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Hydrogeology and Ground-Water Quality, Chippewa Township, Isabella County, Michigan, 2002-05

Scientific Investigations Report 2006-5193

U.S. Department of the Interior
U.S. Geological Survey

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DIRK KEMPTHORNE, Secretary

U.S. Geological Survey
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Conversion Factors, Datums, and Abbreviations

Inch/Pound to SI

Multiply	By	To obtain
	Length	
inch (in.)	2.54	centimeter (cm)
foot (ft)	0.3048	meter (m)
mile (mi)	1.609	kilometer (km)
	Flow rate	
gallon per day (gal/d)	3.785	liter per day (L/d)

Vertical coordinate information is referenced to the National Geodetic Vertical Datum of 1929 (NGVD 29).

Horizontal coordinate information is referenced to the North American Datum of 1983 (NAD 83).

Altitude, as used in this report, refers to distance above the vertical datum.

Specific conductance is given in microsiemens per centimeter at 25 degrees Celsius (µS/cm at 25 °C).

Concentrations of chemical constituents in water are given either in milligrams per liter (mg/L) or micrograms per liter (µg/L).

VES stands for Vertical Electrical Sounding. Resistivities measured during the soundings are reported in ohm-meters (Ω/m).

Hydrogeology and Ground-Water Quality, Chippewa Township, Isabella County, Michigan, 2002–05

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Abstract

The ground-water resource potential of Chippewa Township, Isabella County, Mich. was characterized on the basis of existing hydrogeologic data, water-level records, analyses of water samples, and interpretation of geophysical survey data. Eight ground-water samples were collected and analyzed for major ions, nutrients, and trace-metal composition. In addition, 10 direct current-resistivity soundings were collected throughout Chippewa and Coe Townships to identify potential freshwater in the aquifer system. The aquifer system includes complexly interbedded glaciofluvial, glaciolacustrine, and basal-lodgment tills, which overlie Jurassic or Pennsylvanian sedimentary rocks. In parts of the township, freshwater is present in all geologic units, but in most areas saline water is encountered near the base of Pleistocene glacial deposits and in the Jurassic or Pennsylvanian bedrock. A near-surface sheet of relatively dense basal-lodgment till likely prevents, or substantially retards, significant direct recharge of ground water to glacial and bedrock aquifers in Chippewa and adjacent townships.

Glacial sands and gravels form the principal aquifer for domestic wells (97.5 percent of wells in the township). The single community water supply in the township has wells screened in glacial deposits near the base of the glacial drift. Increased withdrawals of ground water in response to increasing demand has led to a slight decline in water quality from this supply. This water-quality decline is related primarily to an increase of dissolved sulfate, which is probably a function of well depth and dissolution of gypsum, a common mineral constituent in the Jurassic “red beds” , which form the uppermost bedrock unit throughout most of the township. One explanation for the increase in sulfate is upconing of saline water from bedrock sources, which may contain saline water.

Introduction

Chippewa Township, Mich. needs water-resource information to plan for increased development and rapidly growing demands for water as the population of the township increases. Demand for ground water in Chippewa Township is increasing because, in part, the Saginaw Band of the Chippewa Indians has a large resort complex and is developing a large residential area on the Isabella Reservation. Substantial development also is occurring in the southern part of the township, where farmland is being retired for residential use. The U.S. Geological Survey (USGS), in cooperation with Chippewa Township, Mich., began a study of water resources of the township in 2002. The USGS compiled existing hydrogeologic data and supplemented these data with new water-quality information, surface-geophysical data, and water-level data from wells to characterize ground-water resources of Chippewa Township. This study, completed in 2005, is an initial assessment of the ground-water resources in the township. Water-level recorders on the wells used in this study will be maintained as part of a long-term plan to monitor and assist in management of the ground-water resource.

Purpose and Scope

This report (1) describes the major aquifers of Chippewa Township, (2) provides analysis of water levels measured in the township, and (3) describes the quality of ground water in the major aquifer units in the township. The scope of the USGS study was generally limited to water resources of Chippewa Township, but it was necessary to evaluate data for adjacent townships to put the information in context with the subregional hydrogeology. Therefore, a one-township-wide area surrounding Chippewa Township, including three townships in the western part of Midland County, constitutes the study area (fig. 1).

Hydrogeologic Setting

Chippewa Township, Isabella County, Mich., is in the western fringe of the Saginaw Lowlands (fig. 1) in Michigan’s Lower Peninsula. The Saginaw Lowlands is an extensive, relatively flat lying glacial-lake plain that formed when glacial ice retreated northeast from the Gladwin Moraine to Saginaw Bay (Dorr and Eschman, 1970, p. 160). The Gladwin Moraine allowed ponding of meltwater and subsequent deposition of lacustrine sediments when the Saginaw Lobe of glacial ice retreated to Saginaw Bay and formed the Port Huron Moraine.

Glacial deposits consist of complexly interbedded sand and gravel, clay-rich till, and lacustrine deposits, which are typically 280–320 ft thick. There seems to be lateral continuity

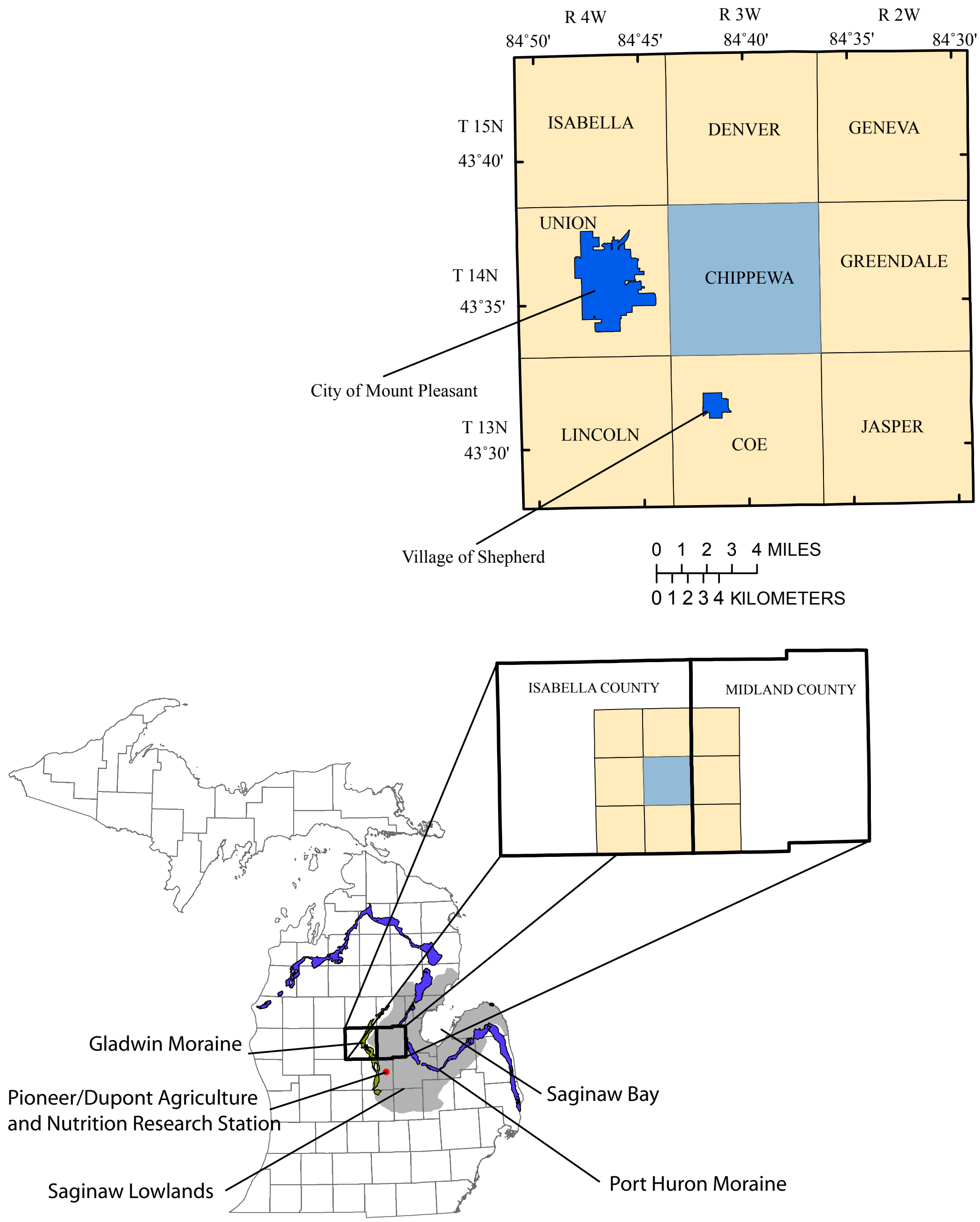


Figure 1. Nine-township subregional study area, Isabella and Midland Counties, Mich.

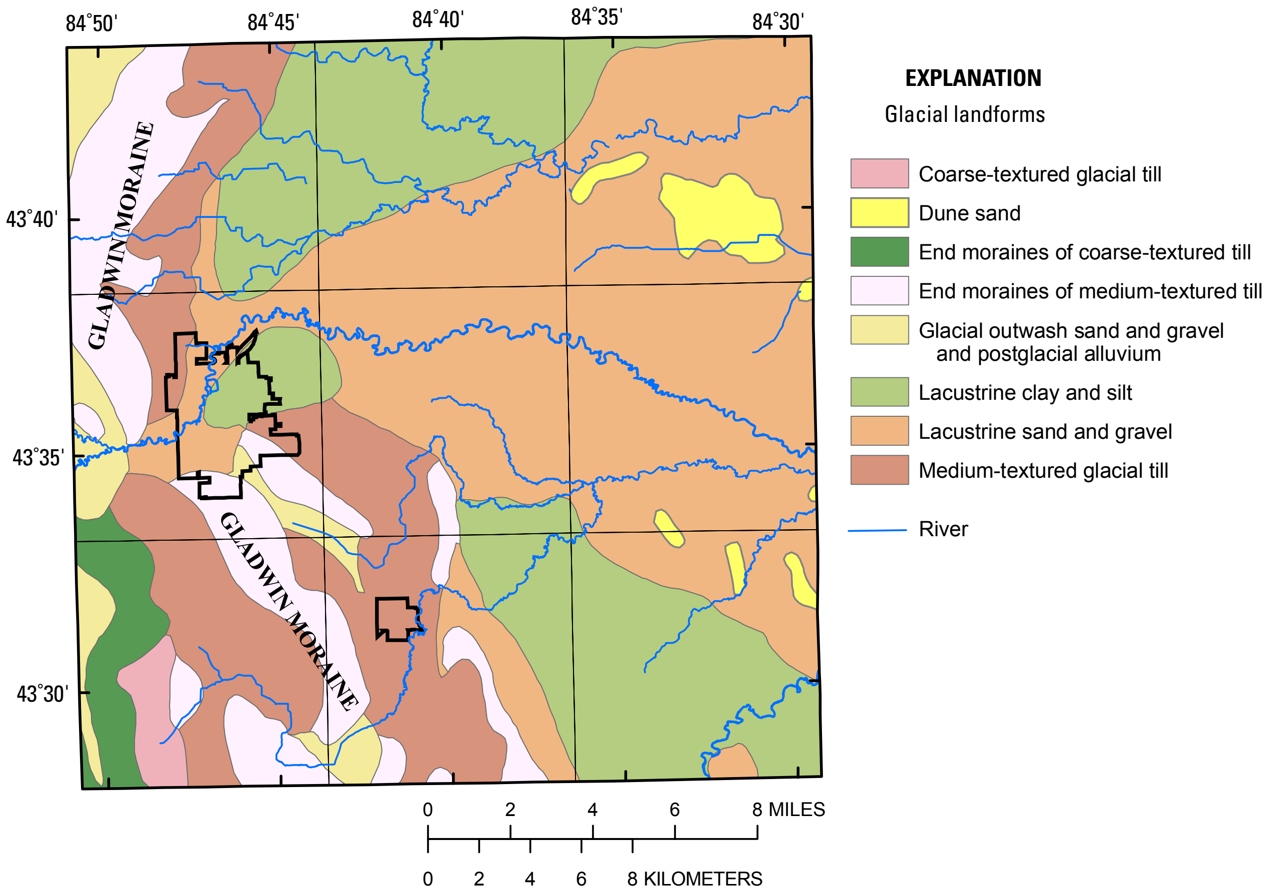


Figure 2. Glacial landforms, the Gladwin Moraine, and sediment types in the study area (modified from Farrand and Bell, 1982).

of surficial sediments (glacial-lake sediment, morainal deposits, and ground moraine) (fig. 2) and also lateral continuity of a sand and gravel layer at about 60–130 ft below land surface (Chippewa Township only). Glacial deposits that underlie this sand and gravel unit seem to be laterally discontinuous and consist of till interbedded with glaciofluvial sediments. In some areas of Chippewa Township and in adjacent townships, glacial sediments form a sole-source aquifer because much of the underlying Jurassic and Pennsylvanian sedimentary rock contains saline water (Westjohn and Weaver, 1998).

