Hydrology and the Effects of Increased Ground-Water Pumping in the Anchorage Area, Alaska

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GEOLOGICAL SURVEY WATER-SUPPLY PAPER 1779-D

Prepared in cooperation with the
Alaska Department of Health and
Welfare and the city of Anchorage

U.S. DEPARTMENT OF THE INTERIOR
March 3, 1849

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By ROGER M. WALLER

CONTRIBUTIONS TO THE HYDROLOGY OF THE UNITED STATES

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HYDROLOGY AND THE EFFECTS OF INCREASED GROUND-WATER PUMPING IN THE ANCHORAGE AREA, ALASKA

By Roger M. Waller

ABSTRACT

The Anchorage area includes about 150 square miles at the head of Cook Inlet in south-central Alaska. It is the principal populated area of Alaska and is undergoing rapid growth in the suburbs. The climate is moderate, and precipitation averages about 14 inches per year, including snowfall of about 60 inches.

The physical features of the area are related to glaciation and consist of morainal hills, an outwash plain, melt-water channels, lakes, and swamps. Several streams, which partly occupy former melt-water channels, disgorge from the Chugach Mountains and traverse the plain.

The principal source of water supply is Ship Creek. During the winter, streamflow diminishes, and the demand exceeds the supply. Increasing water demands and periodic turbidity of the surface water have necessitated an alternate source. Municipal and military well fields were constructed to supplement the surface source with ground water.

The aquifers of the Anchorage area are composed of confined sand and gravel outwash-plain deposits interbedded with clay and silt. The source of recharge is probably Ship Creek and other local streams in limited areas along the mountain front. At the begining of major ground-water development, it became apparent that large-capacity wells could be obtained locally. In addition, because the ground water is relatively warm and consistently of good quality, the water can be used for part or all of the needed supplies. The water is of the calcium magnesium bicarbonate type and is of medium hardness.

Interference among closely spaced wells appears to be a principal problem to be considered. The aquifer is artesian, and pumping results in large drawdowns at relatively great distances from the pumping wells. Construction of additional wells as the need arises will require that they be adequately spaced to avoid excessive pumping lifts. Water levels fluctuate with the seasonal and annual changes in recharge and discharge at Anchorage. Short-term records indicate that very little dewatering of the aquifers has taken place.

Pumpage of ground water is steadily increasing and can be expected to be beneficial by inducing more recharge, dewatering submarginal wetlands, and decreasing the incidence of freezing of the distribution lines. On the other hand, long-term increases in pumpage may interrupt streamflow in the winter and lower lake levels, induce recharge of water of poor quality, and increase hazards of sea-water intrusion.

INTRODUCTION

PURPOSE AND SCOPE OF REPORT

This investigation was started in 1958 by the U.S. Geological Survey in cooperation with the city of Anchorage and the Alaska Department of Health and Welfare. The primary purpose of the 3-year investigation was to observe and interpret the effects of greatly increased ground-water pumpage on the water resources of the Anchorage area. In addition, the study provided for a systematic collection of water data and a further increase in the knowledge of the hydrology of the area. The information obtained during the study will be useful in evaluating the need for expanding the water supply and distribution system of the rapidly expanding city of Anchorage. The report also presents data collected prior to the investigation under Federal programs and presents a more thorough evaluation of the effects of increased use of ground water.

An interim report (Waller, 1961) covering the first 2 years of this study was released to make the preliminary results readily available to the city and other water users.

PREVIOUS INVESTIGATIONS

Several previous reports are available on the geology and water resources of the Anchorage area. The geography and surficial geology were described by Miller and Dobrovolny (1959). Kerr and Cederstrom (1951) and Cederstrom and Trainer (1953) compiled records of well data. Black and Veatch [1] reported on military-base supplies and included data on the Anchorage water supply. Lohr (1957) reported on the chemical quality of Anchorage's water supply. Nyman (1959) published a detailed account of the construction of the city's first large production wells. The Geological Survey (Wells, 1957, 1958a, 1958b, 1960a, 1960b) has published data on the quantity and quality of streams in Alaska, which include streams in the Anchorage area. Cederstrom, Trainer, and Waller (1964) made a study of the geology and ground-water resources which significantly influenced ground-water development by the city of Anchorage and led to the cooperative study covered by this report.

ACKNOWLEDGMENTS

Special acknowledgment for information and helpful suggestions is extended to Messrs. R. B. Smith, City Engineer, J. D. Moore, Jr.,

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[1] Black and Veatch, 1952, Report on development of supplemental water supply Elmendorf Air Force Base and Fort Richardson, Alaska: Mimeo. rept., Kansas City, Mo.

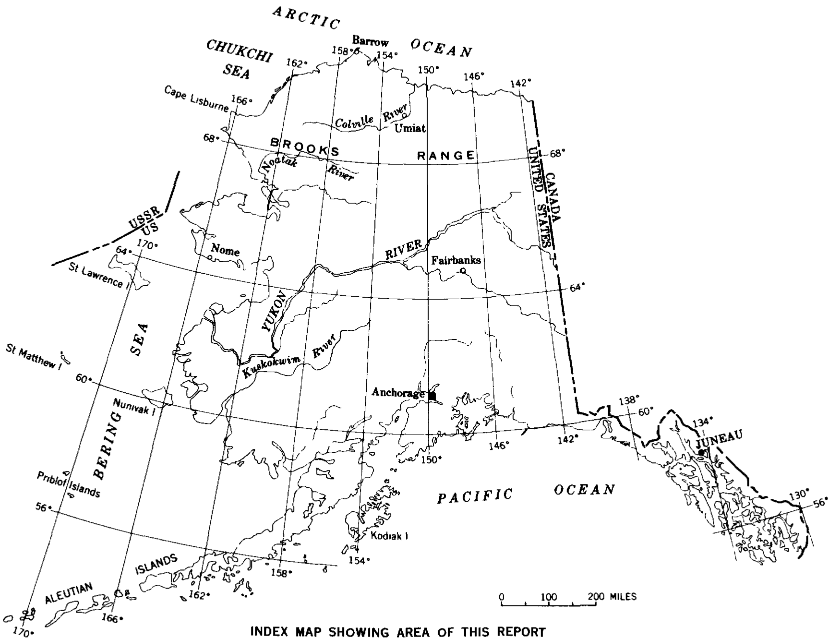
engineer, F. E. Nyman, engineer formerly with the City Engineer's office, and other employees of the Anchorage Public Works Department. Mr. Tim Holte of the Fort Richardson water plant and Mr. H. L. McClure of the Elmendorf Air Force Base water plant supplied water-use data, and several well owners allowed their wells to be used for observation.

GEOGRAPHY

LOCATION AND EXTENT OF THE ANCHORAGE AREA

The Anchorage area is a triangular lowland of about 150 square miles at the head of Cook Inlet in south-central Alaska. (See index map below and pl. 1.) The area of this report extends from Eagle River on the north to Little Rabbit Creek on the south and includes the city of Anchorage, the unincorporated community of Spenard, and Fort Richardson and Elmendorf Air Force Base. The Chugach Mountains form the eastern boundary of the area.

Anchorage is connected to other Alaska communities by the Glenn and Seward Highways (State Highway 1), which connect with the Alaska Highway (U.S. Highway 97). The Alaska Railroad, owned and operated by the U.S. Department of the Interior, serves Anchorage from the south and north and uses Anchorage as its headquarters.



INDEX MAP SHOWING AREA OF THIS REPORT

Several State and interstate airlines serve the city, and international airlines are increasingly making Anchorage a "crossroads of the north."

