Michigan, fragments of such materials are in the drift deposits and may be leached by subsurface water. Sulfates may also be formed by the oxidation of iron sulfides and are in the minerals marcasite or pyrite of bedrock. These minerals are present in varying amounts in many shale formations and to some extent in limestones and dolomites. Sulfates in waters that also contain relatively high proportions of calcium and magnesium cause a hardness which is more difficult to remove and which is known as "non-carbonate" hardness. The precipitate or scale produced by sulfates of calcium and magnesium is more damaging to boilers and similar equipment than scale which is produced by carbonates of calcium and magnesium.

Within Oakland County, the groundwater averaged 23 ppm in sulfates with a range between 0 and 183 ppm. Of 50 determinations, only 5 analyses indicated sulfates in excess of 50 ppm. In analyses of groundwater samples collected from the glacial lake plain, the sulfates were generally less than 10 ppm, and between 10 and 30 ppm in water from the moraine-till and outwash areas.

Chlorides (Cl)

Chlorides are dissolved in small quantities from many rocks. According to the standards accepted by the American Water Works Association, water having a concentration of more than 250 ppm of chlorides is unsuitable for drinking purposes. However, chlorides in amounts less than 400 ppm cannot be tasted by most people, but in increasing amounts salt becomes progressively more noticeable to the taste. The chloride content of water may be several thousand parts per million before it is unsuitable for livestock. Because chloride salts are highly corrosive, most industries require water that is relatively free from such salts.

The average chloride content of groundwater in the county is 53 ppm with a range from 4 to 320 ppm as determined by 54 analyses. Groundwater in the glacial lake plain ranges from 4 to 320 ppm and averages 83 ppm. For the moraine-till plain and outwash areas, the chlorides range from 5 to 47 and 5 to 25 ppm, and average 27 and 15 ppm respectively. The higher chloride content of groundwater from the glacial lake plain makes it distinctive from the groundwater present elsewhere in the county. The occurrence of salt water in the glacial lake plain will be discussed more fully in a subsequent section of this report.

Fluorides (F)

Extremely small amounts of fluorides are in most natural waters. Water containing fluorine in amounts exceeding 1.5 ppm is said to cause the dental defect known as mottled enamel if the water is used for drinking by young children during the period of tooth formation. On the other hand, it is reported that water containing less than 1.5 ppm of fluorine has caused a lower incidence of dental cavities. From 21 analyses, it is shown that groundwater from the county averaged 0.6 ppm of fluorides with a range between 0.2 and 1.5 ppm. For the outwash areas the average is 0.3 ppm; for the moraine-till plain areas 0.5 ppm; and for the glacial lake plain 0.7 ppm. The higher average and greater range of fluorides in groundwater from the glacial lake plain may be due in part to the infiltration of water from the underlying bedrock into the drift.

Dissolved Solids

Dissolved solids are the residue left upon evaporation of a measured quantity of water and are mainly the dissolved mineral constituents in the water. The desirable maximum of dissolved solids for most commercial and industrial uses is about 500 ppm, but water having a greater content of dissolved solids may be suitable if the hardness, iron, and chlorides remain low. From the unconsolidated deposits of the county, the dissolved solids from groundwater samples averaged 398 ppm and ranged from 276 to 834 ppm. The greatest range and highest average of the dissolved solids were found in groundwater of the lake plain section. The range is 276 to 834 ppm and the average 430 ppm. For the outwash the average is 354 ppm with a range from 300 to 496 ppm, and for the moraine-till plain area 384 ppm with a range of 322 to 604 ppm.

Hardness

Hardness is a characteristic of water that receives the most attention in the development of domestic, commercial and industrial supplies. This characteristic is determined by the increase in the quantity of soap that is necessary to produce a lather, or by the minerals that are deposited as scale in boilers and kettles when hard water is heated or evaporated. The total hardness of water includes both the carbonate and non-carbonate hardness. Carbonate hardness is due to the bicarbonates of calcium and magnesium in water, and the non-carbonate hardness is due to the sulfates, nitrates and chlorides of calcium and magnesium. The amount of soap needed is determined by both types of hardness, but the carbonate hardness is more easily removed, whereas the non-carbonate hardness produces a harder scale that is considerably more troublesome in its removal.

Generally water under 60 ppm in hardness is considered soft. Softening it further is not profitable excepting for special uses, as for steam boilers if it approaches the upper limits and is used in very large quantities. Hardness between 60 and 120 ppm does not seriously hamper domestic uses and most industrial needs. Commercial laundry enterprises may find softening economical as by softening the water the consumption of soap would be decreased. If water has between 121 and 200 ppm the hardness is noticeable by anyone, and such hard water generally needs to be softened by any industry using water for the processing of its products. Softening of such water may likewise be profitable for domestic and municipal supplies. Hardness in excess of 300 ppm makes water objectionable for nearly all uses.

Of 57 water samples analyzed in Oakland County, the total hardness ranged from 34 to 480 ppm and averaged 273 ppm. Groundwater from the outwash averaged 298 and moraine-till plain averaged 314 ppm in hardness. Water from the glacial lake plain averaged 238 ppm. Groundwater from the lake plain section is thus distinctive from that of other areas since it is from 60 to 76 ppm softer. Considering the slope of the hydraulic gradient from the interlobate outwash southeastward toward the glacial lake plain, it may appear somewhat unusual that the hardness of groundwater should decrease. On the other hand, analyses of groundwater samples from the lake plain indicate the chlorides in greater concentrations. Sodium and potassium combined are considerably higher here than indicated by water samples from the outwash and moraine-till plain sections. Thus, it is possible that a natural softening of water takes place in the glacial lake plain by the process of base exchange—the exchange of sodium in the sediments of the lake plain for the hardness-producing calcium and magnesium contained in the groundwater. Inflow of bedrock waters high in sodium and potassium salts into the unconsolidated sediments of the lake plain may vary in quantity from time to time, depending upon the piezometric pressure of the various drift aquifers. Thus, it is conceivable that in a period of years when rainfall is below the annual average, the lowering of the piezometric surface may be more rapid owing also to the increase of groundwater pumpage. At such a stage infiltration of rock water into the drift may furnish an excess of sodium ions to the sediments, which may later be used in the base exchange process. It is obvious that the mechanics involved in such a base exchange process are difficult to determine, considering the complexity of sediments and of the percolation of bedrock and drift waters. It is likewise conceivable that the low total hardness of subsurface waters in the glacial lake plain may be indicative that recharge by precipitation that falls directly upon the area is more significant than supposed. Since much of the glacial lake plain consists of waterlaid till and lacustrine deposits, it is likely that a greater quantity of soluble salts had been leached. Thus, the infiltration of meteoric waters falling directly upon the area would eventually cause groundwater to have a lower concentration of hardness-producing compounds in solution.

The hardness of groundwater in the county is primarily carbonate rather than non-carbonate. Of the total determinations, the carbonate hardness averaged 262 ppm and the non-carbonate hardness 16 ppm. Excepting four samples, the non-carbonate hardness was less than 50 ppm. In 29 of the 49 complete analyses, the total hardness was less than or equal to the total alkalinity, in which case the non-carbonate hardness of the water was zero. For the outwash and moraine-till plain areas, the non-carbonate hardness averaged 25 and 26 ppm respectively, and for the glacial lake plain 6 ppm. The majority of analyses of samples from the glacial lake plain showed absence of non-carbonate hardness. From the analyses of water samples taken from the glacial lake plain it was noted that the total initial hardness of water from newly completed wells was owing to the presence of calcium and magnesium bicarbonates. However, after prolonged use and/or heavy seasonal groundwater withdrawal, subsequent monthly or annual analyses revealed either an appearance or an increase in the amount of non-carbonate hardness. Many subsequent analyses indicated the total hardness to exceed alkalinity, and the excess thus represents hardness due to the presence of non-carbonates. Variation in the quality of water will be more adequately discussed later in the report.

QUALITY OF WATER FROM THE CONSOLIDATED SEDIMENTS

In contrast to the water of the glacial mantle, the water recovered from the consolidated sediments is nearly everywhere more highly mineralized. Bedrock wells are not numerous in the county. Most of them were drilled in the glacial lake plain section where thin drift cover, or deposits predominantly clay, made it necessary to drill into the rock formations to secure palatable water. The rock wells in use today are primarily for domestic or stock purposes but a few are for industrial use. No bedrock wells have been developed for municipal systems. In the morainic, till plain and outwash areas, where population density is low in comparison to the lake plain, the demand for water is not as great and the available supply in the unconsolidated sediments is more than ample. In addition, these areas have a thicker drift cover, shallower water levels and a greater abundance of more permeable water-bearing materials. Thus, it is usually not necessary to drill beyond the depth of the surficial mantle in areas other than the glacial lake plain.

Only a few analyses of bedrock water were obtained and are shown in Table 10. Of the analyses included, three represent samples taken from shallow rock wells, and the remaining four are water samples drawn from deep oil and gas exploratory holes. In a comparison of the results of the analyses with respect to reported depths and geologic horizons, several generalizations become apparent and are given in the succeeding paragraphs:

1. The most obvious feature of bedrock water is its high mineralization in contrast to the water contained in the drift. In nearly all wells, the dissolved mineral constituents, excepting iron, silica and some alkalies, show a significant increase, an extremely wide range or both. A comparison of the individual factors of these analyses with the water-classification table (Table 11) reveals that much of the bedrock water is highly objectionable in nearly all respects.

2. Of particular note is the total hardness of the water recovered from bedrock, which ranges from 270 to 45,945 ppm. It is general practice to assume that hardness of water is owing to the carbonates present if the total hardness of the water sample is equal to or less than the alkalinity. If the reverse is shown by the analyses, then the excess of the total hardness is owing to the non-carbonates present in the form of sulfates, nitrates and chlorides. From the tabulated results of bedrock-water analyses, it may be noted that non-carbonate, or permanent, hardness is more dominant. In water associated with drift deposits, the reverse holds true. Of the bedrock-water samples analyzed, the non-carbonate hardness ranged from 42 to 45,907 ppm and the carbonate hardness from 2 to 230 ppm.

3. In general, the quantity of dissolved mineral matter in water increases with increased depth into rock. The total dissolved solids increase from 688 to 175,800 ppm, and the individual constituents increase as follows: Chlorides from 360 to 102,500 ppm, sodium and potassium 517 to 45,908 ppm, calcium 56 to 12,450 ppm, magnesium 26 to 3,600 ppm and sulfates from 0 to 1,881 ppm. As the amount of dissolved mineral matter increases, obviously, the density of the water increases. Specific gravity of water samples increased with depth, the indicated range being from 1.008 to 1.120.

4. A pronounced change in the chemical quality of bedrock water is very apparent in the rock formations older than the Antrim shale. Analyses of samples of water from the Traverse, Dundee, and Detroit River formations strongly suggest the impossibility of recovering palatable water even for livestock purposes from these formations in the area of Oakland County. Hence deep rock wells should not be considered as a possible source for a groundwater supply.

Water from the Antrim shale and younger formations underlying the county is considerably less mineralized but not to the extent that it compares in quality to the water in the drift. The analyses indicate that it may be satisfactory for stock and domestic purposes if necessary. To a large degree the recovery of palatable water from any particular formation will be restricted to its outcrop area beneath the surficial deposits. For example, a few rock wells that penetrate the Berea in its outcrop area (beneath the drift) in the vicinity of Franklin Village (Southfield Township) yield water suitable for domestic use. This is not surprising since it is very probable that the more mineralized water in the Berea sandstone may be subjected, within its outcrop limits, to dilution locally by the infiltration of less mineralized water from the overlying drift. On the other hand, wells ending in the Berea sandstone where it underlies younger rock formations, as in the northern half of the county, may yield water so highly contaminated by mineral matter that it is unsuitable even for stock use. Such mineralization may be anticipated, and is verified by comparison of the water analyses for wells AV-57 and IND-15. The analysis for well AV-57 is of a sample of water recovered from the Berea sandstone where it is overlain directly by drift, and the analysis for well IND-15 is of water from the Berea where it underlies the Sunbury and Coldwater formations. The difference between the tabulated results of the two analyses for dissolved solids, sodium and potassium, chlorides, sulfates and total hardness is marked.

Although the analyses of water samples taken from bedrock appear mainly unfavorable, it is not impossible to develop a greater supply of palatable water from the underlying formations if necessary. Whether or not water recovered from a rock well will be satisfactory depends upon a number of controlling factors, some of which are difficult to foresee in advance, whereas others may be drawn from inference. The most obvious factor is the depth of penetration of the well into the rock formation. It is clearly indicated by the tabulated analyses of bedrock waters that mineral contamination increases with depth. Thus, recovery of water from rock sources must be limited to wells of shallow depth into bedrock. Since the county is underlain principally by shales, mainly of low permeability, the yield from wells penetrating them is small. Where a larger yield is desired it must be produced at greater depth or by an increase in the diameter of the well, or in places both. A greater depth into the rock results in a greater area of seepage, also the well may cut across additional bedding planes, fractures and perhaps lenses of more permeable materials, like the sandstones and scattered limestones in the Coldwater formation. Enlarging the diameter of the well increases the area of seepage without the necessity for added depth. For the known conditions in Oakland County, any desired increase in yield should preferably be obtained by increasing the diameter of the well rather than by added depth.

Another factor that may determine the quality of water recovered from a shallow rock well is its position with respect to the regional topography of the bedrock surface. Rock wells completed in formations that outcrop in the bedrock lowland are likely to be more mineralized than wells which have been drilled into the rock surface of the Thumb Upland. Two facts favor the upland rock wells with regard to quality of water—namely, the position of the groundwater divide and the nature and structure of the formations. As was shown earlier in this report, the groundwater divide is located within the interlobate deposits of outwash materials and scattered morainic hills. The groundwater divide approximates the position of both the bedrock and topographic divides. It is logical to expect the rocks of the upland surface to be subjected to more infiltration of water from the drift because of their location with respect to the major intake basin of the county. The rock surface of the lowland area is less favorable to this form of recharge because the drift deposits are less permeable and, furthermore, because the regional rock topography and structure lend themselves

to an up-dip movement of bedrock water. Thus, the rock wells of this region will yield water that is likely to be higher in the quantity of dissolved mineral contaminants.

To some degree, local bedrock topography may influence the quality of water recovered from a rock well. It is conceivable that a shallow bedrock well located on a divide between rock valleys may yield water of less mineral contamination than one completed within a bedrock valley, since mineralized water, originally present in the area of the divide, may have been flushed out owing to local percolation of drift water into the rock and thence toward the depressions of the bedrock surface. This factor of local topography is of little assistance in searching for a water supply since the detailed configuration of the rock surface is not known. Knowledge of its character will remain unknown until additional bedrock elevations are obtained either by geophysical methods or by the gradual accumulation of well and test-hole records that give bedrock data.

OCCURRENCE OF SALT WATER IN DRIFT OF THE GLACIAL LAKE PLAIN

The presence of water of saline taste, or high in chlorides, in the glacial sediments of Oakland County has been previously reported by Leverett. A number of well logs tabulated in Leverett's report (1905-06) show that salt water was reported in many wells in the eastern part of the drift deposits that in part comprise the Troy flowing-well district. Several of the wells, reported as yielding salt water, were drilled before 1910 when the county as a whole was sparsely populated. It is suggested, therefore, that the chloride water in the drift is not all of recent origin: That is, its occurrence is not a direct result of the rapid development of groundwater-supply systems within the county. The general areas of salt-water occurrence in the county were determined by plotting on a base map all wells for which chlorides were indicated either by notation on the record or by analyses. From this map several facts become apparent which may be worthy of note:

1. Wells for which a salt-water taste was reported on the logs were all located within the limits of the glacial lake plain, particularly in the southeastern half of Troy Township and the northern half of Royal Oak Township. Well records were not available for the southern half of Royal Oak Township as the area is served by the Detroit water-supply system. It is probable that groundwater in this area may be high in chlorides.

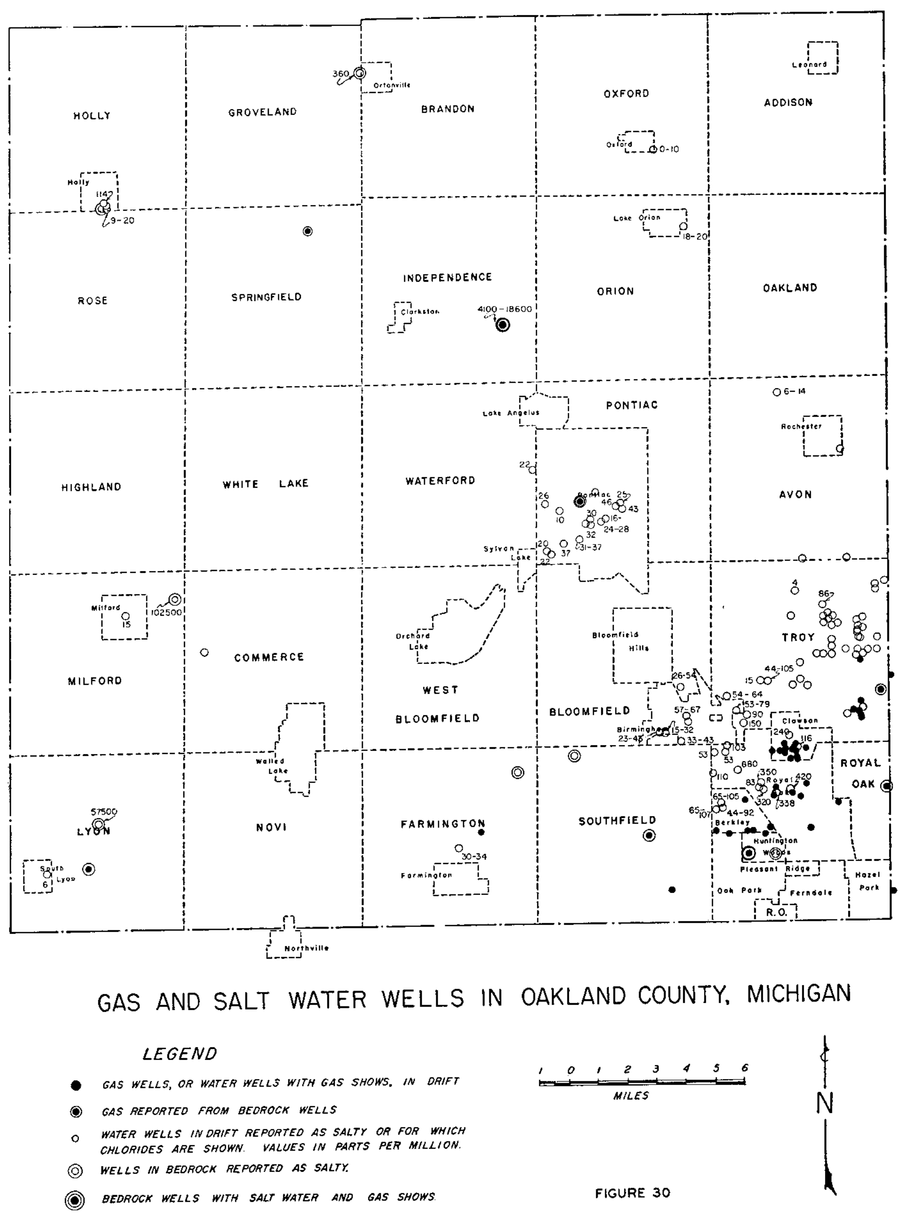

FIGURE 30

2. Nearly all the chemical analyses of water samples that indicated chlorides in excess of 50 ppm or more, were of water from wells within the glacial lake plain section. The only exceptions were two analyses of composite water samples taken from the village of Holly water-supply system. The wells in service at the time were completed in sand and gravel deposits probably in association with a bedrock valley. In the glacial lake plain section the water samples from the various wells showed a range in chlorides from 4 to 420 ppm.

3. From the preceding paragraphs it may be generally concluded that waters of saline taste are most likely to be encountered in the sediments of the lake plain which have been deposited over the bedrock lowland and in part along the lower limits of the rock slope which rises northward toward the rock upland. By reference to the geologic and surficial maps, it is seen that the sediments of the lake plain have been deposited over the Berea sandstone and older formations. From the distribution of the wells for which salt water or high chlorides are indicated (fig. 30), it appears that the upper boundary of the Berea formation marks the northwesterly limit of salt-water occurrence in the drift cover of the glacial lake plain. Surficially, this northwesterly limit is approximately indicated by the general northeast-southwest trend of the Maumee beaches which, in this county, pass through the southeast corner of Avon Township and thence southwestward through Troy, Bloomfield, Southfield and Farmington townships.

4. Analyses showing the highest concentration of chlorides (up to 420 ppm) were of samples taken from municipal wells in Berkley, Clawson and Royal Oak. With respect to the rock surface these wells and test holes are drilled into sediments associated with or deposited over bedrock valleys (fig. 7). Two explanations may account for the fact that drift deposits that fill and cover rock valleys are likely to contain saline water. First, since saline water is of higher density, its infiltration from bedrock into drift would tend to percolate toward unconsolidated sediments that occupy depressions in the bedrock surface. This would be especially true of bedrock-water seepage from the slope of the bedrock upland. Second, the valleys carved into bedrock provide a greater seepage area for percolation of saline water into the drift especially since the bedrock water is under artesian conditions.

5. The chloride values of individual well samples when plotted on the base map increase in amount from Pontiac (10-45 ppm)

southeastward through Birmingham (15-150 ppm) and Royal Oak (44-420 ppm). The increase follows the trend of the major rock valley of the area.

The salt water in the lake plain sediments may be attributed to infiltration from the underlying rock formations. Infiltration may be natural or induced. Induced infiltration results from local over-development of aquifers in the drift, which induces movement of confined water from the bedrock. Additional infiltration may have resulted from the improper grouting of test holes or wells drilled into rock.

