66-6

GEOLOGICAL SURVEY OF CANADA

DEPARTMENT OF ENERGY, MINES AND RESOURCES

PAPER 66-6

GROUNDWATER RESOURCES OF STEINBACH AREA, MANITOBA

(Townships 1 to 12, Ranges 6 to 11, East of Principal Meridian)

(Report and 12 figures)

J. E. Charron

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ABSTRACT

This groundwater study of the Steinbach area, carried out during the summer of 1963, is the fifth on the hydrogeology of the Red River valley in Manitoba. Data on more than 2,600 wells were collected to be scrutinized for analysis.

The study has shown that on the whole the area is a recharge area and that it has a good potable supply of hard water. It proves on the basis of topography, discharge zones, and the hydrochemistry of the groundwater, that in general, the groundwater movement is in a westward direction. It also establishes that flowing artesian zones "undermine" themselves.

GROUNDWATER RESOURCES OF STEINBACH AREA, MANITOBA
(Townships 1 to 12, Ranges 6 to 11, East of Principal Meridian)

INTRODUCTION

This report, the fifth on the hydrogeology of part of the Red River valley in Manitoba, is based on data collected from more than 2,600 wells in the Steinbach area. It deals principally with the qualitative and quantitative aspects and the direction of groundwater movement as derived from the topography, discharge zones, and the hydrochemistry of the groundwater of the area.

Location

The area covered by this report totals 2,586 square miles. It is bounded on the west by range 6 east (approximate longitude 96°46'), on the east by range 11 east (approximate longitude 95°59'), on the south by the International Boundary, and on the north by township 12 (approximately latitude 50°01'). The report covers the municipalities of Stuartburn, La Broquerie, Ste. Anne, the eastern part of Hanover, Tache, and Springfield, the western part of Piney, Birch River, and Whitemouth, the southern part of Brokenhead, and a large area of unorganized territory that comprises the Sandilands and Agassiz Forest Reserves.

Trans-Canada Highway No. 1 crosses the area from east to west, while Highway No. 12 crosses the area from south to north. The western part of the area is more developed than the central and eastern part and a well developed network of gravel and earth roads make the former part easily accessible (Fig. 1). Railway lines of both the Canadian National and Canadian Pacific and one line of the Greater Winnipeg Water District Railway serve the entire area.

The economy of the region is basically agricultural.

Water Supplies

Apart from a few inhabitants who work for the Greater Winnipeg Water District Railway and live along the aqueduct pipe line that parallels the railway tracks, the entire population of the area depends on groundwater for their water supply. Only two towns, Steinbach and Beausejour have deep-well waterwork systems. For the remainder of the population living in smaller towns, villages, and on farms, the water supply consists of a well or wells at each individual home. Potable groundwater can generally be obtained anywhere in the Steinbach area. Where the groundwater supply is not sufficient for all the farm requirements, dug-outs are used as an alternative supply of water for stock. Because the groundwater is usually hard, rainwater is collected in cement or galvanized cisterns and is used as a source of soft water. The use of water-softeners is not yet in vogue.

Well Construction

Most of the wells in the southern part of the area are shallow dug wells, with wooden, galvanized iron, or cement ring cribs. In the west-central part of the area most wells are deep drilled wells with a 2-6 inch steel casing. In the northern part the two types of wells are common. As pump-testing and well-developing techniques such as surging, gravel-packing, or installing well-points or screens, are seldom used, quantitative data are scarce.

Previous Work and Acknowledgments

The only previous groundwater study in this area was done by Johnston (1934). His work, a general one covering the greater part of southern Manitoba, included the surficial geology of the area as well as some general information on the groundwater. For the information available at the time Johnston did his study, it is very accurate and informative.

Appreciation is expressed to the residents of the area and to the various authorities, municipal, provincial and federal, for their excellent cooperation.

PHYSICAL FEATURES AND GEOLOGY

Apart from the flat lacustrine plain of former Lake Agassiz in the northwestern part of the map-area, the Steinbach area is characterized by ground moraine, which slopes gently west and northwestward. The main topographical feature of the area is the highland of Sandilands Forest Reserve in the southeast corner, which consists mostly of glacial outwash of sand and gravel. This highland is completely surrounded by poorly drained bogs, marshes, and swamps (Fig. 2) located on clayey till. All of this is underlain by bedrock. The only bedrock outcrops in the entire area are found in the rapids in the bed of the Whitemouth River in the extreme northeast corner of the area. The bedrock seen at surface is granite.

The bedrock contact between the igneous and sedimentary rocks that underlie the surficial deposits of the area is a particularly significant feature, for it marks the beginning of the sedimentary rock formations, which eventually become the central western plains of Canada. From the point of view of groundwater this is important to bear in mind, for these rocks will be much more soluble than the igneous rocks. In the northeast corner of the area Precambrian granite outcrops. It is overlain by shale and sandstone of the Winnipeg Formation, which in turn is overlain by the dolomite and limestone of the Red River Formation. The borings of deep exploratory wells for oil show that the Winnipeg Formation has a fairly constant thickness of some 190 feet throughout the area. The sandstone part of the formation is also very consistent in thickness, averaging 90 feet. The thickness of the dolomitic limestone of the Red River Formation is 87 feet and 100 feet in the north and the east, respectively, and gradually increases to a maximum of 150 feet at the western margin of the area. Much larger thicknesses of this latter formation are known to exist west of the Steinbach area. Another peculiarity of the bedrock of the area, and one that greatly affects the groundwater, is the erosion of the Red River Formation in the southwest corner where it has been replaced by the red shale of the Amaranth Formation. At Vita the log of a well gives the thickness of the Amaranth Formation as 150 feet. Figure 3 illustrates three different interpretations of the extent of the Amaranth Formation in this area. The first is taken from the stratigraphic map series of Manitoba, 1959; the second is that of Bannatyne (1959), and the third is the interpretation of the writer as derived from the analysis of well inventory data and groundwater movement in the area.

In general throughout the area the bedrock dips west to southwest at approximately 10 degrees. The elevation of the map-area ranges from 800 feet above sea-level in the clay plain in the northwestern corner to a maximum of 1,300 feet above sea-level in the Sandilands Forest Reserve.

GROUNDWATER SUPPLY

Infiltration

Because the author does not intend to illustrate all the glacial features in detail nor try to explain their origin, a surficial geology or Pleistocene map has been replaced by an infiltration map (Fig. 1). It is felt that this map will facilitate the understanding and help to explain the various groundwater phenomena occurring in the area. Of the 2,586 square miles comprising the Steinbach map-area, the clayey till as shown on Figure 1 covers 1,968 square miles whereas the clay plain consists of 202 square miles. Sand covers some 360 square miles, while gravelly areas total 46 square miles. Ridges such as beaches and eskers or drumlins account for some

10 square miles of sand and gravel. Assuming that the area of lacustrine clay is completely impermeable and that the area of ground moraine consisting of clayey till is almost impermeable, this leaves only 416 square miles out of 2,585 square miles, or 16 per cent through which part of the annual precipitation could infiltrate.

As far as groundwater in the Red River valley is concerned, the Steinbach area is important because the sedimentary rocks that traverse the entire valley originate there. It is also the area of recharge for the entire eastern part of the Red River valley basin. Assuming that about 5 per cent of the annual precipitation of 21 inches infiltrates in the permeable area of 416 square miles to form recharge for the aquifers, we arrive at a figure for average annual recharge for the aquifers of the order of 23,000 acre feet. No more accurate estimate can be made because of the lack of detailed data.

Although no proof is available the writer believes that the clayey till covering the largest part of the Steinbach area (1,968 square miles) and on which rests so many bogs and marshes, transmits very slowly but continuously water to the aquifers underlying it. The reason for this belief is that during the field season of 1963 test holes of 250 feet were drilled in the clayey till and it was found to be wet throughout at all times. If the latter reasoning is true then the water transmitted that way can increase appreciably the total recharge calculated in the preceding paragraph.

Unconfined Aquifers

Shallow dug wells 10 to 25 feet deep tap water from unconfined aquifers almost anywhere in the area, but these unconfined aquifers are more important in the southwestern corner of the area where no other major aquifer exists.

In the clayey till wells 10 to 20 feet deep generally encounter thin sandy or gravelly layers, which yield small amounts of water (50 to 100 gallons per day) satisfying only farm needs. In many cases more than one such well is needed. The infiltration of the water in these wells is very slow but fairly constant, thus assuring a supply even during a drought or in the winter time. The static water level in these wells is 5 to 6 feet below surface in a year of average precipitation.

In the sandy or gravelly areas, with the exception of the highlands of Sandilands Forest Reserve, the water enters the wells at a faster rate, and larger amounts of water are available in wet years than in the clayey till aquifers, but the static water level drops considerably more, and faster, during dry years or in winter than in similar wells in the clayey till aquifers. In general the static water level is 8 to 10 feet below the land surface in a year of average precipitation. Sand points could be used successfully in this type of aquifer.

In the highlands of Sandilands Forest Reserve the water-table may be as much as 25 to 35 feet below surface if the thickness of the sand and gravel is considerable. Drilled wells making use of screens would be most effective in this area.

The study disclosed some interesting facts concerning the static water level (depth to water-table) of these unconfined aquifers. On the average the static water level will be 8 feet lower during a period of drought in the summer time than it will be in a year of average precipitation in the summer time. Similarly the static water level of the same well will be 6 feet lower during the winter time than it will be in a year of average precipitation during the summer time, owing to freezing of some of the groundwater because of the shallow depth of the aquifer. Therefore, the difference between the effect of a drought and the effect of the cold of winter on the static water level of shallow wells in unconfined aquifers of this type is 2 feet. The difference is constant anywhere along the hydraulic gradient of the aquifer, thus showing that recharge is local or nearby. This seems logical when one considers that these wells are only 10 to 25 feet deep.

Confined Aquifers

There are three distinct confined aquifers in the Steinbach area. One is in unconsolidated deposits and two are in bedrock. In the three southernmost townships not one well obtains water from a bedrock aquifer.

Most of the drilled wells in the area obtain water from the confined till aquifer. Where the till is not consolidated, which usually implies the clay component is not predominant, the till will yield water. Sand and gravel lenses or sand and gravel layers in the till will yield large amounts of good water. In many instances the contact between the till and bedrock is the best source of water if no sand or gravel is encountered beforehand. The depth at which water occurs in the till depends on the locality and can range from 30 to 200 feet. In the north the maximum depth is limited, because the bedrock is closer to the surface than in the south. Flowing wells producing water from the confined till aquifer occur in many places. Many flowing wells are found in the region of Piney and also in a large area extending northwestward from Marchand towards Steinbach and Ste. Anne. A few more flowing wells can be found in 4-11E, 9-7E, 9-8E, 12-8E, and 12-11E (Fig. 3). The recharge for these flowing wells can be local, but most of it is probably derived from the slow infiltration from the bogs and marshes through the clayey till. Only in the vicinity of Piney and west of Marchand would there seem to be direct recharge from the highlands of Sandilands Forest Reserve.

The principal bedrock aquifer of the area is the dolomitic limestone of the Red River Formation. The largest concentration of drilled wells obtaining water from this formation is found near Steinbach and Ste. Anne.

In the northwestern corner of the map-area, where the same formation almost outcrops, water can be obtained at depths of 40 to 60 feet. But near Steinbach water is obtained from this formation at depths of 100 to 200 feet. As mentioned previously the water may be encountered at the contact of the till with the dolomitic limestone where the bedrock may be weathered. If this zone does not yield water then water may be obtained from fractures within the bedrock itself. The southernmost information available on the Red River Formation is that given by a test hole for oil in 13-5-6E. The thickness of the formation is given there as 133 feet, with the top of the formation at a depth of 160 feet. It is possible that the formation may yield water in the southeast, but the great depth of the formation (300 to 400 feet) at that location and the availability of water at lesser depths has not warranted any drilling into the formation in that region. Artesian flow from this confined aquifer is particularly common in the La Broquerie, Steinbach, and Ste. Anne regions. In the north recharge of this aquifer is due to slow infiltration of the surface waters through the till, because more than half the till area is underlain by this formation. But in the south-central part recharge is from the highlands of Sandilands Forest Reserve.

The third and deepest confined aquifer is the reddish sandstone of the Winnipeg Formation. Very few wells obtain water from this aquifer because of its depth. In 12-9E water is believed to be obtained from this aquifer at a depth of 130 feet simply because the formation subcrops beneath the till at that location (Fig. 3). Near Steinbach wells have to be drilled to depths of 250 feet or more to obtain water from the sandstone of this formation. It is possible that this aquifer exists in the south, around Vita, Gardenton, or Caliento, below the Amaranth Formation at depths of 300 to 400 feet, but the water, if encountered, probably would be salty. The main recharge to this aquifer is provided by the slow infiltration from the bogs and marshes, through the till under which the formation subcrops. Because some wells from this aquifer are flowing it may be that some recharge is derived from the highlands of Sandilands Forest Reserve.

