radioactive isotope of hydrogen that naturally occurs in the atmosphere. However, atmospheric testing of hydrogen bombs from 1953 to the early 1960s greatly increased the concentrations of atmospheric tritium. This tritium combined with the atmospheric water molecules, precipitated as rain or snow, and entered aquifers through surface infiltration. The presence of tritium at more than 10 tritium units (TU) in a ground-water sample indicates recent water (recharged since 1953). Samples with tritium values of 1 or below are interpreted as vintage water (recharged before 1953). Tritium values between 1 and 10 are mixtures of recent and vintage water (Alexander and Alexander, 1989).

The hydrograph and tritium information from these sources that could be associated with the aquifer mapping and stratigraphic conclusions of this study for the Mississippi River valley is summarized on Stearns07miss_vector_200dpi.pdf . The tritium data on the map are symbolized by tritium values and aquifers with the circles representing aquifer 2, the squares representing aquifer 3, and an unmapped aquifer 4 shown as triangles. The colors of these symbols represent tritium value ranges. Yellow symbols indicate no tritium data available. Pink values (tritium greater than 10 tritium units) indicate recent water that entered the ground no more than approximately 50 years ago. Green symbols indicate ground water that is a mixture of recent water and water that is older than 50 years. Recent values indicate a relatively direct recharge connection from the land surface. Mixed values may indicate a less direct recharge connection.

The most significant conclusion from the tritium data available for this portion of the Mississippi River valley is that all the values are either recent or mixed indicating relatively open recharge pathways from the surface. These connections are also evident on most of the cross sections where direct hydraulic connections probably exist between the surficial aquifer system and aquifers 2 and 3. Indirect connections between the land surface and aquifer 3 may also exist in which water passes through aquifer 2 prior to reaching aquifer 3.

The hydrograph data also suggest relatively unrestricted recharge between the surficial aquifer system and the buried aquifer systems. Three hydrographs are shown on Stearns07miss_vector_200dpi.pdf . The hydrograph of Lake No.71-0159 shows water-level fluctuations of Long Lake in the southeastern portion of the study area. The hydrograph shows the following patterns: high lake-water levels during the mid-1980s, no data during the very dry late 1980s, a water level rebound during the mid-1990s, another decline in late 2001, and another rebound after that. This same general pattern is shown by the DNR observation well No. 5005 hydrograph north of Rice, which is screened in aquifer 3, and the DNR observation well No.71026 hydrograph west of Clear Lake, which is screened in the unmapped aquifer 4.

Aquifer 2 is mainly used for domestic water supply especially in an area east of Sauk Rapids in Benton County on the right end of cross-section 046. Fewer wells penetrate the deeper aquifer 3; therefore, the boundaries of aquifer 3 are less certain. The primary uses of aquifer 3 are domestic and irrigation. The irrigation uses of this aquifer are concentrated around the Rice area in northwestern Benton County and an area northwest of Clear Lake in Sherburne County.

Conclusions

This study was designed to achieve two general purposes: to create preliminary maps of some of the major buried aquifer systems in the area and to investigate general recharge characteristics of buried aquifer systems in the Mississippi River valley. Well data were sufficient to map five buried aquifer systems, although mapping in the eastern portion of the study area could be improved if more subsurface stratigraphic information were available. Mapping for this project focused on aquifer systems that could be delineated across relatively large portions of the study area. Future mapping efforts could be extended to include some deeper aquifers, especially in the southwestern portion of the area.

The mapped aquifer systems appear to consist of groups of discrete sand bodies with complex shapes and orientations, with the possible exception of the aquifer 3 system in the Mississippi River valley. Although well data that penetrate this aquifer 3 are limited, this aquifer system may be more laterally extensive than the other mapped aquifer systems.

