DEPARTMENT OF THE INTERIOR
UNITED STATES GEOLOGICAL SURVEY

PREPARED IN COOPERATION WITH
RHODE ISLAND WATER RESOURCES BOARD

WATER RESOURCES INVESTIGATIONS 4-74
(SHEET 2 OF 2)

QUALITY OF WATER

GENERAL ASPECTS

The quality of ground water and surface water are of concern to the ground-water user in the Blackstone River area, because water pumped from most wells is derived partly from aquifer storage and partly from infiltration induced from streams.

The chemical quality of surface water and ground water, with the exception of high concentrations of manganese that develop in water from many gravel-packed wells after they are put into production, is good. Both ground water and surface water are generally soft to moderately hard, slightly acidic, and have a low to moderate dissolved-solids content.

The biological and physical quality of much of the streamflow is very poor. Many reaches of principal rivers are extensively polluted by municipal sewage and industrial waste discharges. During periods of low to moderate flow, water in these reaches is characterized by offensive taste and odor, high turbidity, high concentrations of suspended organic matter and bacteria, and low dissolved-oxygen content. The biological and physical quality of ground water, on the other hand, is generally excellent.

Of particular significance to the ground-water user is the fact that pollutants associated with the organic wastes in streamflow are largely or entirely removed or markedly altered during passage of water through streambed and aquifer materials. The aquifer functions as a highly effective treatment facility, which renovates the quality of induced streamflow to the extent that highly polluted waters are rendered suitable for use in public supply systems with minimal treatment. Infiltration induced into the aquifer from organically polluted streams, however, may be responsible for the occurrence of troublesome concentrations of manganese in water pumped from some wells.

The chemical quality of ground water is known from 122 analyses of water from 76 wells that tap the stratified-drift aquifers; that of surface water from 28 analyses of water from 15 stream sites. The analyses, which were made chiefly by the U.S. Geological Survey and the Rhode Island Department of Health, are contained in a companion basic-data report (Johnston and Dickerman, in press). Many additional analyses, made chiefly by the Rhode Island Department of Health, for iron and manganese in water from public supply wells are contained in an unpublished report prepared by the Rhode Island Water Resources Board (Sreekantham, written comm., 1969).

Information on biological quality of surface water is contained in reports by the Rhode Island Department of Health (1967) and by Mackenthun and others (1965). Information on biological quality of ground water was obtained chiefly by oral communication with John C. Clifford of the Rhode Island Department of Health.

The general chemical character of fresh ground water and surface water is indicated by representative analyses shown in figure 1, and by a summary of chemical data given in table 1.

SURFACE WATER QUALITY

The overall chemical, physical, and biological quality of streamflow is indicated by water-use classifications assigned to stream reaches (fig. 1) by the Rhode Island Department of Health (1967) in conformance with the Federal Water Pollution Control Act (public law 84-660, as amended). The classifications from A to E reflect increasing concentrations of organic and inorganic wastes present in the streamflow. Wastes and their byproducts in those stream reaches bearing classifications C, D, and E are derived chiefly from raw and partly treated municipal sewage and from textile mill discharges. Substantial quantities of industrial chemical process and metal plating wastes are also discharged to the Tenmile River in Massachusetts.

Despite the large volumes of wastes discharged to streams in the study area, streamflow is not highly mineralized. Data in table 1 show that, with the exception of iron and manganese, concentrations of individual mineral constituents are generally well below limits considered acceptable in drinking water by the U.S. Public Health Service (1962). There are, of course, many other constituents, such as heavy metals and pesticides, for which limits have been established but for which few analyses have been made.

Chemical quality of virtually all streams in the study area has been degraded to some extent. However, analyses of samples from Abbott Run and its tributaries (sites 1-3, fig. 1) probably come closest to representing the natural chemical quality of streamflow. Concentrations of the same mineral constituents in samples from other streams (sites 4-10, fig. 1) are substantially higher. The analyses of surface water shown in figure 1 are of samples taken during a period of low flow. Consequently, dissolved mineral constituents were almost at maximum concentrations. During periods of high flow, concentrations normally are lower.