From shallow and from deep borings into the underlying rock strata, brines were reported in nearly all formations from the Detroit River group upward through the Lower Marshall beds. The source of chlorides in the groundwater of the drift is therefore the bedrock. Natural infiltration of salt water into the overlying sediments is due to geologic conditions of rock structure, rock topography, surface topography, and the nature of the surficial deposits. When the glacial and bedrock-surface maps are viewed together, it is clearly seen that the mantle of the lake plain is deposited over the rock lowland surface and along the lower part of the adjacent rock upland slope. Test borings show that the Berea formation constitutes a part of the slope which separates the rock upland from the lowland. The principal source of the salt water in the drift is probably the Berea sandstone, although there is no strong reason (other than degree of permeability) to exclude the formations immediately above and below the sandstone as additional source beds. Excepting variations caused by local structures, the gentle regional dip of the rock formations is to the north. As the groundwater divide is located to the northwest, the movement of confined water in the rock formations would be in an up-dip direction until it entered the unconsolidated sediments of the glacial lake plain. The conditions as described would result in the natural infiltration of mineralized water into the unconsolidated drift overlying the bedrock lowland. The degree of salinity of water in the drift may vary considerably from place to place and from time to time, variation being dependent on a number of factors such as (1) the salinity of the water from the rock formation, (2) the ease of percolation through the rock formation as well as the drift, (3) the amount of dilution caused by the less mineralized water of the drift, (4) the rise and fall of the piezometric surface and (5) the position of the sand and gravel aquifers in the drift with respect to the rock surface. With reference to the last factor, sands and gravels resting directly on the bedrock surface and overlain by clays would generally contain salt water since dilution would be retarded by the confining clays. This is clearly shown by a test hole (RO-37) drilled for the city of Royal Oak. The log of the well reveals 12 feet of sand overlying the Antrim shale and succeeded by unassorted till and lacustrine clay. A sample of water taken from the test hole contained 350 ppm of chlorides. Other bodies of sand and gravel that are more or less confined by clays both above and below, but which extend laterally so as to abut against the wall of a bedrock valley, or perhaps overlap a part of the slope ascending to the rock upland may likewise contain saline water. This may be the character of an aquifer associated with a bedrock valley which has been penetrated by a test hole (RO-25) in the city of Royal Oak. The water-bearing zone consists of sand, sand and gravel, and gravel layers 33 feet thick and confined by less permeable materials above and below. A sample of water taken from the test hole showed 890 ppm of chlorides. It is conceivable and very likely that older buried beaches or marginal outwash materials of pre-Wisconsin or Wisconsin age may have been deposited against the bedrock slope of the rock upland and thus be in a position to receive mineralized waters by infiltration.

The natural infiltration of bedrock waters into the drift appears to be proved by the initially high chloride content of water samples taken from several test holes. An analysis of a sample taken from the original Magnolia well (RO-45), city of Royal Oak, shortly after its completion in 1923, showed chlorides in the amount of 322 ppm. Since this area was not previously developed for a public water supply, the original high chlorides of the sample must suggest a natural rather than induced flow from bedrock sources. And since the Magnolia well is completed in drift which buries a rock valley, it is not surprising to find saline water in the filled depressions of the rock surface.

Additional saline water in the drift may be the direct result of induced infiltration from the bedrock as overlying sand and gravel bodies within the mantle are overdeveloped. The groundwater in the bedrock and in the water-bearing acquifers of the glacial lake plain, is under complete or partial artesian conditions of varying pressures. When, through development, the water pressure of a confined aquifer in the drift is lowered below the pressure of water in the bedrock, induced flow from the rock results. This manner of flow will continue until the reverse conditions of pressure are again re-established between the consolidated and unconsolidated aquifers. This seems to be indicated by analyses of water samples taken at a later time from the Magnolia (RO-45) and Northwood (RO-46) wells in the city of Royal Oak. Both wells are within influence of each other to the extent that the Northwood well has been known to surge, thereby requiring the operation of both wells under partially closed valves. The operation of both wells simultaneously results in overdevelopment, which in turn reduces the pressure in the sand and gravel aquifer sufficiently to induce flow of water from the bedrock. The quality of water from the Magnolia well has been so unsatisfactory that it has been generally kept out of service except when peak demands occur during the summer months. The original Magnolia well, destroyed by a gas explosion in 1925, was replaced by a new well near the original site. Although periodic analyses were not made, Table 12 illustrates the variation in chlorides from samples collected since the new well was completed. The chlorides varied from 140 to 465 ppm, and the variation is undoubtedly related to the pumping schedule of the Magnolia and Northwood wells.

Two of the monthly analyses of water samples taken from each of the wells owned by the city of Birmingham, strongly suggest induced infiltration of water from bedrock sources. The dissolved constituents have been plotted and are shown on Figure 31. Of specific interest to the immediate discussion are the graphs for the Walker and Baldwin wells. The Walker well penetrates the same water-bearing zone as the city of Clawson well (TR-69) and the Bundy Tubing Company well (TR-65) penetrate. From data on hand, all three wells, with respect to the underlying rock surface, are completed in sediments that are along the easterly slope of the principal bedrock valley of the glacial lake plain. Earlier data indicate that the wells are within influence of each other, which again causes local overdevelopment. Monthly water analyses of the Walker well are continuous from May 1950 through October 1953 with but few omissions. From the graphic representation of these analyses it may be noted that chlorides have been increasing gradually. This increase in chlorides for the period covered by the analyses indicates infiltration of bedrock water as a natural consequence of local overdevelopment of drift water.

Induced infiltration from bedrock is again suggested by water analyses collected from the Baldwin well. Records of this well are not continuous since it is occasionally out of service primarily for reasons of quality rather than because of mechanical difficulties. The Baldwin, located in the valley of the River Rouge, is the shallowest of the Birmingham wells, being only 73 feet deep. With reference to the rock surface, the well is drilled in glacial sediments that rest on a bedrock ridge between the major rock valley and a principal tributary that joins it from the northwest. The slope of the rock ridge is to the southeast and is probably formed by the Berea or possibly younger formations—that is, the Sunbury shale and basal Coldwater beds. Of all Birmingham wells, the water analyses collected from the Baldwin show the greatest content of dissolved mineral contaminants. As shown on Figure 31, the dissolved solids, total hardness and non-carbonate hardness have values which greatly exceed those of samples collected from the other six municipal wells. Of particular significance is the behavior of the curves from May 1950 through October 1952 for the total and non-carbonate hardnesses, sulfates and dissolved solids. Two periods are indicated when the well was not in service—the first from January through June 1951 and the other from October 1951 through April 1952. The analyses immediately following the April 1952 period are of prime interest. After a seven-month rest period, the sulfates increased in one month (May to June 1952) from 18 to 236 ppm, dissolved solids from 519 to 902 ppm, total hardness from 244 to 538 ppm and non-carbonate hardness from 0 to 230 ppm. Such a pronounced change in the quality of water again indicates induced infiltration of water from bedrock while the Baldwin well is in frequent service. The more favorable analysis of May 1952 suggests that when not in service the sediments in the vicinity of the Baldwin are recharged by effluent seepage of surface waters from the River Rouge, or possibly from nearby Quarton Lake. The extreme variation in quality is not indicated by the analyses for July and August 1951 immediately following the first period when the Baldwin was out of order. After a six-month interval, it is logical to assume that the water from the Baldwin well should be more favorable in quality but the curves, however, fail to prove such an assumption. Since it is highly improbable that the May and July 1952 analyses are in error, the pronounced change in quality failed to appear for some other reason. The reason may be in the time interval between the date that the Baldwin was again restored to service and the date of sampling, that is, the July 1951 sample was collected several days, or possibly weeks, after the well was back in service, and the May 1952 sample was collected very shortly after the well was in use. If this assumption is correct, it is likely that infiltration of bedrock water into the drift takes place rapidly, and that recharge by effluent seepage from nearby surface bodies of water is ineffective while the well is in daily service. It would seem practical to rest the Baldwin well more frequently in order to maintain a better quality. Chlorides are not especially conspicuous in the water samples taken from the Baldwin well—they range from 48 to 67 ppm. No explanation is immediately apparent. It is possible that the high sulfates reflect the possibility that the mineralized quality of water from the Baldwin well is due to infiltration from the Sunbury and/or Coldwater shales. The Sunbury is a black to brown shale resembling the Antrim shale in color and perhaps contains a higher percentage of iron sulfides, and the Coldwater formation in this area possibly contains more gypsum. It is postulated that the aquifer tapped by the Baldwin well probably extends laterally until it is in more direct contact with the rock formation comprising the ridge. A more positive conclusion regarding induced infiltration of bedrock water into the drift must await additional monthly analyses so that a longer interval of time is represented and so that variations may also be plotted against monthly precipitation data. Other factors to be considered include the length of time the well was in operation before sampling, the influence of precipitation falling upon the area, recharge in the immediate vicinity, and the influence of nearby wells having a high daily production.

Another cause for infiltration of bedrock water into the drift may be owing to improper grouting of unsatisfactory wells and test holes that have penetrated the underlying rock formations. This opinion was expressed on several occasions to the writer by a number of drillers familiar with the region, and although it is undoubtedly true as a contributory cause, it does not account for all the salt water in the drift. Although some abandoned rock wells and test holes were reported, no pertinent data regarding them were obtained.

OCCURRENCE OF GAS IN DRIFT

Gas has been reported in a number of wells and test holes from the sediments of glacial origin. In some localities the gas in the drift is of sufficient quantity and under sufficient pressure to be usable locally for space heating and other purposes. In most of the area the gas is reported as "slight shows" or as very small pockets

which initially may be under several pounds pressure. The presence of gas in the drift is detrimental to any groundwater supply unless proper measures are taken for its removal. Well explosions on several occasions have resulted in personal injury and damage to equipment and property.[1] The original Magnolia well (RO-45), city of Royal Oak, and a school well in Southfield Township are two of the several explosions that came to the attention of the writer during the course of the investigation. The city of Ferndale,[2] which now obtains water from the Detroit system, abandoned groundwater use after a series of minor domestic explosions. In certain areas of Macomb County it is a general practice to install gas-escape valves for hot water tanks. In Detroit a serious gas explosion[3] occurred in a huge raw-water main, approximately 95 feet below surface, which is being constructed by subsurface construction methods. Gas seepage from a two-inch seam of sand took place despite the fact that the underground tunnel is being constructed under pressure, which from time to time is adjusted up to twenty pounds. Groundwater containing a small amount of gas by volume is generally unsuitable for use in steam boiler equipment since it results in frothing of water. Two explanations are offered for its presence. It may be a marsh gas derived from buried deposits of plant matter in the process of peat formation, or it may be natural gas that has seeped into the drift from the underlying bedrock formations.

Deep and shallow wells and test borings in bedrock have reported gas flows in formations ranging from the Detroit River group of Devonian age to the Coldwater shale of Mississippian age. From evidence available, it is the writer's conclusion that the gas in the drift is derived by seepage from bedrock sources. The Disposal Plant well (RO-55), now abandoned by the city of Royal Oak, was originally drilled to 132 feet at which depth the Antrim shale was reached. The water-bearing formation consisted of a gravel stratum 6 feet thick which is immediately above the shale. At some later date, the well was deepened another 138 feet into bedrock to provide storage. This opened so appreciable a flow of gas that an attempt was made to utilize it as fuel for the disposal plant. Improper dynamiting damaged the casing and rendered the well useless. A shallow private well (RO-52) reached the Antrim at 110 feet and blew gas at 111 feet. In this well the flow of gas from the shale

[1] *Detroit News*, September 10, 1950.
[2] Personal communication, August 9, 1949.
[3] *Detroit Times*, November 22, 1950.

was of short duration. Apparently the gas was a local pocket that was confined by overlying clay hardpan. No peat was indicated in any of the records of wells or test holes in which gas was found. Hence the occurrence of gas in the drift is presumed to be seepage into the overlying sediments from bedrock sources.

The thirty wells and test holes for which gas was reported are all located within the limits of the glacial lake plain (fig. 30). Logs of the individual borings or wells revealed that gas was most generally in the coarser clastics. In some wells gas was found in zones described as clay or sand and gravel hardpans. Some gas was reported from soft, soupy or putty-like clays. The gas-bearing zones ranged in depth from 38 to 131 feet below the surface and had pressures up to thirty pounds. Gas was even in water recovered from shallow dug wells that were in the city of Pleasant Ridge.[1] Gas concentration per unit volume was sufficient to discourage use of the water for steam locomotives. It appears that the concentration of natural gas in the buried "pockets or veins" of coarser clastics within the glacial lake plain sediments is made possible by the lacustrine clays and silts or reworked waterlaid tills that are near the surface and serve as confining layers or caps. No gas shows were noted on any records collected for the morainic, till plain and outwash areas, but it is not impossible for gas to seep into the mantle rock of these areas from the underlying rock formations. The apparent absence of gas pockets in these areas of the county is probably owing to the more permeable nature of the mantle which permits its escape.

Wells and test holes for which gas was reported or indicated were plotted on a base map in order to determine the areal distribution and areas of concentration within the limits of the glacial lake plain. The majority of the wells were found to be in sediments which overlie the outcrop area of the Antrim shale formation. Only three wells had positions in the glacial lake plain north of the inferred Bedford-Antrim contact as shown on the geologic map. From the distribution pattern of these wells it is indicated that the primary seepage of the drift gas is from the Antrim shale. The wells beyond the Antrim outcrop area suggest that the gas in that part of the lake plain may be derived directly from the Sunbury or from the Berea-Bedford formations, or may be owing to indirect seepage of Antrim gas into that area by devious courses established by more permeable materials.

[1]Oral communication, City Engineer.

The largest concentration of gas wells is in and around the city of Clawson, in sections 3 and 4, Royal Oak Township. Many of the wells in this area were drilled expressly for gas for space heating and other domestic purposes. Pressures between five and eight pounds were generally reported, but as the number of wells increased within this small area the gas pressures declined, and the infiltration of water began. A majority of gas wells have since been abandoned. On the geologic and bedrock-contour map (fig. 7) it is shown that the gas of this area is concentrated in sediments that bury a tributary rock valley carved into the Antrim shale formation. This valley in the Antrim provides a greater seepage area for the shale gas which eventually finds its way into the confined sand and gravel pockets. Another area of gas wells is located in the southeast corner of Troy Township in sections 24, 25, 26, and 36. The nature of the rock surface and the precise contacts of the underlying formations in this area cannot be too clearly defined on the basis of the available information. However, the gas wells are in drift associated with rock valleys, or in drift along the contact of the Bedford-Antrim beds. Gas pressures up to 30 pounds were recently reported in this area. Gas wells in sections 8, 9, 10 and 14, Royal Oak Township, are located in drift related to the major rock valley.

From the consideration of all known data it is concluded that gas may be anywhere in the glacial lake plain section, but particularly where sediments bury rock valleys. Gas has also been reported from a great number of borings and water wells drilled in the glacial lake plain sediments of Wayne and Macomb counties. Several opportunities were afforded the writer to study logs of test holes drilled along the frontage of the Detroit River for foundation studies. Gas was nearly always encountered in a hardpan presumed as Illinoian till, which is immediately above the bedrock, and below blue or gray clay up to 100 feet thick. Since the Detroit area is underlain by rocks of Dundee through Antrim age, it is concluded that the gas in the sediments of the lake plain may be derived from several rock formations rather than from the Antrim alone as might be inferred from the discussion relating to Oakland County. Although the nature of the rock surface underlying the entire lake plain is not known in detail, it is very probable that gas in larger concentrations will be found in sediments deposited over existing rock valleys. Its presence adds another unfavorable factor to the quality of groundwater found in the lake plain section. However, the data acquired as the result of this investigation should not preclude development of groundwater if the quality is not impaired by other dissolved minerals. If gas is indicated in otherwise suitable water, then measures should be taken to provide for its escape so as to minimize the danger of explosion.

CHANGES IN QUALITY OF GROUNDWATER IN AN AREA OF HEAVY WITHDRAWAL

In an effort to determine the effect of heavy withdrawal on the quality of groundwater, arrangements were made to secure monthly analyses from several municipal wells that are in service daily. The Birmingham wells were selected, primarily because the city has maintained more complete records relating to groundwater than has any other community within the limits of the glacial lake plain in Oakland County. The city maintains seven wells which are operated daily in accordance with a pumping schedule. Monthly water analyses of each well were made available to the writer, the analyses extending over a period of 32 months excepting occasional omissions. Data from current records do not permit positive conclusions, but some features in the quality of groundwater are suggested, as shown by the plotted analyses on Figure 31. For proper evaluation of the data, it is necessary to call attention to the fact that the analyses shown for the period May 1950 through December 1952[1] were made by the city of Birmingham, and those prior to May 1950 were obtained from the Michigan Department of Health or private sources.

Dissolved Solids

The curves representing the dissolved solids show a pronounced increase whenever a comparison is made between the first available analysis and the analysis of May 1950. The significance of such an increase may be questionable, considering the fact that analyses made by different agencies are being used in the comparison. Despite any possible variations, or inherent errors in the method or technique employed by the analysts, the curves for the dissolved solids show increases for each well. Granted also that a "part per million" represents a fine unit of measure, some of the curves should show a trend in the opposite direction if serious differences were made among the analysts. From May 1950 on, the dissolved solids appear to be somewhat constant, despite the minor monthly variations which may be caused by any of a number of factors. Thus from the data as shown, it appears that high-producing wells in this area are likely to show an increase in dissolved solids initially, but with time the dissolved solids may become more or less stabilized if no other new factors are introduced. This change in the quantity of dissolved solids may represent the withdrawal of water from deeper parts of the drift, or else the start of induced infiltration from the underlying rock formations.

[1]Since the completion of the manuscript, monthly analyses through November 1953 have been added to the charts shown on Figure 31.

The Redding is the only well which suggests a downward trend since May 1950 in the quantity of dissolved solids. It will be recalled that the well is 80 feet in depth and located in the River Rouge valley between Endicott and Quarton lakes in the northern part of the Birmingham area. It is not certain if this decrease can be attributed to induced surface-water seepage by virtue of a reduction in the static level about the pumped well. The dissolved-solid curves for the West, Lincoln, and South wells are remarkably similar. Other quality curves, excepting the chlorides and sodium and potassium curves are also similar. This similarity in the quality of water from the South well (249 feet deep) and from the Lincoln and West wells (173 and 172 feet deep) suggests that all three penetrate the same water-bearing zone, or possibly separate zones that are intimately related. The northwest-southeast alignment of the wells coincides with the trend of the buried rock valley in that area. In any event, the similarity in quality of water tends to support an earlier statement that many of the buried "pockets" of coarser clastics are interconnected in devious ways. Also, the similarity in quality of water tends to support the fact that the three wells are within influence of each other, as suggested by the specific-capacity curve for the South well.

Iron

No general, annual or seasonal trends in the iron content are noted in the groundwater of the Birmingham area; rather, the curves are extremely erratic in trend. From a comparison of values, the iron content for each of the wells is generally considerably above the accepted maximum. Water recovered from the Baldwin well has the greatest iron content, and monthly variations are frequently quite pronounced.

Chlorides

For the Lincoln, West, South and East wells the chloride curves show no appreciable change for the period covered by the monthly analyses. The Walker well shows a gradual but definite increase in chlorides for the past two years. Its nearness to the Clawson and Bundy Tubing Company wells has resulted in local overdevelopment of the drift aquifer, which in turn has led to the infiltration of rock water in that vicinity. For the Redding well, the chlorides show a slight but definite downward trend, which agrees with the decline of the curve for dissolved solids. This decline may be the effect of infiltration or seepage from the River Rouge, but additional data are needed to determine this positively.

Calcium and Magnesium

Excepting the erratic character of the Baldwin well analyses, the calcium and magnesium curves fail to indicate any significant trends. The slight increases or decreases noted are of doubtful significance at the present time. One notable characteristic is the convergent nature of both curves in the latter part of 1950 (August-December), after which they appear to diverge. This characteristic is more noticeable in the calcium and magnesium-hardness curves. No explanation is offered for this behavior.

Sulfates

The sulfates, despite their erratic monthly variations, seem to be increasing. Generally, the sulfates when reported are under 50 ppm and compare favorably with the amount present in surface bodies of water in this region. The Baldwin well is most exceptional as may be noted in the May-June 1952 part of the curve. The increase in concentration of sulfates from 18 to 236 ppm strongly suggests bedrock infiltration of water into the drift mantle.

Sodium and Potassium

Monthly changes in the quantity of sodium and potassium are very conspicuous, but no general trends of either annual or seasonal nature are noticeable.

Bicarbonates and Total Alkalinity

Bicarbonates and total alkalinity curves show a slight downward trend since 1950. The high of each curve occurred during the latter half of 1950 and corresponded in time to the convergence of the calcium and magnesium curves.

Total Hardness

From the plotted curves, the total hardness of water in the Birmingham area appears remarkably constant, showing only a few

slightly increased trends. Only the Baldwin well is exceptional, as may be expected from the nature of the other curves. The total hardness curve eventually intersects the total alkalinity curve as shown on Figure 31. The intersection of the curves marks the point where the total hardness of the water is in part due to the appearance of non-carbonates. From the analyses, it seems evident that wells of high production will initially yield water whose total hardness is owing primarily to carbonates, but with time the non-carbonate hardness factor is introduced. This assumption appears to be supported by the fact that sulfates were absent or less than 10 ppm in nearly all of the groundwater samples collected in the glacial lake plain section.

Chapter VIII

SUMMARY AND CONCLUSIONS

It is estimated that a minimum of thirty million gallons of water is recovered daily from wells in Oakland County. The principal recovery is from the unconsolidated sediments of glacial origin. The underlying bedrock formations contribute but a negligible amount to the total daily withdrawal. Approximately 25 million gallons, or 85 per cent of the total daily recovery, is from within the limits of the nine townships of southeastern Oakland County where 84 per cent of the total county population is settled. The prospects of this area for continued growth in population, industry and business are very promising because of its proximity to Detroit. Its rate of growth, however, will be dependent in part upon the amount of water that becomes available, particularly in that area known as the glacial lake plain section.