POPULATION

The 1960 census shows a population of 81,845 for the Anchorage area: 44,237 for Anchorage, 9,074 for Spenard, and 28,634 for the two military bases and the suburbs and rural areas south and east of Anchorage. The population of Anchorage had increased from 11,254 in 1950—an increase of 293 percent.

PHYSIOGRAPHY AND RELIEF

The Anchorage area was subjected to glaciation during the Pleistocene Epoch, and the main topographic features of the lowland were formed during the last glacial advance and retreat. The main geomorphic features consist of an extensive outwash plain, melt-water channels and depressions, and morainal knolls and ridges.

The outwash plain occupies the northern half of the area, in which are located the city of Anchorage, Spenard, and the military bases. The plain is dissected by Ship and Chester Creeks. These creeks and their tributaries occupy broad, shallow valleys cut into the plain by former large melt-water streams discharging from the last glacial ice sheet. Consequently, the valleys or basins of the creeks are not as well defined on the lowland as they are in the mountains.

The knolls and ridges, principally in the western part of the area, represent deposits of glacial debris from older ice sheets. A prominent ridge that extends from Cairn Point to just north of the east junction of the Davis and Glenn Highways represents the terminal moraine of the last ice sheet that came down Knik Arm. Fire Island probably represents a similar moraine of an ice advance that came down Turnagain Arm.

The streams that drained the last ice sheet have greatly altered the glacial topography of the area. Two large streams, the Knik and Turnagain Rivers, each formed from the major discharge of separate ice lobes. The streams cut through the glacial drift and isolated the Anchorage area as a triangular shaped lowland fronting the Chugach Mountains. The Knik and Turnagain Rivers now empty into Cook Inlet through estuaries or arms having extremely large tidal variations, as much as 40 feet in Knik Arm.

Smaller streams from alpine-type glaciers in the Chugach Mountains formerly emptied onto the lowland and occupied some of the large melt-water channels. The disappearance of these alpine glaciers has reduced the flow of these streams. At present these streams—the Ship, Chester, Campbell, Rabbit, and Little Rabbit Creeks (pl. 1)—receive their flow from precipitation and snowmelt. The presence of many swamps, lakes, ponds, and sluggish streams indicates that an integrated drainage pattern has not yet formed on the lowland created by Pleistocene glaciation.

CLIMATE

The weather at Anchorage is greatly affected by the Gulf of Alaska to the south and the mountain range to the east. Summers are usually cool, cloudy, and moist, whereas winters are usually cold, clear, and dry. There are no great extremes in either season. The following summary is from U.S. Weather Bureau records obtained from several stations in Anchorage and vicinity and adjusted to represent observations at International Airport (pl. 1).

The mean monthly temperature is 35.3°F as shown in table 1. The highest temperature ever recorded was 86°F in June 1953, lowest was −38°F in February 1947. The winter season usually begins in early October, when frost and snow form a continuous cover. This cover lasts until the spring "breakup," which usually occurs in early April.

The mean annual precipitation at Anchorage, based on the period 1921–50 and adjusted to the present standard location, is only 14.29 inches. The cool, moist summers belie this semiarid condition, however, as about half of the annual precipitation falls as light rain during the July–September period. September is the month of greatest rainfall (2.71 inches), and December is the month of greatest snowfall (12.4 inches), although December is the only month for which there is a record of no precipitation (table 1). The mean annual snowfall is 60.9 inches.

No records are available of the precipitation in the Chugach Mountains, which provide most of the water for the area's streams. The U.S. Weather Bureau (C. E. Watson, oral commun., 1959) stated that a newly established station east of Anchorage, near Russian Jack Springs on the lowland (pl. 1), records about 3 to 4 inches more precipitation than the station at International Airport. This difference is probably due to the effect of the mountains on air movement; presumably precipitation is substantially greater in the higher parts of the Chugach Mountains.

TABLE 1.—*Climatological data for Anchorage International Airport, Alaska, 1921–50*

[Data from U.S. Weather Bur.]

	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.	Annual
Precipitation (inches):													
Normal monthly total	0.76	0.60	0.60	0.40	0.51	0.89	1.55	2.56	2.71	1.87	1.00	0.84	14.29
Maximum monthly	2.13	3.07	1.61	1.50	2.00	2.94	3.28	5.91	5.16	5.13	2.40	2.67	
Minimum monthly	0.05	T	T	T	.02	.03	.19	.23	.52	.26	.04	.00	
Temperature (°F):													
Normal	13.0	18.6	24.8	35.4	45.7	53.7	57.3	55.6	48.0	36.0	22.3	13.8	35.3
Daily maximum	20.4	26.9	33.8	44.2	55.0	62.8	65.4	63.9	56.3	43.2	29.0	20.4	
Daily minimum	5.5	10.3	15.7	26.6	36.4	44.5	49.1	47.3	39.6	28.8	15.5	7.1	

GEOLOGIC CONDITIONS

The following summary of geologic conditions is based on recent investigations by D. J. Cederstrom, F. W. Trainer, and R. M. Waller. Bedrock in the Anchorage area is composed of metamorphic rocks, which make up the Chugach Mountains, and sedimentary rocks, which underlie the lowland but are exposed only in the Eagle River area (pl. 1). A thick mantle of unconsolidated glacial drift overlies the sedimentary rocks and the lower slopes of the Chugach Mountains.

During the Pleistocene Epoch of great continental glaciers, ice migrated into the Cook Inlet area and left thick deposits of glacial drift. Several episodes of glacial activity have been recognized. In general, ice advanced over the Anchorage area at least three times, and each time left a succession of unsorted material (till), sand and gravel stream deposits, and estuarine or lacustrine clay and silt beds.

A typical sequence of deposition of one glacial advance and retreat is generalized as follows: Glaciers advance into the area and eventually become stagnant, depositing morainal material (till); some of the material is reworked by melt-water streams forming outwash deposits; finer material is carried into a glacial ponded lake or estuary to form clay and silt beds; blocks of ice become buried by sand and gravel and later melt to form depressions (such as present lakes, ponds, and swamps); large channels form from the large flow of melt water; and finally, vegetation grows and normal erosion takes place prior to the next glacial advance.

WATER RESOURCES

GENERAL OCCURRENCE

Water in the form of rain and snow falls and subsequently runs off in streams or percolates into the ground. Some of the water evaporates, and some is consumed and transpired by vegetation. The part of the water that runs off to streams soon discharges into the ocean. The part of the precipitation or streamflow that percolates into the ground may spend many years in underground transit to the sea, may emerge as springflow, or may become trapped by some impermeable barrier and delayed for many additional years before emerging. Thus, water is always in transit from the ocean to the air to the ground and back to the ocean in a never-ending hydrologic cycle, as shown in figure 1.

The surface-water segment of the hydrologic cycle is represented by the streams, lakes, ponds, and swamps. Streamflow varies with the amount of precipitation and the inflow of, or loss to, ground water. Hence, streams vary in their amount of discharge, depending upon the season and geologic environment. Discharge is usually measured in cfs (cubic feet per second) at selected points on streams, the site depending on the purpose of the measurement. For example, some sites are selected for determining the amount of streamflow entering an area and other sites are selected for determining the outflow from an area—usually a particular drainage area.

The ground-water segment of the hydrologic cycle is represented by subsurface water in the voids of unconsolidated sediments and the fissures in consolidated rocks. The upper surface of this zone, called the "zone of saturation," is the water table. Between the land surface and the water table is the "zone of aeration," through which water moves from the land surface to the water table. Ground water then moves through the saturated zone from points of high hydrostatic head to points of lower hydrostatic head. It is discharged naturally through seeps and springs into streams or lakes and by transpiration from plants. Artificial discharge takes place from wells or excavations extending below the water table. If the rock unit yields water in usable quantities, it is termed an "aquifer."