Hydrogeology

Surficial Deposits

The surficial geology of Chippewa Township has been interpreted to consist predominantly of glacial lacustrine sediments (lacustrine sand and gravel, as shown by Martin, 1955, and Farrand and Bell, 1982) and ground moraine (till plain) (fig. 2). However, geologic logs of water wells in the township indicate the presence of a near-surface clay-rich unit in almost all areas. This upper clay unit is probably basal-lodgment till that was deposited by the Saginaw Lobe of glacial ice when ice advanced to the position of the Gladwin Moraine (fig. 2). This alternative interpretation of the persistence of glacial till rather than lacustrine sediments is consistent with the glacial geology observed elsewhere in the Saginaw Lowlands (Martin, 1955; Westjohn and Weaver, 1998; Hoard and Westjohn, 2001).

Geologic descriptions of well drillers' logs stored in the Michigan Department of Environmental Quality (MDEQ) WELLOGIC database were also used to construct the conceptual model of the surficial geology. Inspection of geologic logs indicate that most domestic wells (86 percent) in Chippewa Township are completed at about 60 to 130 ft below land surface (fig. 3) in what is likely glaciofluvial sand and gravel deposits that form the shallow glacial aquifer. These sand and gravel deposits, which underlie the near-surface clay-rich unit, are probably part of an outwash plain that formed prior to the last advance of the Saginaw Lobe of glacial ice. Judging from the many residential wells completed in the shallow glacial

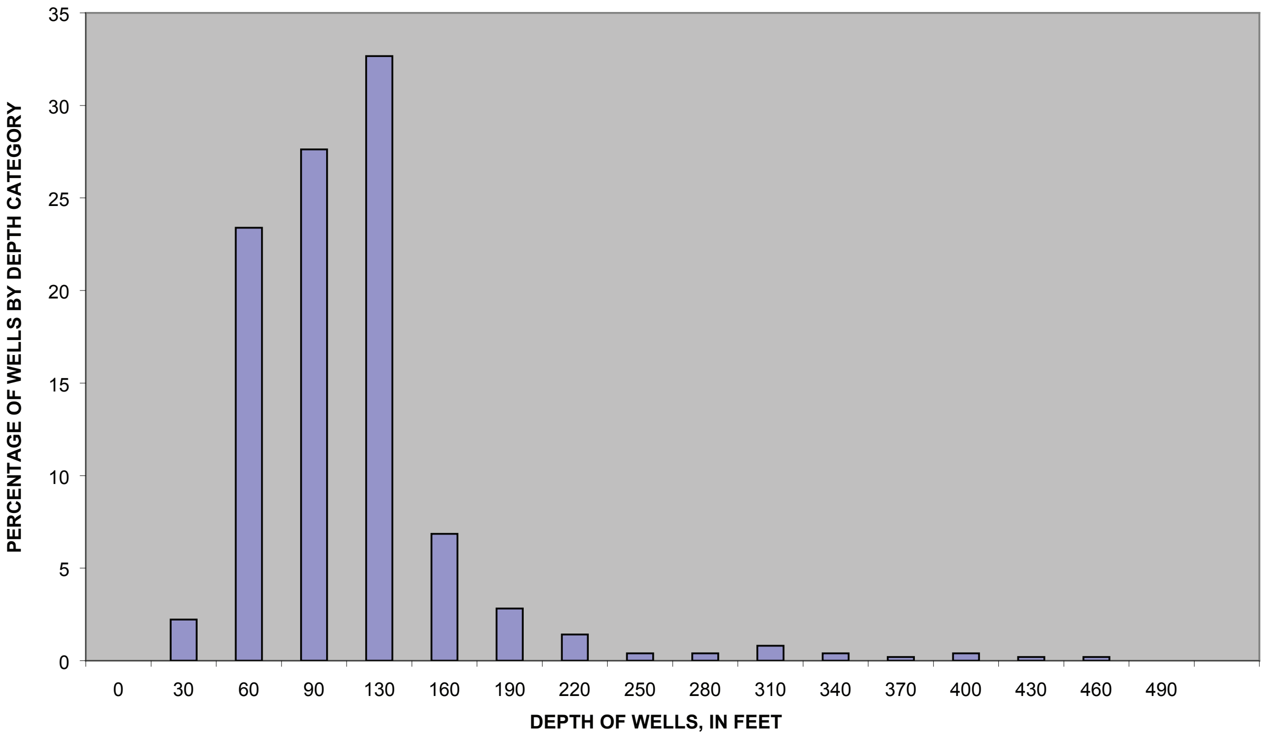


Figure 3. Distribution of wells by depth, Chippewa Township, Isabella County, Mich. Wells at depths equal to and greater than 320 feet are completed in bedrock (total of 496 wells).

aquifer, this unit may be laterally continuous throughout much of Chippewa Township. In addition, glaciofluvial sediments are interbedded with less permeable glacial till beneath the shallow glacial aquifer (130 to about 320 ft below land surface). This package of sediment forms the deep glacial aquifer in Chippewa Township. A study of the geologic logs indicates little if any continuity of the glaciofluvial sediments, which appear to be discontinuous lenses of sand and gravel. The general lack of continuity of glacial deposits is typical of most areas of Michigan.

Bedrock Units

Jurassic "red beds" comprise the uppermost bedrock unit within about 65 percent of the study area (fig. 4). Elsewhere, these rocks are absent, and the Pennsylvanian Saginaw Formation forms the first bedrock unit (fig. 4). Jurassic red beds are thin (typically less than 50 ft thick) and consist of red mudstone, red siltstone/sandstone, and gypsum (Westjohn and Weaver, 1998). Many logs of water wells for Chippewa Township report "red sand" at depths of 320 to 345 ft below land surface. This unit is generally not considered an aquifer. On some logs, gypsum or white limestone (probably gypsum) is reported within the red sand sequence. The so-called red sand occurrences are probably Jurassic red beds. The red bed sequence is reported to be mostly unconsolidated elsewhere in the Michigan Basin (oil and gas records, and Westjohn and Weaver, 1998) and also in Chippewa Township (logs of water wells).

The Pennsylvanian Saginaw Formation underlies the red bed sequence in most parts of the study area, but in places this bedrock unit directly underlies glacial sediments (fig. 4). The Saginaw Formation is mostly sandstone, although siltstone, shale, limestone, finely laminated siltstone/shale, and coal units make up a subordinate part of the formation (Westjohn and Weaver, 1998). Few water wells have been installed in the Saginaw Formation within the study area, so the water-resource potential for this rock unit is poorly known. (See water-quality section that follows.)

Water Levels

The water supply for the Saginaw Chippewa Tribe Isabella Reservation resort and housing development is the only

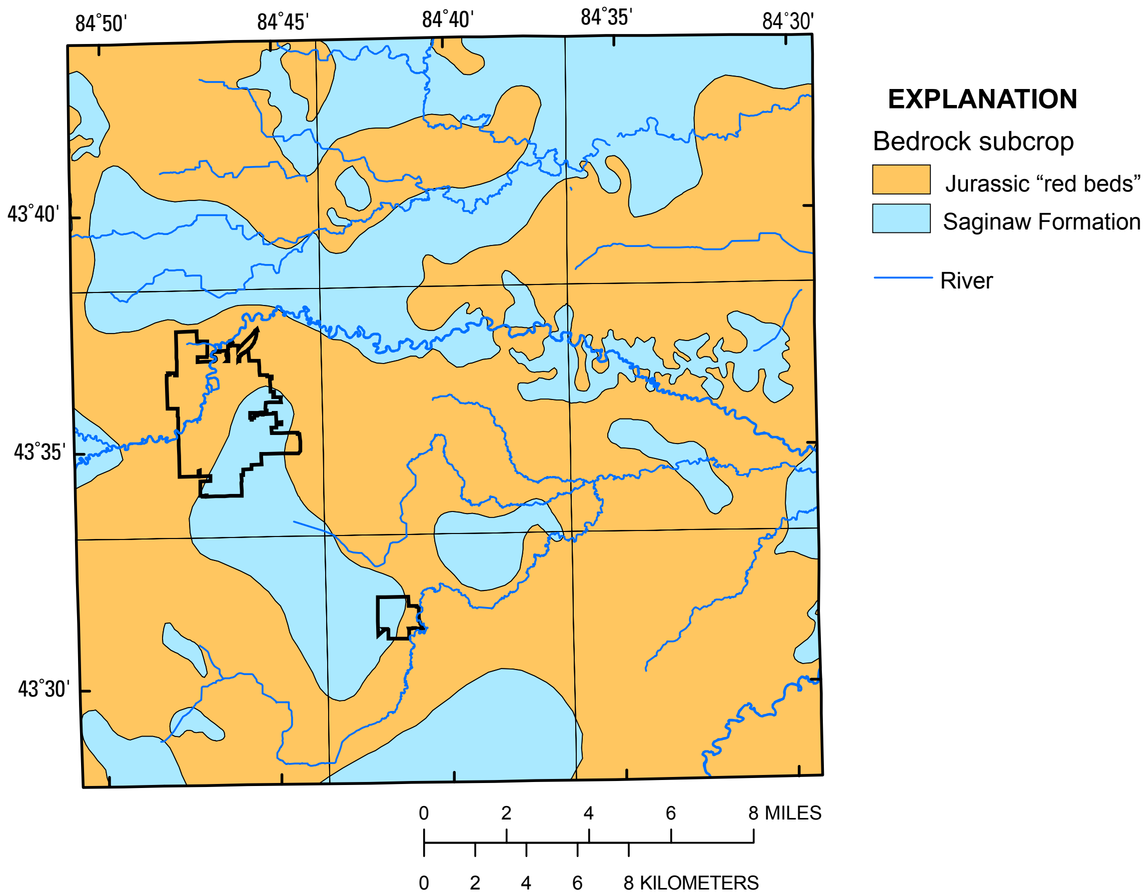


Figure 4. Distribution of bedrock underlying glacial deposits in the study area (modified from Milstein, 1987).

public water supply in Chippewa Township. The wells that make up the public supply are completed in the deep glacial aquifer. Water-level recorders were installed in two wells on reservation land in June 2003 to investigate water-level trends in the shallow and deep glacial aquifers (fig. 5, wells SC-7 and SC-9). Two additional wells were instrumented in 2005, one in the shallow glacial aquifer (fig. 5, well SC-19) and one in the Saginaw Formation (fig. 5, well SC-23). These water-level recorders will be maintained beyond the duration of this study as part of a long-term plan to monitor the water resources of the township. Water levels in observation wells vary as a function of winter/spring recharge events and pumping cycles of distant production wells (fig. 6). Precipitation data for the study were downloaded from the Michigan Automated Weather Network Web site for the Pioneer/Dupont Agriculture & Nutrition Research Station in Ithaca, Mich. (2005). This weather station is approximately 22 mi southeast of the study area (fig. 1), so daily precipitation data should be interpreted as an estimate for the study area.