Future recovery of groundwater will continue to be from the unconsolidated deposits rather than from bedrock sources because quality and yield are better from the glacial drift. Many more data are needed to evaluate the rate of safe withdrawal in some of the rapidly developing areas within the southeastern part of the county. Inability to locate buried water-bearing sands and gravels before drilling has retarded, to some degree, the development of the groundwater resources of this county. The full development of the groundwater resources will require complete integration of glacial studies with studies of the underlying bedrock surface, primarily with reference to the quality and yield. To secure such data, the cooperation of drillers is desired to the extent that they provide the proper agencies with well records and samples. Geophysical methods can be used to provide the details of the rock surface where they are needed.

THE CONSOLIDATED SEDIMENTS

Oakland County occupies a position along the southeastern margin of the structural basin of southern Michigan, the basin containing consolidated sediments of Paleozoic age. According to Kay (1951, p. 21), Cambrian and Ordovician sediments were deposited in a southwestward plunging pre-Middle Ordovician trough which at the time was not restricted by the Kankakee Arch on the southwest. By upper Silurian time the Southern Peninsula area developed into an autogeosyncline, described by Kay as a structural basin unassociated with rising nearby highlands. The source for the sediments deposited in the basin during Paleozoic time came from the adjacent low lying areas or from quite distant highland areas or from both.

Within the limits of the county, deep exploratory oil and gas wells have penetrated Paleozoic formations which range from the basal beds of the Lower Marshall of Mississippian age through the Salina group of upper Silurian age. The Antrim and younger formations outcrop beneath the drift mantle within the limits of the county, but are nowhere exposed at the surface. They consist principally of shales, sandy shales, or shales with interbedded sandstones or scattered layers and lenses of limestone or dolomite. The Berea is the only prominent sandstone in this series of formations. Formations stratigraphically older than the Antrim are predominantly non-clastic and are represented by limestones, dolomites, anhydrite, gypsum, and salt beds. Clastic sediments such as shales and sandstones are subordinate.

The formations within the county strike east-northeast and west-southwest and have a gentle but undulating regional dip of 25 to 50 feet per mile. The regional dip of the strata is in places modified by local structures such as the extension of the Howell anticline into the southwestern extremity of Oakland County. The dip along the northern flank of this structure is approximately 87 feet per mile. Data relating to bedrock were too meager to permit detection of any additional fold or fault structures within the civil boundaries of the county.

The picture of the pre-glacial rock surface remains incomplete over most of the county since only 168 well logs, of 1,138 collected, recorded that consolidated sediments were reached or penetrated. From the data available, it appears that the physiographic subdivisions of the bedrock topography are twofold and consist of (1) the rock lowland of the Erie-Huron plain and (2) a part of the southeastern slope of the Thumb Upland rock surface. Geographically, the bedrock lowland is in the southeastern extremity of Oakland County, specifically in Royal Oak Township and in parts of Southfield, Farmington, Troy and Avon townships. The elevation of this lowland is generally 500 to 550 feet above sea level except where the surface is incised by valleys. The slope of the rock upland underlies the major part of the county and increases in elevation northwestward from 550 feet to 967 feet above sea level to

the highest known point of the bedrock divide. The principal divide, trending northeast-southwest, is in the northwestern third of the county, and passes from Addison Township southwestward through Oxford, Independence, Springfield, White Lake and Highland townships. Available data indicate that the elevation of the divide decreases toward the southwest. From the position of the principal divide, approximately one-third of the area of the rock surface slopes to the northwest and the remaining two-thirds to the southeast. The outcrop of the Berea sandstone formation indicates that the rock upland slope becomes steeper as the lowland of the Erie-Huron plain is approached.

Because more rock wells and test holes have been drilled in the southeastern part of the county than in the other areas, only the configuration of the rock surface of the Erie-Huron lowland and the lower part of the adjacent upland slope could be shown on the bedrock-contour map. The most prominent of the pre-glacial valleys is traceable from the city of Pontiac southeastward through Birmingham, Royal Oak and thence into Wayne County. Between Birmingham and Pontiac the precise delineation of this valley was not possible, owing to the lack of additional bedrock elevations. A good many smaller valleys, which dissect the lowland as well as breach into the lower slope of the rock upland slope, are also present. Most of these valleys have northwest-southeast trends, but determination of their extension in a northwesterly direction, beyond the upper limits of the Berea sandstone and into the upland slope, is not possible to prove as control data are lacking. Very likely the magnitude of these valleys becomes less significant as the principal bedrock divide is approached to the northwest. The delineation of other valleys, and their tributaries, in the upland area must await additional data from borings or geophysical surveys. However, a few scattered bedrock elevations on both sides of the divide indicate such valleys but not clearly enough to be of value in this report. All elevations of the rock surface have been plotted on the map as a matter of record. In Oakland Township drift thickness of 550 feet was reported, which placed the rock surface at an elevation of 435 feet above sea level at this point. The reliability of this elevation could not be verified. If accurate, it suggests a deep valley, but how the valley may be related to the regional drainage pattern of the county is a question. Excepting the small area northwest of the principal divide, the pre-glacial drainage of Oakland County was predominantly to the southeast.

With the exception of Pleistocene and recent sedimentation, post-Paleozoic sediments are absent in Michigan. Therefore the number of erosion cycles that have been initiated, completed, or interrupted during the long time interval between the end of the Paleozoic and the Pleistocene is not known. This is a difficult problem about which to speculate, considering the immense time interval involved and the fact that a detailed knowledge of the rock surface is still unavailable. Erosional surfaces or straths such as those known in the Appalachian region have yet to be recognized if present in Michigan but probably they were destroyed by peneplanation or by repeated Pleistocene glaciation. However, it is reasonable to assume that erosion cycles were initiated after each of the uplifts resulting from the orogenies that closed the Paleozoic and Mesozoic eras and from the disturbance at the close of the Miocene period. From what is now known of the pre-glacial surface, it seems likely that the bedrock lowland is the product of the erosion cycle initiated by the Miocene disturbance. The development of this lowland and others, in their present geographic positions in Michigan, was dependent upon the basin structure and the amount of uplift. In the Oakland County area, the extension of this lowland surface may have been retarded to some degree by the more resistant Berea sandstone. Since the structural basin was developed during the Paleozoic era, it is probable that earlier erosion cycles may have resulted in physiographic units similar to those of the present rock surface although not necessarily of the same areal extent.

The cycle of erosion initiated by the Miocene disturbance was interrupted by a later uplift that caused the system of bedrock valleys of the lowland and adjacent upland slope. The uplift initiating the second cycle of late Tertiary may have occurred in Pliocene time or possibly in the Pleistocene. Since the presence of tills older than Illinoian is not even suggested in Oakland County, it is probable that if the uplift occurred during the glacial regime, it was pre-Illinoian. As far as known in the county, the valleys of the rock lowland are not more than 100 or 150 feet deep. Their original depth is not known, since subsequent repeated glaciation, which interrupted the second cycle, by its erosive action modified the valley depths and the general elevation of the rock lowland. The rock valleys today are buried by glacial drift. The principal valley is filled mainly by waterlaid till, in which are scattered sand and gravel zones. The tributary which joins the main valley at Berkley has

sand and gravel deposits against a part of the south wall, and it is probable that the floor is covered by similar sediments. The valleys in Farmington and Birmingham are filled with sand and gravel as shown by the number of successful wells of high yields completed in them. Their trends suggest possible extension northwestward beneath the marginal outwash deposits and the Inner and Outer Defiance moraines. From the general conditions, the sediments in the rock valleys are favorably situated with respect to local natural recharge and in respect to the piezometric gradient. Future exploration should be directed toward (1) determining the extension of the known valleys and (2) the location of bedrock valleys not yet detected. Inasmuch as the general trend of the valleys is northwest-southeast, it seems appropriate that future test drilling or geophysical surveys be conducted along lines at right angles to the predominant trend. In recent years electrical resistivity methods have been successfully employed in the location of large aquifers within glacial till and for the location of drift-covered valleys (Spicer, 1952).

THE UNCONSOLIDATED SEDIMENTS

Excepting small deposits of recent alluvium along some of the principal streams of the county, the surficial mantle overlying the bedrock formations is of Pleistocene origin and consists of outwash sands and gravels, unassorted till deposits, and lacustrine clays and silts. The till deposits are mainly clays or clays with varying admixtures of sand, gravel and boulders. Within the till may be found interbedded and scattered deposits of sorted sands and gravels of different thicknesses and extent. Some are sufficiently large that they yield moderate to large supplies of water. The bulk of the till deposits forms two belts of morainic hills which trend across the county from northeast to southwest. The more northerly range contains some of the most elevated tracts in the county (1,000-1,100 feet) and is associated with the withdrawal of the Saginaw ice lobe. The major divide, separating the north- and south-flowing drainage systems, can be traced along a good portion of this range. The southerly range, associated with the movements of the Erie-Huron lobe, is somewhat lower in elevation (800-1,000 feet). The waterlaid Birmingham and Detroit Interlobate moraines which are within the glacial lake plain section are likewise composed of till deposits.

The two belts of morainic hills are separated by interlobate outwash deposits that form a sandy and gravelly plain, in which the clays and tills are subordinate. The elevation of the plain increases gradually northeastward, its surface pitted with numerous depressions, many of which contain lakes. The hills rising above the general level of the plain are either kames that formed at the junction of the Saginaw and Erie-Huron ice lobes, or are clusters of morainic hills. Marginal outwash sediments are between the Inner and Outer Defiance moraines. Additional sand-gravel outwash deposits of local extent are irregular patches within the morainic belts.

The sediments of the lake plain section of the county are deposited almost entirely on the surface of the rock lowland and consist of waterlaid till that has been partly reworked by water and covered by a veneer of lacustrine clays and silts. As in the moraines, scattered zones of sorted coarse clastics are interbedded, but the data indicate that they are usually less numerous, of smaller magnitude and more difficult to locate in advance of drilling. The profiles constructed across the lake plain from northwest to southeast suggest that sands and gravels are more abundant to the northwest. A series of beaches, which are deposits of former glacial lakes impounded between the morainic hills and the ice front, interrupts the surface of the lake plain. Additional surface deposits of a sandy to gravelly character are associated with eskers, spits, bars, deltas and river terraces—all of which are associated with the last withdrawal of Wisconsin ice.

The surface features of Oakland County were formed during the last (Wisconsin) period of Pleistocene glaciation. Evidence of earlier ice visitations in the county is meager and very scattered. Leverett (1906-07) referred to Illinoian till in the flowing-well district centered about Ortonville. Stanley (1936, p. 12) referred to a probable Illinoian till exposed at the base of a railroad cut near Birmingham. At this exposure the probable Illinoian till is separated from the younger Wisconsin till by a conspicuous layer of gravel. But this gravel may be also interpreted as an outwash between tills deposited by an earlier substage of Wisconsin ice. Other evidence of possible pre-Wisconsin glacial deposition consists of buried fragments of plant remains reported in well records, cited in the geologic literature, and reported orally to the writer. Some well logs record the penetration of red, brown, yellow or purplish clays which might be interpreted as oxidized zones. Such oxidized zones and the remains of plant matter in drift immediately

above the bedrock in Oakland County were twice noted as the well records were collected and evaluated. These facts may indicate Illinoian till since they correspond to the occurrence of Illinoian till in the Detroit region. Leverett reported that Illinoian till, resting directly on bedrock, was exposed during the excavation of the Livingston Channel in the Detroit River. Also, a number of records of test holes drilled along the Detroit River water front revealed poorly to well cemented, brown sediments immediately over the rock surface, and underlying 80 to 100 feet of blue clay. The oxidized zones at shallower depths are more likely representative of Wisconsin substages of glaciation, and possibly of fluctuations within a substage. Although the evidence is by no means conclusive it seems that the oldest till known thus far found in Oakland County is of Illinoian age, but owing to the erosion by later glaciation only fragmentary patches remain.

Considering the slope of the rock surface, the movement of Wisconsin ice over the area and the resultant features produced, especially over the glacial lake plain, a question has been raised as to whether pre-Wisconsin glaciation, or possibly Wisconsin substages, produced features similar to those seen at the surface today. Thus, if earlier glacial lakes were in existence, then their beaches and associated features were subsequently buried or else partially or completely obliterated by later glaciation. The buried sand and gravel deposits of the glacial lake plain may represent features of earlier glacial lakes or merely local deposits of sorted sediments deposited by glacial meltwaters. Large bodies of gravel in the moraine-till areas may be either outwash separating tills of different ages or substages or merely local outwash deposited by local glacial meltwaters. The correct interpretation of earlier glacial episodes requires more precise data. A series of profiles is needed. They should be constructed at right angles to the major trend of the glacial features and based on a series of favorably spaced borings whose logs bear more precise descriptions of the sediments penetrated. Such a program is not usually practical, unless independently financed, since wells and borings are drilled for other than purely academic purposes involving interpretation of glacial history. However, data for such studies can be obtained if local drillers can be induced to cooperate to the extent of providing the proper agencies with better logs and samples for each well or boring completed in the future. Information would be available for all drillers concerned, and for the integration with the present known facts by students of glacial geology.

OCCURRENCE OF GROUNDWATER IN THE COUNTY

From the description of the bedrock and glacial geology of the area, it is readily apparent that groundwater in the county is under confined and unconfined conditions. Unconfined groundwater is mainly in the interlobate outwash area as shown by the harmony of static levels in wells with the levels of the inland lakes. Exceptions are wells that were completed in the morainic hills that stand above the general level of the outwash. Confined groundwater conditions are found in the many sand and gravel bodies that are interbedded with the unassorted till deposits of the two morainic ranges and the waterlaid moraines of the lake plain. The static levels of wells that penetrate such buried aquifers are usually not in harmony with the level of the inland lakes in the immediate vicinity. The piezometric map constructed for Oakland County thus represents water-table conditions over the interlobate outwash and artesian conditions predominating over most of the remaining area. The map is based on static water levels measured or reported for wells completed during the period 1946-1950. Additional levels for the same period were obtained from private or municipal sources. The resultant map compares favorably with a similar map constructed by Taylor in 1930. The principal groundwater divide is approximately along the junction of the interlobate outwash and the morainic deposits left by the retreat of the Saginaw lobe. The position of the divide also approximates the topographic divide but is slightly offset to the southeast. On the map the divide can be traced from the northeast corner of Brandon Township southwestward through Independence, Springfield, White Lake, and Highland townships, and thence into the adjacent county to the west. The divide has an elevation between 1,000 and 1,050 feet above sea level and slopes to the southwest. Excepting in a small area northwest of the divide, the movement of groundwater in Oakland County is in a southeasterly direction. A secondary divide is near Walled Lake in southwestern Oakland County, in the townships of Milford, Commerce, Novi and Lyon. The position of this divide suggests that Walled Lake, as well as its immediate surrounding area, may be a local recharge basin that serves to maintain the somewhat higher water levels reported for the vicinity.

The contours shown on the piezometric map show an uneven water-table surface which changes its character with each period of significant precipitation. The gradient of the water-table surface is more gentle in the outwash area, in contrast to the steeper gradient associated with the moraine-till area and the glacial lake plain. The bunching of the contours along a northeast-southwest trending belt marked by the junction of the glacial lake plain with the southern morainic belt is of special interest. Southeastward from this belt the contours show a more gentle piezometric gradient over most of the lake plain area of the county. This behavior appears to be in harmony with the nature of sediments as suggested by the several profiles drawn across the lake plain section. It was previously noted that the volume of coarser sediments becomes greater as the junction of the lake plain with the moraine is approached. From this junction the pressure declines more rapidly since the decrease in size and in number of the buried aquifers (and hence volume) offers a greater frictional resistance to percolating water, thereby causing a more rapid loss of head. The present water-table map departs in only two respects from Taylor's map of 1930. The most significant departure is the 75-foot difference in elevation of the southeasternmost contour. This difference indicates the approximate magnitude of the decline in the piezometric surface that has taken place in the southeastern extremity of Oakland County since 1930. The amount of decline decreases in a northwesterly direction. The other departure is that local areas of heavy groundwater withdrawal are shown by the depression contours. Areas of concentrated groundwater withdrawal are in Pontiac, Birmingham, Berkley and the Royal Oak-Clawson areas and align themselves in a northwest-southeast direction: That is, at right angles to the trend of the contours. The regional decline of the piezometric surface in the lake plain area is in part due to the areas of heavy withdrawal, but no doubt other factors have contributed to the decline. These factors include (1) the decrease in the amount of natural recharge by direct precipitation upon the area through the construction of dwellings and roads, (2) the increase in run-off resulting directly from the construction of roads, sewer lines, and drainage ditches, and (3) the drainage of former marsh areas to provide additional land for farming or urbanization. The data collected during this investigation were not of a nature to permit quantitative evaluation of the factors involved.

THE HYDROLOGIC UNITS

From the summary given of the bedrock and surface geology, it appears that at least four distinct hydrologic units are within the limits of Oakland County. The mantle of glacial drift contains three of the hydrologic units, and the consolidated sediments comprise but one. This subdivision is justified on the basis of the following factors, namely (1) the presence of water in consolidated or unconsolidated sediments, (2) the presence of water in conditions of confinement or unconfinement, (3) the quality of the water, and (4) the ease of recovery.

The Bedrock Unit

The first and most widespread of the hydrologic units is the underlying bedrock formations. It is treated as a single entity because recovery of water from this unit is almost negligible and because the amount of usable data is too meager to permit further subdivision of the unit. From the structure of the underlying formations and the nature and distribution of the overlying mantle, it is apparent that water in this unit is under confined conditions, the movement of water contained therein being generally in an up-dip direction. Static levels in the rock wells examined always stood above the elevation of the bedrock surface or above the ground surface, depending upon the geographic and topographic positions of the individual wells. For only 38 of 113 borings and wells that reached or penetrated bedrock were logs kept that bear sufficient information to permit tabulation as to static levels and yields. Of the tabulated wells, eleven were flowing with heads up to 5 feet above ground surface. The remaining non-flowing artesian wells had reported levels as much as 95 feet below the top of the casing or ground surface. Reported yields (natural flow or pumped) of all wells varied from 1.5 to 100 gpm with an average of 20 gpm. The water-bearing characteristics of each of the underlying formations could not be determined from the data obtained, but the records show that the specific capacity of rock wells ranged from 0.06 to 10.0 gpm per foot of drawdown and averaged 2 gpm. The individual yields from most of the wells of this unit were small. Even if the quality of water is disregarded, the quantity is likely to be insufficient to permit utilization as a coolant for refrigerating or air conditioning systems which require large volumes of water.

This unit is distinctive from the other hydrologic units since the quality of water from practically all wells is considerably more

mineralized than the water recovered from the unconsolidated glacial mantle. Excepting iron, silica and some alkalies, the dissolved mineral constituents show a significant increase and/or a wide range when compared to drift water. A comparison of bedrock-water samples factor by factor with the acceptable standards indicates that most water recovered from the bedrock is objectionable in nearly all respects. The available analyses show a hardness ranging from 270 to 45,945 ppm, with non-carbonate hardness varying from 42 to 45,907 ppm and carbonate hardness from 2 to 230 ppm. Thus, water from this hydrologic unit is characterized by a non-carbonate, or permanent, hardness that is largely owing to chlorides and sulfates. The degree of mineralization increases with the depth of penetration into the bedrock. Analyses tabulated with respect to depth show that the dissolved solids increased from 1,570 to 175,800 ppm, chlorides from 360 to 102,500 ppm, sulfates from 0 to 1,881 ppm, sodium and potassium 517 to 45,908 ppm, calcium 56 to 12,450 ppm and magnesium 26 to 3,600 ppm. A pronounced change in the degree of mineralization is most apparent in waters recovered from formations older than the Antrim shale. Analyses of water samples taken from deep borings strongly indicate the impossibility of recovering palatable water even for livestock purposes from the deeper rocks. Bedrock water recovered from within the outcrop limits of the individual formations immediately beneath the mantle is generally less mineralized but not enough to compare favorably with the quality of water taken from the drift. Actually, palatable water from any one particular formation is more likely to be recovered from within its outcrop limits beneath the drift than from areas where that formation is overlain by other rock layers. Although most of the chemical analyses appear unfavorable, it may be possible to obtain additional palatable waters from this unit. Recovery of palatable water from rock wells for domestic, farm and stock purposes will be controlled by such factors as (1) the depth of penetration into rock, (2) the position of the rock well with respect to the regional topography of the bedrock surface, (3) the position of the well with respect to local bedrock topography, and (4) the amount of dilution of bedrock water by infiltration from the overlying sediments.

The Interlobate Outwash Unit

The second hydrologic unit consists of the interlobate outwash deposits between the two ranges of morainic hills. This unit is the major intake area for recharge in the county. Water of the unit is primarily under unconfined, or water-table, conditions as demonstrated by the harmony of inland lake levels with the reported static levels in wells. Inasmuch as natural materials are seldom, if ever, entirely without structure, confined groundwater conditions are scattered within the interlobate outwash. Flowing wells or springs may be in depressions or near the base of relatively steep slopes that have fine sands overlying coarser materials. Wells within this unit average 92 feet in depth but range anywhere between 18 and 320 feet. Actually the depth of any well is more dependent upon the topographic situation than upon the configuration of the water-table surface. Adequate supplies for most domestic, farm and commercial purposes are generally obtained from wells between 20 and 60 feet in depth. Yields range from 1 to 925 gpm and average 70 gpm. From a tabulation of the records it was noted that two-inch driven wells furnished 10 gpm, three-inch wells between 10 and 30 gpm, and six-inch wells between 50 and 300 gpm. Yields from 100 to 925 gpm have been reported mainly from municipal or industrial wells 8 to 12 inches in diameter. Specific capacities ranged from 1.5 to 27 gpm per foot of drawdown and averaged 13 gpm per foot of drawdown. Most of the highly productive wells reported from this area were not developed by any special methods other than continuous pumping. The water level in wells ranged from 1 to 192 feet below ground surface and averaged 33 feet. As far as records show, no decline occurs in the regional water level other than the secular, annual or seasonal fluctuations that occur in response to the variation in the amount of precipitation falling upon the area. Even progressive declines of a local character are notably absent within the limits of this hydrologic unit.