In some places aquifers are confined by a relatively impermeable layer or bed, such as clay. If the confining layer and aquifer are of sufficient extent and have a great enough slope from the recharge area, the ground water will move down the aquifer under pressure. Such an aquifer is termed "artesian," and the water will rise above the top of the aquifer in wells penetrating the formation. The level to which confined water will rise is called the "piezometric surface" and is analogous to the water table. Water in artesian aquifers moves in the direction of decreasing head.

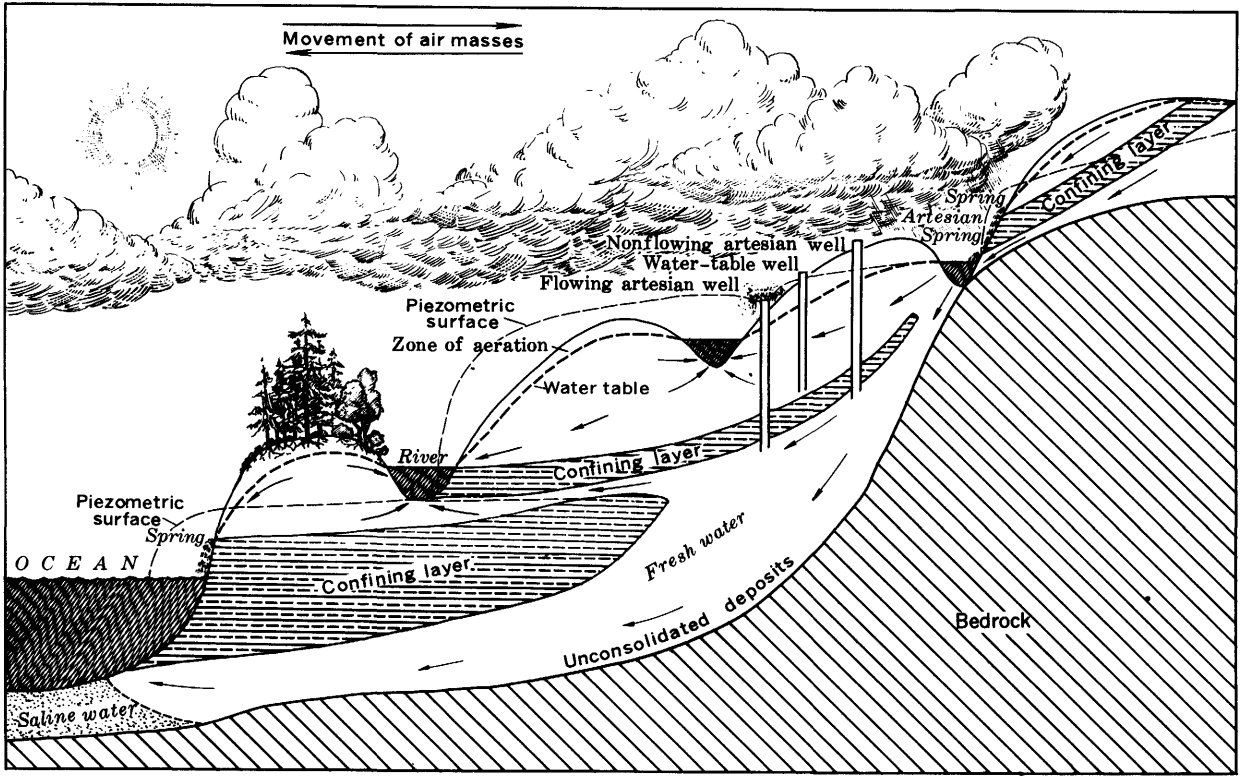


FIGURE 1.—Hydrologic cycle. Adapted from McGuinness (1951).

Measurement of water levels in wells tapping both types of aquifers is a method of obtaining the elevation of the water table or piezometric surface and thereby of determining the direction of ground-water movement. Springs represent ground-water outflow from either water-table or artesian aquifers. Lakes may represent the water table where it intersects topographic lows, or they may represent isolated water tables perched above the main water table.

The quality of both surface and ground water is determined largely by the type of rock with which the water comes in contact. Rainfall and snowmelt soon become mineralized as they react with minerals in the rocks. Surface water usually has a short contact time with rocks and therefore has a lower mineral (dissolved-solids) content than that of ground water. Ground water moves through the rock formations at a much slower rate, and is therefore able to dissolve more minerals than surface water. Laboratory analyses of water permit an evaluation of chemical quality, source, and—under certain circumstances—the rate of ground-water movement.

SURFACE WATER

The surface-water features of the area covered in this report include several streams and numerous lakes and ponds. Five major streams—Ship Creek, Chester Creek, Campbell Creek (including North and South Forks), Rabbit Creek, and Little Rabbit Creek—cross the area. (See pl. 1.) Except for Chester Creek, all the creeks head in the Chugach Mountains. Chester Creek and many of the tributaries of the other creeks originate in the lowland and foothills fronting the mountains.

GROUND WATER

Ground water in the Anchorage area occurs principally in an artesian system. The sand and gravel deposits interbedded with the clay, silt, and glacial till yield water freely to wells. The surface sand and gravel also yield water but have not been developed as a major source of supply.

Generally, the deep wells of the Anchorage area penetrate two or three artesian aquifers (the outwash deposits referred to in the section under "geologic conditions") separated by relatively impermeable material. The fact that the piezometric surface of the water is generally higher than the land surface in the deeper aquifers causes many wells to flow and several artesian springs (Meinzer, 1923, p. 51), such as Russian Jack Springs (pl. 1), to occur. However, as will be discussed later, the aquifers are connected hydraulically and show changes in water level when major withdrawals are made from the artesian system. Cederstrom, Trainer, and Waller (1964) reported on the complexity of the glaciofluvial aquifers in the area and postulated leakage from one aquifer to another through the intervening fine-grained clay and silt layers.

AREAL HYDROLOGY

The close relation of ground-water fluctuation to precipitation and runoff in the Anchorage area is shown on figure 2. The graph compares fluctuations of water level of three lakes and a shallow well, the discharge of Chester Creek and Russian Jack Springs, and the precipitation at Anchorage. Plate 1 shows where the water data were collected.

The hydrographs correlate very well, indicating a gradual rise in the water level and increased spring and stream discharge owing to above-normal precipitation in the past few years. The increasing urbanization in the area has probably contributed to the rising water table and increasing stream discharge: extensive land clearing can result in less transpiration by vegetation; drainage activities lower the water table locally, but permit more water to be transmitted to lower areas; and the tremendous increase in home construction has resulted in greatly increased pumpage from wells tapping artesian aquifers and discharge of sewage waste to shallow septic tanks.

The levels of the lakes in the area probably represent the level of the shallow water table, although during certain seasons a lake may be perched above the normal water table. The fluctuations of the lake levels (fig. 2) indicate recharge from precipitation and ground-water seepage. Water from artesian aquifers probably leaks upward into some of the lakes. A study of precipitation, evaporation, and changing lake levels probably would clarify the major source of recharge to these lakes. Goose Lake and Lake Spenard are of prime value to the area as a city recreation park and a floatplane base, respectively.

SHIP CREEK AREA

Ship Creek drains an area of approximately 91 square miles in the Chugach Mountains. Below the diversion dam at the mountain front (pl. 1), the creek traverses the Anchorage plain for about 8 miles, passing through both military bases and Anchorage before emptying into Knik Arm. The creek apparently loses water as it crosses the eastern part of the lowland. Hence, it recharges the ground water in this area and is considered the major source of recharge to aquifers in the city and military base areas.