The quality of water in streams varies from time to time and from place to place. Marked differences in quality are related chiefly to the location, type, volume, and timing of waste discharges to streams and to the volume of streamflow available for waste dilution. Time variations of specific conductance, pH, dissolved-oxygen content, and temperature of the Blackstone River at Millville, Mass., and the discharge of the river 6 miles downstream at Woonsocket, R.I., are shown in figure 2.

The graph of pH shows that the river water was slightly acidic, a condition typical of most New England streams. Abrupt fluctuations in pH may, in part, be related to changes in the type and concentration of waste being transported by the river.

The daily and seasonal variations in river temperature are controlled chiefly by air temperature. The large seasonal fluctuations are typical of variations in larger streams.

The graph of dissolved-oxygen content illustrates chiefly the variation in response to daily and seasonal fluctuations in water temperature. Also evident, during summer and fall, are the effects of oxygen-consuming decomposition of wastes. Declines in dissolved oxygen below a level of 5 mg/l are caused by oxygen-consuming wastes.

The graph of specific conductance provides an indication of the variation in dissolved-solids content of the river water. The range in specific conductance from 140 to 520 micromhos per centimeter indicates an approximate range in dissolved-solids content of 75 to 285 mg/l. Values of more than 150 micromhos per centimeter (about 80 mg/l) are attributable largely to waste discharge. The generally higher specific conductance of the water during periods of low river discharge results because of the smaller volume of water available to dilute a relatively constant volume of wastes.

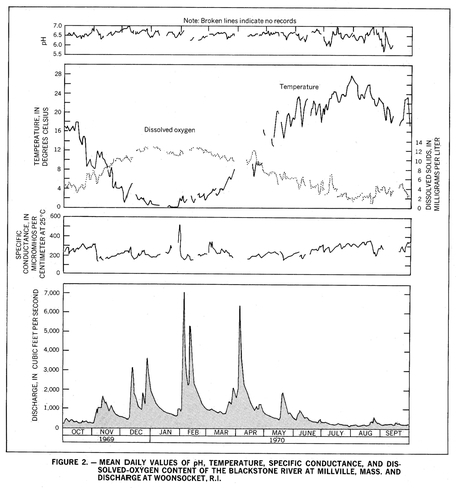


FIGURE 2. — MEAN DAILY VALUES OF pH, TEMPERATURE, SPECIFIC CONDUCTANCE, AND DISSOLVED-OXYGEN CONTENT OF THE BLACKSTONE RIVER AT MILLVILLE, MASS. AND DISCHARGE AT WOONSOCKET, R.I.

Sheet 2, of 2, Figure 2
Delete word solids from right margin.
Add word oxygen.

GROUND WATER QUALITY

Small concentrations of most of the principal mineral constituents commonly present in solution in ground water are derived from the atmosphere through which precipitation recharge has passed. The bulk of the dissolved matter, however, is generally derived from soil and aquifer materials with which the water has been in contact. Within the study area, minerals constituting soils and subsurface materials are only slightly soluble. As a result, the dissolved-solids content of ground water is relatively low. The dissolved-solids content of water in the stratified-drift aquifer is generally less than 150 mg/l. Data in table 1 show that, with the exception of iron and manganese, concentrations of individual mineral constituents commonly analysed are well below limits considered acceptable in drinking water by the U.S. Public Health Service. It should be noted, however, that few data are available for some constituents that are generally not present in natural ground water and that are looked for only when contamination is suspected.

The chemical quality of ground water has been affected by wastes in much of the study area, although not necessarily adversely. The principal effect has been a small to moderate increase in hardness and in the concentration of chloride, sulfate, and nitrate. Sources of the increase include septic-tank and cesspool effluent, fertilizers, salts used to delce highways, leachate from sanitary landfills and dumps, liquid chemicals spilled on the ground, and infiltration induced from chemically degraded streams. Infiltration from streams is the principal source of chemically degraded water pumped from wells.

