The Journal of the Iowa Academy of Science: JIAS

Volume 102 | Number 3-4 Article 3

1995

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Jour. Iowa Acad. Sci. 102(3-4):25-31, 1995

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The hydrogeology of the Devonian-Silurian carbonate aquifer was investigated at a hazardous waste site in northern Cedar Rapids, Iowa. Data collected at the project site included bedrock cores, specific capacity measurements in discrete packer intervals and monitoring wells, hydraulic-head measurements and groundwater samples collected from select Devonian and Silurian wells.

Unconsolidated Quaternary glacial and alluvial deposits overlie limestone and dolomite of the Devonian Otis and Bertram Formation and Silurian dolomites of the Scotch Grove and upper Hopkinton Formations. Three main zones of higher permeability are noted: 1) a highly vugular zone at the base of the lower Coggon Member of the Devonian Otis Formation; 2) a zone of fossiliferous packstone located immediately below the Devonian/Silurian contact in the upper Scotch Grove Formation; and 3) a highly vugular and fossil moldic wackestone unit of the Scotch Grove Formation. These aquifer units are separated by less permeable units consisting of: 1) the Cedar Rapids and upper Coggon Members of the Otis Formation; 2) the Bertram Formation; 3) intercalated mudstone facies variably present in the upper Scotch Grove Formation; and 4) dense cherty and non-cherty dolomite of the lower Scotch Grove and upper Hopkinton Formations. The greatest water-yielding potential occurs in the vugular wackestone unit of the Scotch Grove Formation. Production from this aquifer zone may be similar to the highly permeable Farmers Creek aquifer reported by other investigators.

Groundwater flow is predominantly downward through the upper Otis and Bertram formations and essentially horizontal in the lower Coggon Member and Scotch Grove Formation. Horizontal groundwater flow in the Silurian aquifer is generally southward and is consistent with regional trends. Groundwater from the Devonian-Silurian aquifer yield calcium-magnesium-bicarbonate type water.
INDEX DESCRIPTORS: Cedar Rapids, Devonian, Silurian, aquifer, hydrogeology, water quality

Much of eastern Iowa is underlain by Devonian and Silurian carbonate bedrock which provide a plentiful source of high-quality water for public and private use (Wahl et al.,1978). Numerous private residents and industrial facilities in the Cedar Rapids, Iowa area tap into this productive carbonate aquifer as their primary source of water; however, groundwater yields from the rocks can vary substantially, both areally and vertically. The most productive portions of the aquifer are often difficult to identify without subsurface investigation and correlation of water-bearing zones in the Silurian aquifer generally cannot be made from one location to another with much certainty (Wahl and Bunker, 1986).

The purpose of this investigation was to characterize the hydrogeology of the uppermost bedrock units encountered in the northern Cedar Rapids area (Figure 1). Subsurface data obtained during a remedial investigation at a hazardous waste site were used for identification and delineation of hydrostratigraphic units, evaluation of the production potential of the aquifer and description of the hydrogeochemistry of the Devonian-Silurian carbonate aquifer in the area. The results of this study will be useful for identifying and correlating water-bearing units on both a local and regional scale and aid local and regional planners for implementing water supply and water use restrictions in the northern Cedar Rapids area.

BACKGROUND

Project Site

The 1.5 acre project site is located in Section 2, Township 83 North and Section 35, Township 84 North, Range 7 West, Linn County, Iowa (Figure 1). The site was a disposal area for solid and liquid wastes, including solvents, paint sludge and general industrial refuse in the 1950's (Montgomery Watson, 1993). Monitoring wells were installed to a maximum depth of 350 feet at the site to determine the nature and extent of groundwater contamination (Figure 1). Bedrock coring and packer sampling, water level and specific capacity measurements and sampling of groundwater from monitoring wells serve as the basis for describing the geologic and hydrogeologic setting of the northern Cedar Rapids area. Groundwater contamination at the disposal site is currently under investigation and the results are not presented in this paper.