Cederstrom, Trainer, and Waller (1964) inferred from the chemical quality of water, temperature, and water-level fluctuations that Ship Creek recharges the ground-water reservoir of Anchorage through permeable uncompacted till or through other aquifers which have a

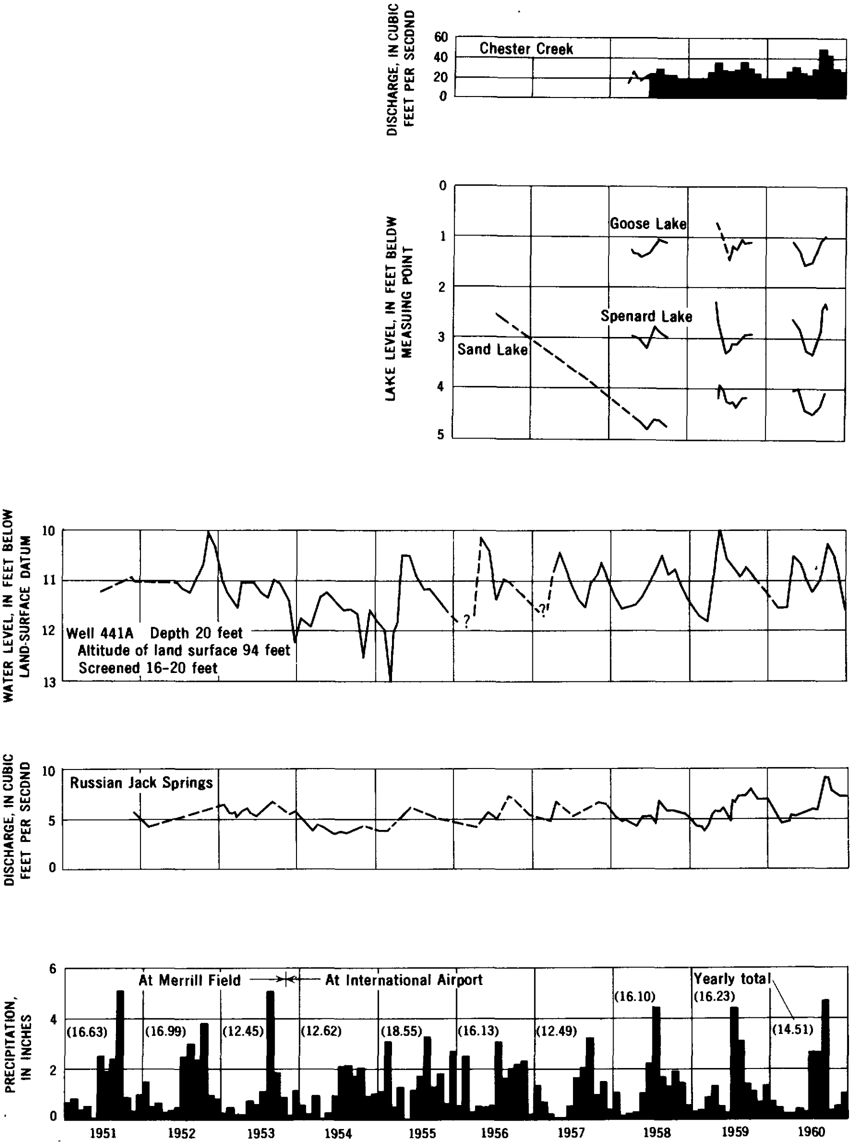


FIGURE 2.—Relation of stream discharge, lake levels, water table, spring discharge, and precipitation in the Anchorage area 1951–60.

hydraulic connection with the stream. They further inferred that such recharge does not take place in the western part of the plain because of underlying clay confining strata. In contrast, shallow ground water contributes additional flow to the creek from springs. These clay strata—the Bootlegger Cove Formation of Miller and Dobrovolny (1960), which is prominently exposed in the bluff between

728-784 O - 64 - 2

Cairn Point and Point Woronzof—extend eastward to the vicinity of the Davis Highway and southward along a line approximately paralleling the Seward Highway, at least as far south as Little Campbell Creek (see pl. 1). Hence, during the investigation, controlled measurements at several sites along the streams were made at various stages of streamflow to delineate areas of losses and gains and to help define the recharge area to the aquifers.

Figure 3 shows a graph of stream loss and gain as determined on Ship Creek at various sites. The Ship Creek discharge measurements show a loss in streamflow in the reach in the eastern part (alluvial fan) of the lowland and a gain in flow west of measuring site 8 at the Davis Highway (approximate Bootlegger Cove Formation boundary). On the basis of the four series of measurements taken on Ship Creek, about 5 to 10 mgd (million gallons per day) of water is recharged in the upper reach of Ship Creek.

Discharge measurements have been made at the gaging station below the diversion dam on Ship Creek (site 2, pl. 1) since October 1947. This station was established to determine streamflow, after diversion for military and city water supply. Streamflow data for the period of record have been published in a report by Wells and Love (1957, 1958a, 1958b, 1960a, and 1960b).

Figure 4 shows the hydrograph for the years of record of the discharge of Ship Creek plus the amount of diversion and the hydrograph of well 64. The graph shows that very little discharge was available after diversion during the low-flow periods January to April in the years 1954–57. On several days during these periods there was no flow immediately below the diversion dam. Since that time the diversions during the critical periods have been reduced, as other sources of water have been used. The close relation of streamflow to the changes in the piezometric level in well 64 tapping an artesian aquifer can be noted. Since 1958, the normal annual low water level in well 64 has probably been lowered slightly by pumping in the area.

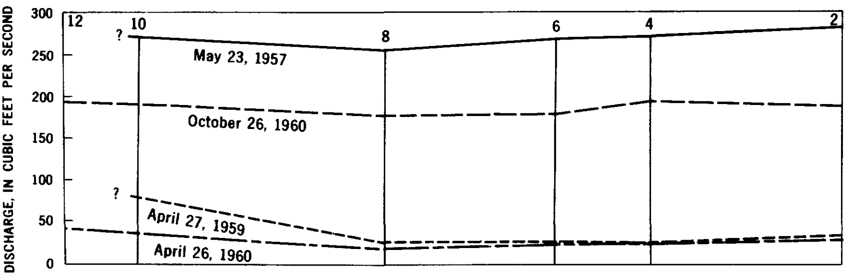


FIGURE 3.—Discharge at selected sites along lower Ship Creek basin showing stream discharge loss and gain, 1957–60. Location of sites shown on plate 1.

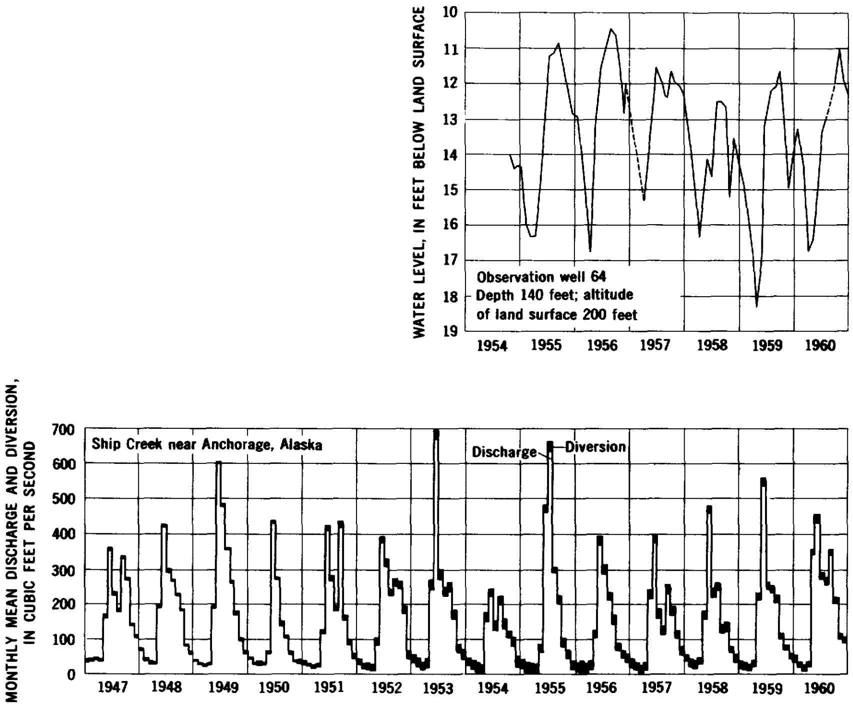


FIGURE 4.—Monthly mean discharge of and diversions from Ship Creek and water-level fluctuations in an artesian well east of Anchorage, 1947–60.