TABLE 1. — SUMMARY OF CHEMICAL CHARACTERISTICS OF WATER FROM THE STRATIFIED-DRIFT AQUIFER AND STREAMS. [1]

(Concentrations in milligrams per liter, except color, pH, and specific conductance)

Constituent or property	Ground water [2]			Surface water [2]			Limit recommended for drinking water by the U.S. Public Health Service (1962)
	Wells sampled	Range	Median	Sites sampled	Range	Median	
Silica (SiO_2)	15	2 — 17	11	15	0.1 — 30	7.3	— —
iron (Fe)	60	.00 — 22	.10	15	.03 — 1.5	.33	0.3
Manganese (Mn)	51	.00 — 6.4	.30	11	.00 — .64	.19	.05
Calcium (Ca)	31	8.6 — 52	17	15	5.4 — 30	15	— —
Magnesium (Mg)	31	1.0 — 24	4.4	15	1.1 — 8.5	2.6	— —
Sodium (Na)	25	5.6 — 31	18	15	5.1 — 71	28	— —
Potassium (K)	25	.5 — 4.2	1.4	15	.6 — 7.2	3.6	— —
Bicarbonate (HCO_3)	17	6 — 138	30	15	0 — 88	14	— —
Sulfate (SO_4)	30	6.2 — 109	19	15	7.4 — 193	32	250
Chloride (Cl)	62	4.0 — 57	22	15	7.8 — 72	24	250
Fluoride (F)	31	.0 — .5	.1	12	.1 — 9.0	.2	1.3 [3]
Nitrate (NO_3)	47	.0 — 41	3.1	15	.0 — 18	1.8	45
Dissolved solids (Residue on evaporation)	35	60 — 319	140	15	47 — 644	145	500
Specific conductance (Micromhos at 25°C)	11	85 — 464	212	12	81 — 476	291	— —
Calcium-magnesium hardness (as $CaCO_3$)	62	26 — 210	68	15	18 — 102	48	— —
pH	52	5.6 — 7.6	6.2	15	2.6 — 7.0	6.6	— —
Color	39	0 — 15	5	15	3 — 45	10	15

1 Based on data contained in companion report by Johnston and Dickerman (In press).

2 Most recent analysis used if more than one available.

3 Upper limit where annual average maximum daily air temperature is 14.6 to 17.7°C (Average is 15.5°C at Providence, Rhode Island).

GLOSSARY

DISSOLVED OXYGEN: The solubility of oxygen in water is mainly a function of temperature and pressure. At the normal atmospheric partial pressure of oxygen, the solubility at 50°F (10°C) is 11.33 mg/l (milligrams per liter) and at 86°F (30°C) is 7.63 mg/l (Hem, 1970, p. 221). Consumption of oxygen by organic and inorganic contaminants in water may cause dissolved oxygen to be depleted below natural levels.

Eh: A symbol denoting oxidation-reduction potential, which is a measure of the relative intensity of oxidizing or reducing conditions. Oxidizing systems are assigned positive potentials, and reducing systems are assigned negative potentials.

HARDNESS: A physical-chemical characteristic of water attributable to the presence of alkaline earths (principally calcium and magnesium) and expressed as equivalent calcium carbonate ($CaCO_3$). The following classification is used by the U.S. Geological Survey: soft, 0-60 mg/l; moderately hard, 61-120 mg/l; hard, 121-180 mg/l; very hard, more than 180 mg/l.

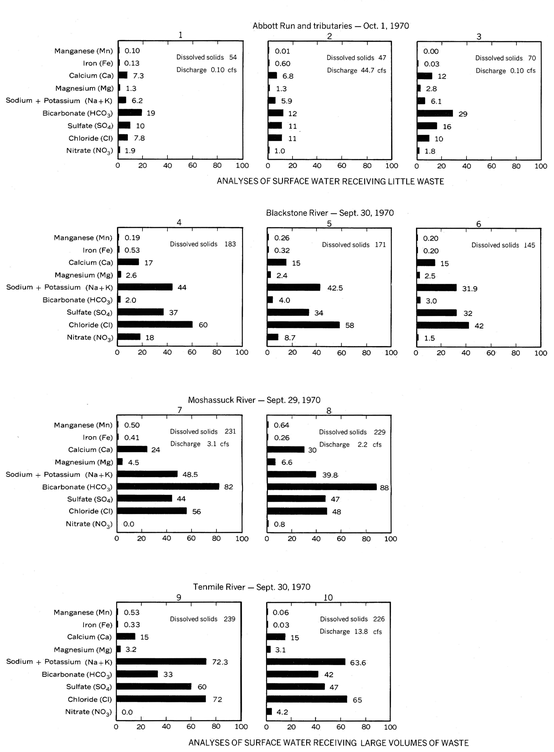
OXIDATIONS AND REDUCTIONS: Chemical reactions where a participating element changes valence number, losing or gaining orbital electrons. In oxidation an element loses electrons, and in reductions it gains them.