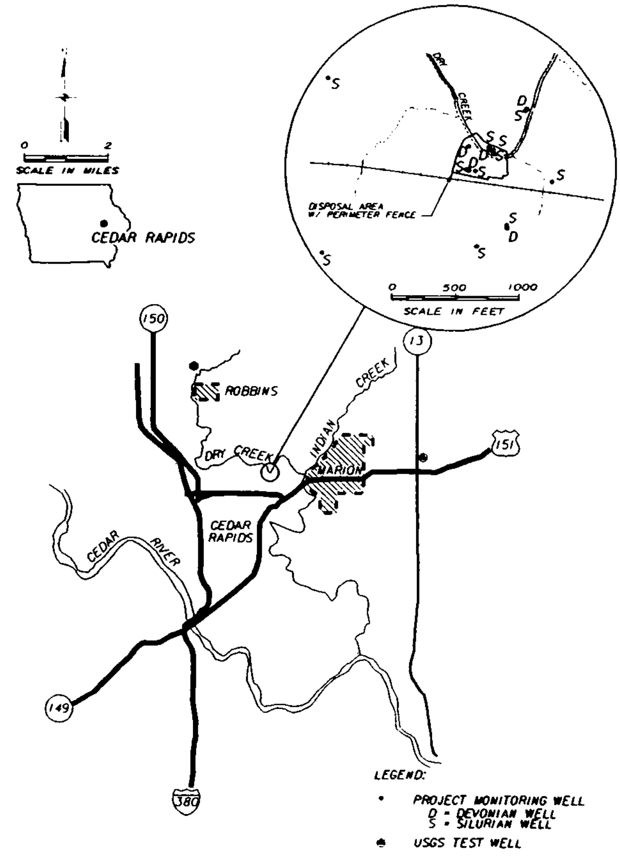

Figure 1. Location map.

Geographic Setting

The Cedar Rapids region lies within the Iowan Surface landscape region, which is characterized by gently rolling to undulating hillslopes with a well developed drainage system (Prior, 1991). The physiography was created by erosion and fluvial dissection of the Pre-Illinoian glacial landscape. In areas adjacent to major stream valleys, the landscape is generally steeper with rock outcrops occasionally forming cliffs. Relief of 150 to 200 feet is occasionally observed in these areas (Wahl and Bunker, 1986). The Cedar River flows southeasterly through the Cedar Rapids area (Figure 1) with tributaries to this river effectively draining the southern two-thirds of the Linn County area (Hansen, 1970). Other major drainage systems in the northern Cedar Rapids area include those of Dry Creek and Indian Creek (Figure 1).

Previous Hydrogeological Investigations

Early reports regarding the groundwater resources of Linn County are found in Norton (1895, 1897, 1935), Norton and others (1912) and Lees (1935). Hansen (1970) provided the first comprehensive evaluation of the groundwater resources of Linn County and described the availability, yield, and chemical characteristics of the aquifers. He noted that municipalities, industries, farm and livestock rely almost exclusively on groundwater from alluvium, buried channel deposits, Devonian and Silurian carbonates, and the Jordan sandstone for water supply purposes. In Cedar Rapids, approximately 65 percent of groundwater comes from the Devonian-Silurian aquifer (Hansen, 1970). A more regional investigation of groundwater availability and use in the Cedar Rapids area focused on a 12 county region in east-central Iowa (Wahl et al.,1978). Wahl and Bunker (1986) also describe the groundwater occurrence, flow and water quality of the Devonian and Silurian carbonate aquifers in the Linn County area. Numerous test wells were installed and the water bearing capability of various units was evaluated with packers, borehole flow meters, borehole geophysics and hydraulic-head measurements. Hydraulic-head data from two test wells were used in the present investigation to estimate the general direction of groundwater flow in the Silurian aquifer.

METHODS

Continuous bedrock cores were collected at several monitoring well locations using an NX-wireline system. An Aardvark NX-wireline packer assembly was used to isolate various five to ten foot intervals of the aquifer for groundwater sampling and hydraulic testing (Schilling and Noteboom, 1994). Specific capacity measurements were conducted in monitoring wells and boreholes during purging of the wells and packer intervals for groundwater sample collection. A submersible pump was lowered inside the drill rods and monitoring wells and pumped at a flow rate ranging from 3 to 5 gallons per minute (gpm). Specific capacity was calculated by dividing the pumping rate (in gpm) by the amount of drawdown (in feet). Water levels were recorded in monitoring wells to the nearest 0.01 foot using an electronic water level indicator.

Groundwater samples for inorganic analyses were collected from two monitoring wells installed in the Devonian aquifer and three wells installed in the Silurian aquifer (two wells in the Scotch Grove Formation and one well in the upper Hopkinton Formation). The water samples were collected using dedicated bladder pumps and low-flow purging and sampling procedures (Barcelona et al., 1994; USEPA, 1992). A dedicated bladder pump was installed at a depth approximately 20 feet below the static water level surface in each well and a drop tube from the pump to the well screen was utilized to purge and sample groundwater from the midpoint of the screen. Groundwater samples collected for inorganic constituents were analyzed by ICP methods by National Environmental Testing, Inc. in Cedar Falls, Iowa. Ion charge balance errors ranged from less than 0.1% to 11.5% for all chemical analyses.