The Precambrian granite can be considered as an aquiclude, at least in the extreme northeastern corner of the area.

GROUNDWATER MOVEMENT

Unconfined Aquifers

As in any other area the water-table fluctuates directly with the precipitation. The water-table will also be lower in winter than in summer, as explained above. Regardless of its depth, the water-table configuration is a subdued replica of the topography in all cases. As the land slopes west and northwest it follows that the direction of flow of the groundwater in the unconfined aquifers of the Steinbach area is mainly westward and northwestward starting from the highlands of Sandilands Forest Reserve. It is also south, east, and northeast on the other side of the highlands. Because recharge to this type of aquifer is of a local nature it is possible for the direction of flow to be locally contrary to the general line of flow mentioned above. On the whole, however, the flow of unconfined groundwater in the map-area is east to west towards the Red River.

Confined Aquifers

The Steinbach area is the recharge area for the 72 mile north-south strip of the eastern part of the Red River valley basin studied by the writer. Starting at the highest point, which is the 1,300 foot contour in the highlands of Sandilands Forest Reserve, it would seem logical to suppose that the water infiltrating through the sands and gravels of the highlands would flow in all directions from that point (Fig. 3). It probably does until it encounters the clayey till that completely surrounds the highlands. The till cannot absorb the water at a fast enough rate, thus causing the water to rise again to the surface to form the bogs and marshes that are found on the till surrounding the highlands. The magnitude of these bogs and marshes can best be shown by pointing out that of the 1,968 square miles covered by clayey till some 608 square miles, or almost 1/3, consist of bogs and marshes in a year with average precipitation.

Figure 3 is used to illustrate the groundwater movement in the Steinbach area. The figure was arrived at by making use of two components: 1) the topography, and 2) the discharge areas (areas of flowing artesian wells). The most interesting of these "flowing" zones is the one stretching northwestward from Marchand towards La Broquerie, Steinbach, Giroux, and Ste. Anne. The main direction of flow in the confined till and bedrock aquifers originating from the highlands of Sandilands Forest Reserve is believed by the writer to be toward this zone. This is best explained by the geology. A main flow should exist towards the southwest. But the southwestern part of the area is largely covered by clayey till (250+ feet thick at Arbakka), underlain by the red shale of the Amaranth Formation (150 feet thick at Vita). These two almost impermeable formations act as a plug or wedge, blocking the southwestward flow of water and forcing it to find another path. This path would be northwestward in the strike of the recharge area of the highlands as indicated by a large arrow on Figure 3. The flow continues northwestward until north of Steinbach, where it seems to turn to the southwest.

With the exception of the Whitemouth River Basin in the extreme northeastern corner of the area, the flow of groundwater in the northern part of the area is southwestward, conforming with the dip of the sedimentary bedrock. The eastern limit of this flow is a line approximating the 'subcrop' contact of the sedimentary rocks with the Precambrian rocks. This flow is indicated by arrows and discharge zones on Figure 3.

Figure 3 also illustrates local movement due to local high areas. Nevertheless, these local flows comply with the general flow pattern. The area of Piney is the discharge region for the southeastern end of the main recharge area of the highlands of Sandilands Forest Reserve. It is a good example of groundwater movement in a confined till aquifer. In 9-7E is an example of a local flow in bedrock as well as in till. In the main discharge area in the southeastern corner of 8-6E, a pocket of flowing wells exists showing deep wells (250 feet deep) together with wells 30, 50, and 80 feet deep. The upward flow may be either from the deep bedrock zone in both cases or from a local recharge area in the case of the shallower zone in the till or a combination of both. Nearby recharge is believed to be responsible for the upward flow in the upper zone and is shown by a smaller arrow (Fig. 3). Recharge in this particular example is believed to occur in the southeast corner of 8-7E in gravels some 75 feet above the discharge area in question.

To summarize: the groundwater movement of both the unconfined and confined aquifers in the unconsolidated deposits of the Steinbach area follows the topography, while in the confined bedrock aquifers the groundwater movement conforms not only to the topography, but also to the dip and plunge of the formations unless the geology alters the course of events, as in the case of the impermeable wedge in the southwestern part of the area.

QUANTITATIVE DATA

The best way to determine the hydraulic characteristics of an aquifer is by a pump test. However very few pump tests were ever carried out in this area, so that little is known on the possible quantities of groundwater that can be yielded by the known aquifers in the area.

Unconfined Aquifers

The yield of individual wells in such aquifers is small (50 to 100 gallons per day in clayey till) and satisfies only farm requirements. On many farms more than one well is required to satisfy the demand. Where springs occur the flow averages 1 to 3 gpm (gallons per minute). These yields are here considered as average, meaning that in dry years the yield would be smaller and in wet years larger. Owing to the low yield of these aquifers the location for a well should be carefully selected. Therefore it is recommended that many test holes be made prior to digging or boring a well to ensure a sufficient supply.

Confined Aquifers

Little is known about the yield of each individual confined aquifer. The town of Steinbach obtains its water from the sandstone of the Winnipeg Formation. Pumping at a rate of 180 gpm the drawdown is 22 feet. This shows that the transmissibility of the aquifer is approximately 16,000 gpd/ft. The daily consumption averages 218,000 gallons. Similarly the Manitoba Cooperative at Blumenort, some 6 miles north of Steinbach, pumps water from the same aquifer at 85 gpm. Thus some 456 acre-feet per year is being pumped from this aquifer at these two places. On the other hand the town of Beausejour obtains its water supply from unconsolidated white sands above the bedrock and for a rate of 120 gpm the drawdown is 15 feet. This would also give as the transmissibility of the white sand 16,000 gpd/ft. The yearly consumption for this town amounts to some 126 acre-feet. These figures are mentioned not as maximums but to show the possibilities of large yields from the various aquifers in the area.

Actually most of the knowledge on the yield of the various confined aquifers is derived from the flowing artesian wells. During the present study the flow of 81 flowing artesian wells was measured. The maximum natural flow of 36 gpm, in one location, occurred in a well obtaining its water from a till bedrock contact, while in another location the same natural flow was obtained from a bedrock formation. The minimum natural flow recorded was 1/3 gpm. At the average height of 2.7 feet above ground-level the average flow of the 81 wells was 4.2 gpm. If this average rate of flow is applied to the 350 flowing wells encountered during the study of the Steinbach area, this would mean that 1,470 gpm are yielded by natural means by the confined aquifers in the area, or a total of 2,848 acre-feet per year. This is more than six times what is being used by the two towns of Steinbach and Beausejour, with a combined population of more than 5,500 inhabitants. It is therefore obvious that most of the annual 2,848 acre-feet of water yielded by these flowing wells is wasted.

Assuming that the average production of each of the other 2,250 wells surveyed in this area is 500 gallons per day, this would amount to 1,514 acre-feet per year. Therefore the grand yearly total of groundwater withdrawn by both natural and artificial means from the unconfined and confined aquifers in the Steinbach area would amount to 4,944 acre-feet. This last figure is much lower than the average annual amount of 23,000 acre-feet that was estimated to infiltrate through the 416 square miles of the recharge area. The writer in 1961 and 1962 found that this recharge area also supplies groundwater recharge for regions farther to the west, as well as to the south and east. Although exact figures are not available, it is apparent that the combined discharge exceeds the amount of recharge, even if additional recharge would take place from the bogs and marshes through the till surrounding the sand/gravel areas.

It can be shown and proven that depletion of the confined aquifers occurs in the Steinbach area. Figure 3 shows that the piezometric surface is lower each year. For many wells the year the well stopped flowing above ground-level is indicated on Figure 3. The surprising point is that the lowering of the piezometric surface does not occur as a straight north-south line regressing eastward (as would be expected from the general east to west flow), but occurs at many places at once, not only on the outer edges of the flowing zone, but also within the flowing zone itself (Fig. 3). In other words this zone of flowing wells "undermines" itself. The reasons why this "undermining" occurs may be numerous. However it seems fair to assume that it is probably due to differences in head at the wells and to different transmissibility and permeability values of the aquifer at these wells. So far no attempt has been made to prove these differences. Because of the steady lowering of the piezometric surface, it is clear that total discharge surpasses total recharge. To keep wastage of groundwater at a minimum, a tighter control should be emphasized over the flowing artesian wells, which are left flowing 24 hours a day, 365 days a year. This may not be sufficient to completely remedy the lowering of the piezometric surface, but it would help to slow down the process.

From the point of view of quantity the best regions of groundwater in the Steinbach area are: 1) the region of Steinbach, Ste. Anne, Giroux, La Broquerie, and Marchand; 2) the Piney region; 3) the northwestern part of the map-area. From the same point of view the southwestern part of the map-area is a poor one, and the worst is the extreme northeastern corner which forms part of the Whitemouth River Basin (Fig. 2).

The writer believes that large quantities of good groundwater exist in the highlands of Sandilands Forest Reserve, where the sand and gravel deposits are thick (150+ feet).

MARSHLAND DRAINAGE PROJECT

During the 1964 field season a Department of Public Works rotary drill was placed at the writer's disposal. It was hoped that drilling would locate aquifers that could be used in the draining of swamps, marshes, or bogs.

As can be seen on Figure 2 a large part of the Steinbach area (some 608 square miles) consists of swamps and marshes. The present method used to drain these areas is by drainage ditches or canals. These ditches usually lead the excess surface water to the closest rivers, which in this case are the Red, Seine, Brokenhead, and Whitemouth Rivers, depending on

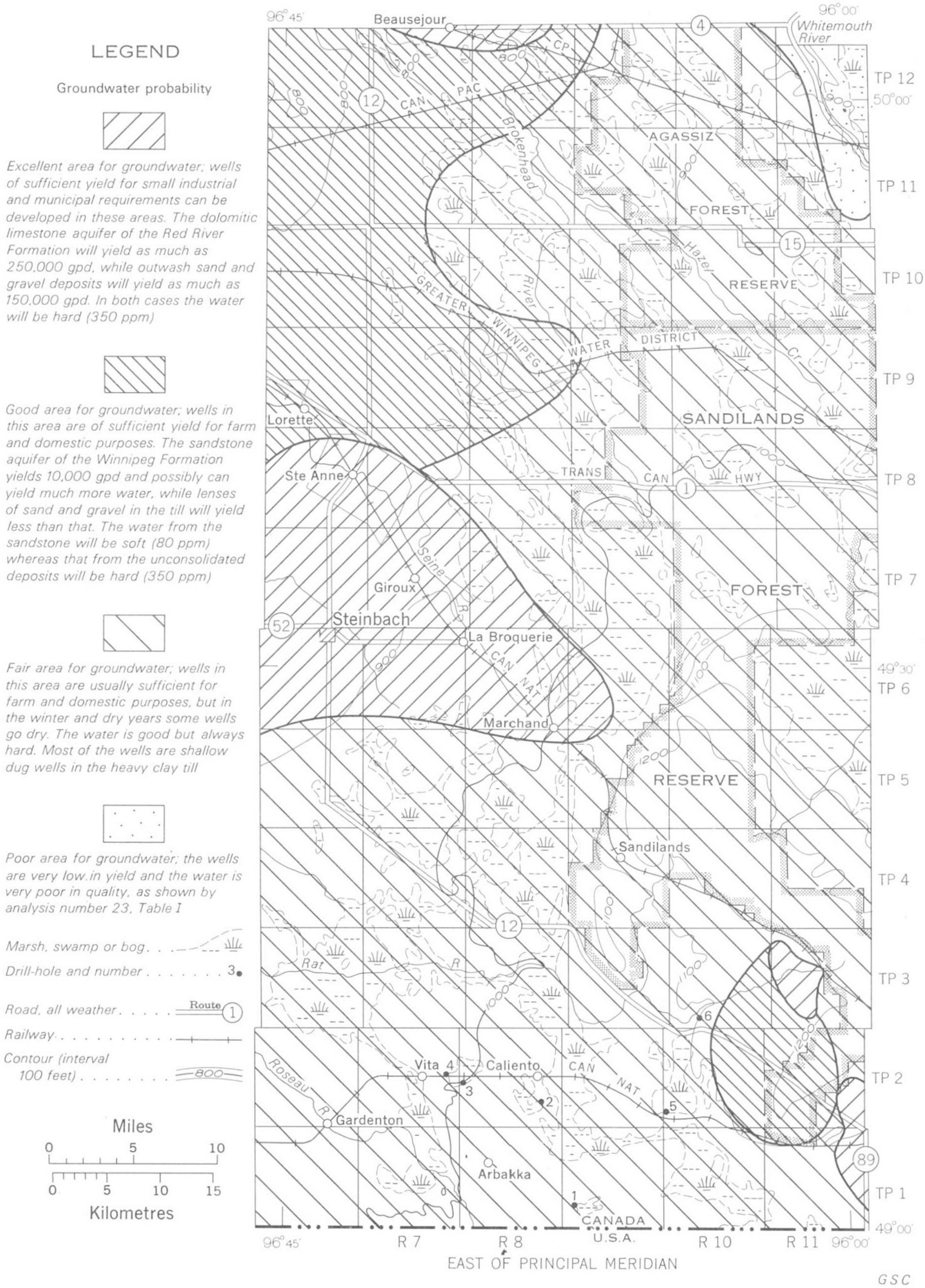


Figure 2. Groundwater availability, marshlands and location of drill-holes for drainage project.

the location. In other words the excess water is not used at all or very little, and it is actually troublesome in the springtime when flooding occurs on these rivers.