Excepting iron, the quality of water recovered from the outwash can be rated satisfactory for most needs. Dissolved solids average 354 ppm, chlorides 15 ppm, and sulfates 29 ppm. The total hardness averages 298 ppm and approaches the upper limit of waters classified as satisfactory. In direct contrast to bedrock water, the total hardness of water from the outwash is dominantly carbonate rather than non-carbonate. The principal communities located within the boundaries of this unit having a groundwater-supply system are the villages of Milford, Lake Orion, Oxford, Holly and South Lyon. On the basis of metered and estimated water consumption, the total combined pumpage of these villages is approximately 1.6 million gallons daily. No water problems have arisen restricting the use of water for any purpose, and from the present data, this unit is capable of extensive groundwater development.

The Unassorted Till Unit

The third hydrologic unit consists of the unassorted till deposits associated with the northern and southern morainic belts of hills that stand above the general elevation of the intervening interlobate tract. The vast number of wells tap sand and gravel aquifers of various dimensions that are interbedded with materials characterized by a poorer permeability coefficient, thus the water contained within the aquifers is under confined conditions and most of the wells of this unit can be classed as artesian, although only a few of them are actually flowing. The few reported flows within the area may be attributed either to their lesser topographic elevation with respect to the altitude of the interlobate outwash intake area, or to local, but individually independent, artesian structures. Unconfined, and even perched, conditions of groundwater are restricted to the scattered surface deposits of coarse clastics. Recharge of the buried aquifers is accomplished partly by the percolation of water from the principal area of intake and partly by precipitation falling directly upon the area. The magnitude of each form of recharge has not been evaluated, but no doubt the depth, extent, and interdependency of each of the aquifers determine to a considerable degree which form of recharge is to be the most effective. The importance of recharge by direct precipitation within the limits of this hydrologic unit cannot be minimized since the topographic character of the surface lends itself favorably to this kind of recharge. The numerous depressions and lakes not only act as reservoirs to regulate stream flow but likewise act as reservoirs for groundwater recharge, especially under conditions of prolonged drought or of heavy withdrawal. The surface deposits of coarse clastics, depending upon their location in relation to higher terrain, likewise constitute storage reservoirs which under proper conditions may slowly release water to the buried aquifers. The profiles drawn in the Pontiac region suggest the probability of many complex direct and indirect connections of surface sands and gravels with sands and gravels buried at various depths.

The depth of wells in this unit is between 24 and 330 feet with the average depth being 129 feet. Approximately 50 per cent of the wells are less than 100 feet in depth and nearly all provide more than adequate yields for domestic purposes. Most wells of high yields, constructed for municipal or industrial purposes were found to penetrate large aquifers at depths of 150 or more feet. The depth to the water level ranged from 17 to 165 feet for the non-flowing wells and averaged 43 feet. Flowing wells are not common, nor are they concentrated in any particular district. The average yield of flowing wells in this unit is 99 gpm with a range from 2 to 1,225 gpm. Two- to four-inch wells furnished as much as 30 gpm, 6-inch wells up to 50 gpm, and 8- to 14-inch wells had yields from 600 to 1,000 gpm. Specific capacities, measured in gallons per minute per foot of drawdown, ranged from 0.1 to 100 and averaged 11.8. The water recovered from this unit is similar in quality to water obtained from the outwash unit. In the majority of wells, the various dissolved constituents were found to have only slightly higher averages; the chlorides show a more prominent, though not serious, change—averaging 27 ppm or 12 ppm more than in the second unit; total hardness averaged 314 ppm, which is slightly more than the upper limits of waters classified as satisfactory; carbonate hardness averaged 289 ppm, and the non-carbonate 26 ppm.

Pontiac and Rochester are the largest communities within the unit. Both towns have public groundwater-supply systems with pumpage that, in 1950, averaged 12.2 million gallons per day for Pontiac and 0.7 mgd for Rochester. The village of Rochester has an excellent system, the supply is more than ample, and so far as is known, no noticeable decline is detectable in the static level. Within the civil limits of Pontiac two areas of heavy groundwater withdrawal are shown on the water-table map. The decline in the smaller of the two areas is owing to three closely spaced industrial wells that have a combined daily capacity of at least 2.6 million gallons. The decline for the larger area has been caused by heavy withdrawal by a concentration of municipal wells that tap a buried marginal outwash deposit which trends across the city from west to east. The wells owned by the city roughly follow the course of the Clinton River. In 1888 the static water level of wells located in the western end of the city stood at ground level. By 1930 the static level declined to 50 feet below surface and by 1950 the average water level was 104 feet. This represents a decline of 1.68 feet yearly since 1888, and a decline of 2.7 feet per year since 1930. With minor exceptions, the groundwater pumpage has increased from an average of three million gallons daily in 1922 to 16 million gallons daily in 1950. In the decade 1940-1950 the population of

Pontiac increased only 9 per cent, but since the termination of World War II, the pumpage chart shows a sharp upward trend which is attributed to the greater consumption of water by both the old and the new industries established in the city. As long as the demand for water increases yearly, the static head will continue to decline, and no stabilization of the water level can be expected until the annual consumption rate becomes stable. Thus, it cannot be stated definitely that the aquifer has been overdeveloped until further hydrologic studies involving pumping tests on the stratum are made. However, the decline in static level may mean that the withdrawal exceeds the rate of replenishment from immediate storage, and if so then a problem of transmissibility exists. The current rate of decline in the static level of the Pontiac wells can be decreased by artificial recharge. This can be accomplished by diverting a part of the Clinton River flow (with prior treatment) directly into the aquifer by means of recharge wells. This form of recharge could best take place during the winter and early spring seasons when (1) the rate of flow of the Clinton River is more than the summer average, (2) the temperature of the water is most favorable, (3) disagreeable tastes and odors are at a minimum, and (4) the recovery of water from the aquifer is at its lowest rate. In addition, the present situation may be partly remedied through the construction of additional wells in the more northerly parts of the city. A carefully planned test-drilling program based on the available knowledge of the region should be followed. The construction of wells in other areas would relieve to some degree the concentrated pumpage which is now taking place from a theoretically "single" aquifer. Reduction in the rate of withdrawal would be reflected either in a rise of the static level within the present area and perhaps lead to equilibrium conditions, or to a lower rate of decline. Considering all factors, the city of Pontiac is most favorably situated geographically for the development of an artificial recharge program, and the geologic conditions within its limits are such that obtaining additional water supplies is possible. Certainly the large number of inland lakes within Pontiac's immediate vicinity is sufficient evidence that an abundance of water is in storage both on and beneath the surface, and that the problem faced by the municipality is primarily one of groundwater transmissibility.

From a review of the well records and geologic conditions of this hydrologic unit, it is concluded that the potential groundwater supply has been only partially developed. Records show that moderate supplies for most purposes are easily obtained but that test drilling will be necessary to locate large buried aquifers for municipal or industrial water supplies.

The Glacial Lake Plain Unit

The sediments within the limits of the glacial lake plain constitute the fourth hydrologic unit in Oakland County. From the limits of the southern morainic belt of hills, the elevation of the lake plain declines gradually to the southeast so that the average elevation of this unit is below the moraines and interlobate outwash. As in the unassorted till unit, recovery of water is largely from buried deposits of sand and gravel in which water is under confined conditions. Some of the sand and gravel deposits are associated with bedrock valleys, as shown by profiles for the cities of Farmington and Birmingham. Other buried sands and gravels may represent either features deposited by meltwater or remnants of beaches and other features formed by earlier glacial activity but similar to those on the present surface of the lake plain. Regardless of origin, the presence and location of such favorable sediments for groundwater recovery are difficult to determine in advance of drilling. Furthermore, fewer beds of buried sands and/or gravels are within the waterlaid till deposits of this unit than in the moraines and tills found elsewhere in the county. This is partially attested by the larger number of dry holes or wells of very low yield that have been drilled in the area. The profiles drawn across the lake plain show that the volume and frequency of coarse clastic deposits decrease southward. The profiles likewise indicate that most of the individual zones of sand and gravel cannot be correlated between the test holes, even though the borings are closely spaced. This fact suggests that many of the aquifers are of small areal extent and of limited storage capacity. Therefore in all probability a well tapping such an aquifer not only obtains water from the bed in which it is completed but also drains other neighboring beds, above and/or below, despite any till barriers between them, since few natural sediments are totally impermeable. Whenever clay zones act as more effective barriers against the drainage of water from higher levels, infiltration from lower sources and even from bedrock will occur if the pumping rate has sufficiently lowered the pressure within the tapped aquifer. This may explain the erratic variation of the chloride content in water samples recovered from relatively

closely spaced wells. Within the unit groundwater is also under water-table conditions, but is limited to the surface deposits of sand and gravel whose origin is associated with the glacial lakes of Wisconsin time or with contemporaneous stream deposition. In the time of early settlement shallow dug wells were commonly constructed in such deposits. Recharge of the buried aquifers is accomplished by percolation of water from the higher land that is to the northwest. To some extent recharge by direct precipitation is possible despite the low permeability coefficient of the sediments, but this form of recharge would be effective only for the replenishment of water in the surface deposits of sand and gravel. Recharge by precipitation is somewhat less effective now than in the past since urbanization normally leads to increased run-off and rapid drainage.

Wells of this unit ranged in depth from 10 to 258 feet and averaged 109 feet. The average depth of wells drilled since 1930, on the whole was not greater than the average depth of wells drilled before 1910. A distinctive feature of this unit is the abundance of flowing wells in contrast to other units. The lake plain area centering about Troy, Royal Oak and Southfield townships is the largest of the flowing-well districts in southeastern Michigan. From the known geologic conditions it can be concluded that flowing wells may be obtained anywhere within the lake plain provided the established head is sufficient to overcome the frictional resistance offered by the highly varied glacial deposits of the area. The number of flowing wells has declined considerably since the time of Leverett's study. In the tabulation of wells drilled before 1910 included in Leverett's report 97 per cent of the total were reported as flowing. Static levels at the time ranged from 9 feet below to 30 feet above ground surface. Of the 193 records collected for this unit of wells which were drilled in the period 1930 to 1950, only 30 wells (approximately 15%) were reported as flowing. Static levels ranged from 137 feet below the surface to 9 feet above. In the past a non-flowing well was the exception rather than the rule; today the flowing well is exceptional. The average static level of the non-flowing wells is 32 feet. The average level below ground surface is 81 feet in Royal Oak Township and 16 feet in Avon Township. The decline in head is clearly shown in the current water-table map by comparison with the map prepared by Taylor in 1930. The areal decline shown for the lake plain unit may be attributed in part to the several areas of concentrated groundwater withdrawal centered about Royal Oak, Birmingham, Berkley, and Clawson and partly to conditions that have resulted from the urbanization of the area.

Reported yields ranged from 0.2 to 1,500 gpm and averaged 102 gpm. The average yield is somewhat high in contrast to the figures cited for the other hydrologic units of the glacial drift, but an explanation is found in the increased diameters of wells and in well improvements, particularly of those wells owned by the several municipalities of the area. Actually, of all the yields reported, 72 per cent were less than 21 gpm. A breakdown of yields in relation to casing diameter revealed that most 2-inch wells furnished less than 10 gpm, and 3- to 6-inch wells not more than 30 gpm. Scattered yields between 50 and 450 gpm were from 8-inch wells, and yields between 500 and 1,000 gpm were furnished normally by 12-inch wells. Exceptionally high yields up to 1,500 gpm required wells having diameters between 18 and 30 inches. The extremely large casings required to produce wells of good yields are an indication of the difficulty involved in developing large water supplies in the lake plain unit. It is not surprising that the specific capacities per foot of drawdown ranged from 0.03 to 166.4 gpm and averaged 22.4 gpm.

The quality of water within the limits of the lake plain has some notable differences which make this hydrologic unit even more distinctive from the others in the mantle. The dissolved solids average 430 ppm, which is greater than is normal elsewhere in the county. The total hardness, calcium, magnesium and sulfates, on the other hand, average generally less when compared with the other units of the drift mantle. The chlorides and the sodium and potassium combined are conspicuously higher, averaging 83 and 68 ppm respectively. Total hardness ranges from 34 to 446 ppm and averages 238 ppm or 60 to 76 ppm less than for the other two hydrologic units. As usual, the carbonate hardness predominates; the non-carbonate hardness averages but 6 ppm. Two possible explanations may account for the lower average value in the hardness of groundwater from this unit. First, the decrease in hardness itself might be an indication that the major recharge of the buried aquifers is not from the moraines and more distant interlobate outwash areas; that precipitation over the area may be significant in recharging the area to the extent of decreasing the hardness factor of the water since percolation in the direction of the hydraulic gradient should bring in water of greater hardness

from the moraine and interlobate outwash areas. Recharge by precipitation through more local intake areas would result in diluting the hardness because a part of the calcium and magnesium of the waterlaid and lacustrine sediments was previously leached away by the waters of the pro-glacial lakes. The second, or alternative explanation for the lower average hardness of groundwater in this unit may be the result of a natural softening brought about by the process of base exchange. Excess sodium ions in the sediments, brought in by periodic infiltration of bedrock waters, may be exchanged for the hardness-producing calcium and magnesium ions more commonly present in the drift waters. Some mechanics of percolation between drift and rock waters must be involved since the mere intermingling of both would not likely result in a decreased hardness. The non-carbonate hardness of water recovered from wells of this unit is extremely low. It was noted in a majority of records that the initial analyses of water samples taken from newly constructed wells always indicated either a total absence of, or a very low value in the non-carbonate hardness content. After the wells had been in use for some time, subsequent analyses generally revealed the appearance of, or an increase in, the non-carbonate hardness. The sulfate content of the water samples averaged but 12 ppm, and in the tabulation of the analyses for the lake plain section the sulfate was parallel to the non-carbonate hardness.

The most conspicuous difference in the quality of water of this unit is in the amount of chloride, sodium and potassium. The chlorides ranged from 4 to 320 ppm and averaged 83 ppm; sodium and potassium combined were 20 to 239 ppm with an average of 68 ppm. It is not surprising that the chloride salts are in tasteable quantity. Salt in the sediments of the lake plain may be accounted for by both natural and induced infiltration from the underlying rock formations. Since the sediments of the lake plain have been deposited over the rock lowland and against the lower part of the upland slope, they are in a favorable position to receive the more highly mineralized bedrock waters whose movement in the consolidated beds is in an up-dip direction. With but rare exceptions, wells reported to have water with a salty taste, or for which analyses revealed 50 ppm or more of chlorides, are within the limits of the lake plain. The chloride content of the water apparently increased southeastward, and its concentration was found greatest in sediments filling, or closely associated with, bedrock valleys.

Additional bedrock infiltration of an induced nature was also caused locally through improper grouting of unsatisfactory rock wells and test holes, or by the heavy withdrawal of drift water in areas where highly productive wells are concentrated. Monthly analyses of water samples taken from two Birmingham wells indicate such induced infiltration from bedrock sources. The few analyses of samples taken from Royal Oak, Berkley and Clawson wells suggest induced infiltration, but cannot be demonstrated graphically.

The quality of water within this unit is further impaired by the gas in the drift. Gas wells and water wells having gas shows were found only within the limits of this lake plain unit. Most of the gas was from coarse sediments interbedded within the clays and tills, and in a few places was reported in clays described as soft, soupy or putty-like. The gas-bearing zones are at various depths beneath the surface and have pressures as high as 30 pounds. The wells when plotted on a base map were found to be mainly in that part of the lake plain mantle immediately overlying the Antrim shale, and particularly in sediments filling or covering the rock valleys carved in the Antrim shale. The largest of the known drift gas areas is centered around the city of Clawson whose inhabitants utilized this gas as a source of fuel for cooking and for space heating. In recent years many of the gas wells have been abandoned owing to declining pressures and the infiltration of water. The source of the gas in the drift is concluded to be principally seepage from the Antrim shale. It is not believed to be marsh gas of more recent origin since logs of holes drilled within the unit fail to show any evidence of peat deposits or other organic matter in sufficient quantity. Owing to the number of well explosions, gas in the drift is considered as another unfavorable factor in the quality of water in this area. However, the presence of gas should not preclude the development of groundwater in this unit if the quality is not impaired by other dissolved constituents since proper measures can be taken for its disposal to avoid explosions.

In addition to several unincorporated subdivisions, the principal communities within the lake plain unit depending totally or partially upon a groundwater supply are the cities of Royal Oak, Berkley, Clawson, Birmingham and Farmington. All but Farmington have been concerned with water problems during the past several years. Because of the perimeter spacing of wells and the operation of wells according to a pumping schedule, the decline of the static level, as shown by the hydrographs, in the Birmingham area has

been slight in contrast to the other areas within the unit. Although Birmingham is concerned over future water demands, artificial recharge is possible by using surface waters from Endicott and/or Quarton lakes during the winter and spring seasons. It appears that the city can continue further development only to the point of limitations placed by the infiltration of rock waters, and to some degree it may be also limited by the laws of riparian rights. The declines centered about Royal Oak, Berkley and Clawson have been difficult to evaluate owing to the lack of hydrographs. However, it appears that withdrawal has been excessive as indicated by a few measurements of water levels, by declining yields and the increase in chlorides. It may perhaps be justifiable to state that the water supply has been overdeveloped at least to the point where induced infiltration of rock water has impaired the quality of drift water. This in itself is also an indication that transmissibility of water from the higher areas to the northwest does not keep up with the present rate of withdrawal. The water-table map shows that these municipalities are situated in an area where the decline of the piezometric surface has been greatest.

An examination on a strictly qualitative basis of the data collected seems to indicate that the lake plain aquifers are incapable, except at great cost and effort, of meeting a demand to be imposed by a future populace with a density comparable to that of the Detroit area. The area is capable of furnishing small supplies for most domestic needs; but a number of small areas already exist where building has not commenced, or else where it has been retarded in further development, owing to an inadequate water supply or to failure in locating and developing one. Without question some additional supplies can be developed to ease the shortages that occur today during the summer season, but it is doubtful if the large population predicted for 1970 for the lake plain area can be entirely supplied by groundwater resources. The basis for this conclusion has been made from the following considerations:

1. The thickness of the drift cover over the rock lowland is thin in comparison to the drift cover found elsewhere. Thicknesses in excess of 150 feet are found only over the buried rock valleys. This limits the number of possible aquifers before bedrock is reached.

2. The profiles constructed across the area suggest that the coarse sediments which may serve as satisfactory aquifers for moderate to large supplies are largely deposited in that part of the

lake plain adjacent to the moraines. Southward, as may be noted, the volume and number of sand and gravel zones seem to decrease.

3. It is doubtful whether large bodies of sand and gravel are buried within the waterlaid and lacustrine deposits. At best, the profiles seem to indicate many small zones, and the heavy withdrawal of water by wells from any one of them no doubt leads to the drainage of water from others in the vicinity. Depending upon the permeability and position of the clay barriers, the transmissibility of water from the surrounding clays into the aquifers may be slow in contrast to the rate of withdrawal. Thus, overdevelopment of such localized aquifers is possible and eventually will lead to the further lowering and enlargement of the depressions already in the piezometric surface.

4. The water-table map shows a gradient to the southeast, and the crowding of the contours in a belt defined by the Maumee beaches suggests a change in the transmissibility coefficient of the sediments in the lake plain area. Thus, the small bodies of sand and gravel in the more southerly area are handicapped in relation to the rate of recharge that could take place by percolation of water from the northwest. Furthermore, because of the lower permeability coefficient of sediments in the area, the rate of recharge by direct precipitation on the area may be slow and ineffective. This form of recharge is further impeded by urbanization which has increased run-off and reduced the size of the area which can absorb rainfall.

5. The valleys incised into the rock lowland, as revealed by the well logs, are not for the most part of exceptional magnitude nor always filled with coarse clastics such as could constitute aquifers of large storage and/or good permeability. From what is known of the glacial history, it is likely that many of the valleys are filled primarily by waterlaid till in which are some lenses of sorted materials. Only two small valleys have been found which are sand- and gravel-filled and have been tapped by wells.

6. Recourse to artificial recharge is limited by the availability of surface-water supplies, and by cost if consideration is given to the utilization of flood waters arising from periods of excessive precipitation. If recharge by surface water is considered, only Birmingham is most favorably located. Other communities must depend on streams whose rate of discharge must be measured before utilization—or else the issue of riparian rights becomes involved.

Utilization of flood waters will be costly since a single system of sewers now exists in the area for the disposal of flood waters and sewage.

7. Recourse to bedrock for additional supplies on a large scale is not possible for reasons of quality if not quantity. Furthermore, it has been demonstrated that the heavy withdrawal of groundwater locally from drift has already resulted in the induced infiltration of bedrock water that is highly mineralized. Thus, certain areas are already approaching overdevelopment since induced infiltration of rock waters has partially impaired the quality of drift water.

8. Development of large supplies of water from the drift of this area to meet future demands cannot be made on a community level, but must be accomplished on a regional level. Development on a community level may result at some time in legal complications. The known good aquifers, as well as those yet to be discovered, are not controlled by civil boundaries. Adjacent communities may tap the same aquifers and legal questions of priority will arise if the water situation becomes more critical. Furthermore, development on a community level restricts exploration largely to its civil limits, and if no additional aquifers are found, then added cost is imposed in obtaining water from beyond its limits. Development on a regional level likewise has problems, involving the organization of an authority, the evaluation of the water problems of the individual units of government, and the procurement of funds for planning, exploration and development. From the preceding statements no attempt is made to argue that groundwater is lacking within the hydrologic unit defined by the limits of the lake plain. The quantity of water in storage is great because a layer of 100 feet of sediments spread over the entire lake plain (approximately 180 square miles) having an arbitrarily chosen porosity of 20 per cent, is capable of storing more than 700 billion gallons of water. However, it is argued that this unit contains major problems involving quality and transmissibility of water. Thus, to recover water from ground sources in sufficient quantity and of acceptable quality may result in the excessive expenditure of funds and effort for a great number of wells without the constant assurance of dependability. It appears that the most reasonable solution, from the standpoint of cost and the immediate availability of water, involves (1) the continuation of groundwater exploration and development within the unit, (2) the extension and development of the facilities of the

Detroit water-supply system into the southern Oakland County area to augment the groundwater supply, and (3) the creation of a regional water commission whose membership is represented by the communities and areas involved. This commission must be given authority to plan and act in the future interests of all. It is conceivable that even the future facilities of the Detroit water-supply system may be inadequate to deal with the demands imposed by surrounding fringe areas. A regional water commission may well justify its existence in planning a surface-water supply system from Lake Huron to serve Oakland and Macomb counties. The rapid development of the Detroit Metropolitan Area is certain when the St. Lawrence Seaway becomes a reality.