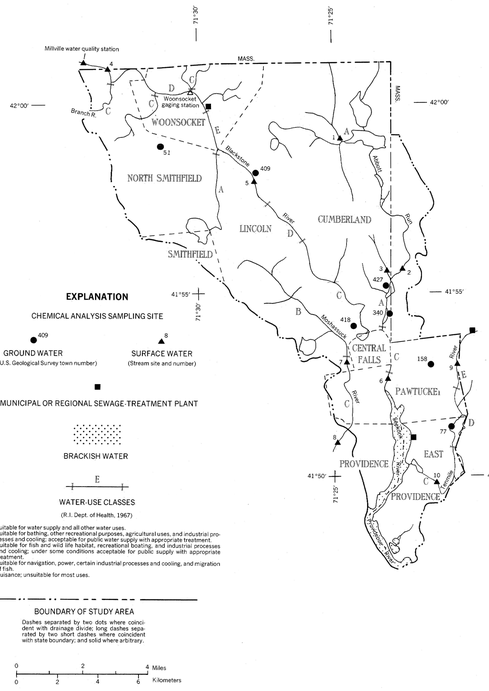
pH: A symbol denoting the relative concentration of hydrogen ions in a solution; pH values range from 0 to 14--the lower the value, the more acid the solution; i.e., the more hydrogen ions it contains. A value of 7.0 is the neutral point; values greater than 7.0 indicate an alkaline condition; values less than 7.0 indicate an acid condition.

SPECIFIC CONDUCTANCE: A measure of the ability of a water to conduct an electric current, expressed in micromhos per centimeter at 25°C. It is related to the concentration of ions in solution and may be used for approximating the dissolved-solids content of water. Multiplying the specific conductance of waters in the study area by a factor of 0.55 gives an approximate measure of dissolved solids, in milligrams per liter.

REPRESENTATIVE CHEMICAL ANALYSES OF SURFACE WATER

(Concentrations, in milligrams per liter)





REPRESENTATIVE CHEMICAL ANALYSES OF GROUND WATER

(Concentrations, in milligrams per liter)

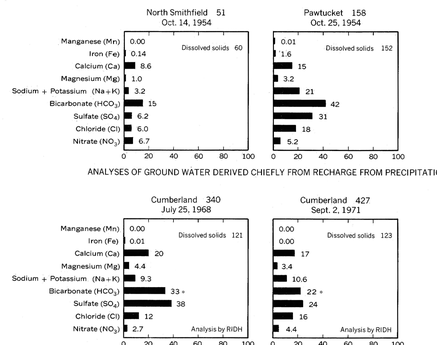


FIGURE 1. — CHEMICAL ANALYSES OF SURFACE WATER AND GROUND WATER IN THE BLACKSTONE RIVER AREA.

EFFECT OF INDUCED INFILTRATION ON GROUND WATER QUALITY

CHEMICAL QUALITY

The chemical quality of water pumped from a well that derives part of its water from induced stream infiltration is intermediate between that of the streamflow and the native ground water. A few chemical constituents dissolved in streamflow may be altered, or removed from solution by ion exchange, precipitation, adsorption, and other processes, as water moves through aquifer materials to well intakes. Many, however, undergo little modification other than a change in concentration, which results from mixing of infiltrated water with native ground water.