RESULTS AND DISCUSSION

GEOLOGY

The geology of northern Cedar Rapids is characterized by unconsolidated Quaternary glacial and alluvial deposits overlying Devonian and Silurian carbonate bedrock. The Quaternary deposits, described in detail elsewhere (e.g., Hallberg, 1980; Wahl and Bunker, 1986; Hansen, 1970), vary from 0 to greater than 60 feet in thickness. Because the bedrock surface is relatively flat in the area, the thickness of the Quaternary deposits generally varies with the land surface elevation. Bedrock surface elevation ranges from approximately 790 feet to 810 feet (Montgomery Watson, 1993; IDNR-GSB Linn County geologic file).

Devonian System

The uppermost bedrock units encountered in the area are assigned to the Middle Devonian Wapsipinicon Group, as described by Witzke et al. (1988), and consist of the Pinicon Ridge, Otis and Bertram Formations (Figure 2). At the project site, the Otis Formation comprises the bedrock surface, although sections of Spring Grove and Kenwood members of the Pinicon Ridge Formation have been mapped in the immediate site area (Wahl and Bunker, 1986).

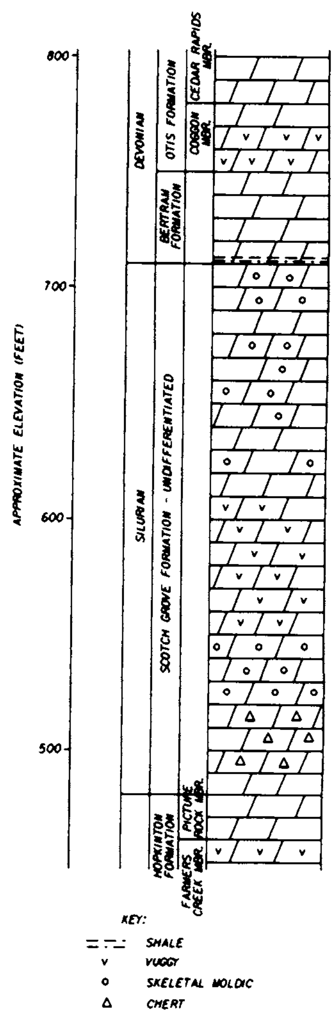

Figure 2. Generalized rock stratigraphy of nothern Cedar Rapids.

The Otis Formation includes the Cedar Rapids and Coggon members and consists chiefly of dense and fine crystalline limestone and dolomite. The Cedar Rapids Member consists of a blue-gray to light tan, lithographic to fine crystalline, hard, dense, thin- to medium-bedded dolomite with some minor limestone. In the upper portions, minor shale partings, stylolites and brecciation are noted, and calcite and quartz veins are prevalent throughout. The member becomes slightly coarser and vugular with depth and grades transitionally into the Coggon Member at a thickness of approximately 25-30 feet.

The Coggon Member consists of a yellow-brown to dark brown, fine crystalline, petroliferous, vesicular to highly vugular dolomite. The degree of vugular porosity is variable in the study area, although most common in the lower 5-10 feet of the unit. Several large (greater than 3 feet) and numerous smaller voids have been observed in the lower Coggon Member at an elevation of approximately 740 to 760 feet. Where the degree of vugular porosity is reduced, secondary calcite is often noted. The texture of the Coggon Member is also variable in the area, ranging from soft and "sandy" coarse crystalline dolomite to hard and dense mudstone. The thickness of this member is approximately 25 feet at the project site.

A sharp contact marks the lithologic boundary between the Otis and Bertram formations in the area. The Bertram is a brown, light gray to blue-gray, sublithographic, highly brecciated, stylolitic, hard and dense dolomite (Figure 2). Although the upper contact of this mudstone with the overlying Coggon Member of the Otis Formation may occasionally be highly fractured and solutionally weathered, in general, the Bertram exhibits very little secondary porosity. Coarse secondary calcite crystals and veins are present throughout the formation filling in small voids and fractures. The lower five to eight feet of the formation is marked by light gray to green, shaley, medium crystalline dolomite and thin beds of green shale. The Bertram Formation is approximately 40 feet thick in the area.

Silurian System

The basal green shale of the Devonian Bertram Formation forms an abrupt contact with the underlying Silurian dolomite at an elevation of approximately 700 feet in the northern Cedar Rapids area. In Iowa, Silurian rock consists nearly entirely of dolomite which have been divided into six formations, which, in descending order, include the Gower, Scotch Grove, Hopkinton, Blanding, Tete des Morts and Mosalem (Witzke, 1992; Bunker et al., 1985).The Tete des Morts and Mosalem Formations are not found in the Cedar Rapids area, whereas the Gower Formation is of limited subsurface extent in eastern Iowa and is not present in northern Cedar Rapids (Witzke, 1992). The Scotch Grove Formation forms the uppermost Silurian formation encountered in northern Cedar Rapids.