Well SC-7 is 301.5 ft deep and its well screen is installed in the deep glacial aquifer near the base of the glacial sediments. This well is completed in the same aquifer as production wells for the reservation public water supply. The reservation production wells (fig. 5, wells SC-1 and SC-2) are about 0.7 mi from wells SC-7 and SC-23. Combined production from the water-supply wells varies from about 300,000 to 600,000 gal/d. The pumping cycles from production wells SC-1 and SC-2 appear to result in approximately 2 ft of drawdown/recovery in well SC-7 (fig. 6).

Well SC-23 is 455 ft in depth and is completed in the sandstone of the Saginaw Formation. A comparison of the water-level records between SC-23 and SC-7 indicates an upward gradient of the head (approximately 3 ft) between the Saginaw Formation and the material above it. The general water-level trend for SC-23 seems to match the trend in well SC-7. However, the distinct sawtooth pattern of the rapid drawdown/recovery from water-supply wells indicated in the SC-7 water-level record is not apparent in the SC-23 record (fig. 6). This difference indicates that effects on water levels in the Saginaw Formation from the pumping of water-supply wells in the deep glacial aquifer are small, if any.

Pumping stress in the Saginaw Formation from an unknown source also appears to be causing drawdown in well SC-23. It is not clear whether this stress is reflected in the water-level record for well SC-7. On the dates of September 23, 2005, and October 14, 2005, the low water level in

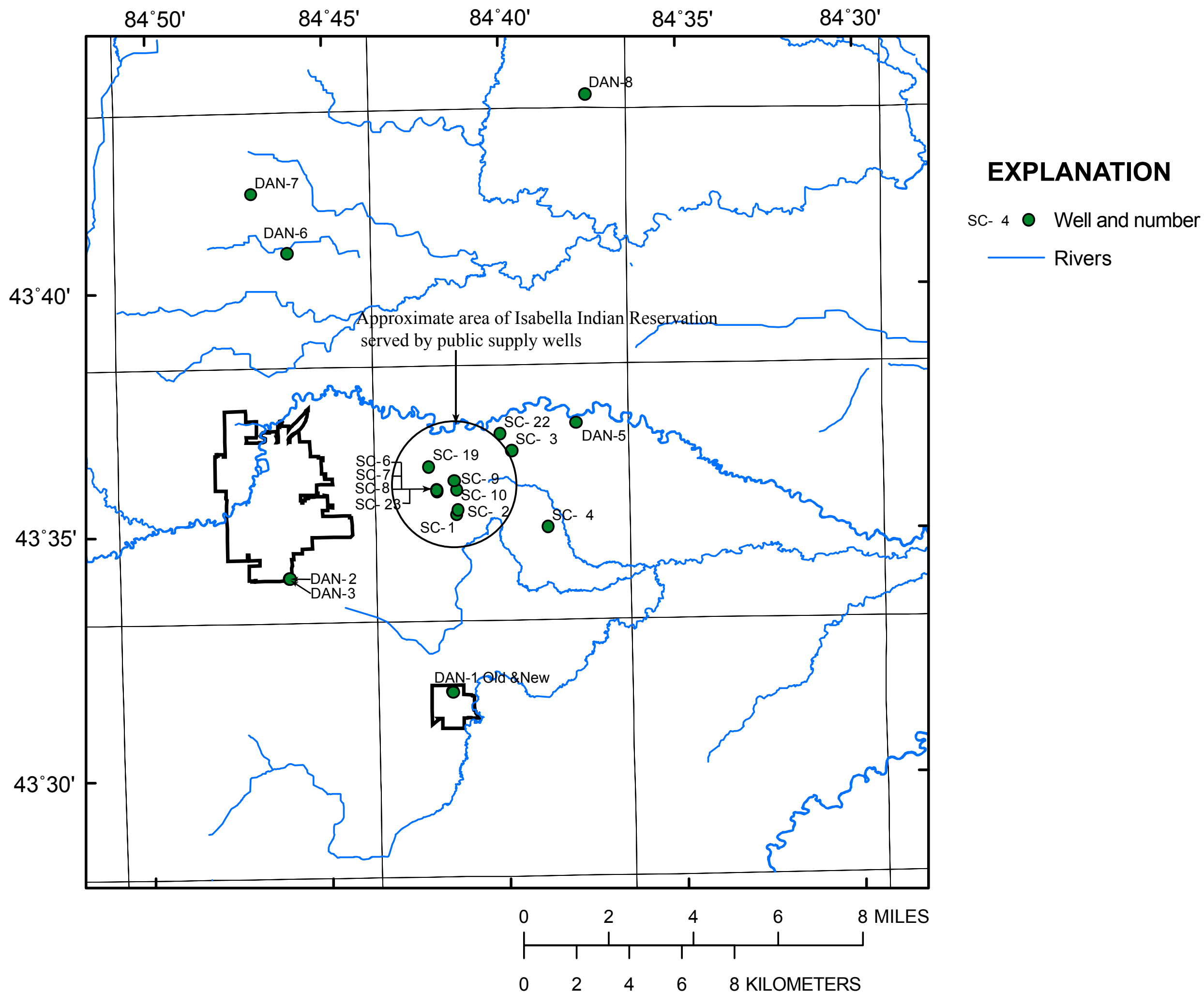


Figure 5. Location of wells that were monitored for water levels and wells sampled for water quality.

the Saginaw Formation (SC-23) does not correspond to the low water level in the deep glacial aquifer (SC-7). However, on November 4, 2005, the low water level and subsequent water-level recovery in the Saginaw Formation (SC-23) and the deep glacial aquifer (SC-7) match closely. The contrasting water-level responses on these dates suggest multiple sources of pumping in the Saginaw Formation with some pumping having an effect on the deep glacial drift. From these data, it is inconclusive how closely water levels in the two aquifers are related.

Well SC-9 (136 ft deep) and well SC-19 (126 ft deep) are both completed in the shallow glacial aquifer and are approximately 0.7 and 1.2 mi, respectively, from tribal production wells. Water levels in neither SC-9 nor SC-19 seem to be affected by pumping stresses, but climatic effects are apparent in these wells (fig. 6). The lack of water-level response to production-well pumping cycles indicates that water levels in the shallow glacial aquifer are not affected by pumping in the deep glacial aquifer system. The water levels in SC-9 and SC-19 react similarly to stresses in the aquifer, with levels in SC-19 being slightly higher than those SC-9. This difference in levels is likely because SC-19 is further to the west, which is further upgradient from SC-9; however, some of the difference may also be due in some part to uncertainty in land-surface elevations.

A composite potentiometric-surface map of ground water in glacial deposits (fig. 7) was constructed from static water levels recorded on geologic logs of water wells in Chippewa and adjacent townships. Water levels from a total of 1,559 logs in 9 townships were used to construct the map, of which

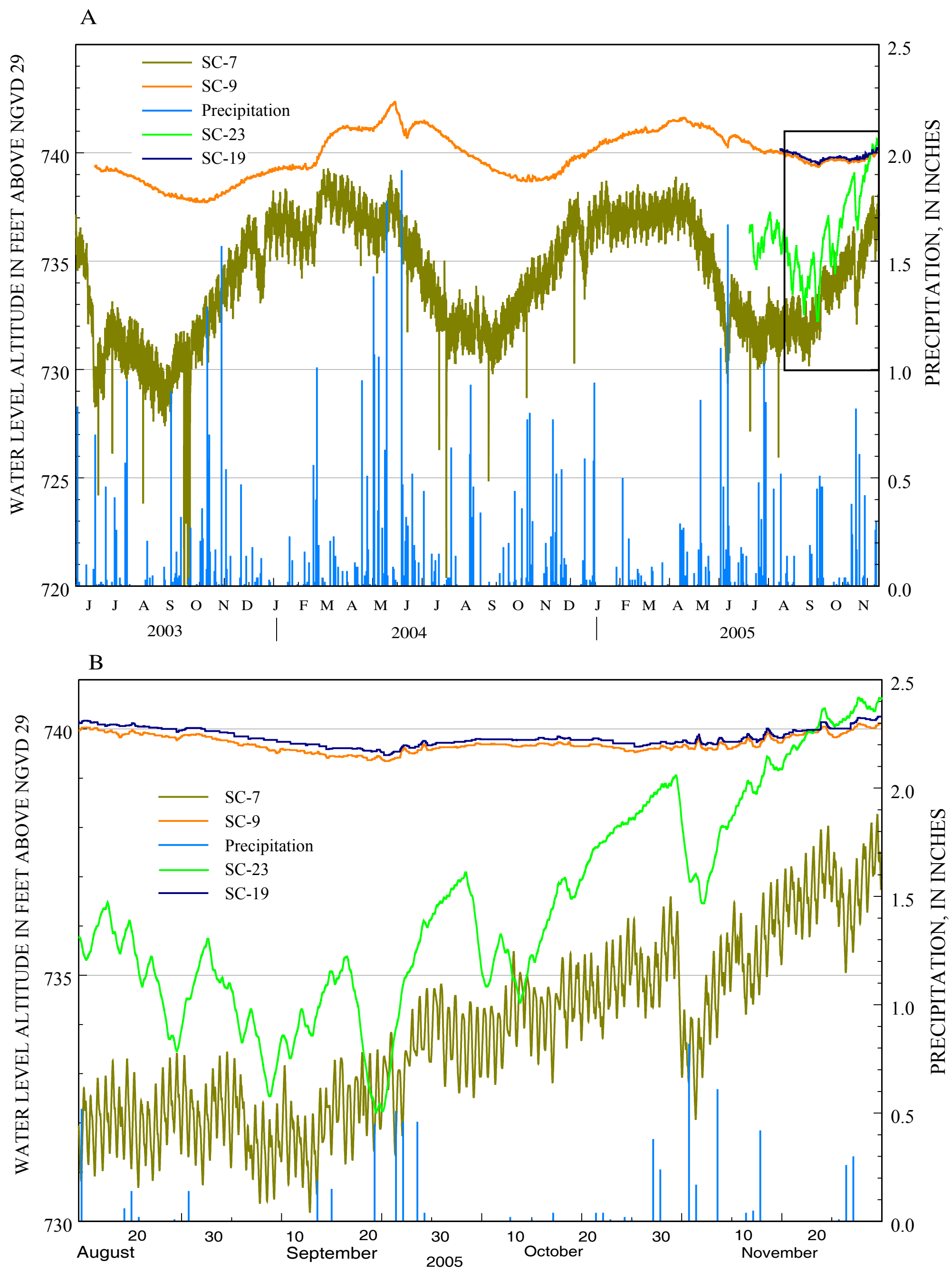


Figure 6. Water levels measured in selected wells at the Isabella Reservation, and precipitation measured at the Pioneer/Dupont Agriculture and Nutrition Research Station, Ithaca, Mich: a) from 6/6/2003 to 11/30/2003; b) from 8/12/2005 to 11/30/2005.