Degradation of the chemical quality of surface water can, therefore, result in degradation of ground-water quality. Figure 3 illustrates the increase in dissolved-solids content in water from an East Providence municipal supply well as a consequence of an increase in the dissolved-solids content of the Tenmile River. The similarity in the pattern of fluctuations and dissolved-solids content of well water and river water indicates that most of the well water consists of infiltration induced from the river.

Salt contamination of ground water resulting from infiltration of brackish water from the Seekonk and Providence Rivers is not known and is not likely to be a problem with the present regimen and pattern of ground-water withdrawals. Nevertheless, the potential for such contamination exists. Moderate withdrawals from wells in the stratified-drift or bedrock aquifers close to these rivers, or large withdrawals from wells in the stratified-drift aquifer farther inland, can cause landward movement of saline water and eventual contamination of well supplies. Salt-water encroachment can be monitored by periodic sampling of water from observation wells placed near the sources of salt water and can be controlled by regulating total ground-water withdrawal from affected aquifers.

PHYSICAL QUALITY

The physical quality of streamflow, with the exception of wide temperature fluctuations, has relatively little impact on the physical quality of water pumped from wells that induce infiltration from streams. Tastes, odors, suspended sediment and organic matter, and turbidity associated with polluted streamflow in the study area are removed from infiltrated water after its passage through a few tens of feet of streambed and aquifer materials. Color present in streamflow, although not entirely removed, is generally reduced.

The temperature of water from a frequently or continuously pumped well that induces part of its supply from a nearby stream follows a cycle governed by the seasonal fluctuations of the stream-water temperature. An example of this cyclic response is illustrated in figure 5. Note that the temperature range of the ground water pumped is less than that of the river water and that the temperature cycle of the pumped water is out of phase with that of the river water. The narrower temperature range and the time lag of high and low temperatures of ground water behind those of the river water are related to the time it takes the infiltrated water to move through the aquifer to the well intake and to the fact that part of the pumpage is native ground water and has a relatively constant temperature.

Water infiltrates an aquifer at different points upstream and downstream from a pumping well, follow paths of different lengths, and moves along these paths at different rates. Accordingly, induced infiltration entering a well consists of water that entered the aquifer at different times at different temperatures. The distribution of water of different temperatures in the vicinity of a pumping well is shown in figure 6.

BIOLOGICAL QUALITY

Bacteria, algae, and other organisms also are largely or entirely removed from infiltrated streamflow by the time it has moved a few tens of feet through the stratified-drift aquifer (fig. 4). Several municipal supply wells, which induce infiltration from the bacteriologically polluted Blackstone and Tennile Rivers, are reported to yield water that is, with very few exceptions, entirely free of bacteria (John C. Clifford, Rhode Island Dept. of Health, oral commun., April 1970). It is suspected, however, that the infiltration of water from streams containing high concentrations of bacteria and other organic pollutants is related to the occurrence of high concentrations of manganese in some wells. This relationship is discussed under the heading of iron and manganese.

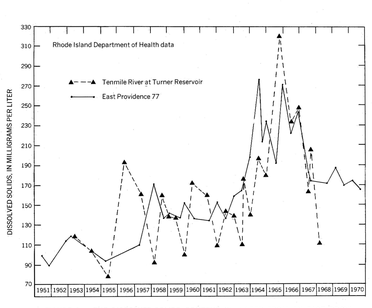


FIGURE 3. — THE DISSOLVED-SOLIDS CONTENT OF WATER FROM AN EAST PROVIDENCE MUNICIPAL SUPPLY WELL FLUCTUATES IN RESPONSE TO CHANGES IN DISSOLVED-SOLIDS CONTENT OF THE TEN MILE RIVER FROM WHICH INFILTRATION IS INDUCED.

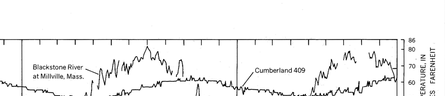


FIGURE 5.— INFILTRATION INDUCED FROM THE BLACKSTONE RIVER CAUSES THE TEMPERATURE OF WATER PUMPED FROM A CUMBERLAND MUNICIPAL SUPPLY WELL TO FLUCTUATE SEASONALLY.