It was believed by the author that a much better use could be made of this swamp water if it could be put into the ground where it could possibly improve the supply to wells downstream from the artificial recharge because of the 200+ feet difference in head between the marshland and the lowest point in the Red River valley. The depth at which the aquifer could be located was considered as the only limiting factor. If the rechargeable aquifer was too deep it would be of no use to the users downstream. Besides, the knowledge of the existence of salty water in the bedrock limited the drilling to the till only. Apart from the usage of the water, the drainage of these marshlands would open up new agricultural land especially where such bogs or marshes are open. At the present time the drainage ditches do not drain this wet land completely.

Thus the drilling sites were chosen near open marshes. The drilling had to be done on solid ground to permit access for the large mobile drilling rig and yet near enough to a marsh (that would be the source of water), so that a short control canal some 10 feet in length could be dug between the open water and the drill-hole. Six sites were chosen and their locations are shown on Figure 2. The deepest hole was drilled to a depth of 261 feet and the shallowest to a depth of 150 feet. It had been hoped that a good coarse sand or gravel lens, or lenses, might be encountered in the till, but no such occurrences were found, as shown by the logs of the six holes (Fig. 4). In general the surficial deposits drilled can be described as saturated clayey till.

With this type of deposit it is obvious that the project was a failure and that the drainage of a marsh was impossible, yet such a project could be recommended southeast of Marchand where the writer believes the main groundwater flow occurs. To the south, where this project was carried out, deeper holes through the till and into the bedrock may yield rechargeable aquifers. A project of this kind may be of interest, even though it would have only one advantage, that of draining the marshland, because the water would become salty and unusable farther downstream. The largest such marsh or bog that would benefit most by drainage is the Caliento-Sundown bog located in townships 1 and 2, ranges 9E and 10E.

QUALITATIVE DATA

Analytical Results

Forty-four groundwater samples were analyzed by the Industrial Minerals Division, Department of Energy, Mines and Resources, Ottawa.

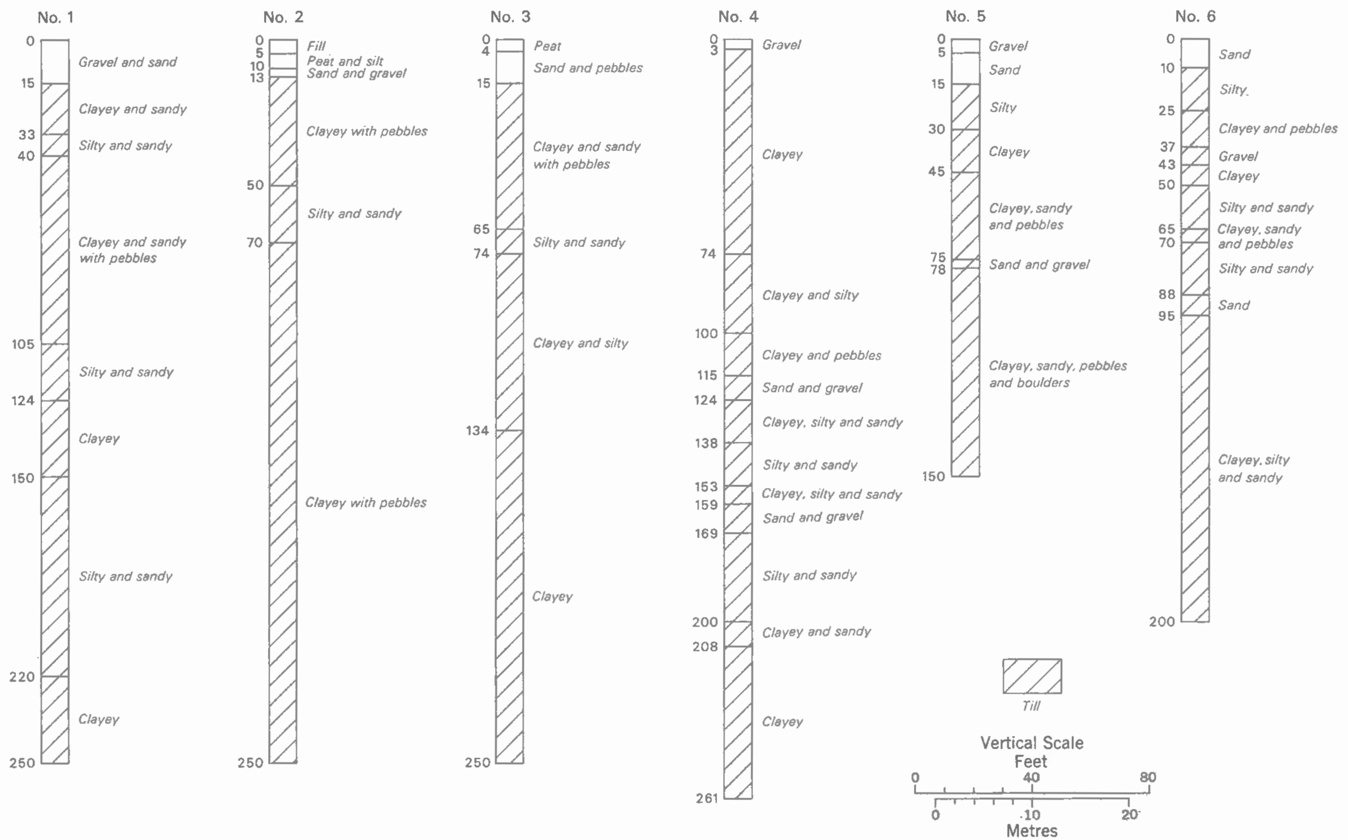


Figure 4. Drill-hole logs of marshland drainage project.

TABLE I - CHEMICAL ANALYSES OF GROUNDWATERS IN THE STEINBACH AREA, MANITOBA

Sample No.	Location	Depth of well (ft)	Temperature (°F)	Colour (Hazen Unit)	pH	Carbon Dioxide (CO_2)	Conductance (Micromhos at 25°C)	CHEMICAL CONSTITUENTS IN PARTS PER MILLION: Hardness as $CaCO_3$ Non-Carbonate	Hardness as $CaCO_3$ Total	Total Alkalinity as $CaCO_3$	Calcium (Ca)	Magnesium (Mg)	Sodium (Na)	Potassium (K)	Iron (Fe)	Bicarbonate HCO_3	Sulphate (SO_4)	Chloride (Cl)	Fluoride (F)	Nitrate (NO_3)	Silica (SiO_2)	Sum of Constituents	% Sodium
1	NE-30-12-11E	42	42	0	7.8	9	582	0	303	313	57.3	38.7	9.4	5.2	0.57	381	10.6	1.9	0.6	0.5	19	331	6
2	NE-32-11-8E	125	43	5	8.2	3	654	0	106	231	17.9	14.9	100.0	7.2	0.29	282	45.1	40.8	0.8	0.4	9	374	65
3	NW-19-11-7E	210	42	5	7.8	8	1566	0	32	257	1.6	6.9	316.0	12.2	0.11	314	164.0	235.0	2.1	0.6	6	898	94
4	NW-8-10-7E	52	42	5	7.9	7	549	0	285	292	55.9	35.3	8.6	2.5	0.99	356	10.6	0.5	0.3	0.6	17	307	6
5	NE-1-4-7E	125	48	20	7.5	16	515	0	198	271	39.2	24.3	36.0	2.3	8.10	331	1.9	4.3	0.4	0.5	23	294	28
6	NW-35-2-10E	100	46	5	8.1	4	481	0	265	271	69.1	22.4	4.7	1.7	2.10	331	4.1	0.2	0.1	0.4	13	279	4
7	NW-1-3-10E	210	50	5	7.9	5	379	0	186	-	44.6	18.2	8.3	2.1	1.20	246	3.4	0.8	0.2	1.1	19	219	9
8	NW-21-3-11E	31	42	5	7.9	5	395	0	202	-	50.0	18.8	5.4	1.8	0.54	254	5.9	0.2	0.1	0.1	26	233	5
9	NE-13-5-10E	155	44	0	7.8	7	423	0	227	-	50.5	24.4	4.2	1.3	3.30	282	2.6	0.5	0.1	0.2	19	242	4
10	NW-34-4-11E	104	46	5	8.0	6	551	0	285	-	63.5	30.7	10.5	2.5	4.50	375	2.8	0.8	0.2	1.2	27	323	7
11	SW-13-2-11E	76	44	0	8.0	4	348	1	179	178	44.6	16.3	3.4	1.5	0.24	216	9.0	0.3	0.1	0.1	23	205	4
12	SE-36-1-11E	25	44	0	8.0	4	379	0	190	199	45.3	18.6	6.4	1.9	0.19	242	7.5	0.4	0.2	0.1	23	223	7
13	NE-12-1-11E	106	43	0	7.8	6	358	0	155	184	12.1	30.2	15.0	2.1	0.28	224	5.2	1.0	0.3	0.8	23	200	17
14	SE-11-1-11E	100	45	0	7.8	5	353	0	132	185	27.2	15.7	24.0	2.6	0.21	226	3.1	1.4	0.4	0.7	23	209	28
15	SW-2-2-11E	104	43	0	8.0	5	476	0	235	241	46.8	28.7	11.5	2.4	0.33	293	19.9	1.1	0.2	0.3	25	280	10
16	NE-25-1-6E	170	52	35	7.6	27	945	0	489	576	92.1	62.8	46.0	3.1	6.50	702	4.1	11.2	0.2	2.4	32	599	17
17	SW-8-9-7E	52	45	5	8.0	5	533	0	246	252	44.0	33.0	16.5	5.1	1.50	307	34.8	1.2	0.4	0.3	13	300	13
18	NW-33-9-7E	105	42	5	7.8	8	506	3	266	263	45.6	36.9	3.5	2.8	0.35	321	13.9	0.9	0.1	0.1	15	277	3
19	NE-14-9-7E	85	43	5	8.0	5	555	9	292	283	48.4	41.6	5.3	2.5	3.80	346	16.8	4.5	0.1	0.3	15	305	4
20	NE-24-9-8E	110	49	5	7.9	5	608	0	86	236	14.1	12.2	99.5	2.8	0.46	287	14.7	41.3	1.0	0.5	11	338	71
21	NW-22-9-8E	84	42	5	7.9	6	486	0	244	253	41.8	33.9	9.8	2.8	0.01	308	8.3	1.8	0.2	2.5	13	266	8