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TABLE I. RECORD OF SELECTED WELLS IN OAKLAND COUNTY, MICHIGAN

(See footnotes at end of table.)

ADDISON (AD) TWP.

No.	Location		Owner	1 SG	Elev	2 YD	3 TD	4 DR	5 WL	6 D	Aquifer	7 YLD	8 U	Remarks
1	NE-NW	2	Smith	T	1015	42	136	....	37	....	Gravel	12	D	
2	SW-NW	2	Gottschalk	M	1005	41	236	....	9	4	Gravel	14	D	
3	NW-NW	5	Stevens	M	1065	43	70	....	36	....	Gravel	10	D	
4	SW-SE	7	Golan	M	1180	45	186	....	165	3	....	30	D	
5	SE-SE	8	Christenson	O	1100	46	117	....	90	4	Gravel	16	D	
6	NW-NW	32	Cote	O	1200	47	216	....	192	6	Gravel	60	D	
7	NE-SW	33	Buhl	M	980	27	60	....	+ 2	10	Gravel	....	F	
8	NE-NE	35	Miller	M	930	50	79	....	+17	....	Sand	....	D	

AVON (AV) TWP.

No.	Location		Owner	1 SG	Elev	2 YD	3 TD	4 DR	5 WL	6 D	Aquifer	7 YLD	8 U	Remarks
1	SE-NW	2	Hopkins	O	800	49	129	....	+ 9	4	Gravel	....	D	Flows 4-inch stream.
2	SW-SW	2	Nat'l Twist Drill	O	790	42	172	....	8	8	Sand-gravel	125	I	
3	SW-SW	2	Nat'l Twist Drill	O	790	42	152	....	3	6	Sand-gravel	12	I	
5	SE-NW	4	Rochester Village	M	900	....	81	....	+ 0	12	Gravel	300	P	Pumped 750 gpm.
6	SE-NW	4	Rochester Village	M	900	....	79	....	+ 0	6	Gravel	200	P	
7	SE-SW	8	Danish Old Folks Home	M	930	40	245	....	90	6	Gravel	40	D	
10	NW-NW	14	Hill Theater	O	755	41	352	195	3	6	Shale-sandstone	66	C	Air conditioning.
13	SW-NW	14	Rochester Paper Co.	G	720	49	127	....	10	10	Gravel	200	I	Pumped 245,000 gpd. DD 60 ft.
14	SW-NW	14	Rochester Paper Co.	G	720	27	115	....	+ 0	6	Gravel	60	I	Pumped 170 gpm. 1950 W.L. —12 ft. Show of chloride 1950.
16	NE-SE	15	Holden	M	810	45	136	....	90	3	....	40	D	
18	NE-SE	15	Dancey	M	800	45	124	....	80	3	....	25	D	
21	NE-SE	15	Morrison	M	780	45	113	....	64	3	....	20	D	
27	NW-SE	27	Avon Gardens Water Association	G	790	49	155	....	+ 3	6	Sand-gravel	30	P	Pumped 200 gpm.
29	SW-SE	28	Felix, Jr.	M	830	47	70	....	21	2	....	6	D	
30	SE-SE	29	Wisehard	G	810	46	45	....	12	....	....	15	D	
34	SW-SW	30	Poet	O	870	45	40	....	20	2	....	10	D	
37	NE-NW	31	Gaff	O	855	49	45	....	20	2	....	20	D	
39	NE-NW	31	Esklin	O	850	47	81	....	12	2	....	15	D	
43	NW-NE	32	SW Avon Community Forum	G	810	49	49	....	6	2	....	15	D	
47	SE-SW	33	Spedding	T	830	40	73	....	18	....	Sand-gravel	6	D	DD 5 ft.
48	SE-SW	33	Harves	M	830	41	76	....	....	....	Sand-gravel	5	D	
51	NE-SE	33	Johnson Real Estate	M	800	50	355	250	....	....	Berea sandstone	30	D	
52	SW-SW	34	Baker	G	780	50	270	210	....	....	Berea sandstone	10	D	Slightly salty.
53	SW-SW	34	Schumaker	G	775	49	213	209	....	....	Gravel	5	D	
54	NE-SE	34	Callahan	G	740	40	135	....	45	....	Gravel	6	D	
55	NW-NW	35	Clieno	G	743	38	121	....	45	4	Gravel	5	D	
56	SW-SE	35	Wenaire Kennels	G	695	49	89	....	15	6	Fine sand	2½	D	Slightly salty.

TABLE 1. RECORD OF SELECTED WELLS IN OAKLAND COUNTY, MICHIGAN.—Continued
(See footnotes at end of table.)

BLOOMFIELD (BL) TWP.

No.	Location		Owner	1 SG	Elev	2 YD	3 TD	4 DR	5 WL	6 D	Aquifer	7 YLD	8 U	Remarks
3	NW-NW	3	GMC Truck Coach	M	940	44	173	....	78	12	Sand-gravel	600	I	
7	SW-NW	3	GMC Truck Coach	M	940	49	171	....	90	14	Sand-gravel	800	I	
8	SE-NW	3	GMC Truck Coach	M	950	47	140	....	68	14	Coarse gravel	1000	I	DD 32 ft.
9	NW-SW	3	Oberlin	M	955	33	159	....	76	4	Hardpan	5	D	
10	NE-SW	3	South Bloomfield Highlands Assoc.	M	940	49	130	....	68	8	Gravel	220	P	DD 52 ft.
12	NW-NE	4	Baldwin Rubber	M	955	30	164	....	81	12	Gravel	375	I	1950 W.L.—89 ft.
13	SE-SW	4	Serota	M	940	48	94	....	80	4	....	60	D	
14	SE-SE	4	Merz	M	960	47	107	....	82	4	....	60	D	
15	NE-SE	5	Freight Lines Kramer Bros.	M	945	50	....	301	95	....	Coldwater shale	13	C	
17	NE-SE	9	McNeill	M	895	49	161	....	65	6	Gravel-sand	10	D	DD 35 ft.
18	NE-SE	12	Fraser	M	860	50	271	208	60	4	Coldwater	18	D	
19	SE-NE	14	Higbie	M	865	30	108	....	36	4	Coarse gravel	10	D	
20	SE-NW	15	Bloomfield Hills Country Club	M	925	30	250	....	71	....	Sand	1225	C	DD 35 ft.
21	NW-SW	15	Ball	M	870	49	119	....	8	6	Sand	25	D	DD 67 ft.
23	NW-NE	18	Couzens Estate	M	950	48	165	....	80	6	Sand	18	D	
24	NW-NE	18	Couzens Estate	M	930	36	215	....	40	....	Gravel-sand	700	...	Pumped to raise W.L. of private lake.
27	NE-NW	24	Severy	G	795	49	203	....	33	....	Gravel	8	D	DD 15 ft.
38	NE-NE	26	Birmingham City	G	741	29	120	....	+ 4	....	Gravel	300	...	Test hole.
39	NE-NE	26	Birmingham City	G	741	29	119	....	+ 6	....	Sand-gravel	50	...	Test hole.
40	NE-NE	26	Birmingham City	G	743	47	83	....	+ 0	12	Sand-gravel	200	P	Redding well. 1950 W.L.—10 ft.
50	SE-SE	31	Levins	M	790	49	265	200	14	....	Berea sandstone	15	D	
52	NE-NW	32	Swanson	O	850	49	34	....	10	4	Sand	10	D	
58	NW-NW	36	Birmingham City	G	727	24	73	....	....	12	Sand-gravel	200	P	Baldwin well. 1950 W.L.—27 ft.
61	SE-SE	35	Birmingham City	G	743	41	249	....	35	26	Gravel-sand	1500	P	South well. 1950 W.L.—41 ft. DD 23 ft.
64	NE-SW	35	Birmingham City	G	735	37	172	....	22	26	Gravel	1000	P	West well. 1950 W.L.—37 ft. DD 22 ft.
65	NE-SW	35	Birmingham City	G	740	32	173	....	14	10	Gravel-sand	400	P	Lincoln well. 1950 W.L.—33 ft.
66	NE-SW	35	Birmingham City	G	735	....	231	230	+ 0	3	Sand-gravel	20	...	Test hole.
67	NE-SW	35	Birmingham City	G	735	....	226	....	+ 0	3	Gravel	30	...	Test hole
70	SW-SW	35	Birmingham City	G	749	42	250	207	45	3	Berea sandstone	12	...	Test hole.
72	NW-NW	36	Birmingham City	G	726	31	165	161	+ 0	3	Berea sandstone	......	...	Test hole. Salty.

BRANDON (BR) TWP.

No.	Location		Owner	1 SG	Elev	2 YD	3 TD	4 DR	5 WL	6 D	Aquifer	7 YLD	8 U	Remarks
3	NW-SE	14	Salemko	O	1075	47	45	....	30	2	....	10	D	
4	SW-SE	14	Lee	M	1070	44	127	....	30	2	....	12	D	
6	SE-NW	18	Brandon Twp. School	M	945	50	205	175	+ 2	6	Coldwater fm.	20	D	Pumped 70 gpm.
7	SE-NW	20	Snyder	M	990	46	96	....	40	2	....	17	D	

TABLE 1. RECORD OF SELECTED WELLS IN OAKLAND COUNTY, MICHIGAN.—Continued
(See footnotes at end of table.)

No.	Location		Owner	1 SG	Elev	2 YD	3 TD	4 DR	5 WL	6 D	Aquifer	7 YLD	8 U	Remarks
BRANDON (BR) TWP.—Continued														
9	SW-NE	21	Camp Nahelu	T	1050	48	130	....	+ 0	4	....	5	D	
9	SW-NE	21	Camp Nahelu	T	1020	48	25	....	5	4	....	60	D	
10	NW-NW	22	Swailes	T	1070	46	32	....	20	2	....	20	D	
11	SE-SE	31	Beckman	O	1080	47	157	....	63	4	....	60	F	
COMMERCE (CO) TWP.														
2	SW-SW	12	Woodbridge	O	945	47	44	....	18	2	Coarse sand	25	D	
3	NW-SE	18	Proud Lake	O	920	....	56	....	15	4	Gravel	75	C	
4	NW-SE	34	Walled Lake Fire Dept.	M	950	45	72	....	20	2	Gravel	13	P	
5	NW-SE	34	Walled Lake Theater	M	945	48	32	....	18	6	....	50	C	
5a	NW-SE	34	Walled Lake Theater	M	945	46	24	....	15	2	....	15	C	
6	NW-NW	35	Beck	M	935	49	85	....	40	2	Sand	10	D	
FARMINGTON (FR) TWP.														
1	SE-SW	1	Gordon	M	845	49	283	230	60	....	Berea sandstone	5	D	Salty.
3	SE-SE	2	Rayner	O	855	49	27	....	16	2	Sand-gravel	7	D	
4	NE-NW	3	Oeftering	T	895	47	56	....	27	3	Sand	30	D	
8	NE-SW	8	Bares	T	870	47	114	....	12	3	Sand	12	D	
11	NW-NE	9	Tandy	O	865	49	64	....	3	2	Sand-gravel	25	D	
12	NE-SE	10	Denniston	O	855	47	28	....	12	2	Sand	9	D	
14	NE-SE	10	Lawrence	O	850	49	76	....	+ 0	2	Sand	10	D	
18	SW-SE	11	Bello	M	825	47	105	....	35	....	Sand	25	D	
30	SW-NW	11	Greskowiak	O	860	47	50	....	38	2	Sand	15	D	
36	SW-NW	11	Forsyth	O	865	49	28	....	12	2	Sand	5	D	
40	NW-SW	12	Berkelo	M	785	50	176	140	+ 0	....	Berea sandstone	3	D	Pumped 12 gpm. DD 60 ft.
44	NE-NW	13	McCrumb	G	790	49	171	132	17	....	Berea sandstone	4	D	
46	NE-NW	14	Clark	M	815	49	186	....	23	6	Sand	6	D	DD 74 ft.
50	NE-SW	15	Kesti	M	840	49	42	....	30	2	Sand-gravel	20	D	
55	SE-SE	17	Bohme	M	835	47	73	....	50	4	Fine sand	10	D	
57	SW-SE	19	Acetylene Plant	M	825	47	108	....	....	....	Hardpan	9	I	
61	NE-SW	22	Hamiel	G	775	49	58	....	+ 0	4	Gravel	3	D	Pumped 70 gpm.
65	SW-SE	22	Thomas	G	757	46	105	....	12	4	Gravel-sand	8	D	
69	SW-SE	22	Petz	G	755	50	87	....	5	4	Sand	9	D	DD 70 ft.
71	NE-NE	22	LaFond	G	790	47	74	....	14	3	Sand	25	D	
77	SW-SE	22	Nebrick	G	750	48	161	150	+ 0	4	Coldwater fm.	10	D	
79	SW-SE	22	Sempowski	G	750	51	147	104	....	4	Berea sandstone	5	D	DD 130 ft.
83	NW-SW	23	Whitehead	G	730	48	83	....	8	....	Coarse gravel	10	D	DD 50 ft.
86	NE-SE	23	LaCroix	G	715	47	52	....	+ 0	....	....	40	D	
87	NE-NW	23	Hughes	G	764	47	47	....	3	3	Sand	4	D	
88	SW-NE	23	Blachut	G	735	49	99	82	+ 0	2	Berea sandstone	8	D	
103	SE-SW	24	Woodbine Improvement Assoc.	G	685	50	108	....	52	8	Sand-gravel	350	P	DD 11 ft. Trace H_2S
104	SW-SW	24	Noble School	G	700	47	82	....	61	6	Fine sand	25	D	
107	NE-SW	25	Shoven	G	667	47	120	....	22	....	Sand	35	D	
119	SE-SE	26	Silkowsky	G	667	47	91	....	25	3	Coarse sand	15	D	
135	SE-NW	27	City of Farmington	G	700	28	174	....	+ 0	6	Coarse gravel	440	P	1950 W.L.—35 ft. 3 additional wells in vicinity.

TABLE 1. RECORD OF SELECTED WELLS IN OAKLAND COUNTY, MICHIGAN.—Continued
(See footnotes at end of table.)

No.	Location		Owner	1 SG	Elev	2 YD	3 TD	4 DR	5 WL	6 D	Aquifer	7 YLD	8 U	Remarks
FARMINGTON (FR) TWP.—Continued														
139	NE-NW	28	Schroder	M	795	49	212	...	25	4	Sand	3	D	2 dry holes in vicinity.
142	SW-SW	31	Brock	M	789	47	206	...	40	...	Sand-gravel	45	D	
147	SW-SW	35	Carrier	G	675	47	98	96	34	4	Gravel	6	D	
151	NE-NW	35	Bernhard	G	680	47	60	...	20	...	Sand	15	D	
GROVELAND (GR) TWP.														
1	SE-NE	12	Mich. Milk Prod.	O	940	47	265	185	+ 0	6	Coldwater	100	I	Salty.
2	NE-NE	23	Girl Scouts	M	1030	45	140	...	70	6	Fine sand	40	D	DD 20 ft.
HIGHLAND (HI) TWP.														
1	NE-NW	10	C & O Ry	O	1030	39	75	...	23	6	Sand-gravel	80	...	DD 3 ft. Test hole.
2	NE-NW	10	C & O Ry	O	1030	39	64	...	23	12	Sand-gravel	200	I	DD 13 ft.
3	NE-NW	10	C & O Ry	O	1030	39	63	...	18	12	Sand-gravel	180	I	
5	NE	27	Dodge Park No. 10	O	...	36	149	...	42	6	Sand-gravel	200	C	DD 17 ft.
HOLLY (HO) TWP.														
4	NE-NE	28	Martin	M	920	43	56	...	9	...	Gravel	7	D	DD 10 ft.
6	SW-SW	34	Holly Village	O	920	38	200	...	+ 0	10	Sand-gravel	470	P	1950 W.L.—0.7 ft.
7	SW-SW	34	Holly Village	O	920	47	220	...	+ 0	10	Sand-gravel	250	P	DD 133 ft.
INDEPENDENCE (IN) TWP.														
2	NW-SW	4	Beck	M	1140	49	109	...	94	3	...	25	F	
3	SE-NW	5	Spears	M	1100	45	60	...	...	2	...	10	D	
4	SE-NW	8	Bell	M	1130	46	141	...	90	3	...	30	D	
5	NW-NE	8	Parker	M	1110	47	94	...	60	3	...	25	D	
7	SW-NE	10	Parsons	O	1050	47	34	...	18	3	...	20	D	
8	SW-NE	10	Purdy	O	1050	48	...	...	21	2	...	15	D	
9	NE-SW	12	Darling	M	1070	45	40	...	26	2	...	15	D	
10	SE-SE	20	Wilson	O	1015	46	118	...	25	3	...	40	D	
11	NE-SW	20	Caribou Inn	O	1005	47	30	...	13	4	...	60	C	
13	SW-SE	20	Walters	O	1010	48	42	...	11	3	...	30	D	
16	SW-SE	29	Rogers and Tallinger	O	995	45	52	...	15	3	...	30	C	
18	SW-NE	29	Comstock	O	1000	48	102	...	11	3	...	30	F	
19	NE-NE	32	Adams	O	1020	49	49	...	35	3	...	25	D	
LYON (LY) TWP.														
1	SW-NE	3	Mich. State Adm. Bd.	O	940	45	250	246	12	6	Gravel	200	C	DD 42 ft.
2	NE-NE	3	Mich. State Adm. Bd.	O	950	45	175	...	18	6	Sand-gravel	250	C	DD 30 ft.
4	SW-SW	20	South Lyon	M	930	49	82	...	20	10	Med. gravel	350	P	

TABLE 1. RECORD OF SELECTED WELLS IN OAKLAND COUNTY, MICHIGAN.—Continued
(See footnotes at end of table.)

MILFORD (MI) TWP.

No.	Location		Owner	1 SG	Elev	2 YD	3 TD	4 DR	5 WL	6 D	Aquifer	7 YLD	8 U	Remarks
4	NE-NE	10	Ford Motor Co.	O	940	38	93	...	36	12	Sand-gravel	500	I	DD 30 ft.
5	NE-NE	10	Ford Motor Co.	O	922	38	83	...	19	12	Sand-gravel	480	I	DD 35 ft.
6	SE-NW	10	Milford	O	920	38	124	...	+ 0	10	Sand-gravel	500	P	1950 W.L.—2 ft.
7	SE-NW	10	Milford	O	920	39	117	...	+ 0	10	Sand-gravel	500	P	1950 W.L.—7 ft.

NOVI (NO) TWP.

No.	Location		Owner	1 SG	Elev	2 YD	3 TD	4 DR	5 WL	6 D	Aquifer	7 YLD	8 U	Remarks
1	SE-NW	2	Intihar	M	950	47	73	...	26	2	Sand	15	D	
2	SE	3	Dodge Park No. 2	O	960	...	102	92	28	6	Coldwater fm.	60	C	DD 20 ft.
3	NE-NW	3	Arbour	O	940	49	64	...	18	2	Sand-gravel	9	D	
5	SW-SW	4	Bates	T	960	...	40	...	23	2	...	9	D	W.L. reported 1950
6	NE-NE	7	Derrick	M	965	49	64	...	35	3	Gravel-sand	20	D	
8	SW-NW	8	Voudung	M	965	...	73	...	30	2	...	7	C	W.L. reported 1949. Nursery
10	NW-NE	12	Gen. Mach. & Tool Wks.	M	900	49	98	...	...	8	Sand	45	I	
12	NW-NE	12	Gen. Mach. & Tool Wks.	M	910	...	92	...	9	...	Sand	80	I	W.L. orig. 9 ft. below surface
13	NE-NW	14	Stoley	M	930	50	92	...	27	4	Gravel	10	D	
15	NW-SE	16	Miller	O	980	50	122	...	63	2	Gravel	14	D	
16	SW-NE	16	Miller's Service	O	980	47	101	...	45	2	Sand-gravel	15	C	
17	SE-SE	18	Mitchell	O	960	46	74	...	29	6	Gravel	300	F	DD 19 ft.
18	SE-SE	18	Mitchell	O	960	47	80	...	20	6	...	150	F	DD 10 ft.
19	NW-NW	19	Eth Mead Farms	O	965	46	37	...	22	2	Coarse gravel	8	F	
21	NW-NW	23	Novi Township	M	910	49	79	...	20	6	Coarse sand	80	D	
22	SW-NW	23	Novi Equip. Co.	M	900	...	90	...	6	6	...	70	I	W.L. reported 1949.

OAKLAND (OA) TWP.

No.	Location		Owner	1 SG	Elev	2 YD	3 TD	4 DR	5 WL	6 D	Aquifer	7 YLD	8 U	Remarks
1	SE-SW	4	Christopher	M	980	49	60	...	43	4	Gravel	25	D	
2	NW-NW	9	Scripps	M	950	48	176	...	14	6	...	60	F	
4	SW-NE	25	Fosclick	M	835	44	210	210	+15	...	...	30	F	
6	SW-SW	28	Gallagher	M	985	38	109	...	67	4	...	10	F	
7	SW-NE	28	Vall	M	850	47	77	...	11	3	Gravel	30	I	
8	SW-NE	28	Avon Industries	M	850	45	57	...	10	4½	Gravel	30	I	
9	SW-NE	28	Allison	M	845	47	115	...	+ 2	3	Gravel	40	D	
10	NW-NE	28	Costoge	M	930	47	202	...	75	4	Gravel	3	D	
11	NW-NW	33	Gallagher	M	990	37	297	...	126	6	Gravel	30	F	
12	NW-SE	35	Sheldon	O	850	42	210	210	...	...	...	17	D	

ORION (OR) TWP.