The dolomite of the Scotch Grove Formation consists of multiple carbonate facies which have been assigned member status in eastern Iowa (Witzke, 1992; Bunker et al., 1985) Differentiation between these members is often very difficult due to the complex stratigraphic and depositional relationship exhibited by the carbonate facies. For purposes of this study, individual members have not been stratigraphically differentiated; however, several distinct lithologic units have hydrologic significance in the area. These lithologic units have been informally classified according to the type of depositional fabric and porosity exhibited by each unit.

The Scotch Grove Formation in northern Cedar Rapids is dominated by three main types of carbonate fabrics (Figure 2): 1) skeletal packstone (consisting primarily of crinoidal debris) with a high degree of intercrystalline porosity; 2) highly vugular and fossil moldic skeletal wackestone; and 3) dense and sparsely fossiliferous non-cherty and cherty mudstone (Schilling and Fuhrmann, 1994; Witzke, 1992; Bunker et al., 1985). The upper 70 to 90 feet of the Scotch Grove is the most variable portion of the Silurian bedrock encountered in the area. The dolomite consists predominantly of skeletal packstone, although the fabrics may range from dense mudstone to highly vugular and coarsely crystalline wackestone (Figure 2). The packstone unit is often characterized by numerous secondary calcite veins and cement which can form crystalline horizons several inches thick. Fractures near the Devonian-Silurian contact are occasionally filled with green shale from Devonian strata. Where fractures are not filled by calcite or clay, the upper 5-10 feet of this unit below the contact exhibit a high degree of secondary porosity.

Dense, medium crystalline dolomite with highly developed vugular and fossil-moldic porosity is observed underlying the variable upper Scotch Grove facies (Figure 2). Many of the vugs and fossil molds have been solutionally enlarged to form interconnected networks of channels generally 0.5 to 3 inches in diameter. Large voids of 5-10 feet in diameter have been encountered in this zone. Some of these voids have been partially filled with unconsolidated black silt and clay containing disseminated pyrite. Coarse dolomite crystals and chert are occasionally observed lining or filling in vugs and fossil molds. The vugular wackestone unit is approximately 60 to 70 feet thick in the site area (Figure 2).

A second skeletal packstone unit is typically found underlying the vugular wackestone at an elevation of approximately 550 feet (Figure 2).This unit is generally yellow-brown, abundantly fossiliferous, soft, crumbly dolomite. Crinoidal debris appears to represent a large proportion of the recognizable fossil population with brachiopods and corals also present in significant quantities. Less variability in the dolomite fabric is typically noted in this lower packstone unit than the upper zone. The lower packstone unit is approximately 40 to 50 feet thick in the area.

Dense, gray, cherty dolomite is encountered at an elevation of approximately 500 to 520 feet in the northern Cedar Rapids area (Figure 2). This dense mudstone facies exhibits relatively little secondary porosity in the form of scattered vugs and fossil molds. Abundant nodules of chert appear "chalky" as described by Witzke (1992). The cherty dolomite unit apparently thickens northwest from the project site towards the town of Robins (Figure 1); there cherty dolomite was observed to be approximately 150 feet thick (Wahl and Bunker, 1986). Approximately 5 to 10 feet of dense, non-cherty dolomite underlie this unit in the area (Figure 2).

The Hopkinton Formation is comprised of four members which, in descending order, include, Picture Rock, Farmers Creek, Marcus and Sweeney Members (Witzke, 1992; Bunker et al., 1985). The upper two Members were encountered in a single borehole installed at the project site at elevations of approximately 480 feet and 460 feet, respectively (Figure 2). The Picture Rock Member is dominated by dense, thick bedded, slightly vuggy dolomite with scattered tabulate corals and stromatoporoid fossils. Only the upper 5 feet of the porous and vuggy dolomite of the Farmers Creek Member was observed in core collected at the project site.

HYDROGEOLOGY

Hydrostratigraphic Units

The occurrence and movement of groundwater in carbonate aquifers are largely dependent upon the degree of secondary porosity developed in the rocks (fractures, vugs, fossil molds, etc.) and the size and degree of interconnection between these rocks openings. Because the depositional fabric and porosity associated with the Devonian-Silurian carbonate aquifers vary in the study area, the water-yielding capacity of the rock units can also vary substantially. In the Silurian aquifer, for example, Wahl and Bunker (1986, p.21) point out that "Skeletal molds in the Silurian dolomites have porosities as much as 39 percent and are laterally equivalent to dolomites with porosities as little as less than one percent."Three main aquifer units have been identified as continuous throughout the area: 1) the lower Coggon