	22	NW-27-10-8E	80	45	5	8.0	4	466	0	112	209	19.1	15.6	57.2	4.0	2.80	255	16.8	11.4	0.8	0.7	12	263	52
	23	NW-1-12-11E	37	44	5	8.0	4	2129	894	1125	231	214.0	144.0	98.0	7.1	1.30	282	1027.0	34.0	0.5	3.5	19	1684	16
	24	SW-22-12-8E	110	45	10	8.1	4	1047	0	40	270	4.6	6.8	220.0	3.0	0.21	329	108.0	93.0	3.4	1.8	8	610	92
	25	SE-35-12-6E	60	41	5	7.9	10	1073	97	574	477	60.7	103.0	24.5	4.4	0.67	582	151.0	2.1	0.5	0.5	16	649	8
	26	NE-21-11-7E	200	43	0	8.1	4	815	0	88	268	15.6	11.8	144.0	10.2	0.32	326	50.1	65.7	1.2	0.7	7	467	76
	27	NE-9-6-6E	253	50	5	7.9	9	651	0	334	362	70.2	38.4	16.2	3.0	2.80	441	2.3	2.1	0.3	2.8	20	372	10
	28	SW-10-6-6E	81	45	5	8.0	7	691	0	354	381	80.2	37.4	14.5	2.7	2.40	465	2.9	2.2	0.2	5.6	25	399	8
	29	NW-33-8-8E	140	52	5	8.1	5	564	0	272	311	46.5	37.9	16.0	3.5	2.10	379	3.1	1.7	0.3	0.4	17	313	11
	30	SW-9-8-8E	140	48	10	8.1	6	719	0	361	404	56.5	53.3	21.8	4.0	2.60	493	1.8	1.0	0.4	3.5	19	404	12
	31	NW-7-7-8E	38	42	5	8.1	4	660	0	220	286	46.5	25.3	54.0	3.3	1.80	349	1.3	41.7	0.4	2.2	17	364	34
	32	NW-33-6-8E	193	42	5	8.2	4	601	0	233	305	49.4	26.6	40.0	4.3	1.30	372	2.1	13.8	0.3	2.9	14	337	27
	33	NE-15-6-8E	110	43	5	7.7	5	370	0	161	186	38.1	16.1	14.2	2.3	0.67	226	2.0	5.8	0.3	0.1	18	208	16
	34	SW-23-5-8E	141	48	5	8.0	5	544	0	280	313	65.4	28.2	15.8	3.6	0.78	381	2.0	2.8	0.4	0.4	22	328	11
	35	SE-30-6-8E	126	42	5	8.0	5	417	0	197	226	39.4	23.9	14.2	2.6	1.20	276	2.0	3.9	0.3	0.2	20	242	13
	36	NE-6-6-7E	185	50	10	8.0	10	771	0	423	437	90.8	47.6	12.2	3.9	6.80	532	2.0	1.3	0.3	4.0	21	445	6
	37	NW-17-6-7E	201	43	5	8.2	4	592	0	300	327	61.3	35.7	15.3	3.7	1.30	398	1.2	2.6	0.3	3.4	17	336	10
	38	NE-28-6-7E	142	54	5	8.1	6	681	0	358	390	76.2	40.8	14.2	3.3	3.00	476	2.6	2.0	0.3	0.6	19	393	8
	39	SW-22-7-7E	130	42	5	8.1	5	686	0	234	329	44.4	29.8	65.2	6.0	3.10	401	3.8	39.7	0.4	0.5	12	399	38
a	40	NW-5-8-7E	228	42	5	7.8	10	604	0	212	313	39.4	27.6	54.5	7.0	0.57	381	1.3	20.5	0.4	0.3	11	349	35
	41	SW-1-8-6E	270	54	5	7.9	7	612	0	208	277	42.7	24.6	51.5	7.4	1.10	338	9.3	30.9	0.7	0.6	8	342	34
	42	NE-32-7-6E	265	53	10	8.1	4	525	0	177	269	37.6	20.2	39.2	14.0	0.26	328	2.8	7.5	0.7	0.6	5	289	30
	43	NE-13-7-6E	140	50	0	8.0	5	477	0	216	248	38.1	29.4	19.5	3.8	1.70	302	6.0	7.7	0.3	0.3	13	267	16
	44	SE-5-7-6E	18	43	5	8.0	6	556	0	250	292	49.4	30.8	24.0	4.1	1.90	356	1.4	10.0	0.4	0.8	17	313	17
b	45	SE-36-12-7E	85	-	-	7.5	-	-	-	332	284	69.0	39.0	59.0	-	3.00	347	53.0	90.0	0.5	-	-	556	-
c	46	SE-35-6-6E	252	-		7.8	8	564	0	248	288	50.9	29.3	25.6	4.3	0.60	352	3.2	12.6	0.1	0.4	14	314	18
	Standards		Permissible		5	6.5 to 9.2	-	-	-	d150	125	75.0	50.0	250.0	-	0.30	180	200.0	200.0	0.5	40.0	-	500	-
			Excessive		50		-	-	-		-	200.0	150.0	-	-	1.00	360	400.0	600.0	1.5	100.0	-	1500	60

a - lot 3, parish of St. Anne.
b - in 1960
c - in 1957

Permissible - Good potable water.
Excessive - Beyond that range water is not considered potable.

d - over 150 ppm is considered hard water.

Date of collection of samples - Sept. 7-8-9-10, 1963.

Analysed by Industrial Minerals Division, Dept. of Mines and Technical Surveys

The samples were taken from representative wells producing water from the various aquifers in the Steinbach area. The analyses show the dissolved mineral content of the water, but do not indicate whether a water that is reported to be chemically potable is bacteriologically safe. The results of the analyses are given in Table I. The last two samples in Table I were supplied by the authorities of the towns of Beausejour and Steinbach. At the end of the table a comparison has been made between the analyses and the recommended minimum quantity standards. In the Steinbach area, water with a sum of constituents less than 500 ppm (parts per million) can be considered as excellent water; less than 1,000 ppm can be considered as good water, and less than 1,500 ppm as fair water. Water containing more than 1,500 ppm cannot be considered as potable although it is being used as such in some cases.

The groundwater of the Steinbach area can be generally considered as excellent, potable, hard water. This is demonstrated (Table I) by the sum of constituents or total dissolved solids (T.D.S.), which is generally less than 500 ppm and a hardness value which is generally more than 150 ppm.

Physical Characteristics

Temperature The temperature of the groundwater of a region usually approximates the mean annual temperature of the region, which in this case is approximately 37°F. Most of the groundwater samples taken had a temperature of less than 45°F. Any higher temperature readings are due to the fact that the sample could not be taken directly at the well and heating of the groundwater occurred in its passage through the water pipes. Because we are dealing mainly with a farming economy the groundwater can be and is used for cooling purposes, especially on dairy farms.

Colour and Turbidity Throughout the area the groundwater was clear. The laboratory analyses show that most of the samples have less than 5 Hazen units.

pH As shown in Table I the water is basic in character, with an average pH of 7.9, a maximum of 8.2, and a minimum of 7.5.

Chemical Constituents

Carbon Dioxide (CO_2) The free CO_2 in the water is generally less than 10. It should be noted that in the two samples (Nos. 5, 16), where the CO_2 value is larger than 10 (Table I) the pH value is low, 7.5 and 7.6, as compared to the other analyses, while the colour value is high, 20 and 35 Hazen units.

Hardness As mentioned before the groundwater of the area is considered hard. Excluding sample No. 23, the average total hardness is in the order of 300 ppm, which is twice the value at which water is considered to be soft water. Four samples (Nos. 3, 20, 24, and 26) all situated in the northeastern part of the area, have low hardness values, the lowest of which is 32 ppm. Sample No. 3 is believed to have been obtained from the sandstone of the Winnipeg Formation, while the groundwater making up the other three samples was obtained from the till aquifer. Nevertheless the low hardness value of these three samples indicates that the bedrock underlying the till could possibly be the sandstone of the Winnipeg Formation. Present geological knowledge places the contact of the Red River and Winnipeg Formations in the vicinity of these analyses with low hardness values, but somewhat to the east of them. Therefore it could be that this assumed contact is more westerly than it is at present situated.

Ca, Mg, Na, K, HCO_3, Cl, F, NO_3 These chemical constituents occur in normal quantities in most analyses and not many irregularities are noticeable, except for analysis No. 23. The analyses with low Ca and Mg values have a low hardness value. The sodium and chloride value is never high, which is as it should be in a recharge area. The highest value for Na and Cl of 316 and 235 ppm respectively, can be accounted for by the depth of the well, which is more than 200 feet. The K and HCO_3 values are all normal, while the F value is in most samples less than 0.5 ppm; it is invariably present, and only in sample Nos. 3 and 24 is it excessive with a value of 2.1 and 3.4 ppm. The nitrate value is low in all the analyses. This is to be expected because all the analyses are of groundwater that is believed to be obtained from a confined aquifer.

Iron (Fe) The iron content of these analyses exceeds the permissible standard of 0.30 ppm in 80 per cent of the samples. The value is over 1.0 ppm in more than half of the samples. This means that iron filters are to be recommended in fifty per cent of the cases where a softener is installed. In three samples, Nos. 5, 16, and 36, the iron value exceeds 5.0 ppm and even though it is known that the aquifer is a sandy or gravelly till in each case, the high iron content may be a reflection of the bedrock (red shale of the Amaranth Formation) underlying it (Fig. 3). It could be that some of the groundwater in the red shale or at the contact of the red shale and the till, infiltrates upwards through the till because of artesian pressure.

Sulphate (SO_4) The sulphate value is less than 10.00 ppm in 2/3 of the analyses. This brings into focus the sulphate reduction phenomenon. The presence of large areas of bogs and marshes (Fig. 2) at the base of the large recharge area, would be more than sufficient to warrant this chemical phenomenon, but the lack of H_2S odour at most of the wells nullifies that explanation. The conclusion is that dissolution of sulphate salts does not take place, for the simple reason that these salts do not exist in this area.

Sum of Constituents In forty of the forty-six analyses the value of total dissolved solids is less than 500 ppm. This indicates that the area is one of recharge.

Per Cent Sodium The per cent sodium value of 60 per cent is generally accepted as the maximum limit at which water can be used for irrigation. In this area the value of most samples is much below that recommended value. Even the samples with high per cent sodium values can be used for irrigation because the absolute sodium value of the samples is low.

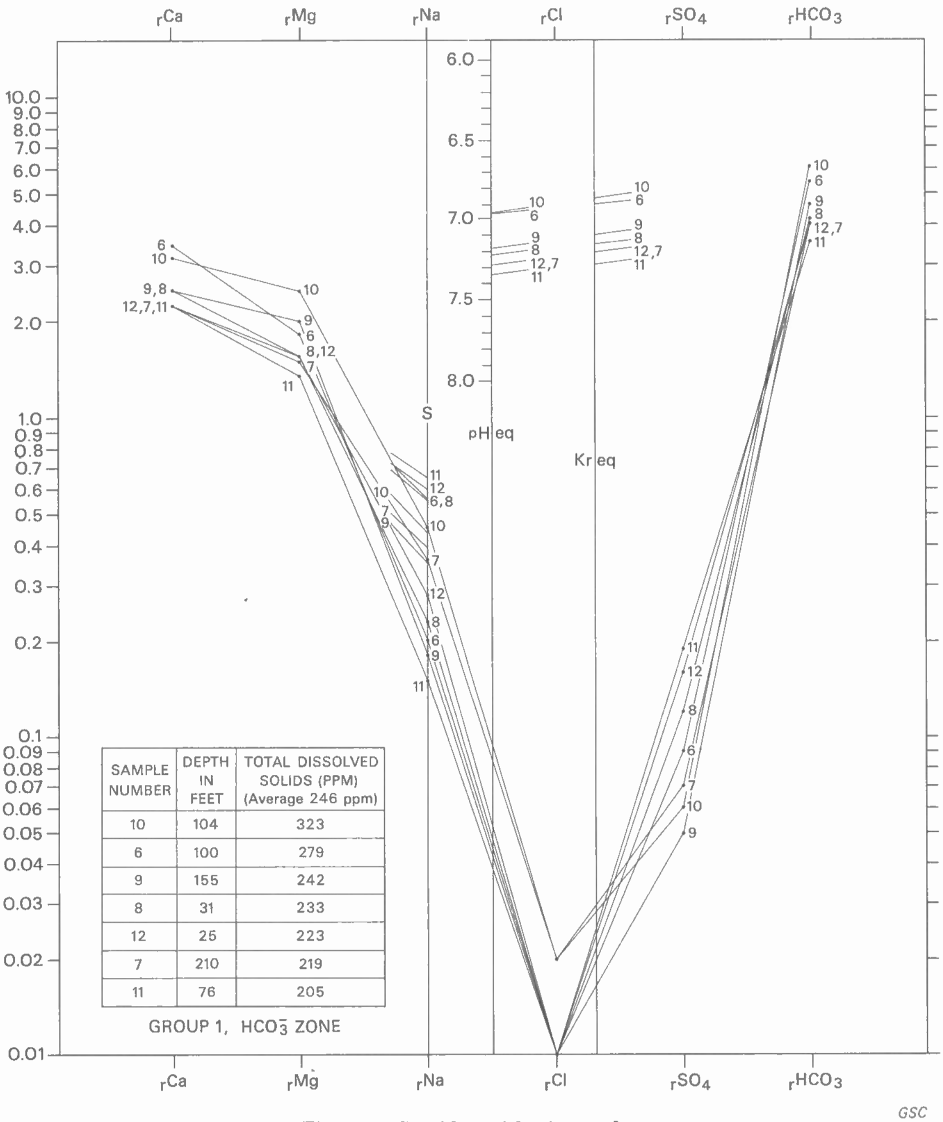
Sample No. 23 A quick glance at Table I shows that this sample is different from all the other 45 samples. First let us say that it is isolated from the others in that it is derived from the Winnipeg River basin and not from the Red River basin as the others. It is also the only sample collected on the east side of Whitemouth River. Therefore the origin or recharge area it comes from is completely different from the recharge area for the other 45 analyses mentioned in Table I. This last part is mentioned in case someone points out that sample No. 1 is also in the same basin as sample No. 23, for the recharge area that supplied the groundwater for sample No. 1 is probably the same as that which supplied the groundwater for sample Nos. 2, 24, 26, etc. Secondly it differs in that, at the location where sample No. 23 was collected, the bedrock underlying the till is granite. Thirdly the matrix of the till is very clayey. This region adjoining the Whitemouth River is known to yield very little groundwater and groundwater of poor quality. Therefore the fact that the till is clayey plus the fact that the T.D.S. value of sample No. 23 is 1,684 ppm, which is relatively high if compared to the other 45 samples, would tend to show that groundwater movement in this part is very slow. The largest increase is in $CaSO_4$ and $MgSO_4$. Why the increase is mainly in sulphate salts is a question that cannot be readily answered at the present time. For no apparent reason the sulphate reduction phenomenon does not exist in this part, although all the basic factors are there for it to manifest itself. Because of the high Ca and Mg values, the water of analysis No. 23 is excessively hard at 1,125 ppm.