CHESTER CREEK AREA

As noted earlier, Chester Creek is principally a lowland stream, as it derives most of its flow from the lowland. Its mountain segment is not directly connected to the lowland segment because the stream proper disappears into a large swampy area. Numerous swamps, springs, and small tributaries contribute water to the stream as it flows across the plain. It occupies a former melt-water channel in its lower reach. The few lakes in the drainage area of Chester Creek probably represent the water-table level.

Measurements of the discharge of Chester Creek at site 8 (fig. 2) were begun in 1958 to determine the amount and variation of flow that can be expected in the lower reach of the stream from the 21-square-mile drainage basin above the site. Miscellaneous measurements of the discharge of Russian Jack Springs had been made previously by the Survey and have been continued. Discharge measurements of Chester Creek have been published by Wells and Love (1960b) and of Russian Jack Springs (Wells and Love, 1957, 1958a, 1958b, 1960a, and 1960b).

CAMPBELL CREEK AREA

The Campbell Creek area includes the drainage basins of the North and South Forks of Campbell Creek and much of the lowland. As in Ship Creek, the headwater areas in the Chugach Mountains contribute much of the flow of Campbell Creek. The creek meanders sluggishly through the lowland and empties into Campbell Lake, a recent manmade lake, (pl. 1).

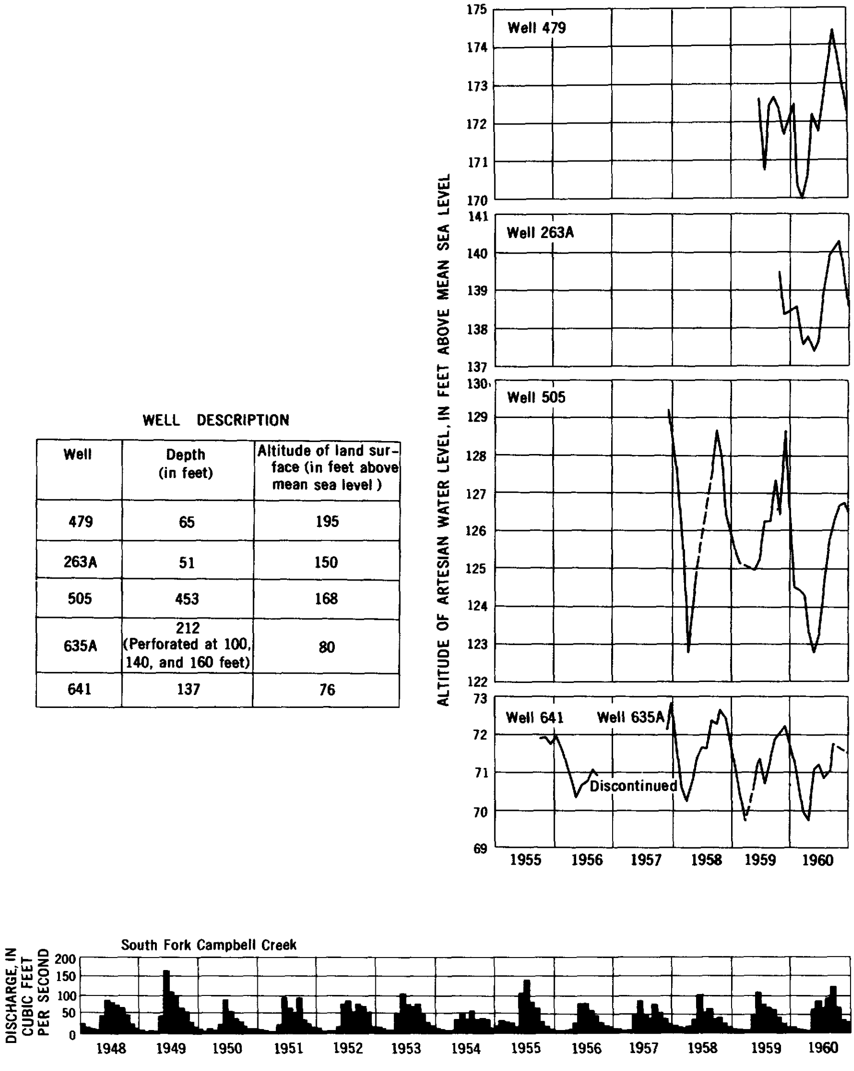
A gaging station was established by the Geological Survey on the South Fork of Campbell Creek (pl. 1) in 1947. The city has obtained water rights to the headwater area of South Fork for a potential water-supply source. Streamflow data on the South Fork, which has a drainage area of approximately 29 square miles, have been published (Wells and Love, 1957, 1958a, 1958b, 1960a, and 1960b).

A hydrograph for the years of record of the discharge of the South Fork of Campbell Creek and fluctuations of water levels in several nearby wells are shown on figure 5. Again, the close relation of streamflow to water-level fluctuations in wells of various depths can be seen. The data for well 641 have been adjusted to correlate with data for well 635A on the basis of the long-term trend of well 441 (fig. 11). The trend of the deeper wells farther west (see pl. 1) shows a lowering of the water level, possibly owing to a lag in the effect of less streamflow in 1956 and 1957. The shallower wells (263A and 479) have shorter periods of record and probably only reflect increased recharge during the year 1960.

Miscellaneous measurements of streamflow for determining changes in flow also have been made at several sites on Campbell Creek. Conditions similar to those at Ship Creek probably prevail here, but the data on streamflow were not conclusive, principally because of lack of measurements of inflow of small tributaries to the main streams. Campbell Creek, in contrast to the single stream of Ship Creek, has many small tributaries. However, on the basis of four series of measurements it appears reasonably certain that the South Fork of Campbell Creek loses water during rising stages of the creek along the stretch of stream above site 4. (See pl. 1.)

RABBIT CREEK AREA

Rabbit and Little Rabbit Creeks do not seem to affect noticeably the hydrology of the lowland near Anchorage. No data have been collected on discharge or quality of these streams. They are principally mountain streams and are probably gaining flow throughout their reaches.



WELL DESCRIPTION

Well	Depth (in feet)	Altitude of land surface (in feet above mean sea level)
479	65	195
263A	51	150
505	453	168
635A	212 (Perforated at 100, 140, and 160 feet)	80
641	137	76

FIGURE 5.—Monthly mean discharge of South Fork Campbell Creek and artesian water-level fluctuations in wells south of Anchorage.

QUALITY OF WATER

A program of periodic sampling and analysis of the chemical constituents of water from wells, streams, and Russian Jack Springs was established early in 1958 as a part of the overall study of the effects of pumping on the water resources of the Anchorage area. Tables 2 and 3 list selected analyses of these waters. A list of definitions of terms with adaptations, used in chemical analyses by the U.S. Geological Survey follows (Wells and Love, 1958a, p. 2).

DEFINITIONS OF TERMS

Parts per million (ppm) is a unit weight of a constituent in a million unit weights of solution. Parts per million may be converted to grains per gallon by dividing by 17.12.