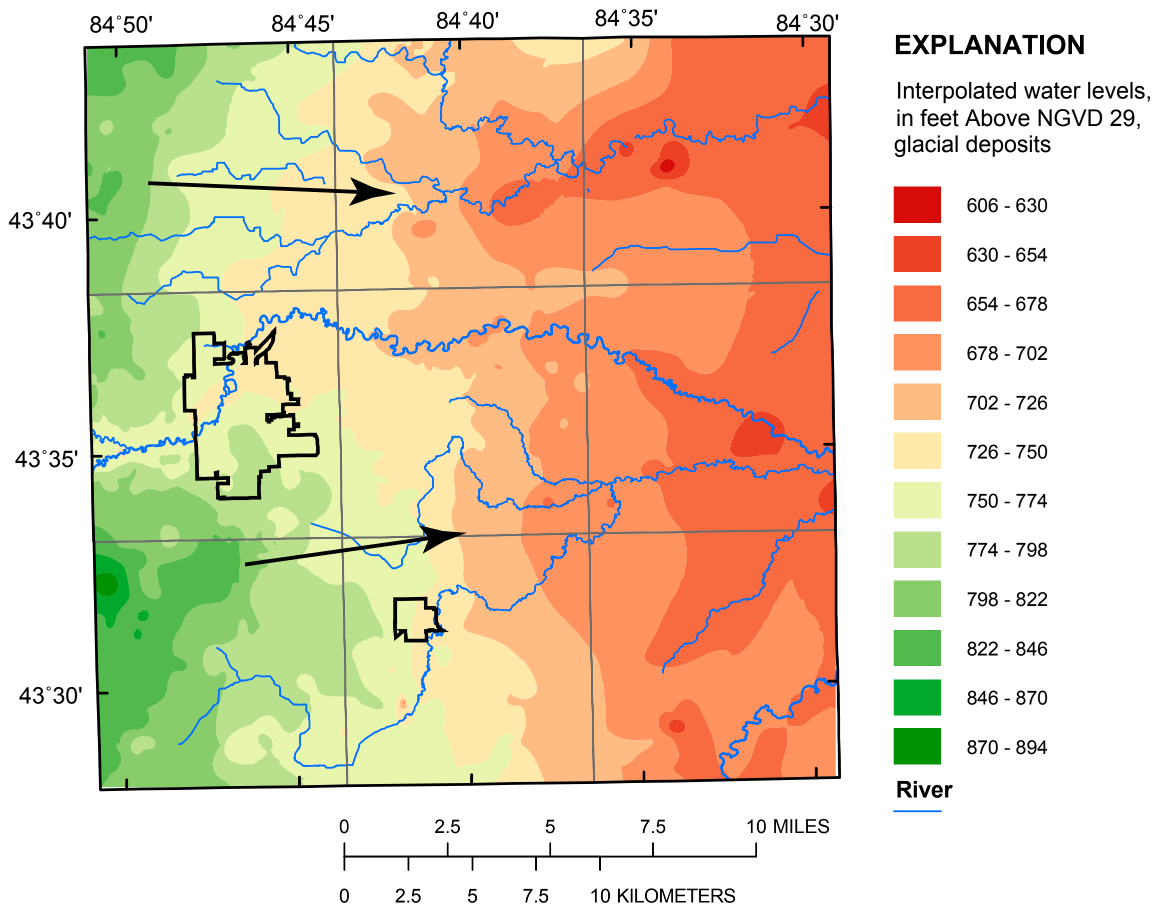


Figure 7. Configuration of the composite potentiometric surface of ground water in glacial deposits, based on static water levels recorded on drillers' logs (1,559 logs). Note: Arrows indicate general direction of ground-water flow.

496 wells were in Chippewa Township. The map is only an approximation of the potentiometric surface because water levels in all glacial aquifers were used to construct the map and may include several different aquifer units that may or may not be hydraulically connected. Seasonal differences in water levels could not be accounted for, and the altitudes of wellheads had to be approximated from topographic maps. However, the potentiometric surface seems to be a close approximation because existing maps that cover most of the study area show a similar surface (Malcolm Fox, City of Mount Pleasant, written commun., 2003).

The map shows a dominant easterly trend of ground-water flow (fig. 7). The potentiometric surface is, in fact similar in trend to land-surface relief (fig. 8), with topographic highs in the west and topographic lows in the east; therefore, the ground-water-flow system seems to be largely controlled by topography.

A map showing the configuration of the potentiometric surface of ground water in the upper-most bedrock was constructed from water-level data recorded on well logs. This map (fig. 9) has the same limitations as the map constructed for glacial deposits, with one additional constraint; far fewer data points were available for bedrock wells (data from 12 bedrock wells in the MDEQ WELLOGIC database) than for wells in the glacial deposits. The potentiometric-surface map for bedrock has the same general configuration as the map for glacial deposits (figs. 7 and 9), indicating that — even at depth — topography probably controls the direction of ground-water flow, which is generally from west to east.

Ground-Water Quality In Glacial And Bedrock Aquifers

The quality of water in the shallow glacial aquifer and in the upper part of the deep glacial aquifer is generally suitable for most uses. Fairly shallow wells (less than 150 ft deep) produce water of the calcium bicarbonate type with low concentrations of dissolved solids (table 1). Calcium and bicarbonate

Table 1. Physical and chemical characteristics for 15 water samples from wells in Isabella County, Mich.
[< , less than; E , estimated value; M , presence verified, not quantified; mg/L, milligrams per liter; µg/L, micrograms per liter; wf, filtered water; LSD, land-surface datum; mV, millivolts; µS/cm, microsiemens per centimeter; deg C, degrees Celsius]

Station number	Station name	Lat-i-tude	Long-i-tude	Depth of well, feet below LSD	Date
433407084460601	DAN-3	43°34′07″N	84°46′06″W	102	08-04-86
433142084424001	DAN-1 new	43°31′45″N	84°41′32″W	151	09-20-02
433142084424001	DAN-1 old	43°31′45″N	84°41′32″W	151	06-22-87
434200084470201	DAN-7	43°42′00″N	84°47′02″W	153	06-22-87
433529084411901	SC-2	43°35′29″N	84°41′19″W	233	09-16-02
433523084412101	SC-1	43°35′23″N	84°41′21″W	287	09-16-02
433554084415501	SC-6	43°35′54″N	84°41′55″W	287	09-23-02
433641084394701	SC-3	43°36′41″N	84°39′47″W	335	09-18-02
433507084384701	SC-4	43°35′07″N	84°38′47″W	342	09-20-02
433702084400601	SC-22	43°37′02″N	84°40′06″W	410	09-03-03
434358084373301	DAN-8	43°43′58″N	84°37′33″W	430	06-29-88
433552084415401	SC-23	43°35′52″N	84°41′54″W	455	03-26-04
433407084460501	DAN-2	43°34′07″N	84°46′05″W	504	08-04-86
433714084375701	DAN-5	43°37′14″N	84°37′57″W	525	06-03-87
433832084481601	DAN-6	43°40′47″N	84°46′02″W	575	05-25-88

Station Name	Oxi-dation re-duction poten-tial, mV	Dis-solved oxygen, mg/L	pH, water, unfltrd field, std units	pH, water, unfltrd lab, std units	Specif. conduc-tance, wat unf lab, uS/cm 25 degC	Specif. conduc-tance, wat unf uS/cm 25 degC	Temper-ature, water, deg C	Hard-ness, water, mg/L as CaCO3	Calcium water, fltrd, mg/L	Magnes-ium, water, fltrd, mg/L	Potas-sium, water, fltrd, mg/L	Sodium adsorp-tion ratio	Sodium, water, fltrd, mg/L
DAN-3	--	.3	7.3	7.4	710	675	11.0	370	96.0	31.0	1.60	.3	14.0
DAN-1 new	210	.3	7.1	7.8	490	545	16.1	260	68.9	22.4	1.60	.4	13.4
DAN-1 old	--	.0	7.4	7.6	552	493	11.0	280	72.0	23.0	1.30	.2	8.90
DAN-7	--	.0	7.6	7.6	1,350	1,310	14.0	560	150	45.0	2.70	1	74.0
SC-2	--	.5	6.9	7.2	738	747	10.7	370	104	25.9	1.52	.6	25.5
SC-1	219	.3	6.9	7.3	566	613	10.3	310	83.4	24.7	1.06	.3	13.0
SC-6	--	--	7.0	7.6	1,600	1,810	--	720	210	46.4	2.63	1	83.0
SC-3	--	--	--	7.1	972	--	--	440	131	26.1	2.67	.9	43.8
SC-4	--	.3	6.6	7.6	2,010	2,090	14.6	1,200	431	40.6	3.42	.5	36.5
SC-22	80	.1	7.1	7.3	1,100	1,160	11.3	390	110	26.8	3.34	2	83.1
DAN-8	--	.0	7.4	7.4	5,560	5,560	11.0	1,500	460	94.0	5.00	7	670
SC-23	--	.1	6.7	7.4	1,320	1,480	11.4	770	234	44.0	2.82	.7	47.4
DAN-2	--	1.5	7.4	7.6	722	755	12.7	320	84.0	27.0	1.90	.9	35.0
DAN-5	--	10.4	6.8	7.3	9,620	9,620	17.0	1,600	490	94.0	20.0	12	1,100
DAN-6	--	.0	7.4	7.6	3,770	3,720	16.0	740	220	46.0	12.0	10	630

are the dominant cation/anion pair for almost all ground water in Michigan's shallow glacial aquifers (Dannemiller and Baltusis, 1990; Western Michigan University, 1981). This is primarily because precipitation is acidic and carbonate-rock fragments (limestone and dolomite) are ubiquitous in the glacial sediments of Michigan's Lower Peninsula; precipitation rapidly comes into chemical equilibrium with glacial sediments by dissolving the fine-grained carbonate-rock fragments.

In general, ground-water quality declines with depth in the study area. In the zone where glacial sand and gravel deposits near the contact with underlying bedrock (especially Jurassic red beds), samples containing in excess of 1,000 mg/L dissolved solids are typically of calcium sulfate type water (table 1). Calcium and sulfate are also the dominant cation/anion pair in water in Jurassic red beds and in deeper rock wells in the Saginaw Formation, where dissolved-solids concentrations exceed 2,000 mg/L (Meissner and others, 1996).

Water quality is highly varied in all aquifers in the study area (table 1). The USGS collected 15 water samples (fig. 5) for determination of physical and chemical characteristics (8 samples for this study, and 7 in a previous study; see Dannemiller and Baltusis, 1990). Of these samples, one was from the shallow glacial aquifer (depth 102 ft), six were from the deep glacial aquifer (depth range 151 to 287 ft), two were from Jurassic red beds (depth range 335 to 342 ft), and six were from the Saginaw Formation (depth range of 410 to 575 ft). Table 1 lists the physical and chemical characteristics mea-

Table 1. Physical and chemical characteristics for 15 water samples from wells in Isabella County, Mich.--continued
[< , less than; E , estimated value; M , presence verified, not quantified; mg/L, milligrams per liter; µg/L, micrograms per liter; wf, filtered water; LSD, land-surface datum; mV, millivolts; µS/cm, microsiemens per centimeter; deg C, degrees Celsius]

Station Name	Sodium, percent	ANC, wat unf fixed end pt, field, mg/L as CaCO3	Alka-linity, wat flt inc tit field, mg/L as CaCO3	Bromide water, fltrd, mg/L	Chlor-ide, water, fltrd, mg/L	Fluor-ide, water, fltrd, mg/L	Silica, water, fltrd, mg/L	Sulfate water, fltrd, mg/L	Residue water, fltrd, sum of consti-tuents mg/L	Residue on evap. at 180degC wat flt mg/L	Ammonia + org-N, water, fltrd, mg/L as N	Ammonia water, fltrd, mg/L as N	Nitrite + nitrate water fltrd, mg/L as N
DAN-3	8	304	--	.14	23.0	.3	16.0	68.0	435	441	--	.250	<.100
DAN-1 new	10	--	268	.06	2.67	.48	17.4	8.2	300	324	.17	.15	<.05
DAN-1 old	7	450	--	<.01	.8	.4	18.0	8.6	405	293	--	--	--
DAN-7	22	160	--	.13	44.0	.4	14.0	510	940	978	--	--	--
SC-2	13	--	273	.08	13.2	.32	18.5	120	475	507	.25	.18	<.05
SC-1	8	--	208	.03	3.91	.35	18.8	26.2	297	357	.19	.11	<.05
SC-6	20	--	166	.34	70.8	.33	17.0	606	1,140	1,250	.36	.39	<.05
SC-3	18	--	229	.13	26.6	.42	11.9	266	651	706	.31	.29	<.05
SC-4	6	--	180	.11	16.3	.34	15.1	1,050	1,710	1,910	.31	.35	<.05
SC-22	32	--	207	.20	80.8	.3	10.9	224	667	716	.34	.24	<.06
DAN-8	49	152	--	3.50	1,100	.4	14.0	1,200	3,650	3,880	--	--	--
SC-23	12	--	171	.08	16.3	.3	16.1	570	1,040	1,080	--	.37	<.06
DAN-2	19	261	--	.10	25.0	.4	16.0	100	448	457	--	.310	<.100
DAN-5	59	200	--	9.10	2,600	.3	7.50	450	4,910	5,130	--	--	--
DAN-6	65	121	--	.74	330	.4	18.0	1,600	2,940	2,920	--	--	--