HYDROCHEMISTRY

In his two latest reports, the writer (Charron, 1965a, b) made use of the chemistry of the groundwater to determine groundwater movement and to explain certain chemical phenomena. This approach is used again in the present report.

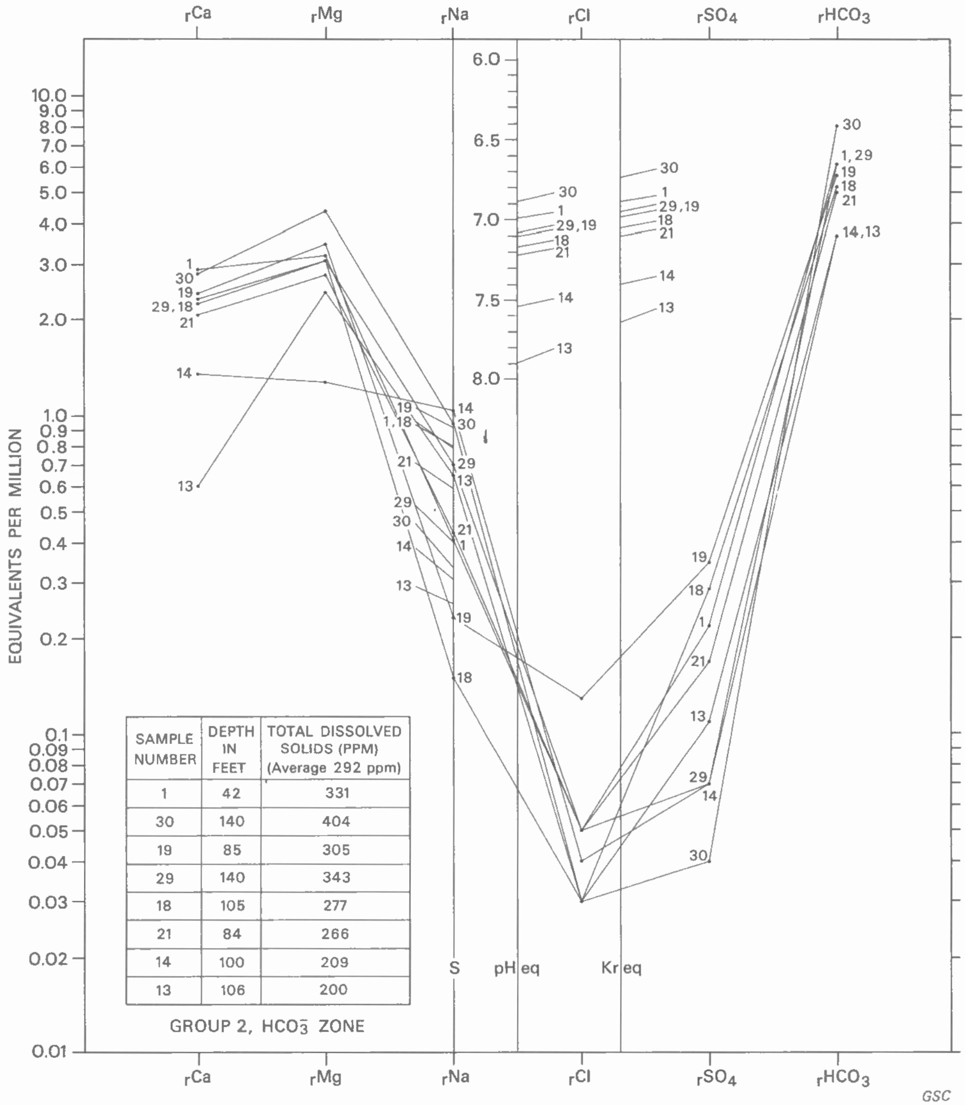
Semi-logarithmic Diagrams

The 46 analyses are represented as graphic patterns (Schoeller, 1962) on semi-log paper and have been divided into six groups (Figs. 5 to 11).



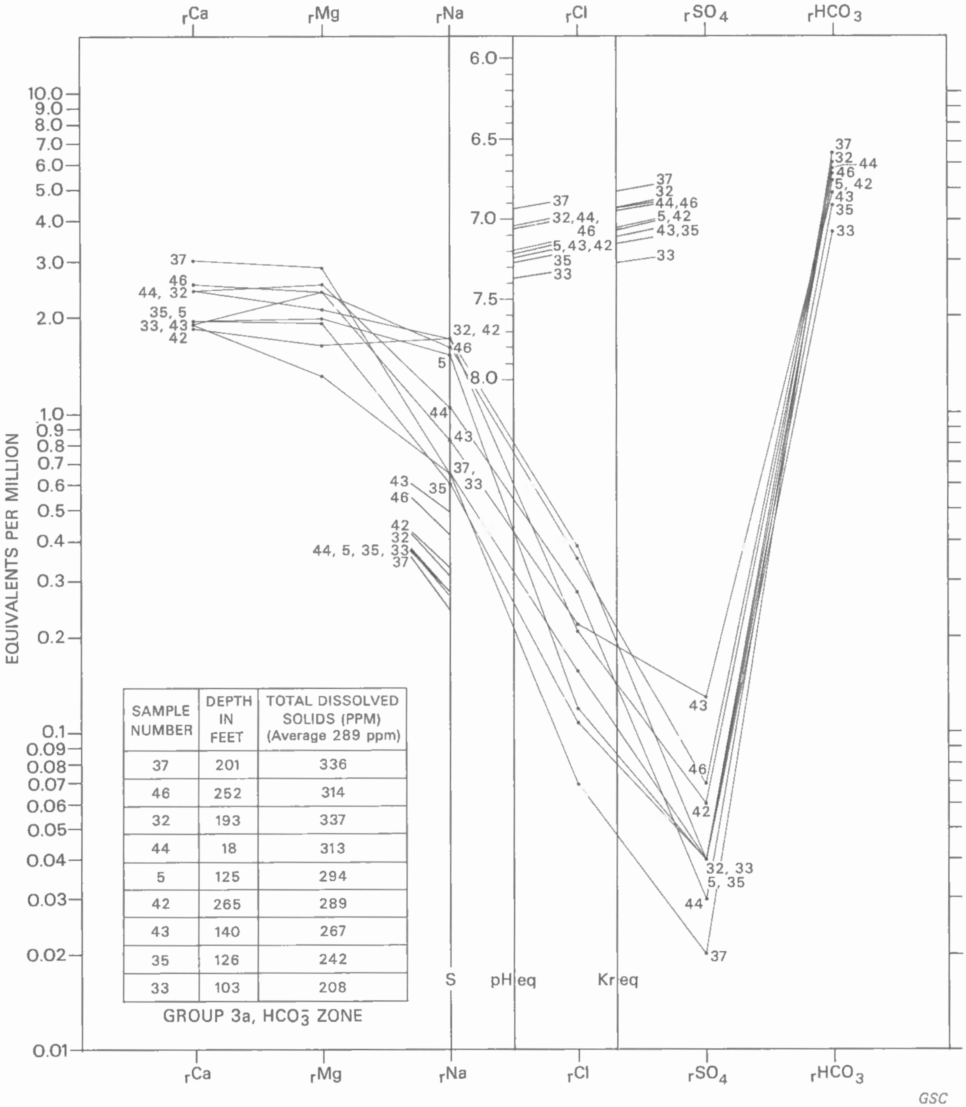
SAMPLE NUMBER	DEPTH IN FEET	TOTAL DISSOLVED SOLIDS (PPM) (Average 246 ppm)
10	104	323
6	100	279
9	155	242
8	31	233
12	25	223
7	210	219
11	76	205

Figure 5. Semi-logarithmic graphs.



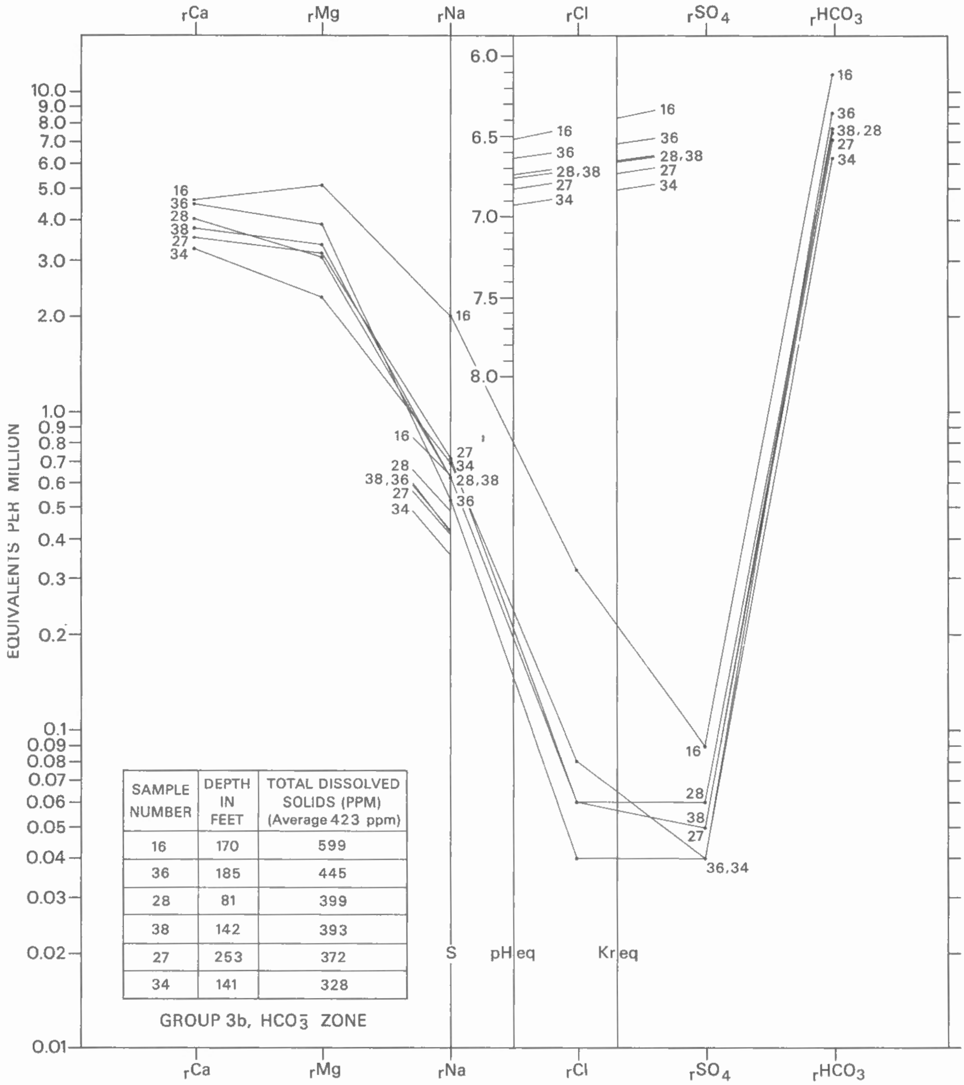
SAMPLE NUMBER	DEPTH IN FEET	TOTAL DISSOLVED SOLIDS (PPM) (Average 292 ppm)
1	42	331
30	140	404
19	85	305
29	140	343
18	105	277
21	84	266
14	100	209
13	106	200

Figure 6. Semi-logarithmic graphs.



SAMPLE NUMBER	DEPTH IN FEET	TOTAL DISSOLVED SOLIDS (PPM) (Average 289 ppm)
37	201	336
46	252	314
32	193	337
44	18	313
5	125	294
42	265	289
43	140	267
35	126	242
33	103	208

Figure 7. Semi-logarithmic graphs.