No.	Location		Owner	1 SG	Elev	2 YD	3 TD	4 DR	5 WL	6 D	Aquifer	7 YLD	8 U	Remarks
2	SW-SW	5	Vantivelt	O	1020	49	73	...	8	3	Gravel	10	D	
3	NE-SE	6	Vantivelt	O	1020	44	58	...	+ 0	3	Gravel	6	D	Pumped 25 gpm.
4	SE-SE	7	Lakefield Farms	M	1050	30	178	...	17	6	Sand-gravel	10	F	
5	SE-SE	7	Lakefield Farms	M	1050	40	79	...	41	4	Sand	6	F	DD 27 ft.
6	SE-SE	9	Poorits Dairy	O	1017	44	267	261	29	...	Fine sand	40	I	

TABLE 1. RECORD OF SELECTED WELLS IN OAKLAND COUNTY, MICHIGAN.—Continued
(See footnotes at end of table.)

ORION (OR) TWP.—Continued

No.	Location		Owner	1 SG	Elev	2 YD	3 TD	4 DR	5 WL	6 D	Aquifer	7 YLD	8 U	Remarks
8	NW-NW	12	Lake Orion Village	O	990	38	172	....	8	8	Gravel	650	P	DD 27 ft.
9	NW-NW	12	Lake Orion Village	O	982	30	137	....	13	12	Gravel	925	P	DD 39 ft.
12	SE-SE	25	Cook	M	985	47	101	....	40	4	....	60	D	
14	NE-SW	33	Sutton	M	1035	49	106	....	46	....	....	7	D	
OXFORD (OX) TWP.														
1	SW-NE	1	Stevens	M	1140	40	160	....	101	6	Fine sand and gravel	14	D	
2	SE-NW	21	American Aggregates Corp.	O	1075	49	....	....	50	2½	....	....	D	
3	SW-NE	21	American Aggregates Corp.	O	1075	49	....	....	50	....	....	....	D	
4	SW-SW	26	Summer	O	1045	49	....	....	29	2	....	....	D	
6	SE-NW	35	Oxford Trailer Sales	O	1049	48	58	....	40	2	....	50	D	
PONTIAC (PO) TWP.														
2	SW-SW	3	Taylor Farm	O	970	41	320	320	20	....	....	40	D	
4	NE-NE	4	Moegle	M	1050	47	104	....	90	3	....	25	D	
5	NE-NW	5	Featherstone	M	1010	47	135	....	100	4	....	75	D	
7	SE-NW	6	Clark	M	990	48	42	....	25	2	....	16	D	
9	SW-SE	8	Marimont Sub	T	980	27	112	....	45	8	Gravel	100	P	DD 39 ft.
11	NW-NW	8	Garrison	O	960	49	75	....	12	2	Gravel	10	D	
15	SW-SW	11	Bird	M	970	47	107	....	85	3	....	30	D	
16	NW-NW	13	Bare	M	960	47	27	....	25	3	....	15	D	
20	SE-NE	14	Hoppe	M	970	47	318	304	90	....	Coldwater fm.	15	D	
23	NW-NW	14	Radd	M	970	45	112	....	85	3	....	30	D	
29	NE-NE	17	Lazenky	T	995	46	79	....	60	2	....	12	D	
39	SE-NE	20	Pontiac Mtr. Co.	T	950	48	288	....	133	16	Sand-gravel	800	I	No. 3 well.
40	SE-NE	20	Oakland Mtr. Co.	T	940	27	296	....	30	....	Gravel-sand	650	I	No. 2 well. Now Pontiac Mtr. Co.
41	SE-NE	20	Oakland Mtr. Co.	T	944	26	298	....	45	....	Sand-gravel	680	I	No. 1 well. Now Pontiac Mtr. Co.
44	NE-SE	20	Mich. Light Co.	M	930	22	185	....	50	8	Sand-gravel	....	C	1929 W.L.—62 ft.
52	SW-SE	22	Kissling	M	940	45	95	....	80	2	....	5	D	
58	NW-NW	27	Pontiac City	M	881	27	180	....	14	12	Gravel	833	P	Featherstone No. 1 well.
61	NE-SW	27	Burrows	M	915	45	237	....	90	3	....	5	D	
62	NE-SW	27	Novac	M	910	45	90	....	40	3	....	30	D	
64	NE-SW	28	Pontiac City	M	900	26	195	....	....	12	Gravel	850	P	Paddock St. well.
65	NE-SW	28	Pontiac City	M	902	25	200	....	20	12	Gravel	608	P	Mechanic St. well.
67	NE-NE	28	Pontiac City	M	903	24	180	....	....	12	Gravel	750	P	E. Blvd. well.
68	NE-NE	28	Pontiac City	M	884	29	195	....	32	12	Gravel	830	P	Featherstone No. 2 well.
71	NW-NE	28	Schlesser	M	920	47	31	....	18	2	....	15	D	
77	NE-SE	29	Pontiac City	M	905	26	197	....	32	12	Gravel	850	P	Market St. well.
78	SE-SE	29	Pontiac City	M	916	29	205	....	38	12	Gravel	741	P	City Hall well.
79	SE-SE	29	Pontiac City	M	915	29	195	....	44	12	Gravel	833	P	Perry St. well.

TABLE 1. RECORD OF SELECTED WELLS IN OAKLAND COUNTY, MICHIGAN.—Continued
(See footnotes at end of table.)

PONTIAC (PO) TWP.—Continued

No.	Location		Owner	1 SG	Elev	2 YD	3 TD	4 DR	5 WL	6 D	Aquifer	7 YLD	8 U	Remarks
83B	SW-NW	29	Pontiac State Hospital	M	930	32	145	....	....	12	Gravel-sand	800	C	W.L. 1950—51 ft. DD 57 ft. Well No. 2.
85	SW	31	Pontiac City	M	930	48	183	....	....	12	Gravel	666	P	Orchard Lake well No. 2.
86	NE-SW	31	Pontiac City	O	930	49	243	....	106	12	Gravel-sand	666	P	Orchard Lake well No. 3.
88	NE-SW	31	Pontiac City	O	926	25	173	....	32	12	Gravel	......	...	Orchard Lake well No. 1. Not in service.
91	NE-NW	32	Pontiac City	O	925	49	211	....	110	12	Gravel-sand	850	P	Branch St. well No. 9.
92	SW-NW	32	Pontiac City	M	925	49	248	....	105	12	Gravel-sand	833	P	Lake St. Yard well No. 5.
93	NW-NE	32	Pontiac City	M	920	23	191	....	40	24	Gravel	......	...	Walnut St. Plant well No. 1. Abandoned.
95	NW-NE	32	Pontiac City	M	920	47	192	....	97	12	Sand-gravel	950	P	Waterworks Yd. well No. 1.
97	SE-NW	32	Pontiac City	O	940	41	234	....	74	12	Gravel-sand	......	...	Well at reservoir, not in service
100	SE-SW	33	Hubbard Spring Co.	M	960	40	157	....	....	5½	Gravel	49	I	DD 1 ft.
106	SW-NW	36	Kengan	O	875	49	47	....	29	3	....	20	D	
108	NW-SW	36	Gingrich	O	880	48	59	....	25	3	....	30	D	
117	NE-NE	36	Petersen Mtr. Sales	O	860	46	25	....	18	2	....	16	D	

ROYAL OAK (RO) TWP.

No.	Location		Owner	1 SG	Elev	2 YD	3 TD	4 DR	5 WL	6 D	Aquifer	7 YLD	8 U	Remarks
1	NW-NW	3	Stark	G	660	40	114	....	....	....	....	......	...	Dry. Gas at 107-112 ft.
3	SE-NE	4	Garrick Products	G	660	42	98	....	....	....	....	......	...	Dry. Gas in sand and gravel at 98 ft. under 6 lb. pressure.
18	SE-NW	5	Royal Oak City	G	700	48	227	225	....	....	....	......	...	Test hole—dry.
25	SE-SE	6	Royal Oak City	G	700	49	197	186	....	6	Sand-gravel	......	...	Test hole. Good supply. Sulphur taste, chlorides 890 ppm.
26	NW-NW	6	Royal Oak City	G	745	49	194	....	....	6	....	......	...	Test hole—dry. Chlorides 53 ppm.
29	NE-NW	6	Royal Oak City	G	732	28	230	....	11	12	Gravel	900	P	DD 66 ft., 1950 W.L.—36 ft. Chlorides 103 ppm. Cooper well.
30	SE-SE	6	Food Fair Mkt.	G	700	50	233	233	....	8	Gravel	50	...	
31	SE-SE	6	Food Fair Mkt.	G	700	50	232	226	90	8	Gravel	72	...	DD 121 ft. Gas show.
35	SW-SW	6	Royal Oak City	G	730	49	215	....	49	12	Gravel-sand	150	P	Greenfield well. Chlorides 110 ppm.
39	SW-SW	8	Roseland Pk. Cemetery	G	685	48	165	....	120	....	Gravel	490	C	DD 23 ft. Gas show.
40	NE-SW	8	Roseland Pk. Cemetery	G	680	42	227	191	120	....	Gravel	320	C	DD 30 ft. Chlorides 320 ppm.
43	NW-SW	9	Royal Oak City	G	665	41	187	183	....	....	Sand	4	...	Test hole. Gas in sand 129-131 ft.
45	NW-SE	9	Royal Oak City	G	650	23	143	....	60	24	Gravel	1058	P	Magnolia well. DD 24 ft. 1949 W.L.—103 ft. Hydrogen sulfide. Chlorides 420 ppm.
46	NW-NW	9	Royal Oak City	G	665	42	160	....	94	30	Sand-gravel	820	P	Northwood well. DD 14 ft. 1947 W.L.—121 ft. Yield 1947—400 gpm. Chlorides 338 ppm.

TABLE 1. RECORD OF SELECTED WELLS IN OAKLAND COUNTY, MICHIGAN.—Continued
(See footnotes at end of table.)

ROYAL OAK (RO) TWP.—Continued

No.	Location		Owner	1 SG	Elev	2 YD	3 TD	4 DR	5 WL	6 D	Aquifer	7 YLD	8 U	Remarks
49	SW-NW	10	Royal Oak City	G	650	41	149	145	94	3	...	10	...	Test hole. DD 1 ft. Gas in fine sand at 112-118 ft.
50	NE-NE	11	Royal Oak Twp.	G	635	24	124	...	...	6	...	21	P	DD 32 ft. 1945 W.L.—63 ft. Wells No. 1 and No. 2.
52	NE-SE	12	Brooks	G	627	49	147	110	60	4	Antrim shale	1½	D	Gas in shale. Abandoned.
53	NW-NW	12	Royal Oak Twp.	G	630	25	156	...	...	6	...	7½	P	Well No. 3. DD 9 ft. 1945 W.L.—56 ft.
55	NW-NW	14	Royal Oak City	G	640	27	270	131	35	12	Gravel	120	...	Disposal plant well. Abandoned—gas interference.
56	NE-NE	14	Fishback	G	633	46	102	...	...	...	Sand	30	D	
61	NE-NW	18	Berkley City	G	700	28	223	223	96	12	Gravel-sand	1050	P	Wells in DPW Bldg. DD 7 ft. 1949 W.L.—140 ft.
62	NW-NW	18	Berkley City	G	700	48	205	...	137	12	Sand-gravel	650	P	Well near school. DD 7 ft.
67B	S½	20	Baker Land Co.	G	665	19	138	...	...	...	Sand	10	...	Well No. 3. Gas show. Abandoned.
70	NE-NE	24	Fagen	G	630	49	138	...	50	3	Sand	10	D	

SOUTHFIELD (SO) TWP.

No.	Location		Owner	1 SG	Elev	2 YD	3 TD	4 DR	5 WL	6 D	Aquifer	7 YLD	8 U	Remarks
1	NW-NE	1	Southfield Twp.	G	745	41	197	...	...	12	Sand-gravel	444	P	DD 116 ft.
2	SW-SW	1	Acacia Park Cemetery	G	725	...	168	...	...	12	Sand-gravel	600	C	High in Fe. and Mn.
3	NW-NW	3	Yeager	G	740	49	108	...	15	2	Gravel-sand	20	D	
5	SW-SE	5	Meyers	G	745	49	174	132	...	4	Berea	5	D	
6	NW-SE	5	Achten	G	750	49	...	147	31	...	Berea	10	D	DD 160 ft., 180 ft. at 12 gpm, 190 ft. at 18 gpm.
8	SE-NW	5	Noder	G	760	49	168	134	+ 0	...	Berea	5	D	Salty.
13	SW-SW	6	Neil	M	825	45	220	...	22	...	Gravel	7	D	DD 20 ft.
16	SE-NW	6	Vacant Lot	M	815	50	53	...	20	4	Sand	15	...	
18	NE-SE	6	Dixon	M	785	50	...	151	10	...	Sunbury-Berea	18	D	DD 50 ft.
21	NE-SE	6	Kristenson	M	810	43	...	225	65	...	Berea	16½	D	
22	NE-NW	7	Pickard	G	810	49	278	204	35	4	Berea	8½	D	
25	NW-SW	7	Buckland	G	770	49	56	...	20	2	Sand	6	D	
26	NW-SE	7	McQuilan	G	750	49	131	...	+ 0	3	Sand	30	D	
30	NE-NE	8	Hudson	G	715	41	80	...	15	...	...	7	D	DD 56 ft. Csg. down 60 ft., balance of hole gravel filled.
31	SW-SW	9	Ferguson	G	690	41	76	...	31	4	Sand	6	D	
32	NE-SE	12	Bush	G	715	49	220	...	+ 0	4	Gravel	20	D	
34	NW-NE	15	Cottrell	G	710	50	114	...	95	4	...	20	D	
38	NW-NW	17	Fox	G	703	47	55	...	4	2	Sand	12	D	
40	NE-NE	18	George's Inn	G	713	49	51	...	5	3	Sand	40	C	
43	NE-NW	18	Robertson	G	740	49	136	100	2	...	Berea	6	D	
44	SE-NE	20	Sturman	G	665	47	123	...	50	2	Fine sand	10	D	
47	SW-NW	21	Southfield Twp.	G	680	47	167	...	51	6	Coarse sand	50	D	DD 36 ft.

TABLE 1. RECORD OF SELECTED WELLS IN OAKLAND COUNTY, MICHIGAN.—Continued
(See footnotes at end of table.)

No.	Location		Owner	1 SG	Elev	2 YD	3 TD	4 DR	5 WL	6 D	Aquifer	7 YLD	8 U	Remarks
SOUTHFIELD (SO) TWP.—Continued														
48	NE-NE	22	Miencke	G	675	49	385	175	....	....	....	.....	..	Abandoned. Gas at 381 ft. under 70 lb. pressure. Salt water at 385 ft.
50	NE-NE	22	Miencke	G	680	49	150	....	....	....	Gravel	10	D	Yield drops after 6 hrs. of pumping.
54	NE-NW	29	Williams	G	660	47	100	....	55	4	Sand	10	D	
56	NE-SE	30	Huelmantel	G	650	50	108	80	....	4	Gravel-sand	5	D	DD 60 ft.
57	SE-NE	30	Buddemier	G	660	49	28	....	15	2	Sand	8	D	
SPRINGFIELD (SP) TWP.														
2	NW-NE	11	Murray	O	1110	45	132	....	95	3	....	40	D	
4	SE-NE	18	Davisburg School	T	990	50	91	....	50	4	Clayey sand	20	D	DD 9 ft.
TROY (TR) TWP.														
1	SE-NE	3	Gray	G	700	49	91	....	23	....	Gravel	6	D	DD 32 ft.
4	NW-NE	4	Flood	M	820	49	185	....	30	....	Gravel	5	D	DD 60 ft.
5	SW-SE	4	Davis	G	775	46	155	....	+ 0	3	....	100	D	Flowing.
7	NE-NW	7	Barnes	M	880	49	76	....	30	....	Gravel	4	D	DD 11 ft.
9	NE-NE	9	St. Onge	G	755	48	105	....	+ 0	4	Gravel	70	D	Flowing in 1950.
10	NE-NE	9	Belyea	G	750	39	104	....	50	....	Hardpan	½	D	
12	SW-SE	9	Dupont Mfg.	G	750	45	144	....	+ 0	....	Gravel	2	I	Flow fails in summer.
14	SE-NW	10	Close	G	712	38	89	....	18	....	Sand-gravel	1	D	Cloudy.
17	SE-SE	10	Standard Service	G	670	....	110	....	+ 0	....	Gravel	.....	C	Salty. Not flowing at present.
18	SE-SE	10	Salt Water Pool	G	670	....	150	150	+ 0	....	Gravel	.....	C	Salty. Not flowing at present.
20	NW-SW	12	Dare	G	655	46	75	....	4	....	Gravel	6	D	DD 15 ft.
22	SE-SE	13	Meserve	G	640	48	94	92	8	....	Berea	6	D	DD 9 ft.
23	SW-SE	13	Klinkhamer	G	640	42	90	....	....	....	Gravel	3	D	
24	NW-SE	14	Williams	G	660	48	95	....	8	....	Gravel	15	D	DD 13 ft.
26	SW-SW	16	Temple	G	730	46	102	....	12	....	Gravel	2	D	DD 80 ft.
28	SW-SW	19	Anderson	G	635	42	78	....	10	....	Sand	6	D	DD 12 ft.
31	NE-SE	21	Taylor	G	680	42	95	....	6	4	Gravel	15	D	DD 13 ft.
32	SE-SE	22	Johnson	G	660	49	93	....	+ 1	....	Gravel-clay	3	D	
33	NE-NE	23	Sentgerath	G	647	38	89	....	....	4	Sand-gravel	3	D	
34	SW-NW	24	Sellers	G	645	40	92	....	32	....	Gravel	10	D	
39	NW-SW	25	Mitchell	G	640	44	95	....	....	....	Gravel-sand	1	D	
43	SW-SW	25	Yeokum	G	640	48	99	....	....	4	Gravel	4	D	Gasshow at 80ft. Slightly salty.
52	SE-SE	30	Birmingham City	G	738	49	193	....	48	18	Sand	800	P	Walker well. DD 12 ft. 1950 W.L.—58 ft.
54	NW-SE	30	Birmingham City	G	762	29	137	....	23	26	Gravel-sand	900	P	East (Derby) well. DD 75 ft. 1950 W.L.—46 ft.
66	SW-SW	32	Groves	G	715	15	223	223	+ 0	....	Sand-gravel	40	D	
69	NW-NW	32	Clawson City	G	735	49	188	....	76	12	Gravel	1070	P	New well. DD 21 ft.
75	NW-SE	33	Clawson City	G	670	28	230	226	30	12	Gravel	750	P	Well No. 3. 1949 W.L.—93 ft. Yield 250 gpm.
80	NW-NW	36	Jossin	G	635	49	117	....	....	4	....	.....	..	Dry. Gas at 117 ft., 28 lb. pressure.

TABLE 1. RECORD OF SELECTED WELLS IN OAKLAND COUNTY, MICHIGAN.—Continued
(See footnotes at end of table.)

WATERFORD (WA) TWP.

No.	Location		Owner	1 SG	Elev	2 YD	3 TD	4 DR	5 WL	6 D	Aquifer	7 YLD	8 U	Remarks
1	SW-NE	4	Lady of the Lakes	O	980	49	38	...	...	2		20	D	
3	SE-SE	6	Douglas	O	990	48	39	...	29	2		15	D	
4	NE-NE	8	Schutt	O	980	47	28	...	18	2		17	D	
5	NE-NE	10	Gravelle	O	975	44	28	...	20	2		20	D	
8	SW-SE	10	Doremus	O	980	49	55	...	45	3		20	D	
10	SE-NW	11	Mouser	O	965	46	24	...	17	3		18	D	
11	SW-SE	12	Lane	T	960	46	50	...	14	2		17	D	
12	NW-SE	13	Likkens	T	980	46	88	...	39	4		120	D	
15	SE-NW	13	Parsons Punch Co.	T	970	44	89	...	...	4		10	I	
17	SW-NE	13	John's Drive Inn	T	977	47	66	...	30	2		10	C	
21	SE-SW	14	Wilson	T	975	46	37	...	29	3		20	D	
23	NE-NE	14	Bowes	T	970	49	44	...	34	2		10	D	
28	SE-NE	15	Newman	O	965	45	53	...	18	2		12	D	
30	SE-NW	16	Wilmott	O	970	49	28	...	21	2		15	D	
34	SE-NE	20	Waterford Center School	O	960	48	27	...	18	2		15	...	
35	NE-NE	21	Waterford Twp. High School	O	960	49	71	...	22	6	Sand	50	...	Test well. DD 22 ft. Existing 12-inch well 150 gpm.
36	SE-SW	21	Mattingly	O	950	47	28	...	6	2		17	D	
37	SW-SW	22	Conklin	O	940	47	64	...	15	2		17	D	
40	SW-SE	23	Stockwell	T	1015	46	200	...	...	4		10	D	
41	SW-SE	23	McNally	T	1015	47	69	...	55	3		30	D	
47	SE-SW	24	Huron Gardens	T	974	49	330	...	70	12	Sand-gravel	850	P	DD 33 ft.
48	SW-NW	24	Waterford Twp. School District No. 3	T	975	29	100	...	...	...	Sand	70	...	
49	SE-NW	24	Mott	T	975	48	70	...	40	2		10	D	
53	NW-SE	25	Huron Gardens	T	978	39	255	...	70	12	Sand	150	P	DD 14 ft.
54	SE-SW	25	Donelson School	T	970	...	117	...	...	6	Gravel	100	...	1930 W.L.—65 ft.
57	SW-NE	26	Hayes	M	940	49	58	...	35	3		30	D	
61	NW-NW	27	Walsh	T	940	46	53	...	4	2		15	D	
64	NW-NW	28	Norris	O	945	49	48	...	13	2		20	D	
68	SE-SE	31	Woodard	O	980	46	59	...	40	2		15	D	
71	NW-SE	34	Purdy	M	950	45	63	...	16	2		15	D	
71A	SW-SE	34	Dodge State Park No. 4	O	970	...	215	...	48	...	Sand	126	P	
73	NW-SW	35	Willard	M	990	47	98	...	50	3		30	D	
76	SE-SE	35	Venice of Lakes	O	935	...	280	...	...	6	Sand-gravel	23	P	1930 W.L.—10 ft.
77	NW-NE	36	Huron Gardens	T	960	39	102	...	50	12	Sand-gravel	250	P	Well No. 2. DD 16 ft.