Hardness as $CaCO_3$ is the amount of calcium and magnesium expressed as an equivalent amount of calcium carbonate.

Noncarbonate hardness is the hardness caused by the calcium and magnesium in excess of the bicarbonate and carbonate or alkalinity hardness. It is sometimes called permanent hardness.

Specific conductance is a measure of the ability of the water to conduct electricity, and is roughly proportional to the dissolved-solids content. Specific conductance in micromhos is 1 million times the reciprocal of specific resistance at 25°C. Specific resistance is the resistance in ohms of a column of water 1 centimeter long and 1 square centimeter in cross section.

pH is the hydrogen-ion concentration, and is expressed as the negative logarithm of the gram ions of hydrogen per liter.

Dissolved solids, as used in this report, is the sum of determined constitutents in which the value for bicarbonate is converted to an equivalent amount of carbonate. This conversion is made for bicarbonate to the form in which it would normally exist in an anhydrous residue.

SURFACE WATER

The chemical quality of surface waters of the area is generally very good. Owing to the short time that most of the water is in contact with the minerals in the ground, the dissolved-solids content of the water remains low. During the winter, when the streams are receiving only ground-water discharge, the mineral content of the water gradually increases as dilution from rainfall decreases. Figure 6 shows the trend of specific conductance during 1958–59, which indicates the seasonal variation of the chemical quality of the water. The distinct dip in the curves in late May and June represents the dilution of the stream as snowmelt contributes to the streamflow. Chester Creek shows a greater specific conductance than the other streams during most of the year. This greater specific conductance is probably related to the greater proportion of ground water in the stream throughout the year. The almost identical trends of Ship Creek and the North Fork of Campbell Creek suggest probable similarity of the rock types and terrain these streams traverse. The lower concentration of dissolved solids of the South Fork of Campbell Creek may indicate that the water has a shorter contact time with the rocks or that the rocks are of a different character and do not dissolve as readily as those in the Ship Creek and the North Fork of Campbell Creek valleys.

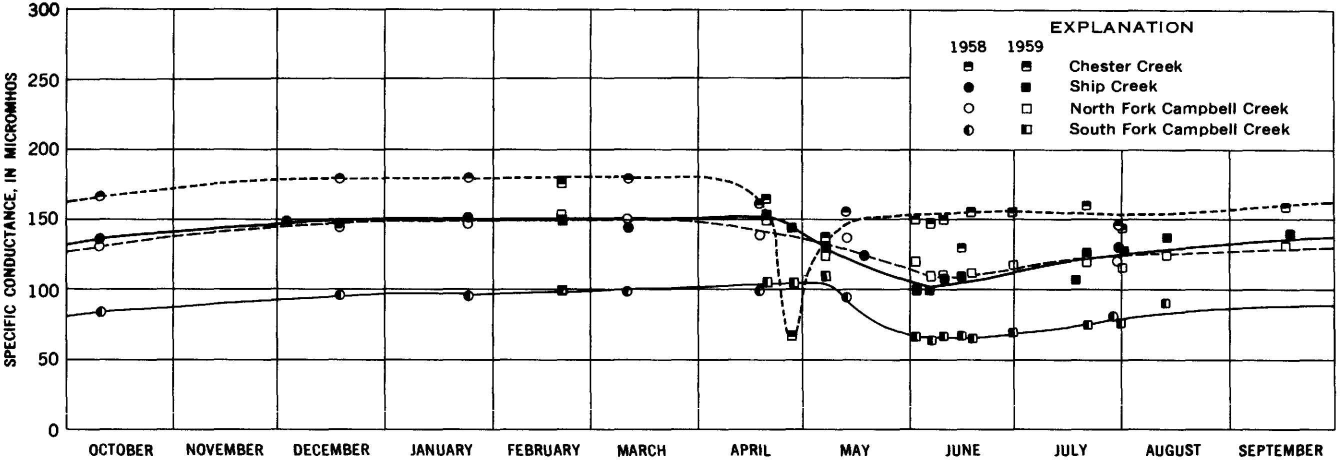


FIGURE 6.—Seasonal variation in chemical quality of surface water, 1958–59 composite water years.

Table 2 shows two selected chemical analyses of water from each stream at different seasons. The winter (March) analyses show the quality of the ground water which supplies the base flow of the streams, whereas the summer (July) analyses show the quality of the water at higher discharge rates resulting largely from rainfall and late snowmelt in the mountains. Previous analyses on chemical quality of Anchorage area streams have been published (Wells and Love, 1957, 1958a, 1958b, 1960a, and 1960b).

The turibidity of the creeks is extremely variable. Heavy rainfall in the mountains, snowslides and landslides, spring breakup, and fall freezeup can all create disturbances in the streamflow and add sediment to the water. The sediment problem will be remedied in the future when the water treatment plant is constructed by the city of Anchorage. The military already has such a plant.

GROUND WATER

Water percolating through soil and rocks dissolves some of the material with which it comes in contact. The amount and character of the dissolved-mineral matter in ground water depend on the chemical and physical composition of the rocks through which the water moves, the duration of the contact, and other factors such as temperature and pressure. Chemical analyses from each city well and Russian Jack Springs are listed in table 3.

Water in the Anchorage area glacial deposits is predominantly of the calcium bicarbonate type, as calcium makes up 50 percent or more of the bases and bicarbonate, 50 percent or more of the acids. The ground water is of medium hardness, as determined by equivalent quantities of calcium and magnesium in the water. Table 3 shows that the hardness of the city well water ranges from 82 to 118 ppm. A comparison with the analyses of surface water given in table 2 shows that the hardness is less and that the general quality of the stream water is better. Concentrations of sulfate in well water near Ship Creek were noted by Cederstrom, Trainer, and Waller (1964) and were thought to reflect recharge to ground water by the stream. They also stated that deep wells in the lower Ship Creek area had higher sodium-potassium content than other wells in the area. Water from well 3 (table 3) is of this character. They postulated that the deep well water from the lower Ship Creek area has been softened naturally by ion exchange.

TABLE 2.—*Selected chemical analyses in parts per million, of surface water in the Anchorage area, Alaska*

Date of collection	Mean discharge (cfs)	Silica (SiO_2)	Iron (Fe)	Manganese (Mn)	Calcium (Ca)	Magnesium (Mg)	Sodium (Na)	Potassium (K)	Bicarbonate (HCO_3)
Ship Creek									
3-11-58	22	7.7	0.17	0.00	21	3.6	2.0	0.4	63
6-18-59	622	5.8	.02	.00	15	3.8	1.4	.4	44
Chester Creek									
3-11-58	[1] 14	13	0.00	0.02	24	5.6	2.6	0.7	92
6-18-59	26	13	.10	.00	21	5.7	2.8	.6	79
North Fork Campbell Creek									
3-11-58	----------	9.3	0.07	0.02	23	3.3	1.5	0.4	64
6-18-59	----------	6.3	.02	.00	16	3.3	1.4	.5	39
South Fork Campbell Creek									
3-11-58	10	8.3	0.00	0.00	14	2.3	1.2	0.2	41
6-18-59	138	5.8	.02	.01	9.5	2.6	.6	.2	24

---

[1] Estimated.