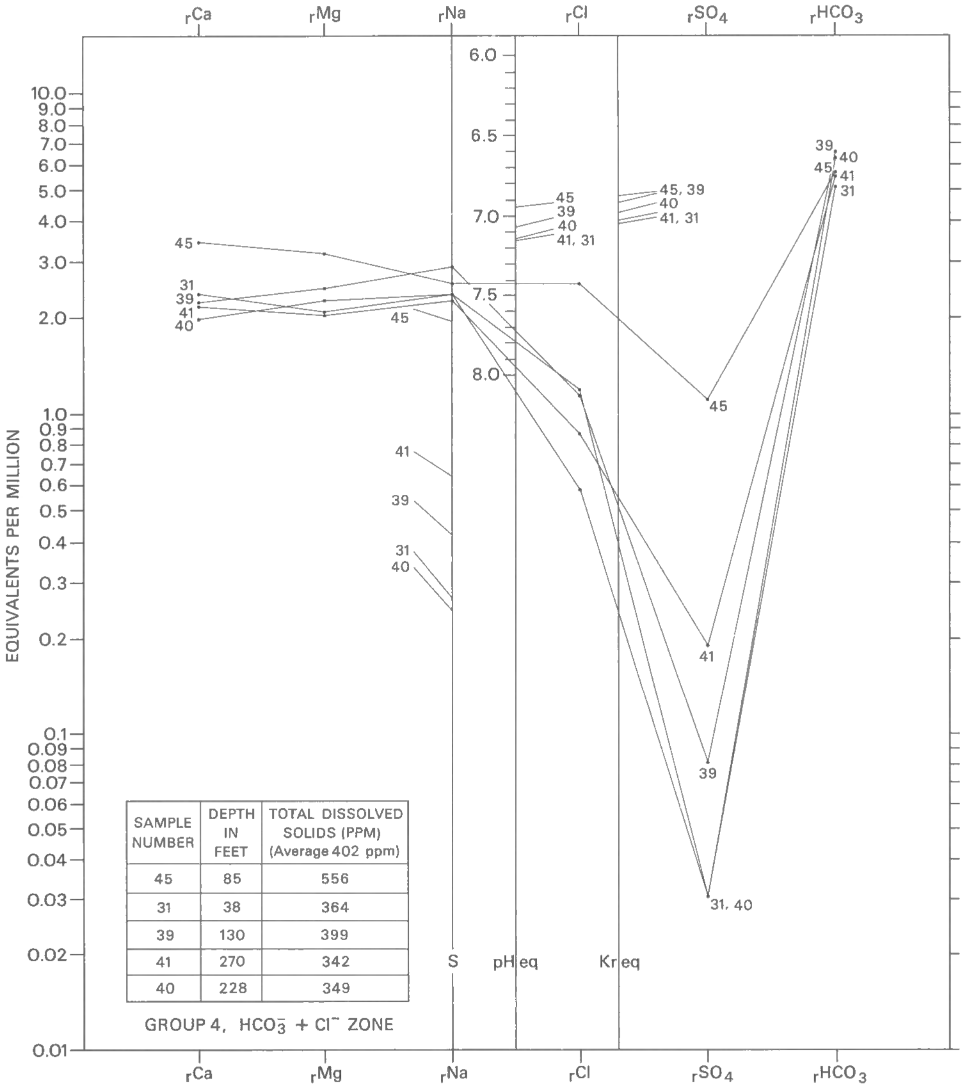


SAMPLE NUMBER	DEPTH IN FEET	TOTAL DISSOLVED SOLIDS (PPM) (Average 423 ppm)
16	170	599
36	185	445
28	81	399
38	142	393
27	253	372
34	141	328

GROUP 3b, HCO_3^- ZONE

Figure 8. Semi-logarithmic graphs.

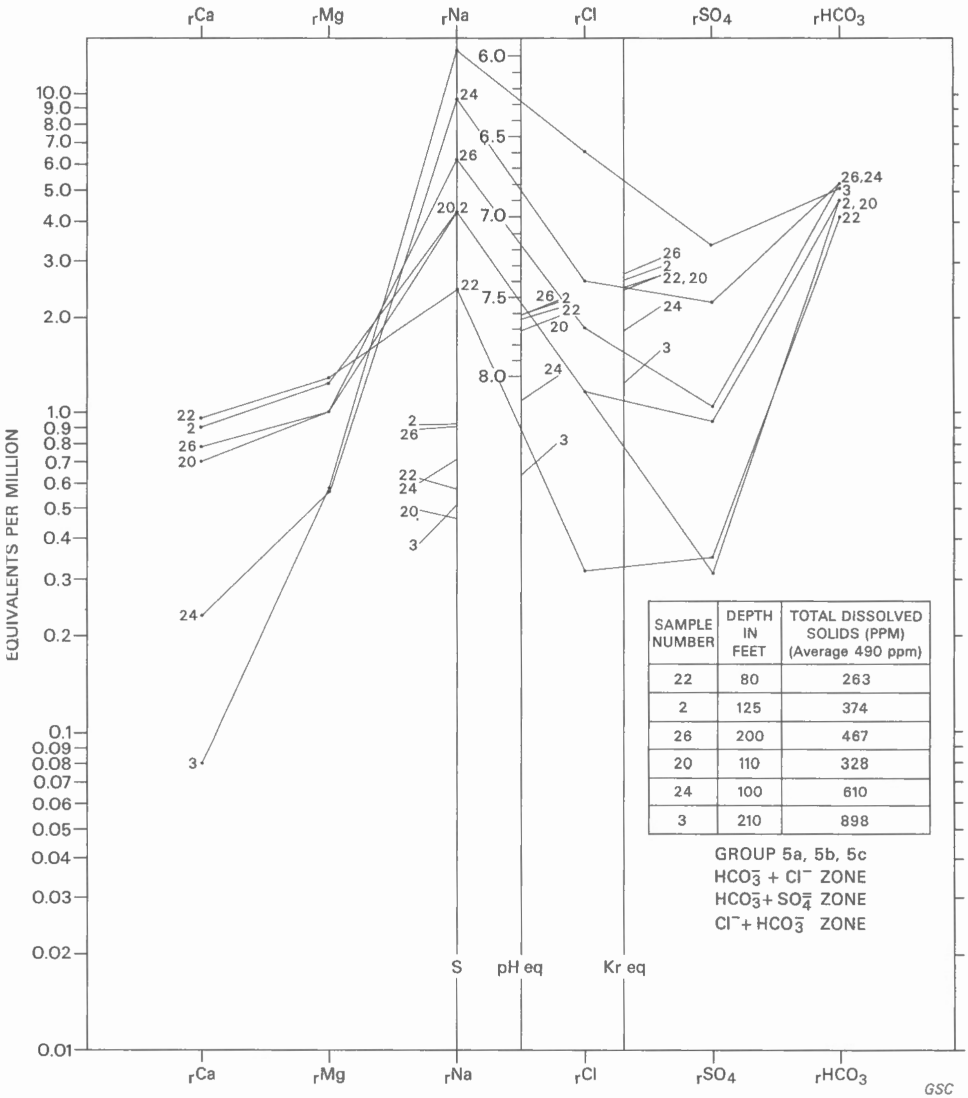
GSC



SAMPLE NUMBER	DEPTH IN FEET	TOTAL DISSOLVED SOLIDS (PPM) (Average 402 ppm)
45	85	556
31	38	364
39	130	399
41	270	342
40	228	349

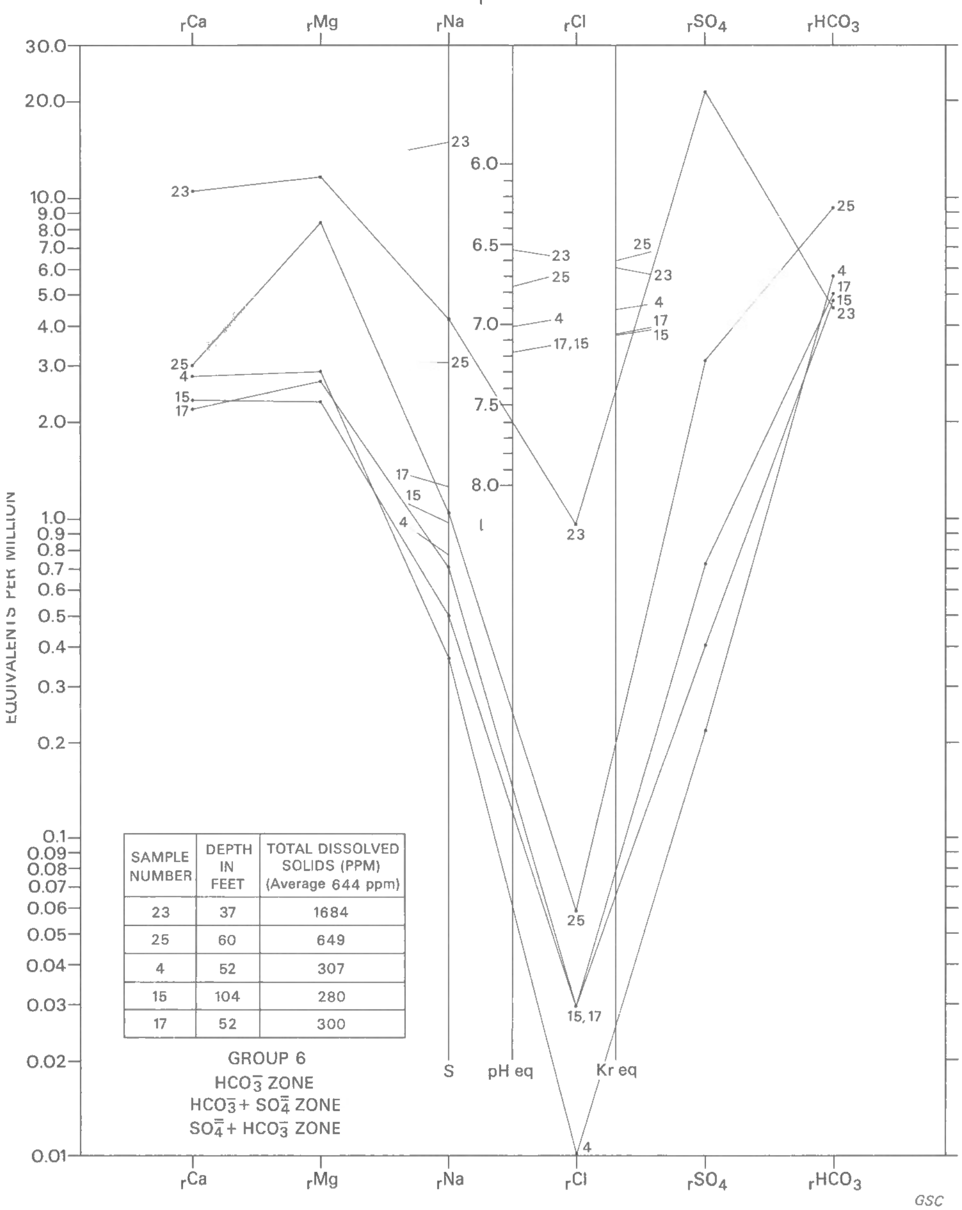
Figure 9. Semi-logarithmic graphs.

GSC



SAMPLE NUMBER	DEPTH IN FEET	TOTAL DISSOLVED SOLIDS (PPM) (Average 490 ppm)
22	80	263
2	125	374
26	200	467
20	110	328
24	100	610
3	210	898

Figure 10. Semi-logarithmic graphs.



SAMPLE NUMBER	DEPTH IN FEET	TOTAL DISSOLVED SOLIDS (PPM) (Average 644 ppm)
23	37	1684
25	60	649
4	52	307
15	104	280
17	52	300

Figure 11. Semi-logarithmic graphs.

Before the study of the Steinbach area was begun, it was believed that it was an area of recharge. Therefore the groundwater should be predominantly a bicarbonate (HCO_3^-) type of water. This is well substantiated by five of the six groups of analyses and is also very well demonstrated on Figure 9. As can be seen on Figure 9, only water in the northwest corner of the area is not a truly bicarbonate type of water. This area will be used to demonstrate the advantages that semi-logarithmic graphs have over other presentations, to help in the understanding of hydrochemical or hydrogeological problems. As stated before, the Steinbach area was supposed to yield a bicarbonate type of water. Without the semi-logarithmic diagrams, this could have been seen and proven simply by looking at the analytical values of Table I, but nothing else could have been added to that.

Now with the help of the semi-logarithmic diagrams the analyses have already been divided into six groups. Secondly the bicarbonate type of water is divided into three sub-bicarbonate zones (Fig. 12), which proves that this method of presentation of the analyses will differentiate even groundwater with a low T.D.S. content. Of the six groups represented here, group 1 is most prominent. The groundwater of this group is in every case, very near to the recharge area. The graphic lines which join each radical for the various analyses are almost all parallel to one another, which means that the ratio of these elements $r\frac{Mg}{Ca}$, $r\frac{Na}{Mg}$, $r\frac{SO_4}{Cl}$ is the same. More important is the fact that even though this area is considered strictly as a recharge area, the order in which the six groups have been placed demonstrates a certain continuing change, so that slight groundwater movement is discernible from the semi-logarithmic graphs of the six groups.

Basically the first four groups and the sixth group have concave patterns, which offer little variation (Figs. 5, 6, 7, 8, 9, and 11). In groups 1 and 2 the $_rSO_4$ value is greater than the $_rCl$ value, although in group 2 it can already be seen that the $_rCl$ value is picking up on the $_rSO_4$ value. In group 3 the $_rCl$ value has surpassed the $_rSO_4$ value. Noticeable also in group 3 is the increase in $_rNa$, which was also faintly discernible in group 2 as compared to the $_rNa$ value in group 1. The process is continued in group 4 and finally in group 5 the graphic patterns have a convex shape, which is mainly due to an increase in NaCl. Consequently the groundwater movement is from group 1 to group 5. Group 6 will be discussed later on.

S, pH of Equilibrium and Kr of Equilibrium Lines

In this report, as distinct from the preceding two (Charron, 1965a, b), three new lines (S., Ph eq., and Kr eq.) have been added to the semi-logarithmic graphs. These lines give us the solubility product values of $[SO_4][Ca]$ and $[CO_3][Ca]$ that tell us if the saturation point has been reached (Schoeller, 1962).