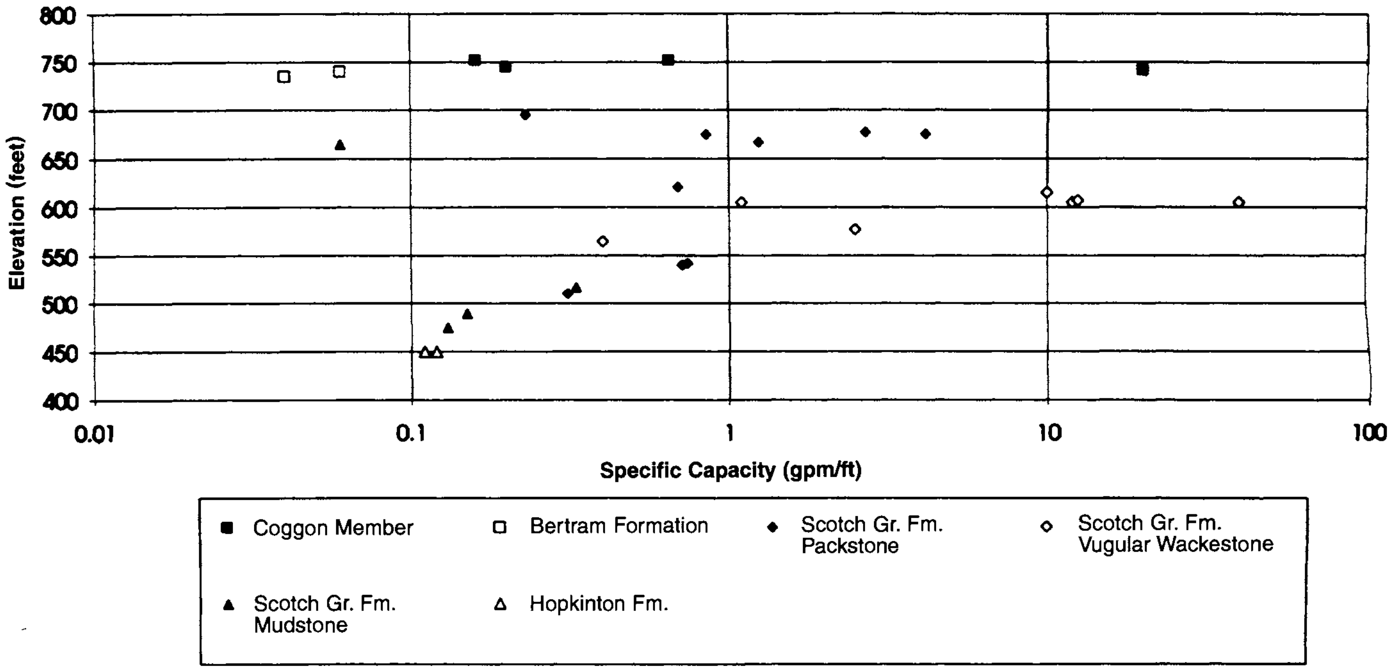

Figure 3. Specific capacity of various hydrogeologic units in northern Cedar Rapids.

Member of the Devonian Otis Formation; 2) a zone of 10-20 feet in the upper Scotch Grove Formation located immediately below the Devonian/Silurian contact; and 3) the vugular wackestone unit of the Scotch Grove Formation. These aquifer units are separated by the less permeable stratigraphic units consisting of the Cedar Rapids and upper Coggon Members of the Otis Formation, the Bertram Formation, intercalated mudstone facies which are variably present in the upper Scotch Grove Formation, and the dense cherty and non-cherty dolomite of the lower Scotch Grove Formation and upper Hopkinton Formation. Although fractures and secondary porosity developed within these strata are capable of transmitting groundwater, these hydrologic units are not productive and continuous aquifers.

The results of the specific capacity measurements are presented in Figure 3. The highest specific capacity values were generally determined in the vugular wackestone unit of the Scotch Grove Formation where several measurements ranged from 10 to 50 gallons per minute per foot of drawdown (gpm/ft). Specific capacity determination in the upper Scotch Grove Formation and lower Coggon Member also ranged greater than 1 gpm/ft, although more variability is noted in these horizons (Figure 3). In particular, groundwater yields from the upper Scotch Grove Formation reflect the geologic variability of facies in the area. Wells in the porous and fossiliferous packstone portion of this unit yield large amounts of water (approximately 1-10 gpm/ft), whereas the specific capacity of a laterally equivalent mudstone facies is nearly three orders of magnitude less at 0.04 gpm/ft.

The specific capacity in the Scotch Grove Formation appears to decline with depth in the lower packstone unit, cherty mudstone and into the upper Hopkinton Formation (Picture Rock and Farmers Creek Members) (Figure 3). The Farmers Creek aquifer of the middle Hopkinton Formation described in Wahl and Bunker (1986) was not penetrated during drilling conducted for this study. The Farmers Creek aquifer is located in the basal part of the Farmers Creek Member approximately 70 to 105 feet above the base of the Silurian section (Wahl and Bunker, 1986). Yields from the Farmers Creek aquifer are believed to be comparable or exceed the expected yields from the vugular wackestone unit of the Scotch Grove Formation.