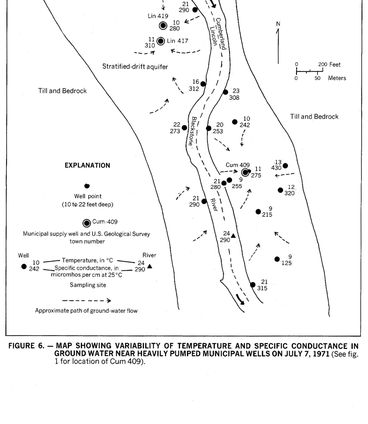


FIGURE 6. — MAP SHOWING VARIABILITY OF TEMPERATURE AND SPECIFIC CONDUCTANCE IN GROUND WATER NEAR HEAVILY PUMPED MUNICIPAL WELLS ON JULY 7, 1971 (See fig. 1 for location of Cum 409).

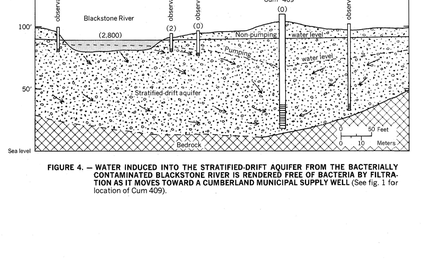


FIGURE 4. — WATER INDUCED INTO THE STRATIFIED-DRIFT AQUIFER FROM THE BACTERIALLY CONTAMINATED BLACKSTONE RIVER IS RENDERED FREE OF BACTERIA BY FILTRATION AS IT MOVES TOWARD A CUMBERLAND MUNICIPAL SUPPLY WELL (See fig. 1 for location of Cum 409).

IRON AND MANGANESE

GENERAL ASPECTS

Troublesome concentrations of manganese and, in some places, iron in water pumped from many wells that tap stratified drift constitute the principal ground-water quality problem in the Blackstone River area. Their presence in water poses no threat to human health, but concentrations smaller than 1 mg/l can cause incrustation of well screens, turbidity, objectionable taste, and staining of plumbing fixtures, laundry, and swimming pools. Accordingly, only concentrations much less than 1 mg/l of iron and manganese are acceptable in public water supplies (table 1) and in some industrial supplies. Although they can be removed from water by several methods of treatment, attempts to remove excessive manganese from water from a few public-supply wells in the study area have proved so costly and difficult that pumping from them has been discontinued.

Generally, neither manganese nor iron are present in amounts greater than 0.3 and 0.05 mg/l, respectively, in water pumped from newly constructed wells in the study area. Manganese and, less commonly, iron increase gradually, and typically reach troublesome concentrations only in some wells after several months or years of pumping (fig. 7).

SOURCES OF IRON AND MANGANESE

Iron and manganese are common constituents of most rocks and soils, although iron is generally much more abundant than manganese. Within the study area, iron-bearing minerals are common in the bedrock. Manganese is a primary constituent in several uncommon oxide and silicate minerals that occur locally in the bedrock (Quinn and others, 1948, p. 21) and may occur as a minor constituent in some of the common iron-bearing minerals. Because much of the glacial drift is derived from local bedrock, iron- and manganese-bearing minerals may be assumed to be present in the stratified-drift aquifer.

Iron and manganese play an important role in both animal and plant metabolism, so that animal wastes and decaying vegetation in soils and swamps are also potential sources.

Water infiltrated from streams that contain iron and manganese in solution may be a source of these constituents in some well water. However, the concentration of iron in stream water is commonly higher than that in water from nearby wells, and, conversely, the concentration of manganese in stream water is commonly lower than that in well water.

Whether or not streamflow is a source, the streambed and aquifer materials undoubtedly contain more than enough iron and manganese in soluble form to account for the concentrations observed in well water.

SOLUBILITY OF IRON AND MANGANESE

The solubility of iron and manganese in water is controlled by hydrogen-ion concentration (pH), oxidation-reduction potential (Eh), temperature, pressure, and other factors (Hem, 1970). A change in one or more of these factors may cause an increase or decrease in the amount of dissolved iron and manganese in water.