The S line is placed half way between $_rCa$ and $_rSO_4$. To obtain the solubility product of [SO_4]and [Ca]it is only necessary to join the $_rCa$ and $_rSO_4$ value of the analysis. The point where this line (S_1) cuts the vertical S line gives us the solubility product value of that analysis. Now if the line (S_1) cuts the vertical (S) line below the point of saturation then saturation in $CaSO_4$ has not been reached. On the contrary if the point of intersection is above the saturation point, the water is supersaturated in $CaSO_4$. Knowing that the saturation point of $CaSO_4$ in pure water is 30.8 epm, it is obvious that in the forty-six analyses saturation has never been reached, because the graph showing the highest solubility product is that of sample No. 23 in group 6 and its value is only 15.11 epm (see also Table II).

The pH corresponding to the amount of CO_2 of equilibrium in the water is called the pH of equilibrium (Schoeller, 1962). The intersection point of a line joining $_rCa$ and $_rHCO_3$ with the vertical pH of equilibrium line gives us the pH equilibrium of the analysis. Now if the laboratory pH value of the water is less than the pH equilibrium, the groundwater is not saturated in $CaCO_3$ and can still dissolve carbonate rocks. On the contrary, if it is greater, the water is supersaturated. Some allowance has to be made for temperature and ionic strength. Table II shows that only one sample, No. 3, is not saturated in $CaCO_3$. Nevertheless analysis No. 3 is very near the saturation point.

The Kr of equilibrium represents the amount of $CaCO_3$ in epm that the groundwater can dissolve. It is obtained in the same way as the pH of equilibrium except that the intersection point is with the vertical Kr-equilibrium line. Because in the majority of the analyses the groundwater is saturated in $CaCO_3$, the Kr-equilibrium value takes on a great importance, for in that case it becomes the value of free CO_2 dissolved in the water. Therefore, as seen on the semi-logarithmic diagrams and Table II, the Kr-equilibrium value is always larger than the pH-equilibrium value with the exception of analysis No. 23, group 5. Thus, even though the saturation point in $CaCO_3$ has been reached, the groundwater can still be considered as aggressive. To conclude this discussion on saturation it can be stated that in the Steinbach area the groundwater is nearly always saturated in $CaCO_3$, but never saturated in $CaSO_4$.

The writer has found one more use for these intersecting lines, which give the solubility-product value. These lines are extremely useful to set up the groups. For example the slope of these lines in group 1 is similar and the grouping of the lines is close, thus showing a close similarity between the analyses.

Base Exchange Index

The base exchange index or b.e.i. value of an analysis (Schoeller, 1962) can be calculated as is done in Table II or it can also be seen directly

34	3b	3.26	2.32	0.69	0.08	0.04	6.25	0.71	0.30	0.50	- 7.63	0.36	5.03	4.51	12.64	0.009	0.35	23	+0.04	8.0	4.90	6.8	
27	3b	3.50	3.16	0.71	0.06	0.05	7.23	0.90	0.22	0.83	-10.17	0.42	5.68	5.03	14.71	0.011	0.39	24	+0.02	7.9	5.44	6.7	
38	3b	3.80	3.35	0.62	0.06	0.05	7.80	0.88	0.19	0.83	- 9.33	0.44	6.14	5.44	15.68	0.011	0.39	24	+0.02	8.1	5.85	6.7	393 p.p.m.
28	3b	4.00	3.07	0.63	0.06	0.06	7.62	0.77	0.21	1.00	- 9.50	0.49	6.15	5.62	15.44	0.011	0.39	23	+0.04	8.0	5.95	6.7	Irregular T.D.S. 399 p.p.m.
36	3b	4.53	3.92	0.53	0.04	0.04	8.72	0.87	0.14	1.00	-12.25	0.43	7.01	6.28	17.78	0.013	0.42	24	+0.02	8.0	6.72	6.6	
16	3b	4.60	5.16	2.00	0.32	0.09	11.51	1.12	0.39	0.28	- 5.25	0.64	8.48	7.28	23.68	0.017	0.48	25	0.00	7.6	7.76	6.4	
41	4	2.13	2.03	2.24	0.87	0.19	5.54	0.95	1.10	0.22	- 1.57	0.64	4.03	3.44	13.00	0.009	0.35	25	0.00	7.9	3.79	7.1	
31	4	2.32	2.08	2.35	1.18	0.03	5.12	0.90	1.13	0.03	- 0.99	0.26	3.93	3.45	13.08	0.009	0.35	23	+0.04	8.1	3.84	7.1	
40	4	1.97	2.27	2.37	0.58	0.03	6.25	1.15	1.04	0.05	- 3.09	0.24	4.25	3.51	13.47	0.009	0.35	24	+0.02	7.8	3.88	7.1	
39	4	2.22	2.45	2.84	1.12	0.08	6.58	1.10	1.16	0.07	- 1.54	0.42	4.58	3.82	15.29	0.010	0.37	24	+0.02	8.1	4.21	7.0	
45	4	3.44	3.21	2.57	2.54	1.10	5.69	0.93	0.80	0.43	- 0.01	1.95	4.81	4.42	18.55	0.013	0.42	23	+0.04	7.5	4.88	6.8	Town of Beausejour
20	5a	0.70	1.00	4.33	1.17	0.31	4.71	1.43	4.33	0.26	- 2.70	0.47	2.49	1.82	12.22	0.007	0.31	24	+0.02	7.9	2.15	7.6	
22	5a	0.95	1.28	2.49	0.32	0.35	4.18	1.35	1.95	1.09	- 6.78	0.58	2.55	1.99	9.57	0.006	0.28	24	+0.02	8.0	2.29	7.5	Irregular T.D.S.
2	5a	0.89	1.23	4.35	1.15	0.94	4.62	1.38	3.54	0.82	- 2.78	0.91	2.67	2.03	13.18	0.008	0.33	25	0.00	8.2	2.36	7.5	
26	5a	0.78	0.97	6.26	1.85	1.04	5.35	1.24	6.45	0.56	- 2.38	0.90	2.82	2.04	16.25	0.010	0.37	24	+0.02	8.1	2.43	7.5	
24	5b	0.23	0.56	9.57	2.62	2.24	5.39	2.43	17.09	0.85	- 2.65	0.72	1.88	1.11	20.61	0.012	0.40	24	+0.02	8.1	1.53	7.9	
3	5c	0.08	0.57	13.75	6.62	3.41	5.15	7.13	24.12	0.52	- 1.08	0.52	1.28	0.64	29.58	0.017	0.48	25	0.00	7.8	1.12	8.1	Not saturated in $CaCO_3$
15	6	2.34	2.36	0.50	0.03	0.41	4.80	1.01	0.21	13.66	-15.67	0.98	3.78	3.35	10.44	0.008	0.33	25	0.00	8.0	3.68	7.1	
17	6	2.20	2.71	0.72	0.03	0.73	5.03	1.23	0.27	24.33	-23.00	1.27	3.82	3.33	11.42	0.008	0.33	24	+0.02	8.0	3.68	7.1	
4	6	2.79	2.90	0.37	0.01	0.22	5.83	1.04	0.13	22.00	-36.00	0.78	4.56	4.03	12.12	0.009	0.35	25	0.00	7.9	4.38	7.0	
25	6	3.03	8.44	1.07	0.06	3.15	9.53	2.79	0.13	52.50	-16.83	3.09	6.50	5.37	25.28	0.020	0.52	23	+0.04	7.9	5.93	6.7	
23	6	10.68	11.80	4.26	0.96	21.38	4.62	1.10	0.36	22.27	- 3.44	15.11	6.11	7.02	53.70	0.049	0.80	24	+0.02	8.0	7.84	6.5	Winnipeg River Basin

TABLE II - CHEMICAL ANALYSES OF GROUNDWATERS IN THE STEINBACH AREA, MANITOBA

Sample No.	Group	Chemical constituents and solubility products in E.P.M. (equivalents per million) and ratios														Ionic Strength μ	$3.618\sqrt{\mu}$ ΔpH.	Temp. @ Testing (°C)	Correction for Temperature Θ	pH	Θ + ΔpH + pH eq (pH eq Corrected)	pH eq Corrected from Scale	REMARKS
		Calcium ($_rCa$)	Magnesium ($_rMg$)	Sodium ($_rNa$)	Chloride ($_rCl$)	Sulphate ($_rSO_4$)	Bicarbonate ($_rHCO_3$)	$_rMg/_rCa$	$_rNa/_rMg$	$_rSO_4/_rCl$	$\frac{_rCl - _rNa}{_rCl}$ (b.e.i.)	$\sqrt{(_rCa)(_rSO_4)}$ S.	$\sqrt[3]{(_rHCO_3)^2(_rCa)}$ Kr. eq.	$\sqrt{(_rCa)(_rHCO_3)}$ pH. eq.	Total Dissolved Solids T.D.S.								
11	1	2.23	1.34	0.15	0.01	0.19	3.54	0.60	0.11	19.00	-14.00	0.65	3.03	2.81	7.46	0.006	0.28	24	+0.02	8.0	3.11	7.2	
7	1	2.23	1.50	0.36	0.02	0.07	4.03	0.67	0.24	3.50	-17.00	0.40	3.31	3.00	8.21	0.006	0.28	25	0.00	7.9	3.28	7.2	
12	1	2.26	1.53	0.28	0.01	0.16	3.97	0.68	0.18	16.00	-27.00	0.60	3.29	2.99	8.21	0.006	0.28	24	+0.02	8.0	3.29	7.2	
8	1	2.50	1.54	0.23	0.01	0.12	4.16	0.62	0.15	12.00	-22.00	0.55	3.44	3.22	8.56	0.006	0.28	24	+0.02	7.9	3.52	7.1	
9	1	2.52	2.01	0.18	0.01	0.05	4.62	0.80	0.09	5.00	-17.00	0.35	3.77	3.41	9.39	0.007	0.31	24	+0.02	7.8	3.74	7.1	
6	1	3.45	1.85	0.20	0.01	0.09	5.43	0.54	0.11	9.00	-19.00	0.56	4.67	4.33	11.03	0.008	0.33	25	0.00	8.1	4.66	6.9	
10	1	3.17	2.52	0.46	0.02	0.06	6.15	0.79	0.18	3.00	-22.00	0.44	4.93	4.35	12.38	0.009	0.35	24	+0.02	8.0	4.72	6.9	
13	2	0.60	2.48	0.65	0.03	0.11	3.67	4.13	0.26	3.66	-20.67	0.25	2.01	1.48	7.54	0.005	0.26	24	+0.02	7.8	1.76	7.7	200 p.p.m.
14	2	1.36	1.29	1.04	0.04	0.07	3.70	0.95	0.81	1.75	-25.00	0.31	2.65	2.24	7.50	0.005	0.26	24	+0.02	7.8	2.52	7.4	Irregular T.D.S. 209 p.p.m.
21	2	2.09	2.79	0.43	0.05	0.17	5.05	1.33	0.15	3.40	- 7.60	0.60	3.76	3.25	10.58	0.008	0.33	24	+0.02	7.9	3.60	7.1	
18	2	2.28	3.04	0.15	0.03	0.29	5.26	1.33	0.05	9.66	- 4.00	0.81	3.98	3.46	11.05	0.008	0.33	25	0.00	7.8	3.79	7.1	
19	2	2.42	3.43	0.23	0.13	0.35	5.67	1.42	0.07	2.69	- 0.77	0.92	4.27	3.70	12.23	0.009	0.35	24	+0.02	8.0	4.07	7.0	
29	2	2.32	3.12	0.70	0.05	0.07	6.21	1.34	0.22	1.40	-13.00	0.40	4.47	3.80	12.47	0.009	0.35	23	+0.04	8.1	4.19	7.0	
1	2	2.86	3.18	0.41	0.05	0.22	6.24	1.11	0.13	4.40	- 7.20	0.79	4.81	4.22	12.96	0.010	0.37	25	0.00	7.8	4.59	6.9	Winnipeg River Basin
30	2	2.82	4.38	0.95	0.03	0.04	8.08	1.55	0.22	1.33	-30.67	0.34	5.69	4.77	16.30	0.012	0.40	23	+0.04	8.1	5.21	6.8	
33	3a	1.90	1.32	0.62	0.16	0.04	3.71	0.69	0.47	0.25	- 2.88	0.28	2.97	2.66	7.75	0.006	0.28	23	+0.04	7.7	2.98	7.3	
35	3a	1.97	1.96	0.62	0.11	0.04	4.52	0.99	0.32	0.36	- 4.64	0.28	3.43	2.98	9.22	0.007	0.31	25	0.00	8.0	3.29	7.2	
43	3a	1.90	2.42	0.85	0.22	0.13	4.96	1.27	0.35	0.59	- 2.96	0.50	3.60	3.07	10.48	0.007	0.31	24	+0.02	8.0	3.40	7.2	
42	3a	1.88	1.66	1.71	0.21	0.06	5.38	0.88	1.03	0.29	- 7.14	0.34	3.79	3.18	10.90	0.007	0.31	25	0.00	8.1	3.49	7.2	
5	3a	1.96	2.00	1.57	0.12	0.04	5.43	1.02	0.79	0.33	-12.08	0.28	3.87	3.26	11.12	0.007	0.31	24	+0.02	7.5	3.59	7.1	
44	3a	2.47	2.53	1.04	0.28	0.03	5.83	1.02	0.41	0.11	- 2.71	0.27	4.38	3.79	12.18	0.009	0.35	24	+0.02	8.0	4.16	7.0	
46	3a	2.54	2.41	1.61	0.36	0.07	5.77	0.95	0.46	0.19	- 2.08	0.42	4.39	3.83	12.26	0.009	0.35	-	-	7.8	4.18	7.0	Town of Steinbach
32	3a	2.47	2.19	1.74	0.39	0.04	6.10	0.89	0.79	0.10	- 3.46	0.31	4.51	3.88	12.93	0.009	0.35	23	+0.04	8.2	4.27	7.0	
37	3a	3.06	2.94	0.67	0.07	0.02	6.53	0.96	0.23	0.29	- 8.57	0.25	5.07	4.47	13.29	0.010	0.37	24	+0.02	8.2	4.86	6.8	

on the semi-logarithmic graphs. It is given by the slope of the line joining $_rNa$ and $_rCl$. The b.e.i. is negative when the $_rNa$ value is greater than the $_rCl$ value and positive when the opposite is true. At recharge the b.e.i. value should be negative and this is true for all forty-six analyses in the Steinbach area. Moreover the closer the groundwater is to the recharge area the more negative is the b.e.i. value, as shown by group 1.