Station Name	Nitrite water, fltrd, mg/L as N	Ortho-phos-phate, water, fltrd, mg/L as P	Phos-phorus, water, fltrd, mg/L	Alum-inum, water, fltrd, ug/L	Arsenic water, fltrd, ug/L	Barium, water, fltrd, ug/L	Boron, water, fltrd, ug/L	Iron, water, fltrd, ug/L	Lithium water, fltrd, ug/L	Mangan-ese, water, fltrd, ug/L	Stront-ium, water, fltrd, ug/L	Zinc, water, fltrd, ug/L
DAN-3	--	--	--	<10	7	--	40	1,400	9	51.0	470	16
DAN-1 new	<.008	.69	2.90	1	6.8	71	28	915	3.8	33.2	389	6.9
DAN-1 old	--	--	--	<10	8	79.0	20	1,300	11	36.0	390	8
DAN-7	--	--	--	<10	2	22.0	170	710	31	73.0	2,900	11
SC-2	<.008	<.02	.006	<1	2.2	35	92	564	13.4	109	1,200	67.5
SC-1	<.008	<.02	.012	<1	.9	31	43	180	4.8	250	372	31.4
SC-6	E.004	E.01	.008	<1	.6	12	202	1,280	25.3	236	3,170	6.3
SC-3	<.008	<.02	<.004	<1	.4	11	134	1,740	14.5	68.5	1,980	1,530
SC-4	<.008	<.02	E.002	<1	2.2	7	212	1,390	28.3	64.1	3,370	121
SC-22	<.008	<.02	E.002	M	.9	13	309	487	35.0	23.0	1,830	11.5
DAN-8	--	--	--	<10	<1	<100	220	2,800	50	140	7,300	1,500
SC-23	<.008	<.006	<.004	<2	1.1	9	197	1,530	34.4	98.4	3,380	1.8
DAN-2	--	--	--	<10	1	--	80	300	15	9.0	990	9
DAN-5	--	--	--	<10	<1	<100	630	1,700	340	77.0	13,000	20
DAN-6	--	--	--	<10	<1	<100	1,600	3,200	120	31.0	1,900	20

sured. In general, dissolved-solids concentrations (indicated by residue sum of constituents column, table 1) increase with depth. Concentrations of Sulfate and dissolved-solids illustrate the wide range of dissolved constituents in all aquifer units: in the glacial aquifers, sulfate ranged from 8.2 to 606 mg/L, and dissolved solids ranged from 297 to 1,140 mg/L; in the Jurassic red beds, sulfate ranged from 266 to 1,050 mg/L, and dissolved solids ranged from 651 to 1,710 mg/L; and in the Saginaw Formation, sulfate ranged from 100 to 1,600 mg/L, and dissolved solids ranged from 448 to 4,910 mg/L. Although bedrock contains relatively low dissolved-solids concentrations (448 to 667 mg/L) in some areas, the distribution of freshwater and saline water is poorly known.

Classification of ground-water chemistry by dominant cation/anion species is a convenient way to analyze water-quality data in situations where the chemistry of ground water is varied. In most Michigan aquifers, dominant cations are sodium, calcium, and magnesium; dominant anions are bicarbonate, chloride, and sulfate. Graphical plots developed by Piper (1944) are used to display water-chemistry data for samples collected in the study area. The wide range in the content of chemical constituents is shown in figure 10. As mentioned previously, water from shallow glacial deposits (less than 150 ft) is predominantly a calcium bicarbonate type as classified using the Piper diagram (fig. 10), and water from Jurassic red beds and the underlying Saginaw aquifer is typically calcium sulfate dominant. The range of water chemistry noted in the samples is best explained by mixing of water from glacial and bedrock aquifers in the study area. A mixture of end-member types—calcium bicarbonate type in glacial aquifers and

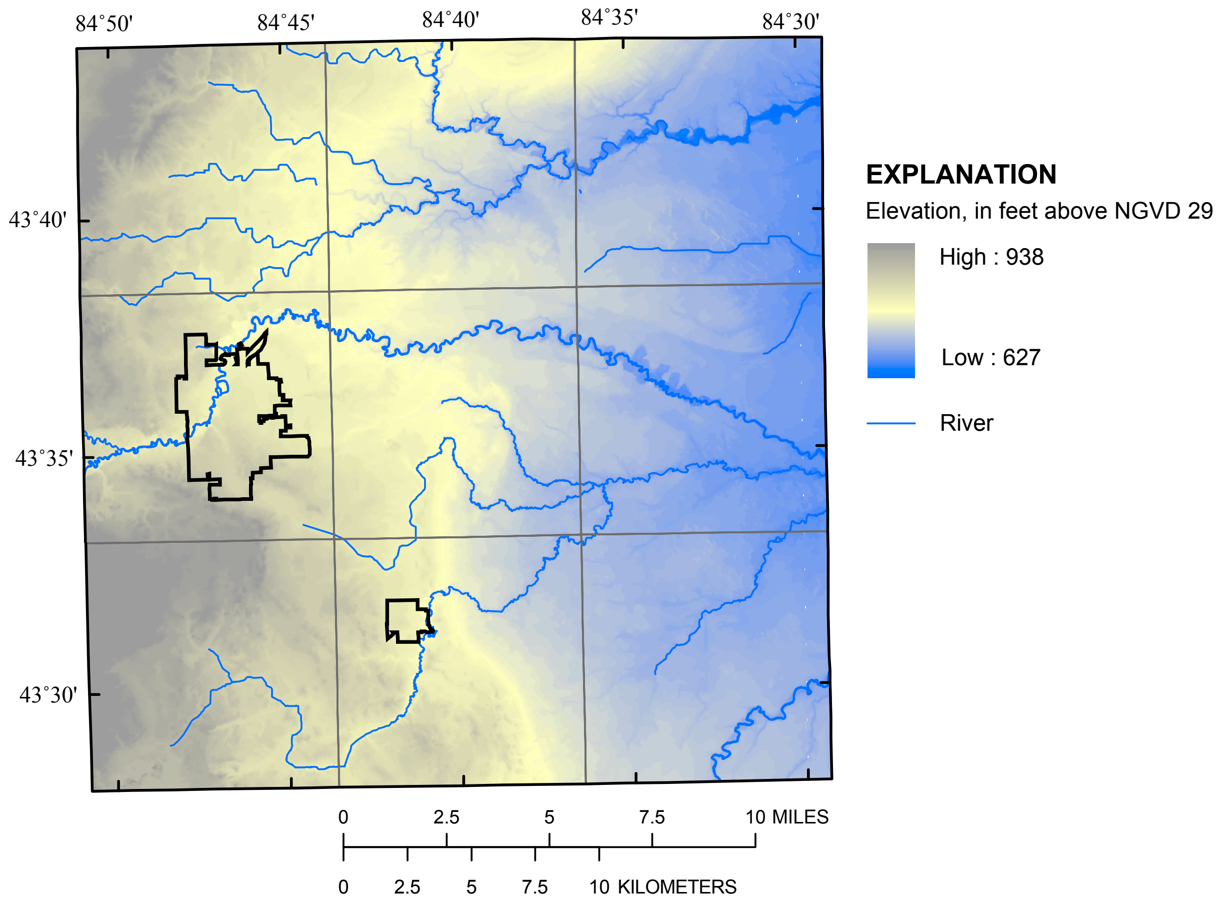


Figure 8. Topography and surface-water drainage features in the study area.

calcium sulfate type in bedrock — is consistent with the water chemistry of all samples collected in the study area.

High concentrations of sulfate and dissolved solids are a significant problem in the study area as they lead to objectionable water quality, and water produced from deep wells in Chippewa Township needs to be treated (Ginger Van Conet and Stan Sineway, Saginaw Chippewa Tribal Utilities Authority, oral commun., 2003). Various reports also indicate water quality degrades with pumping, especially in deep wells (Ginger Van Conet and Stan Sineway, oral commun., 2003). On the basis of this information, large-scale production from deep wells tapping near-bedrock zones cannot be sustained without compromising water quality.

The City of Mount Pleasant (fig. 1, within Union Township) has one production well completed in the Saginaw Formation, but large withdrawals of water from this well has led to a substantial increase in dissolved constituents (Malcolm Fox, City of Mount Pleasant, oral commun., 2004). The city has rectified this problem by reducing production from this well and blending water from this well with water derived from glacial, bedrock, and river-recharge wells. The potential for bedrock to yield a large, sustainable ground-water supply with acceptable water quality seems unlikely.

Review of existing data and recently collected data by the USGS indicates that additional withdrawals from large-capacity wells in parts of the deep glacial aquifer or the Saginaw Formation will likely require treatment to improve water quality for human consumption.

Surface Geophysics

In the southern part of Chippewa Township, water wells and water-quality data are sparse because the area is predominantly farmland. In addition, water-quality data are lacking for the Saginaw Formation, so the water-resource potential of this unit is unknown. Direct-current (DC) resistivity methods were used to try to characterize water availability and water quality (freshwater as distinguished from saline water) of this part of the study area. The DC resistivity method indicates electrical resistivity contrasts caused by sediment/rock types, degree of water saturation, porosity, and pore-fluid salinity.

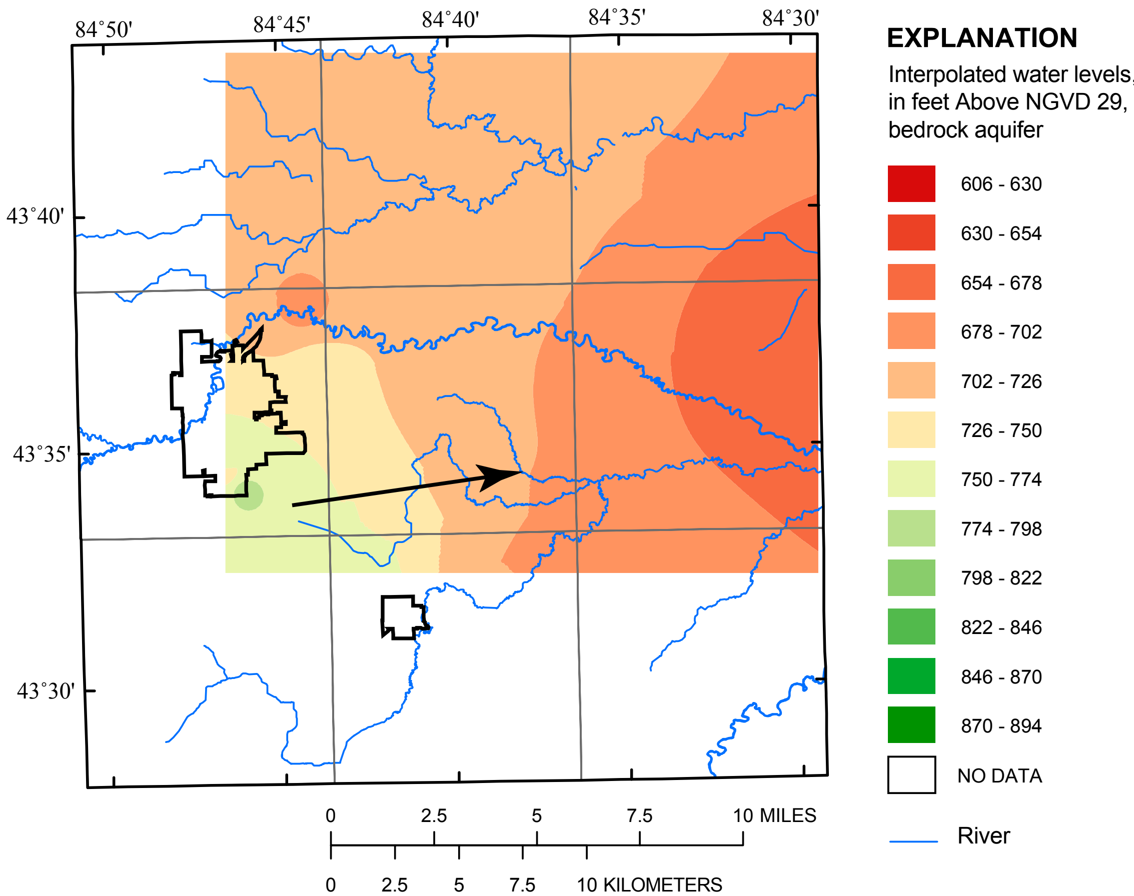


Figure 9. Configuration of the composite potentiometric surface of ground water in bedrock units. Note: Arrow indicates general direction of ground-water flow.