Date of collection	Sulfate (SO_4)	Chloride (Cl)	Fluoride (F)	Nitrate (NO_3)	Dissolved solids (residue at 180°C)	Hardness as $CaCO_3$		Specific conductance (micromhos at 25°C)	pH	Color
						Calcium, magnesium	Noncarbonate			
Ship Creek										
3-11-58	18	1.0	0.1	1.0	86	68	16	145	7.4	0
6-18-59	19	1.0	.0	.0	68	53	17	107	7.2	0
Chester Creek										
3-11-58	11	2.5	0.1	2.1	107	83	8	179	7.3	7
6-18-59	15	3.0	.1	1.3	101	76	12	156	7.6	10
North Fork Campbell Creek										
3-11-58	19	0.5	0.1	1.9	91	71	18	151	7.3	7
6-18-59	21	1.0	.0	.5	69	54	22	112	7.2	0
South Fork Campbell Creek										
3-11-58	12	0.5	0.0	1.1	60	44	11	98	7.3	0
6-18-59	14	1.0	.0	.1	46	34	14	66	7.2	0

TABLE 3.—*Chemical analyses in parts per millions, of ground water from Anchorage city wells and Russian Jack Springs*

[Locations shown on pl. 1]

Date of Collection	Phosphate (PO$_4$)	Temperature (°F)	Silica (SiO$_2$)	Iron (Fe)	Manganese (Mn)	Calcium (Ca)	Magnesium (Mg)	Sodium (Na)	Potassium (K)	Bicarbonate (HCO$_3$)	Sulfate (SO$_4$)	Chloride (Cl)	Fluoride (F)	Nitrate (NO$_3$)	Dissolved solids (residue at 180° C)	Hardness as CaCO$_3$		Specific conductance (micromhos at 25°C)	pH	Color
																Calcium, magnesium	Noncarbonate			
City well 1																				
4-57	--------	--------	14	0.00	0.1	25	9.5	8.2	1.3	137	6.5	2.0	0.2	0.1	134	101	0	227	7.9	0
12-27-57	--------	--------	12	.32	.01	26	9.6	8.5	1.6	144	2.5	.0	--------	.0	132	104	0	224	7.6	0
1-30-58	--------	--------	12	.00	.02	24	12	7.8	1.2	144	6.0	2.5	.1	.0	137	110	0	223	7.8	0
3-3-58	--------	--------	--------	--------	.02	24	9.9	7.7	1.1	139	5.3	1.0	--------	--------	--------	100	0	217	7.7	0
4-2-58	--------	--------	13	.00	.00	25	9.3	8.0	1.2	137	4.5	1.5	.1	.0	130	100	0	220	7.6	0
4-30-58	--------	--------	13	.00	.02	23	11	8.7	1.1	140	1.0	2.5	2.0	.0	129	102	0	220	7.8	0
10-27-58	--------	--------	--------	--------	--------	24	9.6	8.2	1.0	133	3.0	3.5	--------	--------	--------	100	0	226	7.8	5
4-21-59	--------	--------	13	.02	.12	24	9.7	8.5	1.3	138	7.0	2.5	.1	.1	134	100	0	228	7.4	0
2-8-60	--------	--------	14	.05	.04	25	9.3	7.4	1.3	131	6.0	3.0	.1	.0	130	100	0	222	7.9	0
City well 2																				
10-17-55	--------	--------	15	0.1	0.24	23	7.7	7.6	1.0	125	4.0	1.2	0.1	0.1	122	90	0	195	8.1	------
3-3-58	--------	38	14	.00	.02	21	7.2	13	1.0	133	3.3	.0	.2	--------	126	82	0	208	7.4	0
4-2-58	--------	37	14	.00	.00	22	7.7	7.2	.9	120	3.3	1.0	.0	.0	115	86	0	194	7.4	0
11-16-59	--------	--------	14	.28	.28	21	8.7	7.4	.9	115	6.0	2.5	.0	.4	118	88	0	186	8.0	0
4-12-60	0.11	--------	15	1.6	.01	20	9.0	7.6	.8	115	3.0	6.0	.0	.2	120	87	--------	191	7.7	10
12-29-60	.26	37	18	.87	.01	24	8.3	7.3	1.7	123	4.0	3.0	.0	.8	128	94	0	196	7.8	5
City well 3																				
4-1-58	--------	38	13	0.00	0.01	25	7.1	17	1.9	147	4.5	3.0	0.0	0.0	144	92	0	240	7.7	5
11-12-58	--------	--------	14	.04	.02	21	10	17	1.8	143	5.0	5.0	.1	.2	146	94	0	239	7.6	0
5-2-59	--------	--------	--------	.03	--------	--------	--------	--------	--------	155	4.0	--------	--------	--------	--------	112	0	239	7.9	5
4-13-60	0.16	--------	16	.14	.02	24	9.0	17	1.7	148	7.0	4.0	.3	.1	152	97	--------	238	8.0	5

City well 4																				
2-4-58	----	37	12	0.00	0.00	25	10	3.5	0.8	131	8.0	1.5	0.0	0.4	126	106	0	213	7.8	5
3-3-58	----	38	----	----	.01	29	8.1	2.9	.8	129	7.3	3.0	----	.0	----	106	0	212	7.7	0
4-2-58	----	38	12	.00	.01	29	8.3	3.3	.8	128	6.8	2.5	.0	.6	126	106	2	214	7.5	0
4-16-58	----	----	12	.00	----	26	11	3.6	.8	133	9.0	2.5	.0	.3	131	110	1	213	7.5	0
12-11-58	----	----	14	.00	.01	29	11	4.8	.9	133	13	6.0	.1	.7	144	118	8	216	7.9	0
5-2-59	----	----	----	.05	----	----	----	----	----	132	6.0	----	----	----	----	82	0	223	7.7	0
4-13-60	0.07	----	14	.00	.02	32	6.2	4.0	.8	125	7.0	5.5	.2	.07	132	106	3	232	8.0	0
12-29-60	.12	36	16	.11	.00	30	10	4.5	1.0	142	10	3.0	.0	.00	145	116	0	228	8.1	0
Anc 282 (old SUC 1)																				
4-21-53	----	----	19	0.02	----	29	8.1	6.7	1.2	143	5.1	1.5	0.0	0.5	142	107	----	219	----	----
4-28-60	----	----	17	.03	0.04	27	7.4	6.2	.6	132	3.0	2.0	.1	.0	128	98	0	209	8.0	0
Anc 398 (old SUC 2)																				
5-19-55	----	----	18	0.08	0.5	26	8.7	7.0	1.6	136	1.0	1.5	0.0	0.9	132	101	----	215	----	----
1-17-58	----	----	16	.18	.02	24	8.7	6.0	1.2	132	.0	1.5	.1	.2	123	96	0	203	7.7	5
Anc 316A (old SUC 4)																				
9-15-58	----	36	14	0.48	0.04	29	10	4.4	1.0	144	7.0	2.0	0.1	0.0	138	114	0	234	7.5	0
8-11-59	----	35	14	.17	.13	28	14	4.8	.8	143	10	3.0	.2	.1	145	128	10	221	8.1	----
Russian Jack Springs																				
12-10-52	----	----	14	0.03	----	24	6.0	2.6	1.1	101	9	3	----	1.6	111	85	----	183	----	----
3-11-58	----	----	12	.00	0.00	30	6.8	2.8	.6	113	12	2.0	0.1	1.9	124	103	10	206	7.4	0
10-10-58	----	----	13	.06	.00	29	11	4.0	.9	122	14	4.5	.0	2.0	138	118	18	224	7.3	0
3-21-59	----	----	12	.00	.00	25	10	3.9	.4	116	14	4.5	.0	2.3	129	104	8	213	7.5	0
7-21-59	----	----	----	----	.00	30	7.4	3.1	.4	113	0	4.0	----	----	----	106	13	208	8.0	0
10-27-60	0.00	----	16	.02	.00	32	6.4	3.6	.9	115	14	3.0	.1	2.2	134	106	12	220	7.2	0
12-28-60	.03	----	17	.00	.00	30	9.0	3.8	.8	111	17	6.5	.0	1.6	140	112	21	204	7.6	0

WATER UTILIZATION

HISTORY

Surface water from Ship Creek has been the major source of water supply for the Anchorage area since the establishment of the "tent city" of 1915, although ground water has been utilized for domestic supplies outside the city and at some outlying military sites for many years. The population of the area has increased during the 7-year period 1954–60 from an estimated 70,000 to 81,845. Most of the increase in population has been in the suburban area outside the city. The military population has decreased, whereas the population served by the city has steadily increased as suburban areas have been annexed to the city.