Groundwater Flow System

A hydrograph of continuous hydraulic-head measurements conducted in wells installed in the Devonian lower Coggon Member and Silurian Scotch Grove Formation over a month-long period is presented in Figure 4. The hydrograph suggests a downward component of groundwater flow from the Devonian aquifer to the Silurian aquifer. Vertical hydraulic gradients measured between nested wells installed in Devonian and Silurian rocks range from approximately 0.02 to 0.05 ft/ft (Montgomery Watson, 1993). Hydraulic head fluctuations observed in Devonian and Silurian wells suggest the aquifers are nearly identical in their response to environmental conditions. The Devonian Bertram Formation appears to be a semi-confining bed between the Devonian and Silurian aquifers.

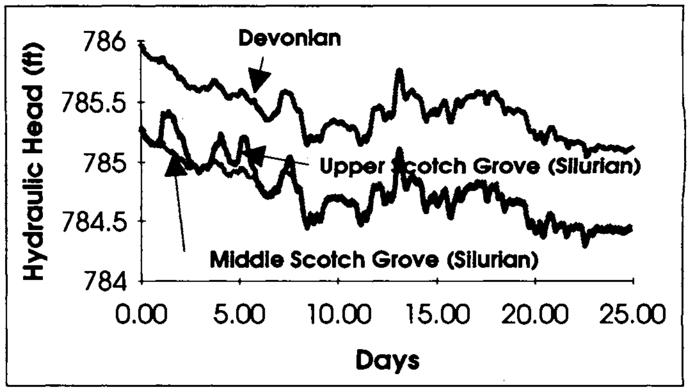

Figure 4. Hydrograph of nested wells installed in Devonian and Silurian aquifer.

Very little vertical hydraulic gradient is noted within the Silurian groundwater system from the upper Scotch Grove packstone unit to middle Scotch Grove vugular wackestone (Figure 4). This phenomenon is observed at all nested well locations where multiple wells have been installed in the Scotch Grove Formation, regardless of geologic facies screened. Vertical hydraulic gradients measured in the Scotch Grove Formation are typically on the order of 0.0005 ft/ft (Montgomery Watson, 1993). Lack of significant vertical gradients suggests that groundwater flows horizontally in the Scotch Grove Formation. Based on the groundwater elevation measured in a single well installed in the Hopkinton Formation, a slight upward hydraulic gradient (0.001 ft/ft) appears to exist between the Hopkinton Formation and Scotch Grove Formation (Montgomery Watson, 1994). The small vertical hydraulic gradients within the Scotch Grove and Hopkinton formations support the general concept of treating the entire Silurian section as single aquifer in the Linn County area for water supply purposes (i.e., Wahl and Bunker, 1986; Hansen, 1970).

A conceptual model for groundwater flow in the Devonian-Silurian carbonate aquifer in the northern Cedar Rapids area is presented in Figure 5. Groundwater flows horizontally in the lower Coggon Member and Scotch Grove Formation, whereas vertical downward flow is typical through the upper Otis and Bertram Formations (Figure 5).

The direction of horizontal flow of groundwater in the Scotch Grove Formation is generally southward (Figure 6) based on water levels measured in two U.S. Geological Survey test wells installed near the towns of Robins and Marion (USGS, 1994) and water levels measured in Silurian monitoring wells at the project site (Figure 1). Flow of groundwater to the south in the Silurian aquifer is consistent with historical regional trends (Wahl and Bunker, 1986; Hansen,1970). According to Wahl and Bunker (1986), discharge from the Silurian aquifer primarily occurs to major stream valleys (Cedar River) and pumping centers.

Hydrogeochemistry

Chemical analyses of water samples from the Devonian and Silurian aquifers are similar and both aquifers yield calcium-magnesium-bicarbonate type water (Hem, 1989) (Table 1). This type of groundwater is consistent with water collected from carbonate aquifers in Linn County (Wahl and Bunker, 1986; Hansen, 1970) and east-central Iowa (Wahl et al., 1978). Sodium, chloride and sulfate are also detected at measurable concentrations (Table 1). Groundwater from both aquifers would be considered hard, with hardness ranging from approximately 500 mg/L in the Devonian to about 300 mg/L in the Scotch Grove Formation. A further decrease in hardness is noted in the upper Hopkinton Formation (Table 1).