The DC resistivity method relies on induction of an electrical current into the subsurface by use of metal rods (current electrodes) and an amplified current source (battery or generator); the electrical potential from the induced current is measured interior to the current electrodes (potential electrodes). This method is described for general application by Zohdy and others (1974); uses in Michigan are described by Westjohn and Carter (1989). Some limitations of using geophysical methods to characterize hydrogeology of the subsurface include the presence of cultural disturbances (buried pipelines, power lines, and other buried metal objects) and lateral heterogeneities in subsurface materials (nonlayered earth).

Ten DC resistivity soundings were made in the southern part of the study area using the Schlumberger array for electrode placement (a logarithmic arrangement of current and potential electrodes; Zohdy and others, 1974). As the arrays of electrodes are expanded laterally from the survey midpoint, the depth investigated increases. The general rule of thumb is that the depth of investigation is approximately one-third of the separation distance between current electrodes. In the case of DC resistivity soundings made for the study, the maximum separation of current electrodes ranged from 300 to 550 m, with an interpreted depth of investigation of about 100 to 180 m (about 330 to 600 ft). Cultural features prevented expanding current electrodes beyond this range for the surveys. The depth to bedrock is estimated to be about 330 to 400 ft, so most, if not all, of the 10 surveys likely investigated at least the upper part of the bedrock aquifer.

The program ATO (Zohdy and Bisdorf, 1989) was used to process the DC resistivity sounding data and generate the interpretive plots presented in the appendix. The black, solid lines in these plots indicate the depth of interpreted geologic layers estimated from the results of the DC resistivity survey. When examining the plots in regards to the interpreted geologic layers, the x-axis of the plot is depth of the layer and the y-axis is the apparent resistivity of the layer. Lines that have a high apparent resistivity indicate freshwater-bearing glacial sand/gravel deposits or sandstone, whereas lines with low apparent resistivity indicate either clay/shale deposits or saline water in an aquifer unit.

Typical resistivities of these geologic materials may span a large range, which may lead to some uncertainty in interpre-

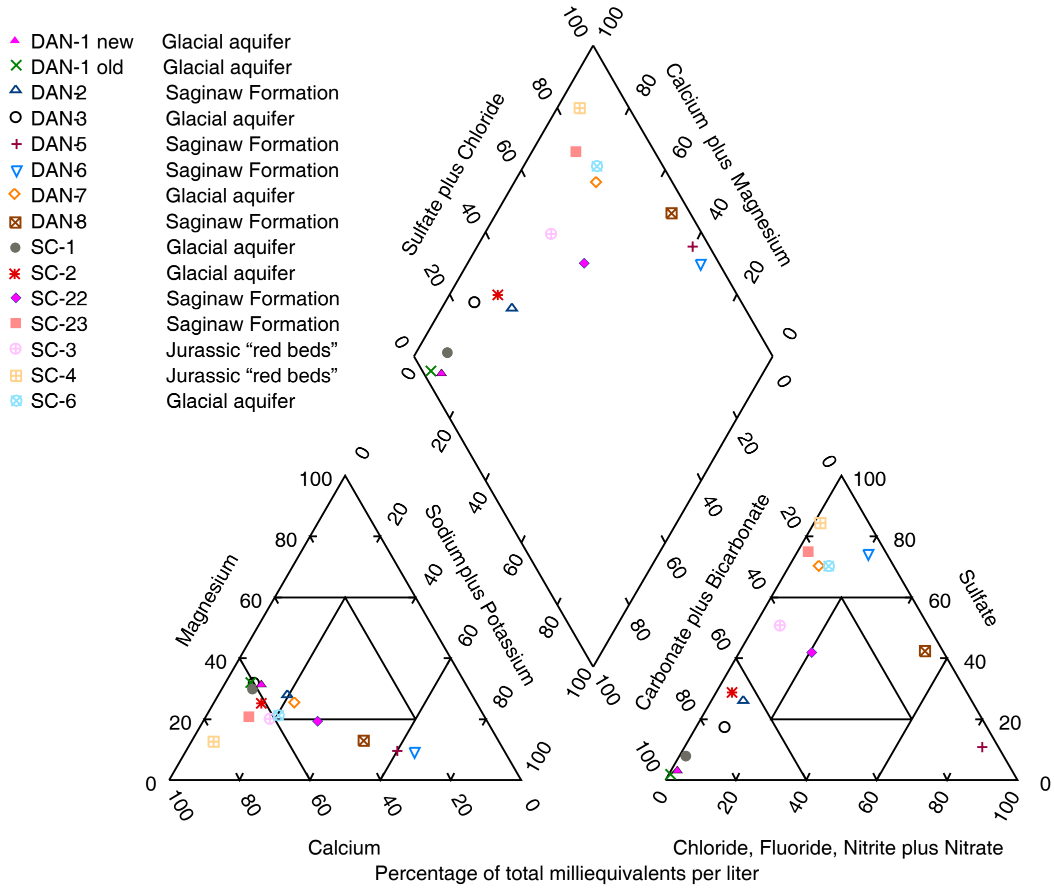


Figure 10. Piper diagram illustrating water-chemistry of 15 ground-water samples from the study area.

tation. Generally resistivity in sand and gravel ranges from 30 to 225 Ω/m, in clay from 1 to 100 Ω/m, in shale from 20 to 2,000 Ω/m and sandstone from 1 to 740,000,000 Ω/m (Reynolds, 1997). The effect of saline pore fluids on a material is to lower the bulk resistivity of the material. For this study, materials with resistivities greater than 60 Ω/m were considered freshwater-bearing sands, gravels, and sandstones, whereas materials with resistivities less than 60 Ω/m were considered to be either clays, or shales, or sands, gravels, and sandstones containing saline water.

Two of the lines (1 and 4, appendix) indicate the presence of freshwater in the upper bedrock. The sequence of layering from land surface to depth for line 1 appears to be a low-resistivity clay layer for the upper 4 meters, followed by a high resistivity sand/gravel layer from about 4 to 20 meters, then another low-resistivity clay layer from 20 to 60 meters, followed by a high resistivity sand/gravel from 60 to 125 meters. The final layer includes the upper part of the Saginaw Formation and the high resistivity of the layer indicates that the Saginaw Formation is freshwater bearing. Similarly the results of line 4 show a low resistive clay near land surface followed by a high resistivity sand/gravel from about 5 to 30 meters, followed by a low resistivity clay unit from 30 to about 100 meters, followed by a high resistivity layer at 100 meters. The last layer is interpreted as fresh water bearing Saginaw Formation due to the layers depth (100 meters) and high resistivity.

All but one survey line indicates the presence of freshwater-bearing sand/gravel layers/lenses. Eight lines are interpreted to indicate the absence of freshwater in bedrock; these interpretations are consistent with hydrogeologic and water-quality data from other parts of the study area. These data suggest that although there may be places where the upper bedrock aquifer contains freshwater, the glacial deposits are a more likely source of freshwater, especially in the southern part of Chippewa Township.

Summary

As a result of recent growth in Chippewa Township in Isabella County, Michigan, the demand on ground-water resources has increased. The USGS, in cooperation with Chippewa Township, began a study to assess the factors that affect the ground-water resources in the area in an effort to provide for more effective water-resource management. Analysis of historical and new data collected during 2002-05 indicate that glacial deposits are the primary source of ground water that has acceptable quality for most uses in Chippewa Township and the surrounding area in Isabella County, Mich. Water-level data indicate that the shallow glacial aquifer does not appear to be affected by withdrawals from either the deep glacial aquifer or the Saginaw Formation; however, the relation between water levels in the deep glacial aquifer and the Saginaw Formation is unclear at this time.

Indication from prior and eight new water samples are that ground-water quality in Chippewa Township is highly varied. A general pattern of degradation of water quality with depth has been noted by local water users, and wells completed near the base of glacial deposits in the deep glacial aquifer contain objectionable concentrations of dissolved sulfate. Water quality from deep wells in glacial deposits and wells in bedrock likely will degrade as a consequence of large withdrawals, and water from parts of the deep glacial aquifer and Saginaw Formation will require treatment to make water acceptable for use.

A surface geophysical method, DC resistivity, was used to interpret the geology and water quality in the southern part of the township. Results of the geophysical survey are consistent with the limited hydrogeologic and water-quality data in the area. While geophysical results suggest some freshwater may be found in upper Saginaw Formation, they show the glacial deposits are a more reliable source of freshwater in the study area.

Acknowledgments

The following individuals provided insight regarding water-supply issues, and assistance in the collection and analysis of hydrogeologic data: George Grim, Chippewa Township supervisor; Sally Kniffen, Jon Monasmith, and all the members of the planning department of the Saginaw Band of the Chippewa Indians: and Stan Sineway and Ginger Van Conet, from the Saginaw Chippewa Tribal Utilities Authority.

Cover photographs—Drill rig performing specific capacity test on a well in Chippewa Township. Photograph by Jon Monasmith. Technician servicing a water-level recorder in Chippewa Township; well in Chippewa Township. Photographs by Chuck Whited.

References

Dannemiller, G.T., and Baltusis, M.A., 1990, Physical and chemical data for ground water in the Michigan Basin, 1986–89: U.S. Geological Survey Open-File Report 90–368, 155 p.

Dorr, T.A., and Eschman, D.F., 1970, Geology of Michigan: Ann Arbor, Mich., University of Michigan Press, 476 p.

Hoard, C.J., and Westjohn, D.B, 2001, Simulated effects of pumping irrigation wells on ground-water levels in western Saginaw County, Michigan: U.S. Geological Survey Water-Resources Investigations Report 01–4227, 25 p.

Farrand, W.R., and Bell, D.L., 1982, Quaternary geology of southern Michigan: Ann Arbor, Mich., Department of Geological Sciences, University of Michigan, scale 1:500,000.

Martin, H.M, comp., 1955, Map of the surface of the Southern Peninsula of Michigan: Michigan Geological Survey Publication 49, scale 1:500,000.

Meissner, B.D., Long, D.T., and Lee, R.W., 1996, Selected geochemical characteristics of ground water from the Saginaw aquifer in the Michigan Basin: U.S. Geological Survey Water-Resources Investigations Report 93–4220, 29 p.

Michigan Automated Weather Network, 2005, Climate data available on the Web: Station, Ithaca, location, Pioneer/Dupont Agriculture & Nutrition Research Station, accessed November 30, 2005, at *http://www.agweather.geo.msu.edu/mawn/station.asp?id=ith&rt=24*.

Milstein, R.L., comp., 1987, Bedrock geology of southern Michigan: Michigan Geologic Survey, scale 1:500,000.

Piper, A.M., 1944, A graphical procedure in the geochemical interpretation of water analyses: American Geophysical Union Transactions, v. 25, p. 914–923.

Reynolds, J.M., 1997, An Introduction to Applied and Environmental Geophysics: Chichester, England, John Wiley and Sons, 796 p.

Western Michigan University, Department of Geology, 1981, Hydrogeologic atlas of Michigan: U.S. Environmental Protection Agency Underground Injection Control Program Report, 35 pl., scale 1:500,000.

Westjohn, D.B., and Carter, P.J., 1989, Direct-current vertical electrical-resistivity soundings in the Lower Peninsula of Michigan: U.S. Geological Survey Open-File Report 89–244, 57 p.