Discussion of Table II

Table II is simply the mathematical equivalent of the semi-logarithmic diagrams of the forty-six analyses. The values are in equivalents per million (epm) as compared to parts per million in Table I. In Table II the analyses have been grouped as was done for the semi-logarithmic graphs, with but a few exceptions. Consequently, analyses at the top of the table are closer to the recharge area than the analyses at the bottom of the table. The absolute values are given for the six radicals used to build up the diagrams. The relative values are given for three ratios. Also included is the b.e.i., solubility products, and the total dissolved solids (T.D.S.) value, which in this case is the sum of the six radicals that make up the semi-logarithmic graph pattern. The remainder of the table shows the correction factors for ionic strength and temperature, which have to be added to the pH of equilibrium of the water, so that it can be compared with the real pH of the water, to indicate if the water is saturated in $CaCO_3$ or not. The actual place of each analysis within a group is based on two values: the T.D.S. value and the value of the pH of equilibrium corrected. In Table II the T.D.S. and pH-equivalents-corrected value increase within each group with one exception, i.e. the T.D.S. value of sample No. 22 in group 5.

As groups 5 and 6 contain some analyses with irregularities they are discussed below.

Group 5

This group as shown on Figure 9 consists of six analyses. Nevertheless only three of these analyses, Nos. 2, 20, and 26, are compatible as seen on Table II. Analysis No. 22 has been placed here even though its T.D.S. value does not follow the trend shown on Table II, because its pattern on semi-log paper followed the general pattern of this group better than that of any other group.

Sample Nos. 3 and 24 also fit the general pattern of group 5 and so were included in this group, although in reality they do not belong in this group at all as is shown on Table II. Analysis No. 3 is definitely a groundwater obtained from the sandstone of the Winnipeg Formation, as indicated by the very low $_rCa$ and $_rMg$ values. The groundwater represented by sample No. 24 was not obtained from the sandstone of the Winnipeg Formation, but it would seem to have been influenced by it due to mixing with groundwater from the sandstone aquifer. Therefore the graphs of these two analyses should have figures of their own just as they have been separated in Table II. Nevertheless their inclusion with group 5 does not alter the value of Figure 10, because of the similarity of the patterns.

Group 6

First it should be stated that analyses Nos. 23 and 25, although appearing with group 6 on Figure 11, do not belong in this group at all. The remaining three analyses Nos. 4, 15, and 17 would in a way fit the picture if as a group they were placed in a group ahead of what is now called group 1. If this was done it would have to be assumed that recharge in the three cases would be local. This is probably true for the case of analyses Nos. 4 and 17 as is shown on Figure 3. If recharge is not local then one would have to assume that the groundwater is either mixed with surface water or with some water from an unconfined aquifer.

The water of analysis No. 25 was obtained very close to the bedrock, which is a dolomitic limestone. This may account for the fact that the water has a high magnesium content if compared to the calcium value. The higher sulphate value of 151 ppm (9.53 epm) is not uncommon with groundwaters associated with the clays of former Lake Agassiz and as sample No. 25 is near the clay contact it may be affected by it. Analysis No. 23 has already been discussed in detail but this much should be added. Assuming that gypsum dissolution is impossible in the region where sample No. 23 is located, because gypsum layers or beds do not exist, then the only solution to explain the relatively high sulphate content of this water is the oxidation of sulphides. As stated before, this region should be one to illustrate the sulphate reduction phenomenon, and therefore the relatively high sulphate value comes as a surprise. There is a large bog to the east (Bannatyne, 1964), which could be the source for the required micro-organisms. Therefore the lack of the sulphate reduction phenomenon in this region may be regarded as proof that penetration from the surface downward is at a minimum if any exists at all.

Zonation

The forty-six analyses can be further subdivided according to the predominant chemical ion or ions. This is called zonation. The zonation is here discussed in a horizontal sense and is used to illustrate groundwater movement according to the Chebotarev sequence - $HCO_3^- \rightarrow HCO_3^- + Cl^- \rightarrow Cl^- + HCO_3^- \rightarrow Cl^- + SO_4^{=}$ or $SO_4^{=} + Cl^- \rightarrow Cl^-$ (Chebotarev, 1955). This sequence follows the well known fact that the chemical composition of a groundwater will change as it moves slowly through an aquifer or aquifers. Figure 12

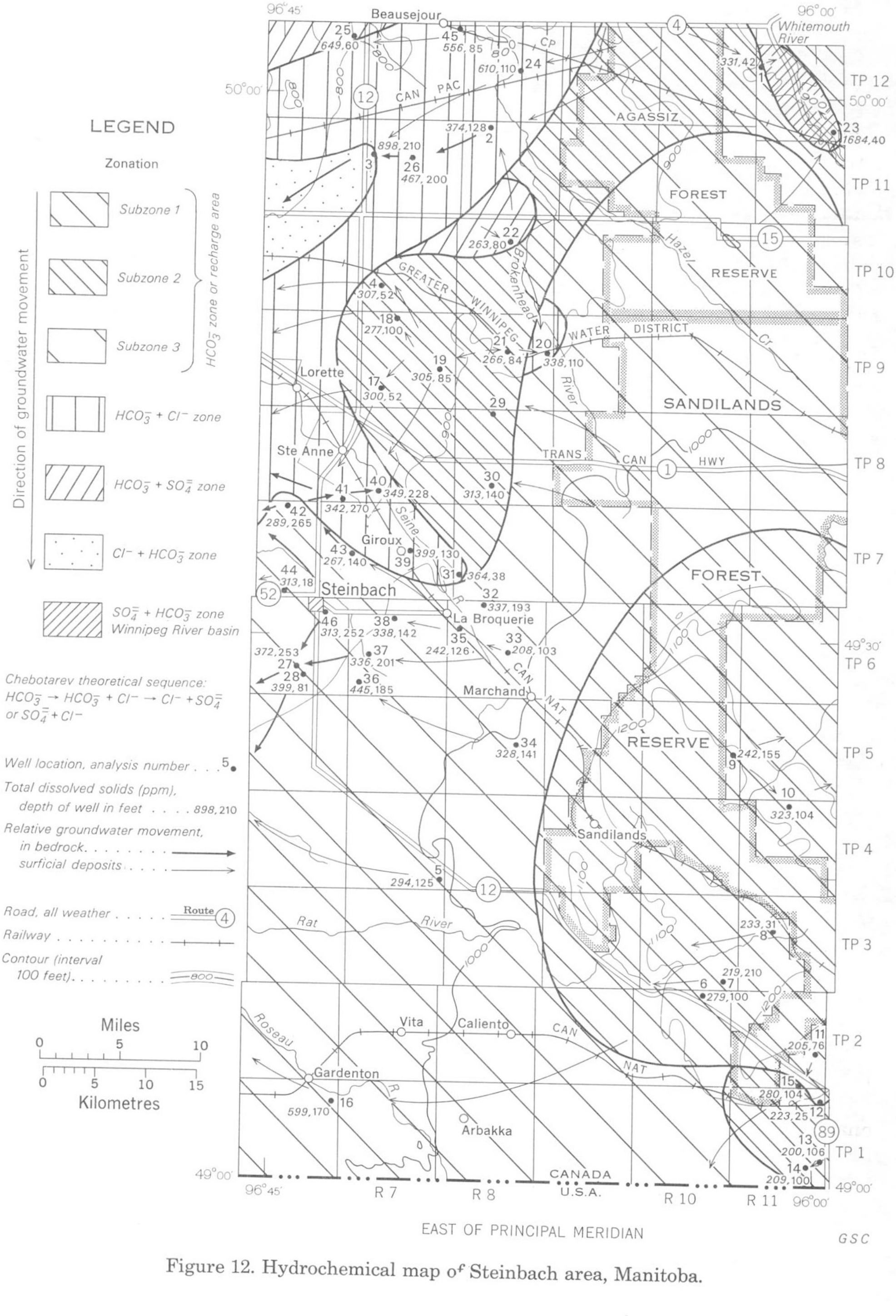


Figure 12. Hydrochemical map of Steinbach area, Manitoba.

shows the various chemical zones in the Steinbach area. It is obvious that a complete sequence such as given by Chebotarev is impossible, because we are dealing here mainly with a recharge area. Three subdivisions of the bicarbonate zone are shown on Figure 12. The first bicarbonate sub-zone is at the main recharge area, which is Sandilands Forest Reserve, and is based on the analyses of group 1. The second bicarbonate sub-zone is at the base of the recharge area. In one instance the recharge area is again the highland of Sandilands Forest Reserve (analyses Nos. 13, 14, 15), and in the other instance the recharge area could be partly local as in the case of analyses Nos. 1, 4, and 17. The main difference between the first and second bicarbonate sub-zone is in the different $_rMg/_rCa$ ratio. It is <1 in the first zone and >1 in the second. The third bicarbonate sub-zone is simply a continuation of the first bicarbonate sub-zone, but farther downstream from the recharge area. It is based on the analyses in groups 3a and 3b. The main difference between the third sub-zone and the first two is the $_rSO_4/_rCl$ ratio, which is <1 in the third. By the time the groundwater has gone through the bicarbonate zone it changes its composition and becomes an $HCO_3^- + Cl^-$ type of water. This zone as shown on Figure 9 is based on the analyses in group 4 and most of the analyses of group 5. The cut-off point between the HCO_3^- zone and the $HCO_3^- + Cl^-$ zone is when the $_rCl$ value exceeds 1 epm or the $_rNa$ value exceeds 2 epm or that both values are exceeded at the same time.

The other zones shown in Figure 12 are not so well illustrated because they are patchy and therefore tend to reflect local influences.

On Figure 12 the location is shown where each of the forty-six groundwater samples was collected. At each location point the number of the sample is marked as well as the T.D.S. in parts per million and the depth of the well. Using the criterion that the T.D.S. value of a groundwater increases as it moves through an aquifer, small arrows are introduced between the location points. The direction is in every case from a low T.D.S. value to a higher value, taking into consideration the depth of the aquifer. The groundwater movement illustrated in this manner is called by the author, relative groundwater movement. It is relative between the locations of two groundwater samples. It is not to be taken as the true direction of groundwater at that point. Nevertheless the relative groundwater movement as shown by the small arrows agrees with the general groundwater movement as shown by the chemical zones and it is also in agreement with the groundwater movement as illustrated on Figure 2, which is derived from the topography and a recharge-discharge relationship.

To conclude, this hydrochemical interpretation has confirmed that the Steinbach area is basically an area of recharge, as shown by the bicarbonate groundwater. Even though the groundwater was predominantly bicarbonate this interpretation using the semi-logarithmic graphs has helped to scrutinize more deeply the forty-six representative analyses and to some degree it has also demonstrated a groundwater movement in an east to west direction.

SUMMARY

This report has brought out three facts. (1) It confirms what was already known, that in terms of quantity the flowing artesian zones around the towns of Steinbach and Piney have the largest amount of groundwater to offer. (2) It proves on the basis of hydrochemistry that the Steinbach area is a recharge area with the groundwater movement being in a westward direction. (3) Finally, it establishes that a flowing artesian zone does not decrease in extent regularly with the lowering of the piezometric surface, as was formerly believed, but that it "undermines" itself a little at a time.

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