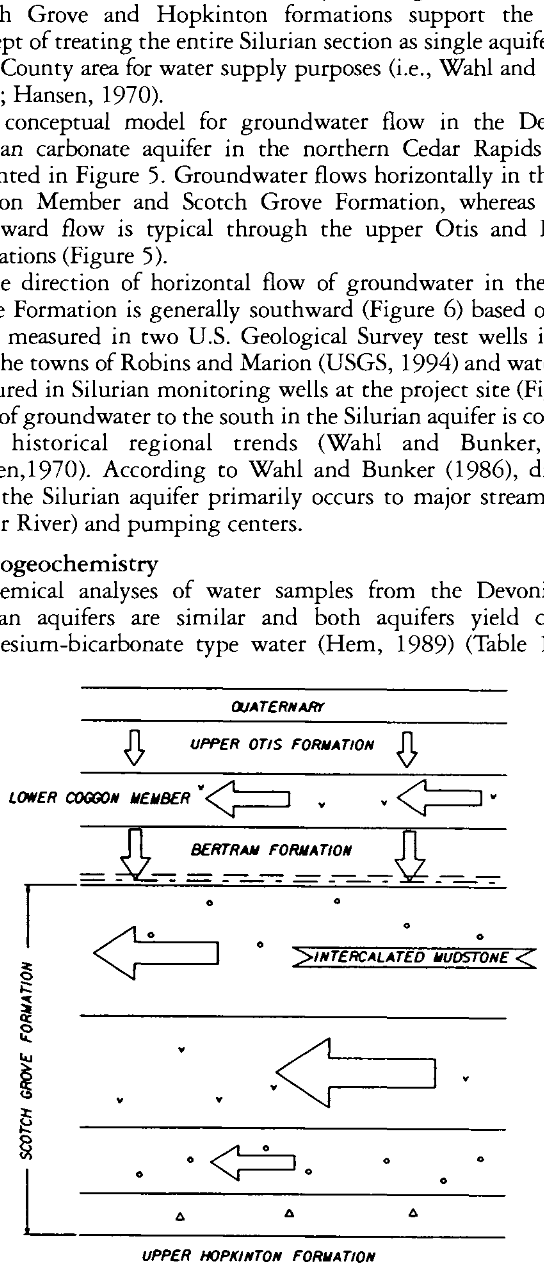

Figure 5. Conceptional groundwater flow system in northern Cedar Rapids. Arrow size proportional to flow rate.

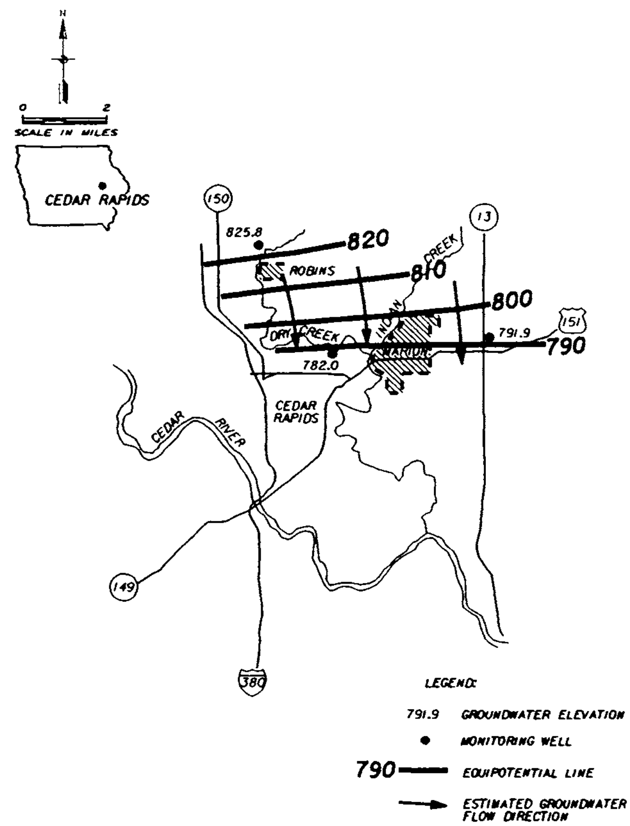

Figure 6. Approximate groundwater flow direction in undifferentiated Silurian aquifer.

Dissolved-solids concentrations decrease with depth, from the lower Coggon Member to the Scotch Grove and Hopkinton Formations (Table 1). A Stiff diagram graphically illustrates, in milliequivalents per liter, the decrease in major ion composition with depth (Figure 7). The change in water quality with depth in the Silurian aquifer is contrary to previous work in Linn County which had indicated that water quality within the Silurian aquifer was consistent with depth at a given location (Wahl and Bunker, 1986). Additional work is needed to verify whether these water quality differences at a single location are applicable to a more regional scale.