WEST BLOOMFIELD (WB) TWP.

No.	Location		Owner	1 SG	Elev	2 YD	3 TD	4 DR	5 WL	6 D	Aquifer	7 YLD	8 U	Remarks
3	SE-NE	2	Rodden	O	935	47	49	...	27	2		10	D	
7	NE-SW	8	Denman	O	950	48	40	...	18	2		15	D	
8	NW-SW	9	Scotch School	M	950	49	187	...	18	6	Gravel	70	...	DD 40 ft. at 150 gpm. DD 180 ft.
9	SW-NW	10	Kalina	M	945	47	70	...	22	3	Sand	12	D	
10	NW-NW	14	Hutchins	M	960	48	163	...	58	6	Sand	20	D	DD 2 ft.
12	NE-SE	15	Beglinger	M	940	47	49	...	13	2	Sand	25	D	
14	SE-NW	16	Gregg	M	940	48	98	...	15	3	Sand	20	D	

TABLE 1. RECORD OF SELECTED WELLS IN OAKLAND COUNTY, MICHIGAN.—Concluded
(See footnotes at end of table.)

WEST BLOOMFIELD (WB) TWP.—Continued

No.	Location		Owner	1 SG	Elev	2 YD	3 TD	4 DR	5 WL	6 D	Aquifer	7 YLD	8 U	Remarks
16	SW-SW	20	Bussell	M	960	...	62	...	...	...	...	7	D	1949 W.L.—30 ft.
17	NE-NW	21	Underhill	M	980	46	55	...	35	2½	...	20	D	
18	SE-SE	24	Dingwall	M	920	46	95	...	60	4	...	10	D	
21	NE-NE	25	Nixon	M	900	49	77	...	34	2	Sand-gravel	10	D	
25	SW-NW	25	Noble	M	880	50	60	...	13	4	Sand	20	D	
26	SE-SW	25	Lotz	M	900	...	130	...	...	6	Gravel	25	D	1950 W.L.—66 ft.
29	SW-SW	26	Maloney	T	910	47	114	...	50	2	Sand	8	D	
31	SW-SW	36	Sechrist	O	865	47	57	...	51	3	Sand	15	D	

WHITE LAKE (WL) TWP.

No.	Location		Owner	1 SG	Elev	2 YD	3 TD	4 DR	5 WL	6 D	Aquifer	7 YLD	8 U	Remarks
1	SE-SE	3	McClure	O	1010	44	29	...	...	2	...	12	D	
5	SE-NW	21	Trebble	O	975	47	...	...	34	...	...	15	D	
6	NE-NW	23	Howard	O	970	49	127	...	16	2	...	17	D	
7	...	25	Lewis	O	...	48	112	...	+ 6	2½	...	17	D	

Footnotes:
1. SG—Surficial geology = M—Moraine; T—Till; O—Outwash; G—Glacial Lake Plain.
2. YD—Year drilled.
3. TD—Total depth.
4. DR—Depth to bedrock.
5. WL—Reported water level.
6. D—Casing diameter.
7. YLD—Yield in gallons per minute (gpm).
8. U—Use = D—Domestic; F—Farm; I—Industrial; C—Commercial; P—Public water supply.

TABLE 2. METEOROLOGICAL DATA—PONTIAC, MICHIGAN

	Length of Record	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.	Annual
Average Monthly Precipitation	54	1.81	1.86	2.12	2.86	3.42	3.03	2.67	2.65	2.85	2.36	2.25	2.06	29.94
Average Monthly and Annual Snowfall	58	8.8	9.7	5.9	2.1	0.1	0	0	0	0	1.7	3.0	7.4	38.7
Average No. of Days with 0.01″ or More of Precipitation	58	8	7	8	8	9	8	8	7	7	7	9	8	94
Average Temperature	62	23.1	22.8	32.6	45.4	56.8	66.7	71.4	69.2	62.8	51.1	38.0	27.0	47.2
Average Maximum Temperature	62	30.2	30.6	41.5	55.6	67.9	77.5	82.3	80.1	73.4	60.7	45.3	33.4	56.5
Average Minimum Temperature	62	16.0	15.0	23.9	35.3	45.8	55.9	60.4	58.6	52.3	41.5	30.8	20.6	38.0
Highest Temperature	62	66 1950	64 1944	81 1910	89 1925	95 1911	100 1934	104 1938	102 1918	98 1898	87 1900	79 1950	60 1941	
Lowest Temperature	62	-18 1918	-22 1918	-8 1925	6 1923	23 1909	31 1901	41 1904	38 1915	28 1899	20 1936	2 1929	-12 1924	
Prevailing Winds		WE	NW	SW	SW	SW	SW	SW	SW	SW	SW	SW	SW	

Frost data: Length of record 47 years.
Average date—last killing frost or freezing temperature May 10.
Average date—first killing frost or freezing temperature October 9.
Average length of growing season—from last killing frost to first killing frost 152 days.
Latest date of killing frost or freezing temperature May 31.
Earliest date of killing frost or freezing temperature September 11.

Above data through 1950.

Source: Weather Bureau, U. S. Department of Commerce, East Lansing, Michigan, March 1951.

TABLE 3. POPULATION CHART OF OAKLAND COUNTY, MICHIGAN

NOTE: Township figures include only the unincorporated part of the township and DO NOT include either the cities or villages. 1950 figures are preliminary census releases.

	1950	1947	1940	1930	1920	1910	1900	1890	1880	1870
ADDISON TWP.	894	772	739	674	682	730	781	863	975	1063
Leonard Village	383	320	276	280	264	313	335	276	....	....
AVON TWP.	8878	6890	5017	3407	1321	1141	1049	1046	1279	1850
Rochester Village	4269	4179	3759	3554	2549	1516	1535	900	996	....
BLOOMFIELD TWP.	3821	3012	1771	1352	2392	1226	1126	1145	1219	2105
Birmingham City[1]	15370	12683	11196	9539	3694	1607	1170	899	733	....
Bloomfield Hills City	1413	1413	1281	1127	....	....	....	....	....	....
BRANDON TWP.	1453	1165	999	794	759	752	1179	1260	1367	1284
Ortonville Village	686	654	622	553	445	377	....	....	....	....
COMMERCE TWP.	7350	4858	2957	1789	914	986	1124	1113	1263	1392
FARMINGTON TWP.	10676	8206	5695	3512	1317	1224	1223	1319	1463	1927
Farmington City	2312	1619	1510	1243	853	564	530	320	377	....
GROVELAND TWP.	980	914	930	674	662	772	828	917	1126	1180
HIGHLAND TWP.	2926	2407	1726	1206	1075	1040	1142	1393	1414	1241
HOLLY TWP.	1366	1211	1036	918	790	741	847	854	950	1008
Holly Village	2644	2596	2343	2252	1888	1537	1419	1266	1443	1429
INDEPENDENCE TWP.	3362	2827	1127	1164	662	799	831	910	1386	1586
Clarkston Village	689	759	653	639	419	345	360	387	....	....
LYON TWP.	1641	1494	1324	1030	797	812	912	953	1143	1298
South Lyon City	1316	1388	1017	844	615	615	657	707	418	....
MILFORD TWP.	1044	1040	913	654	651	687	758	824	949	1767
Milford Village	1896	1785	1637	1364	1088	973	1108	1138	1251	....
NOVI TWP.	3809	3189	2316	1484	1227	1226	1245	1306	1278	1351
Northville City (part)[2]	256	181	112	87	....	....	....	....	....	....
OAKLAND TWP.	1344	1155	966	792	706	702	870	896	1041	1086
ORION TWP.	4759	4045	2400	1373	657	676	751	775	863	847
Lake Orion Village	2373	2342	1933	1369	929	717	756	522	429	304
OXFORD TWP.	1828	1495	1213	923	746	743	818	952	1036	1367
Oxford Village	2282	2344	2144	2052	1668	1191	1172	1128	851	....
PONTIAC TWP.	6078	5220	3465	2669	1216	953	1016	947	1000	1075
Lake Angelus Village (all)	120	99	139	27	....	....	....	....	....	....
Pontiac City	73112	73752	66626	64928	34273	14532	9769	6200	4509	4867
ROSE TWP.	1119	952	797	661	707	842	862	958	1159	1169
ROYAL OAK TWP.	20976	20069	7040	17472	12320	1730	1544	1844	1709	1520
Clawson City (all)[3]	5176	4241	4006	3377	....	....	....	....	....	....
Berkley City	17913	12358	6406	5571	....	....	....	....	....	....
Ferndale City	29670	27392	22523	20855	2640	....	....	....	....	....
Hazel Park City	17791	16665	15000	....	....	....	....	....	....	....

TABLE 3. POPULATION CHART OF OAKLAND COUNTY, MICHIGAN—Concluded

NOTE: Township figures include only the unincorporated part of the township and DO NOT include either the cities or villages. 1950 figures are preliminary census releases.

	1950	1947	1940	1930	1920	1910	1900	1890	1880	1870
ROYAL OAK TWP—Continued										
Huntington Woods City	4919	3461	1705	655	....	....	....	....	....	....
Oak Park City	5243	1703	1169	1079	....	....	....	....	....	....
Pleasant Ridge City	3565	3796	3391	2885	472	....	....	....	....	....
Royal Oak City	46817	35319	25087	22904	6007	1071	468	....	....	....
SOUTHFIELD TWP	18408	13912	8486	3174	1319	1288	1378	1444	1634	1547
SPRINGFIELD TWP	1802	1650	1273	923	857	821	906	1064	1272	1378
TROY TWP	10062	8459	6248	3867	2520	1507	1527	1470	1586	1541
WATERFORD TWP	24087	19211	12019	7942	1354	1065	1079	1163	1324	1362
WEST BLOOMFIELD TWP	8580	8040	5597	3522	1963	1113	999	1229	1096	1143
Orchard Lake Village	683	774	295	178	....	....	....	....	....	....
Sylvan Lake City (all)[4]	1143	1166	1041	799	....	....	....	....	....	....
WHITE LAKE TWP	4183	3413	1643	1114	632	642	718	857	998	1180
TOTAL	393467	366469	254068	211251	90050	49576	44792	41245	41537	40867

[1]Partly in Bloomfield Twp. and partly in Troy Twp.
[2]Only that portion of the city that is within Oakland County.
[3]Partly in Royal Oak Twp. and partly in Troy Twp.
[4]Partly in West Bloomfield Twp. and partly in Waterford Twp.

Sources: [1]Bureau of the Census, Department of Commerce. Census data 1870-1940.
[2]Official Directory of Oakland County for 1949-50.
[3]Detroit News, December 15, 1950. Preliminary 1950 Census data.

TABLE 4. TYPES OF INDUSTRIES AND EMPLOYMENT DATA
Oakland County, Michigan

S.I.C.[1]		Plants[2]		Employment[2]	
		1940	1950	1940	1950
20	Food products	22	30	229	338
21	Tobacco manufactures	1	0	2	0
22	Textile mills products	1	1	10	3
23	Apparel	2	8	11	38
24	Lumber and wood products	4	37	18	222
25	Furniture and fixtures	3	15	15	86
26	Paper and allied products	2	4	18	88
27	Printing and publishing	1	12	20	217
28	Chemicals and allied products	15	36	656	1,388
29	Products of petroleum and coal	1	4	29	12
30	Rubber products	2	6	630	1,129
32	Stone, clay and glass products	29	45	174	287
33	Primary metals	9	37	1,534	3,908
34	Fabricated metals	21	176	544	5,614
35	Machinery and machine tools	33	302	966	7,359
36	Electrical machinery	4	23	25	287
37	Transportation equipment	18	43	17,154	31,279
38	Professional and scientific instruments	3	11	13	517
39	Miscellaneous industries	12	83	115	571
	TOTALS	183	873	22,173	53,371

	1939[3]	1947[3]
Manufacturing plants	132	537
Manufacturing employment	16,102	36,829
Water-using Industries[2]	**1940**	**1950**
Plants	103	468
Employment	3,698	14,282
Retail Trade[4]	**1939**	**1948**
Stores	2,832	3,419
Employment	7,994	15,089
Sales	$83,019,000	$313,918,000

[1]Standard Industrial Classification.
[2]Drawn from 1940 and 1950 Director of Michigan Manufacturing, 1950 M.U.C.C.* data, Bureau of Labor Statistics and other sources.
[3]From 1939 and 1947 U. S. Census of Manufactures.
[4]From 1939 and 1948 U. S. Census of Business.
(Compiled by Research Department, Detroit Metropolitan Area, Regional Planning Commission.)
**Editor:* Michigan Unemployment Compensation Commission, now Michigan Employment Security Commission.

TABLE 6. BEDROCK WELL DATA

Geologic Subdivision	No. Wells	Range in WL	Range Yield	Remarks
L. Marshall-Coldwater fms.	2	flowing	2.5–100	One well—yield 100 gpm when pumped.
Coldwater fm.	10	+ 2 to −95	10–70	Average yield 28 gpm. One flow at 20 gpm.
Coldwater-Sunbury fms.	1	−3	66	
Sunbury-Berea fms.	1	−10	18	
Berea fm.	21	+ 5 to −95	5–30	Average yield 9 gpm. Flows up to 8 gpm.
Bedford-Antrim fms.	1	....	5	
Antrim fm.	2	−60 to −94	1.5–10	
Summary	......	+ 5 to −95	1.5–100	

TABLE 7. SPECIFIC CAPACITIES OF WELLS IN BEDROCK

Well No.	Dia. In.	Water Level	Yield gpm	Draw-down Ft.	Specific Capacity	Remarks
FR-40	......	0	12	60	0.2	Berea fm.
FR-79	......	......	5	130	0.4	Berea fm.
NO-2	......	28	60	20	3.0	Coldwater fm.
RO-49	3	94	10	1	10.0	Antrim fm.
SO-6	......	31	10	160	0.06	Berea fm.
SO-18	......	10	18	50	0.4	In shale. Sunbury or Berea fm.
SO-56	......	......	5	60	0.8	Bedford or Antrim fm.
TR-22	......	8	6	9	0.7	Berea fm.

TABLE 8. WELL DATA—GLACIAL LAKE PLAIN SECTION

Township	Yield gpm			Average WL of NF Wells		Well Depths 1930-1950		Well Depths Prior 1910		Flowing Wells					
										Prior 1910			1930-1950		
	NR	Range	Aver-age	NR	Average WL	NR	Average Depth	NR	Average Depth	NR	NF	F	NR	NF	F
Avon	11	2.5–200	43	26	−16	43	59	4	136	5	0	5	28	26	2
Bloomfield	13	8.0–1500	288	15	−25	32	166	7	50	9	0	9	23	15	8
Farmington	64	1.0–440	25	53	−29	83	91	1	30	1	0	1	59	53	6
Royal Oak	20	1.5–1188	297	16	−81	33	155	3	159	4	0	4	18	16	2
Southfield	23	5.0–600	59	16	−37	25	108	18	113	16	0	16	21	17	4
Troy	36	0.2–1070	108	35	−26	132	114	60	111	76	3	73	44	36	8
Total Lake Plain	167	0.2–1500	102	161	−32	348	109	93	109	111	3	108	193	163	30

NR—Number of records; WL—Water level; F—Flowing; NF—Non-flowing.

TABLE 9. SPECIFIC CAPACITIES OF WELLS IN DRIFT

Well No.	Dia. In.	WL Ft.	Yield gpm	Drawdown Ft.	Specific Capacity	Aquifer	Remarks
MORAINES AND TILL PLAINS							
AV-47	....	18	6	5	1.2	Sand-gravel—5 ft.	
BL-8	14	68	1800	52	34.6	....	General Motors Corp.
BL-10	8	68	220	52	4.2	Gravel—13 ft.	
BL-17	6	65	10	35	0.3	Sand-gravel—7 ft.	
BL-20	....	71	1225	106	11.6	Sand-gravel	
BL-21	6	8	25	67	0.4	Sand	
BL-23	6	80	18	40	0.5	Sand—25 ft.	
FR-46	6	23	6	74	0.1	Sand	
FR-51	....	40	20	19	1.1	Sand	
GR-2	6	70	40	20	2.0	Sand—3.5 ft.	
HO-4	....	9	7	10	0.7	Gravel—5 ft.	
OR-5	4	42	8	27	0.3	Sand	
PO-9	8	45	100	39	2.6	Gravel	
PO-97	12	74	1100	10	110.0	Sand-gravel	
PO-100	5	85	....	....	49.0		
SP-4	....	50	20	9	2.2	Sand	
TR-4	....	30	5	60	0.1	Gravel	
TR-6	....	16	7	5	1.4	Gravel	
TR-7	....	30	4	11	0.4	Gravel	
WA-47	12	70	850	33	26.0	Sand-gravel	
WB-8	6	17.5	70	40	1.8	Gravel	
WB-10	6	....	150	180	0.8	Gravel	
OUTWASH DEPOSITS							
HI-1	6	23	80	3	27.0	Fine sand	C & O Ry.
			100	5	20.0		
HI-2	12	23	200	13	15.4	Sand-gravel	C & O Ry.
HI-3	12	18	200	17	11.7	Sand-gravel	C & O Ry.
HO-7	10	0	250	133	1.9	Gravel	Village of Holly
			200	105	1.9		
LY-1	6	12	200	42	4.8	Gravel	
LY-2	6	18	250	30	8.3	Sand-gravel	
MI-4	12	38	550	30	18.3	Sand-gravel	Ford Motor Co., Well No. 1.
MI-5	12	19	480	35	14.0	Sand-gravel	Ford Motor Co., Well No. 2.
NO-17	6	29	300	19	16.0	Gravel—9 ft.	
NO-18	6	20	150	10	15.0	Sand	
OR-8	8	8	650	27	24.0	Gravel	Village of Orion
OR-9	12	13	925	39	24.0	Gravel	Village of Orion
OR-11	8	35	120	8	15.0	Fine gravel	
SO-10	....	18	9	6	1.5	Gravel	
WA-35	6	22	50	20	2.5	Sand	Southfield Twp. High School

TABLE 9. SPECIFIC CAPACITIES OF WELLS IN DRIFT—Concluded

Well No.	Dia. In.	WL Ft.	Yield gpm	Drawdown Ft.	Specific Capacity	Aquifer	Remarks
GLACIAL LAKE PLAIN							
AV-13	10	10	200	60	3.3	Gravel—8 ft.	Rochester Paper Co.
BL-27	....	33	8	15	0.5		
BL-40	12	....	200	....	4.4	Gravel	Birmingham—Redding well.
BL-58	12	....	200	....	6.6	Sand-gravel	Birmingham—Baldwin well.
BL-61	26	....	1450	....	166.4	Gravel	Birmingham—South well.
BL-64	26	....	1000	....	41.5	Gravel	Birmingham—West well.
BL-65	10	....	400	....	16.2	Sand-gravel	Birmingham—Lincoln well.
FR-62	4	62	20	12	1.7		
FR-69	4	5	9	70	0.6	Sand	
FR-83	....	8	10	50	0.2	Gravel	
FR-103	8	52	350	11	31.8	Sand-gravel	Woodbine Improvement Association
RO-29	12	11.5	900	55	16.4	Gravel	Royal Oak—Cooper well.
			750	49	15.3		
RO-29a	30	78	1200	34	35.3	Gravel	Royal Oak—Buckingham well.
RO-31	8	90	72	121	0.6	Gravel	
RO-39	12	120	490	40	12.3	Sand-gravel	Roseland Park Cemetery
			450	33	13.6		
			415	29	14.4		
			280	21	13.3		
RO-40	....	120	320	30	10.7	Gravel	Roseland Park Cemetery.
RO-45	25	60	1188	24	49.5	Gravel	Royal Oak—Magnolia well (1923)
		57	1058	29	36.5	....	Royal Oak—Magnolia well (1924)
		45	1000	55	18.2	....	Royal Oak—Magnolia well (1950)
RO-46	18	94	820	14	58.5	....	Royal Oak—Northwood well
		95	700	20	35.0	....	Royal Oak—Northwood well (1942)
RO-50	6	63	22	32	0.7		
RO-51	6	63	22	32	0.7		
RO-53	6	56	7.5	9	0.8		
RO-61	12	96	1050	7	150.0	Sand gravel	Berkley—DPW Bldg. well (1928)
RO-62	12	137	650	7	93.0	Sand gravel	Berkley—New well near School (1948)
SO-1	12	....	444	116	3.8	Sand-gravel	Southfield Twp. well.
SO-13	....	22	7	20	0.4	Gravel	
SO-30	....	15	7	56	0.1		
SO-47	6	51	50	36	1.4	Sand	
TR 1	....	23	6	32	0.2	Gravel	
TR-19	....	5	10	2	5.0	Gravel	
TR-20	....	4	6	15	0.4	Gravel	
TR-21	....	4	6	15	0.4	Gravel	
TR-24	....	8	15	13	1.2	Gravel	
TR-26	....	12	2	80	0.03	Gravel	
TR-28	....	10	6	12	0.5	Gravel	
TR-31	4	6	15	13	1.2	Gravel	
TR-52	18	....	800	....	75.1	Sand	Birmingham—Walker well.
TR-54	26	13	900	75	14.0	Gravel	Birmingham—East well.
TR-69	12	76.5	1070	21	51.0	Gravel	Clawson—New well (1949)

TABLE 10. CHEMICAL ANALYSES OF WATER SAMPLES FROM WELLS IN OAKLAND COUNTY, MICHIGAN.
(Data collected from Michigan Department of Health and private sources)