Under natural conditions, a state of chemical equilibrium is approached at a given location and depth in an aquifer, because the slow movement of ground water allows time for completion of slow chemical reactions between the water and aquifer materials. For this reason, concentrations of iron and manganese are likely to be constant with time at a given point in an aquifer. Concentrations may vary from site to site and at different depths in an aquifer, however, because of natural variations in pH, Eh, and other controlling factors.

Under pumping, the increased rate of movement of water through an aquifer may alter equilibrium conditions sufficiently to cause changes in the iron and manganese content of ground water. Probably of greater importance in the study area, however, are the changes in equilibrium conditions that result from stream infiltration. Figure 2 indicates, for example, that significant changes in the temperature, pH, and dissolved-oxygen content, which affects Eh, are to be expected in water in those parts of the stratified-drift aquifer that are recharged by infiltration from the Blackstone River. Examples of variations in pH, iron, and manganese in ground water within a well field recharged by infiltration from this river are shown in figure 8.

A decrease in Eh and increases in dissolved iron and manganese may be expected in ground water whose dissolved-oxygen content is depleted by oxygen-consuming organic matter contained in water infiltrating an aquifer, according to Stumm and Morgan (1970, p. 545). Displacement of native oxygenated water in an aquifer by stream infiltration having a lower dissolved-oxygen content, whether or not it contains organic matter, may also be expected to cause a decrease in Eh and increases in iron and manganese in ground water. Effects of changes in Eh and pH on the solubility of iron and manganese in water are illustrated in graphs presented by Hem (1970, p. 118-128). They show, for example, that at very low Eh (an indication of strong reduction) and at pH values of 6 to 7, typical of ground water in the study area, iron may become insoluble, while manganese remains highly soluble. The existence of strong reducing conditions in the stratified-drift aquifer caused by infiltration of water low in dissolved oxygen and containing organic matter may, therefore, be an explanation of the unusual occurrence of high concentrations of manganese and low concentrations of iron in water pumped from many wells in the study area.

Graphical relations in figure 7 show that increases in annual pumpage from wells or well fields in the stratified-drift aquifer are commonly accompanied by increases in dissolved solids and manganese content in the well water. An increase in dissolved solids is to be expected where increases in pumpage cause an increase in infiltration of stream water of higher dissolved-solids content. Similarly, an increase in the volume of organic matter infiltrating the aquifer from streams may intensify conditions that cause dissolution of manganese from streambed and aquifer materials.

It seems likely that invasion of the stratified-drift aquifer by infiltration induced from rivers containing organic wastes is related to the occurrence of high concentrations of manganese in water from heavily pumped wells in the study area. However, additional study is required to confirm this hypothesis.

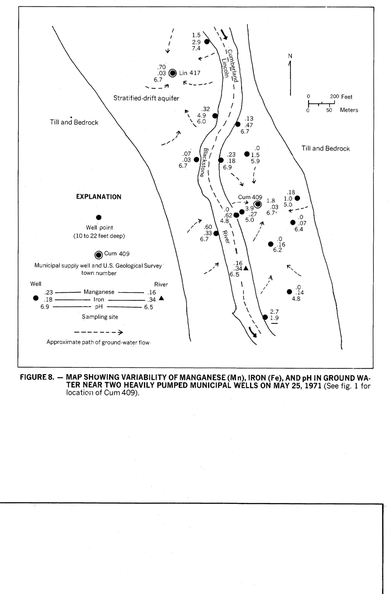


FIGURE 8. — MAP SHOWING VARIABILITY OF MANGANESE (Mn), IRON (Fe), AND pH IN GROUND WATER NEAR TWO HEAVILY PUMPED MUNICIPAL WELLS ON MAY 25, 1971 (See fig. 1 for location of Cum 409).