SUMMARY

Hydrogeological investigation of the Devonian-Silurian carbonate formations in northern Cedar Rapids, Iowa indicates that the uppermost bedrock units are comprised of Devonian Otis and Bertram Formation carbonates overlying dolomite of the Silurian Scotch Grove and Hopkinton Formations. The Otis Formation is approximately 50 feet thick and consists of dense and fine crystalline limestone and dolomite of the Cedar Rapids Member overlying coarse crystalline and often vugular dolomite of the Coggon Member. Approximately 40 feet of hard, dense and sublithographic

Table 1. Results of Chemical Analyses of Water from Selected Devonian and Silurian Wells (in mg/L)

Formation	Ca	Mg	Na	K	Mn	Fe	Alk (as $CaCO_3$)	Cl	SO_4	F	N (as NH_3)	TDS	Hard
Devonian													
Otis	140	36	17	<2.0	0.22	0.79	370	100	40	0.22	<0.2	580	510
Otis	140	33	30	2.2	<0.01	<0.1	380	50	80	0.21	<0.2	620	470
Silurian													
Scotch Grove	100	28	9.4	3.7	1.6	1.1	250	18	32	0.23	0.65	350	270
Scotch Grove	91	27	16	3.1	0.047	<0.1	290	20	44	0.27	<0.2	410	340
Hopkinton	49	14	2.8	<2	0.021	0.26	180	<3	6.8	0.37	<0.2	200	170

dolomite of the Bertram Formation complete the Devonian package in the area. The Silurian Scotch Grove Formation is highly variable, consisting of multiple dolomite facies dominated by three main types of carbonate fabrics: 1) skeletal packstone with a high degree of intercrystalline porosity; 2) highly vugular and fossil moldic skeletal wackestone; and 3) dense and sparsely fossiliferous non-cherty and cherty mudstone. The Scotch Grove Formation is approximately 240 feet thick in the northern Cedar Rapids area. Picture Rock and Farmers Creek members of the upper Hopkinton Formation underlie the Scotch Grove Formation.

Three main zones of higher permeability are noted in the area: 1) the lower Coggon Member of the Devonian Otis Formation; 2) a zone of 10-20 feet in the upper Scotch Grove Formation located immediately below the Devonian/Silurian contact; and 3) the vugular wackestone unit of the Scotch Grove Formation. These aquifer units are separated by less permeable stratigraphic units consisting of the Cedar Rapids and upper Coggon Members of the Otis Formation, the Bertram Formation, and the dense cherty and non-cherty dolomite of the lower Scotch Grove Formation and upper Hopkinton Formation. The greatest water yielding potential identified in the area is in the vugular wackestone unit of the Scotch Grove Formation which exhibits specific capacities greater than 10 gpm/ft. Production from this aquifer zone may be similar to the highly permeable Farmers Creek aquifer reported by Wahl and Bunker (1986).

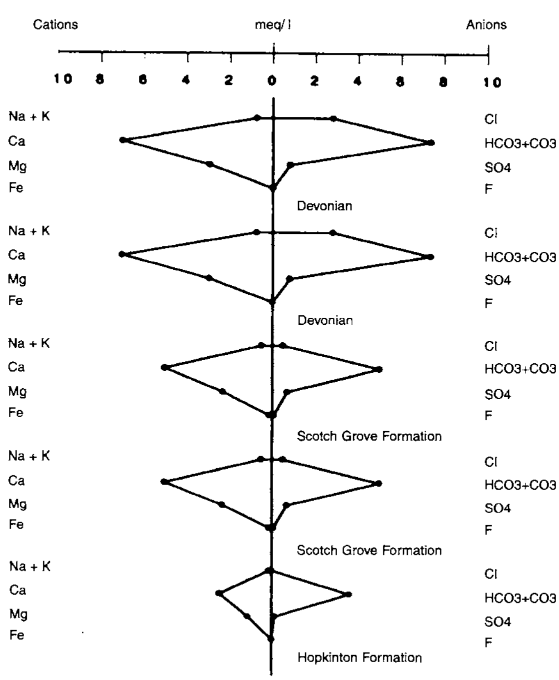

Figure 7. Stiff diagram of major ion concentrations in select Devonian and Silurian (Scotch Grove and Hopkinton Formation) wells.

Groundwater flow is predominately downward through the upper Otis and Bertram formations and horizontal in the lower Coggon Member and Scotch Grove Formation. The direction of groundwater flow in the Silurian aquifer is generally southward in northern Cedar Rapids and is consistent with regional trends. Chemical analyses of Devonian and Silurian groundwater are similar and yield calcium-magnesium-bicarbonate type water. Dissolved-solids concentrations appear to decline with depth from Devonian to Silurian strata, although this remains to be verified regionally.

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