Portions of the study area where buried aquifers are not shown on the maps (low-resolution map Stearns07_page_raster_100dpi.pdf ; high-resolution map Stearns07sec_vector_200dpi.pdf) can be explained by three general conditions: a real lack of buried aquifers due to a thin layer of Quaternary sediment, lack of sufficient well data density, and lack of well data of sufficient depth. A real lack of buried aquifers exists in the eastern portion of Stearns County in an area approximately from Sartell (shown on the right side of cross sections on 034_040.pdf) south to a line approximately defined by a west-east line from Richmond to Clear Lake (right side of cross sections on 074_080.pdf). This area has also been defined by previous reports (Meyer, 1995, Plate 4; Falteisek, 1998, Plate 9). This area seems to have a general lack of ground water resources that should be considered in any development plans for the area. South of the line between Richmond and Clear Lake, in the southeastern portion of Stearns County, the lack of buried aquifers shown on the map is mostly a lack of data issue since most of the wells in this area are relatively shallow. Finally, the northwestern portion of Stearns County is another area where few buried aquifers have been mapped due to a scarcity of located wells in that area.

Three types of evidence indicate relatively unrestricted recharge of the buried aquifer systems from the surficial aquifer system in the Mississippi River valley between Rice and Clear Lake. The evidence includes stratigraphic evidence from cross sections, limited geochemical data, and area hydrograph comparisons of lake and monitoring well data. The extensive set of geologic cross sections shows many stratigraphic and probable hydraulic connections between buried sand bodies of the aquifer systems 2 and 3 and the surficial aquifer system. Geochemical ground-water residence time indicators (tritium) from MDH and MPCA studies suggest that much of the water in the buried aquifer systems recharged relatively recently. Tritium values from six ground-water samples collected from aquifer systems 2, 3, and 4 had recent or mixed values. Finally, comparisons of an area lake hydrograph and monitoring well hydrographs show the same general patterns of lower water levels during dry periods and higher water levels during wet periods.

References cited

Alexander, S.C., and Alexander, E.C., 1989, Residence times of Minnesota groundwaters: Minnesota Academy of Sciences Journal, v.55, no.1, p.48-52.

Berg, J.A., 2006, Hydrogeology of buried aquifers (Plate 7) *in* Geologic Atlas of Pope C, Minnesota: Minnesota Department of Natural Resources County Atlas Series C-15, part B, scale 1:100,000.

Ellingson, J.B., 2002, Surficial geology, Benton County, Minnesota (Plate 3) *in* Aggregate resources of Benton County, Minnesota, Report 356: Minnesota Department of Natural Resources, Division of Lands and Minerals, Scale 1:50,000.

Eng, M.T., and Katsoulis, M.P., 1987, Classification of aggregate resources, Sherburne County, Minnesota (Plate B) in Aggregate resources of Sherburne County, Minnesota, Report 352: Minnesota Department of Natural Resources, Division of Minerals, scale 1:100,000.

Falteisek, J., (project manager) 1998, Geologic Atlas of Stearns County, Minnesota, County Geologic atlas series, C-10, Part B, Minnesota Department of Natural Resources, Division of Waters, scale 1:100,000.

Harris, Ken, and J. A. Berg 2006, Quaternary Stratigraphy, Plate 2 *in* Traverse – Grant Regional Hydrogeologic Assessment Part A, Minnesota Geological Survey, University of Minnesota, St. Paul, Minnesota, scale 1:100,000.

Lehr, J.D., 1990, Aggregate resources and Quaternary geology of Wright county, Minnesota, Report 294: Minnesota Department of Natural Resources, Division of Minerals, scale 1:100,000.

Meyer, G.N., project manager, 1995, Geologic atlas, Stearns County, Minnesota, County Atlas Series, C-10, Part A, Minnesota Geological Survey, University of Minnesota, St. Paul, Minnesota, scale 1:100,000.

Meyer, G.N. and Lynn Swanson, 1996, Text Supplement to the Geologic atlas, Stearns County, Minnesota, County Atlas Series, C-10, Part C, Minnesota Geological Survey, University of Minnesota, St. Paul, Minnesota. P.34-35.

Ripley, David, 2000, The water resource characteristics of the West Fargo aquifer System: North Dakota State Water Commission, North Dakota Ground-Water Studies Number 106 – Part II.

Setterholm, D.R., project manager, 2007. Geologic Atlas of Todd County, Minnesota, County Atlas Series C-18, Part A, Minnesota Geological Survey, University of Minnesota, St. Paul, Minnesota, 6pls. Scales 1:100,000 and 1:200,000.