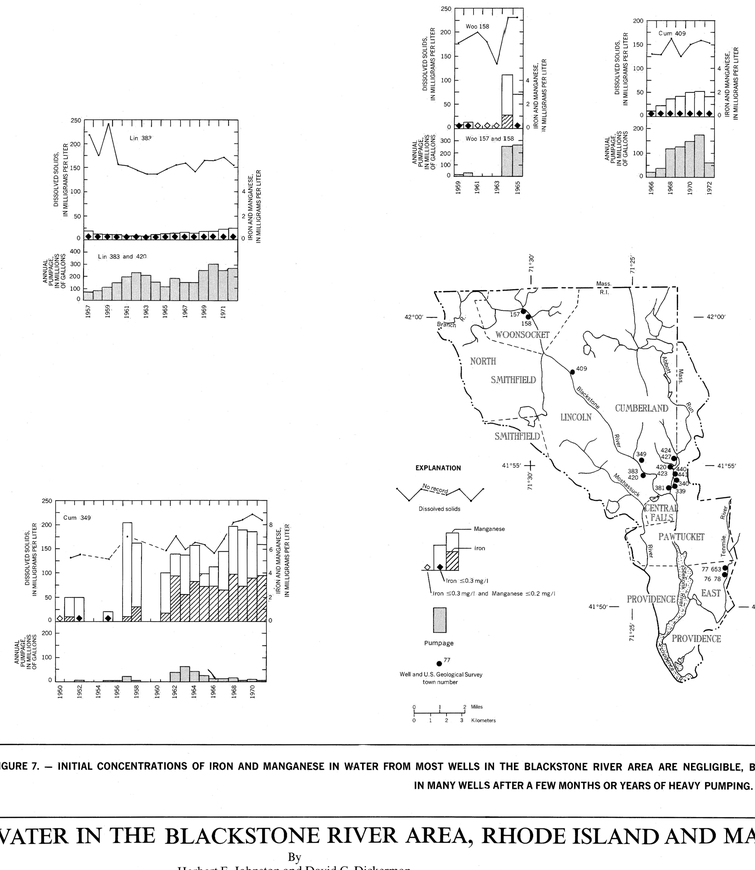


FIGURE 7. — INITIAL CONCENTRATIONS OF IRON AND MANGANESE IN WATER FROM MOST WELLS IN THE BLACKSTONE RIVER AREA ARE NEGLIGIBLE, BUT MANGANESE AND, IN SOME PLACES, IRON, INCREASE TO TROUBLESOME LEVELS IN MANY WELLS AFTER A FEW MONTHS OR YEARS OF HEAVY PUMPING.

CONCLUSIONS

Surface water in the Blackstone River area is generally of good chemical quality. The Blackstone and Tennile Rivers and to a lesser extent the Mohassuck River, however, are degraded by organic wastes derived chiefly from municipal sewage and textile mills, so that the biological and physical quality of much of the surface water is poor. Native water in the stratified-drift aquifer, on the other hand, is generally of excellent quality in all respects. Moreover, infiltration induced from streams contaminated by organic wastes is rendered free of bacteria, odor, suspended matter, and other undesirable biological and physical characteristics as it moves relatively short distances through the aquifer to well intakes.

Unfortunately, infiltration of organically contaminated streamflow into the stratified-drift aquifer seems to be a causative factor in the development of excessive concentrations of manganese in water from heavily pumped wells after they are put into production. Nearly all heavily pumped wells near the polluted Blackstone and Tennile Rivers have eventually developed high manganese, while those near relatively unpolluted Abbott Run have not. The presence of high manganese is the principal ground-water quality problem in the study area, because its removal from water has proven costly and difficult.

The biological and physical quality of water in the Blackstone and Tennile Rivers may improve, as additional and more effective waste-treatment facilities are constructed. If this happens, conditions causing dissolution of manganese from streambed and aquifer materials may diminish, thereby resulting in lower concentrations of manganese in well water.

Development of treatment facilities that will effectively and inexpensively remove manganese from well water will markedly increase the utility of ground water in the Blackstone River area.

Because municipal and many industrial waste-treatment plants remove few, if any, dissolved chemical constituents from water, the dissolved-solids content of the Blackstone and Tennile Rivers can be expected to increase if the volume of wastes discharged to them increases. This will result in an increase in the dissolved-solids content of water pumped from wells that induce infiltration from these rivers. Although the dissolved-solids content of ground water has already increased in most well fields near the Blackstone and Tennile Rivers, the increase has been moderate and well within limits acceptable in water used for public supply and many other uses.

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