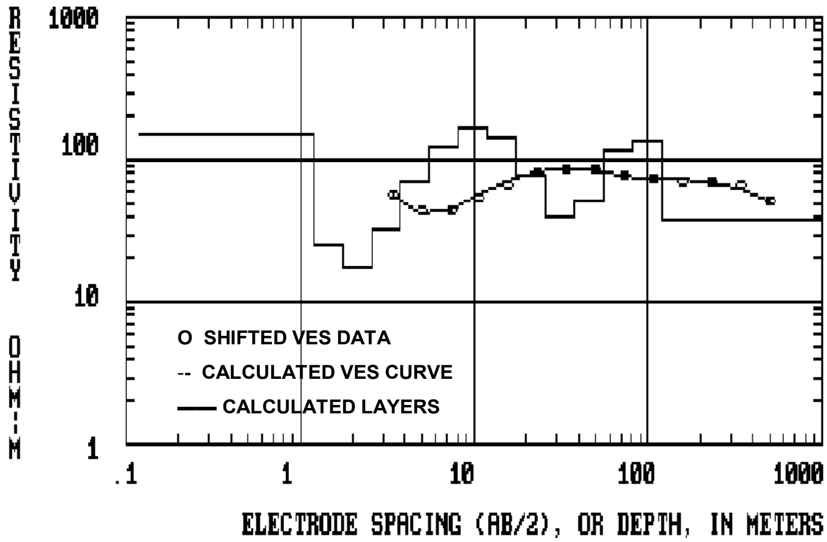
Westjohn, D.B., and Weaver, T.L., 1998, Hydrogeologic framework of the Michigan Basin Regional Aquifer System: U.S. Geological Survey Professional Paper 1418, 47 p.

Zohdy, A.A.R., and Bisdorf, R.J., 1989, Program for the automatic processing and interpretation of Schlumberger sounding curves in QUICKBASIC 4.0: U.S. Geological Survey Open-File Report 89–137, 16 p.

Zohdy, A.A.R., Eaton, G.P., and Mabey, D.R., 1974, Applications of surface geophysics to ground-water investigations: U.S. Geological Survey Techniques of Water-Resources Investigations, book 2, chap. D1, 116 p.

Appendix A—Logarithmic plots of modeled DC-resistivity soundings.

Line 1 Chippewa Township

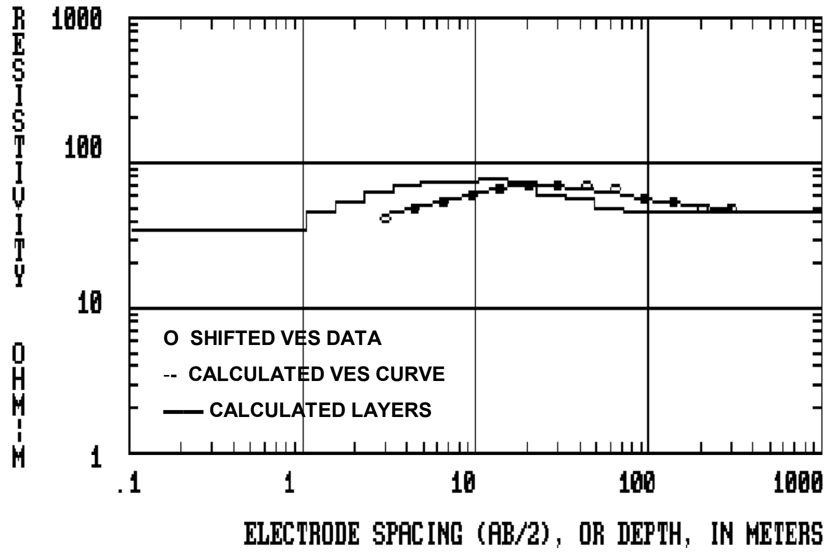


AB/2 spacing (meters)	Observed resistivity (ohm-meters)
3	74.3
4	52.5
5	47.8
5	47.5
6	46.2
6	45.5
8	49.8
10	56.6
10	54.1
14	67.9
14	65.0
20	78.5
30	89.3
30	88.1
40	90.7
40	88.9
60	84.3
80	79.3
100	77.2
100	73.4
140	71.1
140	69.4
200	68.5
300	68.3
300	68.9
400	60.4
400	61.2
500	50.4

Interpreted depth (meters)	Interpreted resistivity (ohm-meters)
3.41	57.07
5.00	43.64
7.34	45.05
10.77	54.69
15.81	67.06
23.21	81.60
34.06	87.19
50.00	85.51
73.39	78.80
107.72	75.13
158.11	69.22
232.08	70.77
340.65	66.07
500.00	50.40

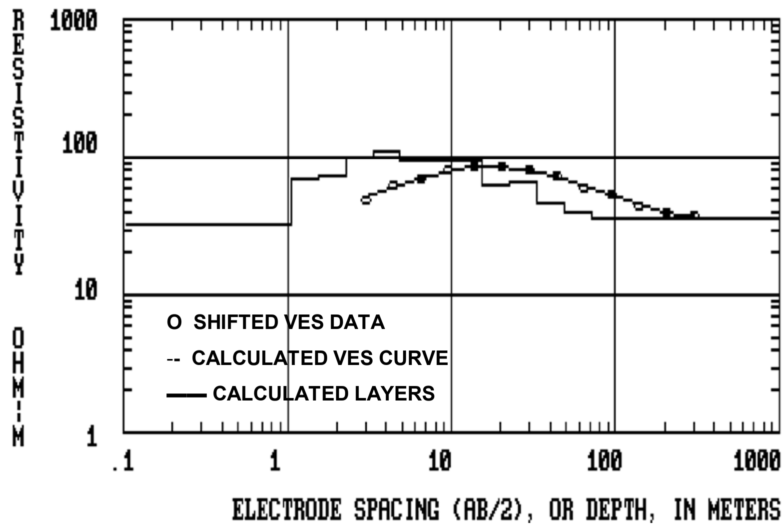
***Note: VES stands for Vertical Electrical Sounding**

Line 2 Chippewa Township



AB/2 spacing (meters)	Observed resistivity (ohm-meters)	Interpreted depth (meters)	Interpreted resistivity (ohm-meters)
3	44.4	3.00	34.16
4	48.9	4.40	40.05
5	55.3	6.46	45.28
5	55.3	9.49	49.96
6	58.2	13.92	53.79
6	58.1	20.44	55.95
8	60.6	30.00	56.45
10	66.4	44.03	55.39
10	64.1	64.63	48.86
14	70.7	94.87	43.32
14	68.9	139.25	47.47
20	70.6	204.39	43.47
30	71.3	300.00	42.55
30	77.6		
40	70.7		
40	76.9		
60	69.1		
80	63.0		
100	59.2		
100	57.2		
140	64.8		
140	54.1		
200	50.2		
300	48.8		
300	42.6		

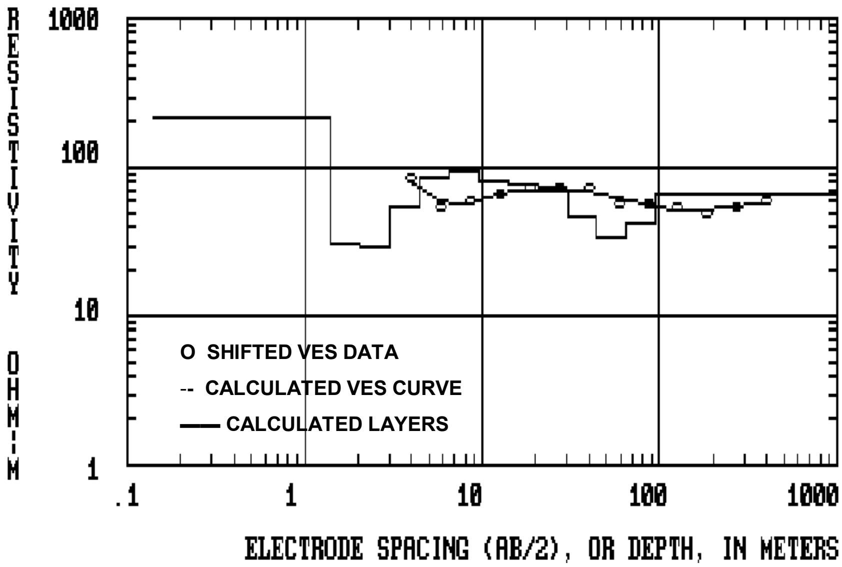
Line 3 Chippewa Township



AB/2 spacing (meters)	Observed resistivity (ohm-meters)
3	47.3
4	56.9
5	62.7
5	70.0
6	65.2
6	72.9
8	72.6
10	77.6
10	76.8
14	80.1
14	79.4
20	79.3
30	75.8
30	70.2
40	72.4
40	66.9
60	60.4
80	53.0
100	49.3
100	52.9
140	41.9
140	44.9
200	41.4
300	38.9
300	38.4

Interpreted depth (meters)	Interpreted resistivity (ohm-meters)
3.00	51.24
4.40	64.68
6.46	70.74
9.49	73.88
13.92	78.97
20.44	77.40
30.00	74.09
44.03	70.04
64.63	61.41
94.87	53.48
139.25	45.11
204.39	40.76
300.00	38.40

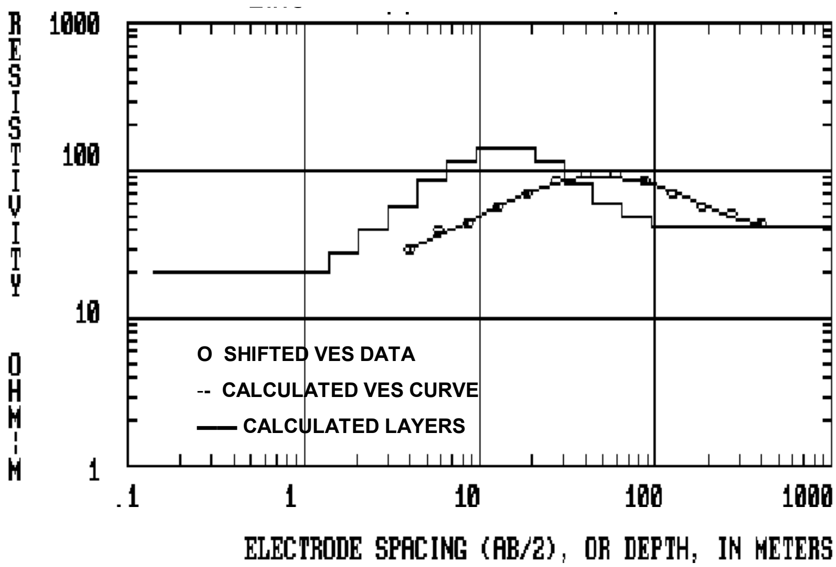
Line 4 Chippewa Township



AB/2 spacing (meters)	Observed resistivity (ohm-meters)
3	201.3
4	91.5
5	64.3
5	68.6
6	59.4
6	61.6
8	65.2
10	61.7
10	67.6
14	74.5
14	74.6
20	82.8
30	85.6
30	83.1
40	80.7
40	77.4
60	61.4
80	140.1
100	63.8
100	59.1
140	72.9
140	50.2
200	50.1
300	52.6
300	47.0
400	59.0
400	34.0

Interpreted depth (meters)	Interpreted resistivity (ohm-meters)
4.00	36.16
5.87	23.67
8.62	24.38
12.65	26.44
18.57	31.53
27.25	31.02
40.00	30.70
58.71	23.37
86.18	46.17
126.49	25.26
185.66	29.92
272.52	29.89
400.00	34.00