GLACIAL LAKE PLAIN

No.	Date	Owner	Depth	Dis Sol.	SiO_2	Fe	Ca	Mg	Na + K	Cl	SO_4	HCO_3	Total Alk	Ca Hd	Mg Hd	Total Hd	Carb Hd	Non Carb Hd	F	pH
BL-	10–18–46	Lone Pine Court	....	....	....	1.6	45.	20.	117.	33.	4.3	295.	242.	112.	83.	195.	195.	0.	....	....
BL-45	8–45	Bloomfield Village	193	323.	8.8	1.1	68.	23.	23.	18.	7.6	342.	280.	170.	94.	264.	264.	0.	0.5	....
BL-49	3–50	Birmingham—T.H. 33	193	482.	....	3.0	67.	24.	20.	18.	0.	368.	286.	167.	100.	267.	267.	0.	....	....
BL-38	2–47	Birmingham Redding well	83	406.	15.0	1.7	78.	27.	37.	39.	18.	482.	395.	195.	111.	306.	306.	0.	....	....
BL-58	4–49	Birmingham Baldwin well	73	834.	23.0	3.1	118.	37.	53.	58.	152.	393.	322.	293.	153.	446.	322.	124.	0.5	....
BL-61	2–47	Birmingham South well	249	342.	9.6	0.9	64.5	23.4	56.	42.	1.3	334.	274.	160.	95.	255.	255.	0.	0.5	....
BL-64	11–46	Birmingham West well	172	319.	9.0	1.2	65.	24.	20.	20.	3.	405.	332.	163.	98.	261.	261.	0.	....	....
BL-65	2–47	Birmingham Lincoln well	173	330.	10.4	1.2	64.	24.	35.	23.	2.6	405.	332.	160.	99.	258.	258.	0.	0.5	....
TR-52	2–47	Birmingham Walker well	193	388.	10.	2.4	67.	24.	48.	55.	4.	429.	352.	168.	99.	267.	267.	0.	....	....
TR-54	2–47	Birmingham East well	137	430.	11.	1.1	71.	27.	54.	56.	5.	480.	394.	179.	110.	289.	289.	0.	....	....
TR-49	10–21–46	Birmingham—T.H. No. 7	193	....	1.7	0.6	68.	25.	42.	50.	28.3	345.	283.	169.	104.	273.	273.	0.	....	7.6
TR-70	9–45	Clawson-Pine St.	169	570.	11.2	1.0	78.	27.	107.	150.	6.6	390.	320.	195.	110.	305.	305.	0.	0.6	....
TR-30	47	Troy Twp. No. 1	125	460.	8.8	1.4	68.	28.	70.	105.	8.2	342.	280.	170.	115.	285.	280.	5.	0.7	....
TR-	....	Troy Twp. No. 2	118	326.	7.2	....	65.	25.	21.	15.	6.0	345.	283.	162.	100.	262.	262.	0.	0.5	....
TR-	....	Rochester Road and 18 Mi.	....	....	....	6.2	....	....	....	86.	....	....	....	....	....	250.	....	....	....	....
TR-	....	Livernois Road and 19 Mi.	....	....	....	1.4	....	....	....	4.	....	....	....	....	....	335.	....	....	....	....
FR-135	1936	Farmington w.ll No. 4	160	358.	12.8	0.6	70.	28.	26.	30.	7.9	357.	293.	175.	110.	285.	285.	0.	....	....
SO-	1946	Grand River Homes	....	276.	12.8	0.4	40.	15.	39.	22.	tr	262.	215.	100.	60.	160.	160.	0.	0.8	....
RO-26	....	Now Buckingham well Royal Oak-T.H. No. 20	194	377.	18.	0.2	37.	14.	97.	53.	0.	342.	280.	92.	58.	150.	150.	0.	8.2	....
RO-37	1950	Royal Oak-T.H.	153	....	....	....	....	....	....	320.	....	....	....	....	....	135.	....	....	....	....
RO-41	1949	Royal Oak-T.H.	144	....	....	....	....	....	....	320.	....	....	....	....	....	135.	....	....	....	....
RO-29	1942	Royal Oak Cooper well	230	437.	6.8	0.6	60.	24.	76.	80.	7.2	355.	291.	151.	99.	250.	250.	0.	0.5	....
RO-33	1949	Royal Oak Greenfield	215	....	....	0.3	....	....	....	110.	....	....	....	....	....	235.	....	....	....	....
RO-45	1942	Royal Oak Magnolia	143	750.	9.6	0.2	24.	12.6	238.5	300.	1.6	272.	223.	60.	51.	111.	111.	0.	1.5	....
RO-46	1942	Royal Oak Northwood	160	402.	7.6	tr	8.	3.4	150.	80.	3.7	288.	236.	20.	14.	34.	34.	0.	1.5	....
RO-61	1944	Berkley-DPW well	223	378.	12.8	0.5	45.	27.2	63.9	55.	5.2	341.6	280.	113.	111.	224.	224.	0.	0.8	....
RO-62	1948	Berkley New well	205	396.	7.2	0.8	52.	28.8	66.2	65.	2.3	363.5	298.	130.	118.	248.	248.	0.	0.8	....
RO-	....	Beverly Park Sub.	....	447.	10.4	0.6	42.	20.8	101.	105.	4.8	314.5	258.	105.	85.	190.	190.	0.	....	....

TABLE 10. CHEMICAL ANALYSES OF WATER SAMPLES FROM WELLS IN OAKLAND COUNTY, MICHIGAN.—Continued
(Data collected from Michigan Department of Health and private sources)

No.	Date	Owner	Depth	Dis Sol.	SiO_2	Fe	Ca	Mg	Na + K	Cl	SO_4	HCO_3	Total Alk	Ca Hd	Mg Hd	Total Hd	Carb Hd	Non Carb Hd	F	pH
OUTWASH																				
MI-6	1938	Milford Village	124	328.	4.8	....	79.	24.	9.	11.	31.	327.	268.	199.	99.	298.	268.	30.	....	....
MI-2	1938	Milford Test Hole	106	....	....	2.8	....	....	....	....	....	....	....	....	....	295.	....	....	....	....
HO-6	1950	Holly Village-Well No. 1	....	496.	8.0	1.9	107.	36.	20.	20.	97.	400.	328.	266.	146.	412.	328.	84.	0.2	....
....	1950	Holly Village-Well No. 2	130	374.	8.0	1.6	83.	30.	16.	12.	24.	395.	324.	207.	123.	330.	324.	6.	0.3	....
HO-7	1950	Holly Village-Well No. 3	....	334.	7.2	0.5	74.	29.	16.	7.	13.	383.	314.	185.	117.	302.	302.	0.	0.5	....
LY-4	1933	South Lyon Village	78	352.	9.6	1.5	93.	26.	32.	6.	27.	375.	307.	231.	104.	335.	307.	28.	....	....
....	....	West Acres Sub	60	....	....	1.7	....	....	....	....	....	....	....	....	....	290.	....	....	....	....
....	1935	Oxford Village	96	322.	12.3	1.0	80.	25.	2.	5.	39.	310.	254.	200.	100.	300.	254.	46.	....	....
OR-8	1937	Orion Village	172	300.	4.0	0.7	72.	4.	45.	21.	10.	307.	252.	180.	15.	195.	195.	0.	....	....
....	1924	Orion Village	120	391.	11.0	tr	65.	24.	12.	18.	10.	308.	252.	163.	99.	262.	252.	10.	....	....
BL-49	1946	Birmingham-Test Hole	311	301.	16.4	1.5	60.	30.	1.3	25.	14.2	289.	237.	150.	123.	273.	237.	36.	....	7.8
PO-88	1941	Pontiac-Orchard Lake No. 1	200	342.	11.6	1.0	64.	30.	25.	20.	29.	334.	274.	159.	121.	280.	274.	6.	....	....
MORAINE AND TILL PLAIN																				
AV-4	1939	Rochester Village	60	348.	12.	1.8	77.	29.	12.	10.	18.	369.	302.	192.	118.	310.	302.	8.	....	....
PO-	1947	L. Angelus Sub	....	322.	15.	1.4	83.	24.	tr	5.	15.	351.	288.	207.	98.	305.	288.	17.	....	....
WA-46	1929	Oakland Co. Infirmary	237	330.	12.	1.3	75.	23.	19.	22.	tr	360.	295.	187.	93.	280.	280.	0.	....	....
PO-47	1929	Pontiac-N. End well	289	369.	7.2	1.0	64.	27.	43.	47.	10.	350.	287.	160.	110.	270.	270.	0.	....	7.4
PO-58	1929	Pontiac-Featherstone No. 1	180	350.	10.4	1.5	57.	27.	24.	43.	10.	338.	277.	142.	111.	253.	253.	0.	....	7.3
PO-64	1929	Pontiac-Paddock	195	364.	16.8	1.4	78.	29.	17.	16.	55.	332.	272.	195.	119.	314.	272.	42.	....	7.3
PO-65	1950	Pontiac-Mechanic	200	460.	8.0	1.8	94.	34.	18.	23.	87.	354.	290.	234.	138.	372.	290.	82.	0.5	7.2
PO-67	1929	Pontiac-E. Blvd	180	380.	16.0	0.9	77.	30.	28.	45.	8.	372.	305.	192.	123.	315.	305.	10.	....	7.3
PO-68	1950	Pontiac-Featherstone No. 2	195	400.	12.0	1.2	80.	32.	27.	22.	28.	400.	328.	200.	130.	330.	328.	2.	0.6	....
PO-77	1929	Pontiac-Market	197	362.	12.8	0.9	73.	28.	20.	31.	11.	368.	302.	182.	113.	295.	295.	0.	0.	7.3
PO-78	1941	Pontiac-City Hall	205	362.	....	0.9	72.	29.	....	....	18.	....	....	180.	117.	297.	....	....	....	7.5
PO-79	1941	Pontiac-Perry	195	387.	14.8	0.9	75.	32.	25.	32.	22.	371.	304.	188.	132.	320.	304.	16.	....	....
PO-85	1950	Pontiac-Orchard Lake No. 2	183	386.	8.0	1.3	79.	29.	27.	22.	40.	367.	301.	204.	121.	325.	301.	24.	0.6	....
PO-92	1929	Pontiac-Lake St.	248	376.	4.8	1.1	70.	31.	40.	45.	28.	316.	259.	174.	126.	300.	259.	41.	....	....
PO-93	1929	Pontiac-Walnut Plt. No. 6	191	372.	7.2	1.0	69.	28.	34.	31.	17.	361.	296.	170.	110.	280.	296.	0.	0.5	....
PO-83B	1945	Pontiac State Hospital	145	356.	4.2	1.3	75.	24.	17.	10.	23.	348.	285.	187.	98.	285.	285.	0.	0.5	....
PO-83E	1931	Pontiac State Hospital	260	604.	8.8	2.3	139.	33.	20.	25.	183.	367.	301.	346.	134.	480.	301.	179.	....	....

TABLE 10. CHEMICAL ANALYSES OF WATER SAMPLES FROM WELLS IN OAKLAND COUNTY, MICHIGAN—Concluded
(Data collected from Michigan Department of Health and private sources)

BEDROCK

No.	Date	Owner	Depth	Dis Solids	Ca	Mg	Na + K	Cl	SO_4	HCO_3	★Total Alk
AV-57....	1931	Rochester Village........	178	1570.	56.	32.	517.	820.	12.8	278.	228.
RO-25....	1950	Royal Oak City Test....	197	1750.	74.	26.	549.	890.	0.	281.	230.
GR-1.....	1947	Mich. Milk Producers....	265	....	....	....	....	360.	....	....	....
GR-1.....	1952	Mich. Milk Producers....	265	688.	142.	27.	....	472.	18.	293.	240.
LY-6.....	1932	Smith Petroleum Co.....	920	125000.	6000.	2371.	26914.	57500.	1881.	251.	206.
IN-15....	1934	Independent O. & G. Co..	1005	8120.	316.	71.	2650.	4100.	883.	170.	139.
IN-15....	1934	Independent O. & G. Co..	1415	35360.	1850.	664.	8800.	18600.	251.	3.	2.
MI-1.....	1932	Milford Oil & Gas.......	1595	175800.	12450.	3600.	45908.	102500.	1105.	46.	38.

★See fourth column on next page for continuation of this table.

★

No.	Date	Owner	Ca Hd	Mg Hd	Total Hd	Carb Hd	Non Carb Hd	F	pH	Geologic Sub.
AV-57....	1931	Rochester Village........	140.	130.	270.	228.	42.	......	......	Berea-Bedford
RO-25....	1950	Royal Oak City Test....	187.	113.	300.	230.	70.	......	8.1	Antrim
GR-1.....	1947	Mich. Milk Producers....	....	....	324.	....	....	......	......	L. Marshall-Coldwater
GR-1.....	1952	Mich. Milk Producers....	356.	11.	367.	240.	127.	......	7.8	L. Marshall-Coldwater
LY-6.....	1932	Smith Petroleum Co.....	15000.	9721.	24721.	206.	24515.	......	......	Dundee
IN-15....	1934	Independent O. & G. Co..	790.	290.	1080.	139.	941.	......	......	Berea
IN-15....	1934	Independent O. & G. Co..	4625.	2722.	7347.	2.	7345.	......	......	Traverse
MI-1.....	1932	Milford Oil & Gas.......	31185.	14760.	45945.	38.	45907.	......	......	Detroit River

TABLE 11. AVERAGE QUALITY OF WATER BY HYDROLOGIC UNITS IN OAKLAND COUNTY, MICHIGAN

Factor[4]	PHYSICAL AND CHEMICAL STANDARDS (Michigan Department of Health): Excellent	Satisfactory	Objectionable	BEDROCK[1]: No.[2]	Range	Aver[3]
Nitrates (NO_3)	0–5	10	over 20	.....	.....	.....
Total Solids	250	500	over 1000	7	688–175,800	.....
Silica (SiO_2)	0–5	15	over 25	2	5.0–9.2	.....
Iron (as Fe)	0–0.2	0.3–0.5	over 0.5	3	0.2–0.5	.....
Manganese (Mn)	0	0.15	.....	.....	.....	.....
Calcium (Ca)	50	100	over 250	7	56–12,450	.....
Magnesium (Mg)	10	20	over 40	7	2.7–3,600	.....
Sodium (Na) & Potassium (K)	10	30	over 100	6	517–45,908	.....
Chloride (Cl)	0–10	50	over 250	8	360–102,500	.....
Sulfates (SO_4)	25	100	over 250	7	0–1881	.....
Bicarbonates (HCO_3)	.....	.....	.....	7	3–293	.....
Carbonates (CO_3)	.....	.....	.....	.....	.....	.....
Carbonate Alkalinity	.....	.....	.....	1	0	.....
Bicarbonate Alkalinity	.....	.....	.....	1	230	.....
Total Alkalinity	.....	.....	.....	7	2–240	.....
Calcium Hardness	.....	.....	.....	7	140–31,185	.....
Magnesium Hardness	.....	.....	.....	7	11–14,760	.....
Total Hardness	50–100	200	over 300	8	270–45,945	.....
Carbonate Hardness	.....	.....	.....	7	2–240	.....
Non-Carbonate Hardness	.....	.....	.....	7	42–45,907	.....
Fluoride	1.0	0–1.5	over 1.5	.....	.....	.....
pH	7.0–10.5	7.0–10.5	under 7.0 over 10.5	2	7.8–8.1	.....
Odor	none	slight	strong	.....	.....	.....
Free CO_2	.....	.....	.....	.....	.....	.....

UNCONSOLIDATED DEPOSITS

Factor[4]	Outwash: No.[2]	Range	Aver	Moraine-till: No.[2]	Range	Aver	Lake Plain: No.[2]	Range	Aver	Oakland Co.–Unconsol.: No.[2]	Range	Aver
Nitrates (NO_3)	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....
Total Solids	10	300–496	354	17	322–604	384	21	276–834	430	48	276–834	398
Silica (SiO_2)	10	4.0–16.4	9.3	16	4.8–16.8	10.6	21	1.7–23.0	10.7	47	1.7–23.0	10.4
Iron (as Fe)	12	0–2.8	1.2	17	0.9–2.3	1.3	26	.0–6.2	1.2	55	.0–6.2	1.2
Manganese (Mn)	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....
Calcium (Ca)	10	60–107	78	17	57–139	78	23	8–118	59	50	8–139	70
Magnesium (Mg)	10	4–36	26	17	23–34	29	23	3–37	23	50	3–37	26
Sodium (Na) & Potassium (K)	10	1–45	18	16	tr–43	23	23	20–239	68	49	tr–239	43
Chloride (Cl)	10	5–25	15	16	5–47	27	28	4–320	83	54	4–320	53
Sulfates (SO_4)	10	10–97	29	17	tr–183	34	23	0–152	12	50	tr–183	23
Bicarbonates (HCO_3)	10	289–400	343	16	316–400	358	22	262–482	360	48	262–482	355
Carbonates (CO_3)	.....	23	.....	.....	.....	.....	.....	0–80	.....	4	0–80	.....
Carbonate Alkalinity	.....	.....	.....	.....	.....	.....	.....	0–12	.....	.....	0–12	.....
Bicarbonate Alkalinity	.....	237	.....	.....	.....	.....	9	268–395	.....	11	237–395	.....
Total Alkalinity	10	237–328	281	16	259–328	293	23	215–395	297	49	215–395	293
Calcium Hardness	10	150–266	194	17	142–346	197	23	20–293	148	50	20–346	174
Magnesium Hardness	10	15–146	105	17	93–138	117	23	14–153	95	50	14–153	104
Total Hardness	12	195–412	298	17	253–480	314	28	34–446	238	57	34–480	277
Carbonate Hardness	10	195–328	274	16	253–328	289	23	34–322	232	49	34–328	262
Non-Carbonate Hardness	10	0–84	25	16	0–179	26	23	0–124	6	49	0–179	16
Fluoride	3	0.2–0.5	0.3	5	0.5–0.6	0.5	13	0.5–1.5	0.7	21	0.2–1.5	0.6
pH	1	7.8	.....	7	7.2–7.5	7.3	2	7.6–8.2	7.9	10	7.2–8.2	7.5
Odor	.....	.....	.....	.....	.....	.....	.....	H_2S—slight	.....	.....	.....	.....
Free CO_2	.....	.....	.....	.....	15–35	26	.....	.....	.....	6	15–35	26

[1] Includes samples from deep oil and gas exploratory holes.
[2] Number of analyses for particular factor.
[3] Averages not determined due to insufficient samples, particularly from shallow bedrock wells.
[4] Except for hydrogen-ion concentration (pH), all values shown in ppm by weight.

TABLE 12. QUALITY OF GROUNDWATER, CITY OF ROYAL OAK, MICHIGAN

MAGNOLIA WELL	12- -23[2]	5-10-26	7-17-30	7- 6-33	9-23-36	7- 3-40	7-29-42	10-16-44	11- 8-45	7-16-48	4-13-49	4- 4-50	4- 7-50
Iron (Fe)	tr	tr	tr	2	0.3	0.3	0.2	0.2	0.2	2.4			
Calcium (Ca)	28.	29.2	15.5	26.	22.5	20.6	24.		30.				
Magnesium (Mg)	15.6	13.5	5.6	8.6	11.2	10.2	12.6		11.				
Sodium and Potassium	245.	283.	172.		250.	345.5	238.5		258.				
Chloride (Cl)	321.5	365.	140.	290.	290.	272.	300.	465.	300.	350.		360.	420.
Sulfate (SO_4)	6.8	5.	2.6		4.6		1.6		20.				
Bicarbonate (HCO_3)	251.	274.	285.5		280.	452.	272.	280.	288.				
Total Hardness	134.	128.	60.	100.	102.	93.	110.	146.	114.	116.	150.	160.	165.
Non-Carbonate Hardness													
Total Dissolved Solids	740.	846.	474.		736.		750.						
Hydrogen-Ion Conc. (pH)[1]						8.7		7.8	7.5	7.6			

[1]Excepting pH, all values in ppm by weight.
[2]Original Magnolia well damaged by explosion; new Magnolia near old site.

TABLE 12. QUALITY OF GROUNDWATER, CITY OF ROYAL OAK, MICHIGAN—Continued

NORTHWOOD WELL	7- 6-42[2]	11- 8-44[3]	2- 5-45[3]	2-19-45[3]	3- 3-45[3]	8-17-45	1-29-48	7- 7-48	8-13-48	1-24-49
Iron (Fe)		0.3	0.2	0.1	0.2	0.1	0.2	tr	0.6	0.2
Calcium (Ca)	8.	21.							72.	
Magnesium (Mg)	3.4	5.							46.	
Sodium and Potassium	150.	146.							697.	
Chloride (Cl)	80.	88.				103.	110.	120.	338.	
Sulfate (SO_4)	3.7	12.							1.	
Bicarbonate (HCO_3)	288.	309.	302.	296.	281.				476.	
Total Hardness	34.	82.	100.	100.	115.	136.[4]	120.	165.	118.	145.
Non-Carbonate Hardness										
Total Dissolved Solids	402.									
Hydrogen-Ion Conc. (pH)[1]		7.5				8.5			7.9	

[1]Excepting pH, all values in ppm by weight.
[2]Collected soon after drilling.
[3]Well operating 24 hours per day.
[4]Soap hardness.

TABLE 12. QUALITY OF GROUNDWATER, CITY OF ROYAL OAK, MICHIGAN—Concluded

COOPER WELL	11-13-28[2]	9-20-30[3]	9- -36	7-29-42[4]	11- 8-44[5]	4-21-48	8-12-48	2-28-49	8-17-49	1-10-51
Iron (Fe)		1.	0.7	0.6	0.4	0.4	0.9			0.2
Calcium (Ca)	46.8	34.7	6.4	60.	52.	122.	143.			
Magnesium (Mg)	16.6	30.	25.6	24.	18.	87.	91.			
Sodium and Potassium	8.6	140.5	95.8	75.5	102.	152.				
Chloride (Cl)	31.9	104.	120.	80.	72.	90.	103.			
Sulfate (SO_4)	2.8	27.8	2.6	7.2	20.	3.				
Bicarbonate (HCO_3)	120.	429.	365.5	355.	358.	268.	278.			
Total Hardness	97.1	211.	262.	250.	220.	209.	234.	210.	225.	220.
Non-Carbonate Hardness	24.7									
Total Dissolved Solids			500.							
Hydrogen-Ion Conc. (pH)[1]					7.3	7.7	7.6			

[1]Excepting pH, all values in ppm by weight.
[2]Well idle 3 months.
[3]Well operating 5-9 p.m. daily.
[4]Well operating 24 hours daily.
[5]Well idle 4 months.

INDEX