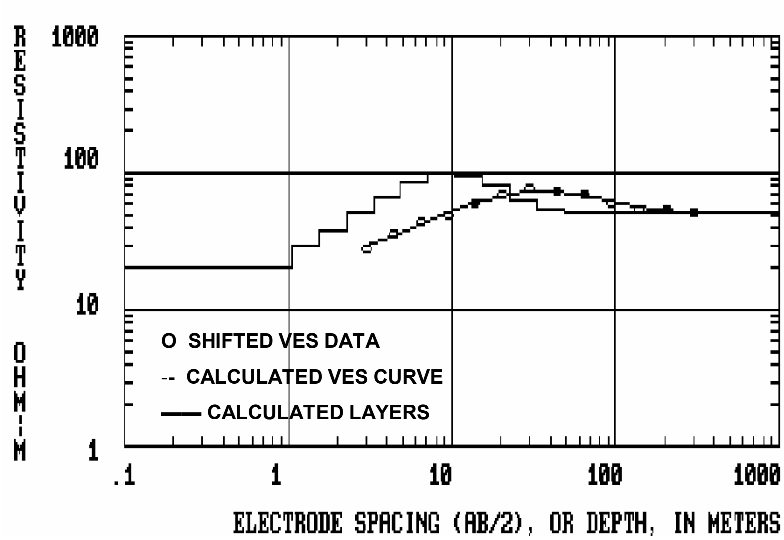
Line 5 Chippewa Township



AB/2 spacing (meters)	Observed resistivity (ohm-meters)
3	21.1
4	25.8
5	28.8
5	28.5
6	31.8
6	36.3
8	37.5
10	44.1
10	45.3
14	52.0
14	53.8
20	66.2
30	82.5
30	84.3
40	86.7
40	88.4
60	85.3
80	80.7
100	73.3
100	78.3
140	60.2
140	63.9
200	53.2
300	50.1
300	49.8
400	44.0
400	44.5

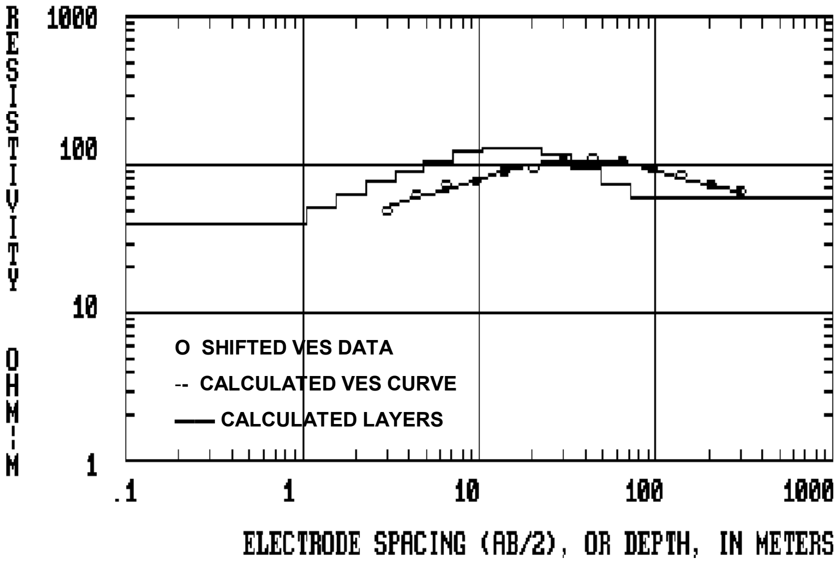
Interpreted depth (meters)	Interpreted resistivity (ohm-meters)
4.00	33.35
5.87	40.82
8.62	44.19
12.65	55.45
18.57	69.62
27.25	86.45
40.00	94.90
58.71	95.22
86.18	84.62
126.49	69.18
185.66	56.18
272.52	50.83
400.00	44.50

Line 6 Chippewa Township



AB/2 spacing (meters)	Observed resistivity (ohm-meters)	Interpreted depth (meters)	Interpreted resistivity (ohm-meters)
3	27.1	3.00	28.22
4	32.9	4.40	36.26
5	36.9	6.46	43.08
5	37.1	9.49	49.74
6	40.0	13.92	58.68
6	40.4	20.44	68.21
8	44.4	30.00	75.81
10	49.1	44.03	73.62
10	47.4	64.63	69.49
14	56.9	94.87	60.80
14	55.2	139.25	54.50
20	63.4	204.39	54.07
30	71.2	300.00	52.07
30	71.9		
40	69.9		
40	70.9		
60	67.4		
80	61.9		
100	57.2		
100	61.8		
140	52.3		
140	57.2		
200	56.3		
300	54.2		
300	52.1		

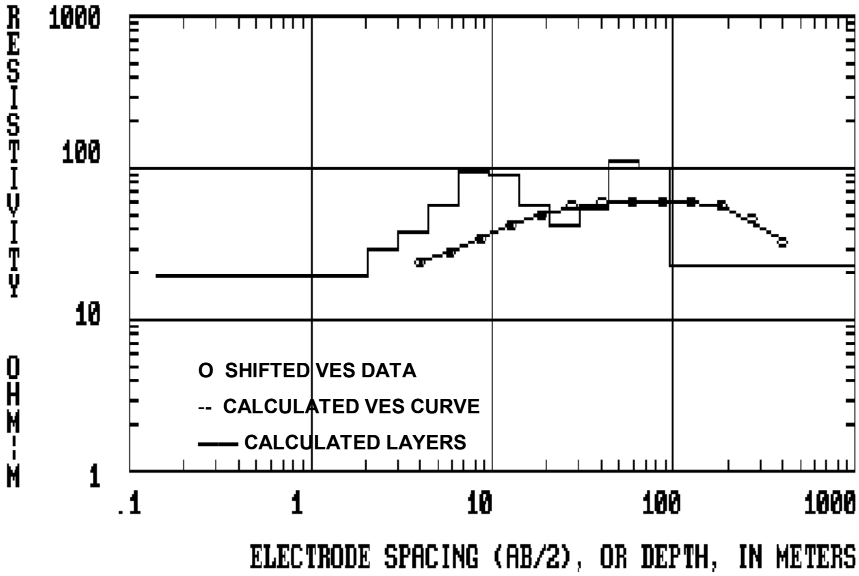
Line 7 Chippewa Township



AB/2 spacing (meters)	Observed resistivity (ohm-meters)
3	41.8
4	50.1
5	57.4
5	58.5
6	61.1
6	62.8
8	62.9
10	70.3
10	70.1
14	77.2
14	77.5
20	85.2
30	92.6
30	97.9
40	94.9
40	100.5
60	97.8
80	92.8
100	86.6
100	92.4
140	78.4
140	83.6
200	73.4
300	64.5
300	65.0

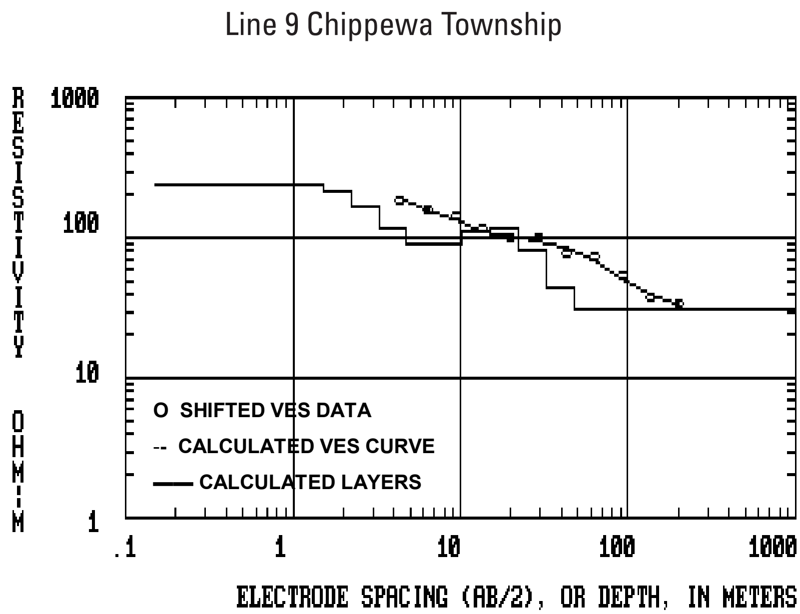
Interpreted depth (meters)	Interpreted resistivity (ohm-meters)
3.00	48.97
4.40	62.65
6.46	71.75
9.49	77.73
13.92	88.30
20.44	97.37
30.00	105.14
44.03	108.20
64.63	103.91
94.87	94.72
139.25	84.39
204.39	73.29
300.00	64.95

Line 8 Chippewa Township



AB/2 spacing (meters)	Observed resistivity (ohm-meters)
3	20.0
4	23.1
5	25.7
5	25.2
6	26.7
6	26.3
8	30.7
10	34.7
10	35.1
14	40.1
14	40.7
20	47.9
30	53.9
30	53.6
40	57.2
40	57.0
60	57.4
80	56.7
100	56.1
100	57.9
140	55.2
140	56.6
200	52.4
300	42.0
300	41.3
400	32.1
400	33.0

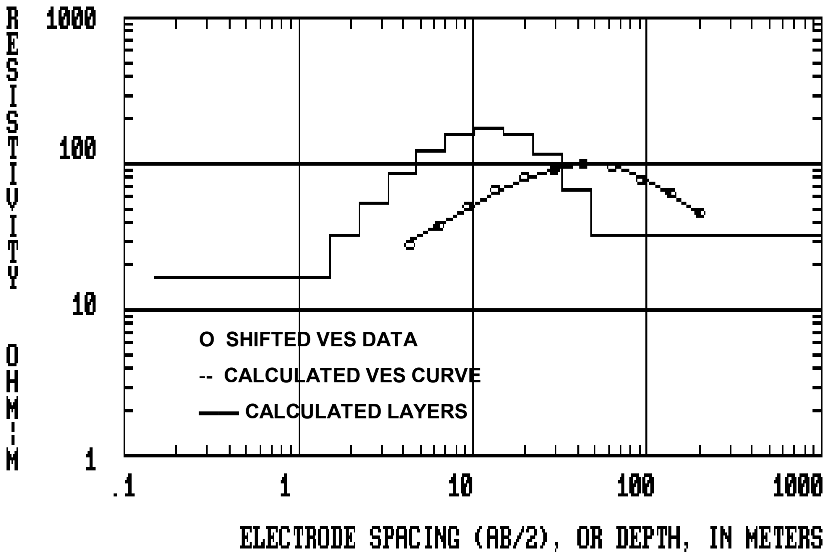
Interpreted depth (meters)	Interpreted resistivity (ohm-meters)
4.00	24.26
5.87	27.96
8.62	34.16
12.65	40.86
18.57	48.74
27.25	56.42
40.00	59.95
58.71	60.02
86.18	59.58
126.49	59.19
185.66	56.43
272.52	46.21
400.00	32.97



AB/2 spacing (meters)	Observed resistivity (ohm-meters)
3	118.0
4	103.0
5	99.4
5	122.9
6	110.8
6	116.1
8	109.7
10	94.9
10	92.4
14	78.4
14	75.9
20	66.6
30	65.4
30	69.8
40	56.2
40	67.5
60	62.6
80	54.2
100	43.8
100	47.8
140	36.5
140	38.9
200	34.7

Interpreted depth (meters)	Interpreted resistivity (ohm-meters)
4.31	185.70
6.32	160.31
9.28	140.41
13.63	117.11
20.00	99.63
29.36	100.72
43.09	76.20
63.25	71.78
92.83	54.83
136.26	38.68
200.00	34.71

Line 10 Chippewa Township



AB/2 spacing (meters)	Observed resistivity (ohm-meters)	Interpreted depth (meters)	Interpreted resistivity (ohm-meters)
3	21.6	4.31	28.19
4	27.9	6.32	38.05
5	34.2	9.28	51.32
5	35.2	13.63	64.75
6	40.1	20.00	79.93
6	41.6	29.36	91.53
8	52.1	43.09	101.97
10	61.7	63.25	95.91
10	62.4	92.83	78.93
14	76.3	136.26	63.53
14	78.3	200.00	45.53
20	94.5		
30	109.9		
30	103.4		
40	111.9		
40	108.5		
60	106.0		
80	92.8		
100	81.9		
100	78.9		
140	63.6		
140	61.2		
200	45.5		

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