The estimated average daily use of water in the Anchorage area for the 7-year period 1954–60 is shown in figure 7. Water use is shown by source and user for as many years as reliable data are available. Water used by Anchorage and most of that used by the military is metered. Estimates of ground-water use by other users are based on an assumed use of 100 gallons per day per capita because of the predominance of domestic users.

Although the population has increased greatly, the use of water has decreased. Water use has steadily decreased from an average of 16 mgd (million gallons per day) in 1956 to less than 13 mgd in 1960. Several explanations were reported to, or are proposed by, the author for this decrease in water use: the decreasing military population has a greater per capita use than the increasing suburban population; increased use of relatively warm (37°F) well water in the winter months curtailed the practice of allowing taps to run in the homes to prevent the distribution lines from freezing, whereas previously only cold (32°F) water from Ship Creek had been used; wetter summers in the years 1958–60 have probably reduced lawn sprinkling and the use of water on unpaved streets for dust prevention. The decrease in other ground-water use in 1958 (see fig. 7) resulted from annexation of suburbs into the city and extension of the water system to replace individual well sources.

SHIP CREEK SUPPLY

The city of Anchorage had been completely dependent upon Ship Creek for its water supply until 1958. The military bases have been diverting water from Ship Creek since before World War II.

Since 1950 the water for the military bases and the city of Anchorage has been diverted at a small concrete dam, about 8 miles upstream from Anchorage (pl. 1). The monthly diversion of water and the discharge of Ship Creek below the diversion dam since 1947 are shown on figure 3. The shortage in the surface-water supply in the years through 1956 had become critical (fig. 3) during the low-flow periods, but since 1956 the supplemental use of well water has made the supply adequate. The average daily use of surface water by the two users for the period 1954–60 (fig. 7) has decreased substantially, primarily owing to a decrease in the military population and to an increase in use of ground water by the city of Anchorage.

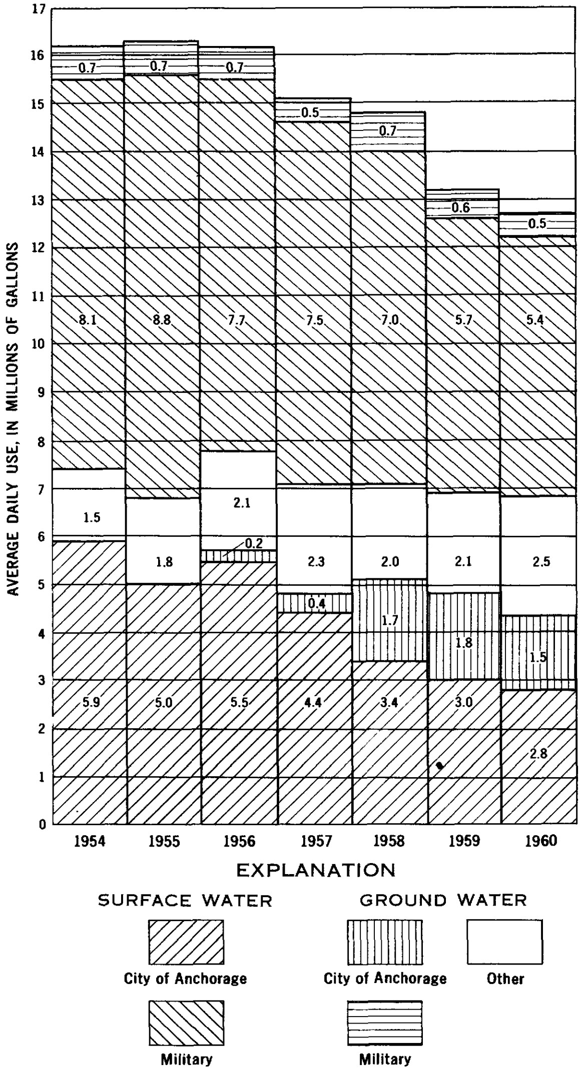


FIGURE 7.—Estimated average daily use of water for the period 1954–60 in the Anchorage area, Alaska.

GROUND-WATER SUPPLY

Utilization of ground water in the Anchorage area has increased during the period 1954–60 (fig. 7). The average daily pumpage has increased from 2.2 mgd in 1954 to 4.5 mgd in 1960. The gradual increase in ground-water use during the 1954–57 period can best be attributed to the gradual increase in the suburban population. The sharp increase in use in 1958 and 1959, almost double that in 1957, is due to the pumping from eight large-production wells—four on the military bases and four in the city. The military and city wells are pumped only when the supply from Ship Creek is inadequate or of poor quality during periods of low flow or high turbidity. Consequently, each well was pumped only for a total of about 60 to 120 days in 1958, 1959, and 1960.

CITY OF ANCHORAGE

The city of Anchorage completed its first well (well 2, pl. 1) in 1956, which was put into use for a few weeks during March and April. In 1957 the second well (well 1, pl. 1) was completed and pumped alone for several weeks in March and April. A total of four large-capacity wells had been completed by 1958 (Nyman, 1959, p. 10), and they all were in service during the first half of 1958 and periodically in service in subsequent years. The four wells have a combined capacity of about 5,500 gpm (gallons per minute). Thus, if all wells were pumped simultaneously, which would not be necessary at present, they would be capable of producing a total of nearly 8 mgd, which in an emergency could easily supply the present city demand of about 4.3 mgd (fig. 7).

An estimated 28,000 people are currently served by the Anchorage water system (J. D. Moore, Jr., oral comm., 1960). Some areas of the city, particularily recently annexed areas, are not yet fully served. The majority of the consumers are domestic and commercial businesses. There are no large industrial consumers at present which would require considerable quantities of city water.

SUBURBAN AND MILITARY

The remaining 56,000 users of water in the area make up the suburban (in part, rural) and military population. Water use by these users is also shown in figure 7.

Most of the suburban population resides in the lowland east of Anchorage and south to Rabbit Creek. This area and that part of the city not serviced by the water system depend almost entirely on individual wells for their water supplies. In addition, some housing developments and contiguous areas are served by private water systems. In 1955 the Anchorage City Planning Commission (1955, p.

24) estimated that about 3,500 people were served by private water systems. The number of such systems had increased each year until July 1960, when the city of Anchorage purchased a major system of public-supply wells in the Spenard area. Therefore, the figure of 3,500 may still be valid.

Use of ground water by the military agencies has not changed appreciably (fig. 7). Four large-production wells were put into operation in 1958, but, like those of the city of Anchorage, are pumped only as a supplement to Ship Creek water.

EFFECT OF WATER UTILIZATION ON THE HYDROLOGY

Water is a renewable resource which is continually being replaced, directly or indirectly, by precipitation, as was described in the discussion of the hydrologic cycle (p. D7). If a stream or an aquifer is developed to provide a long-term yield, then the rate of utilization must equal the rate of replenishment or recharge. A decrease in stream discharge and the lowering of the water level, or piezometric level, usually accompany the development of a water supply.

GROUND-WATER RESERVOIR CHANGES

WATER-TABLE AQUIFER

Changes of water level in a well are usually indicative of recharge to and discharge from the ground-water reservoir. Water levels in the water-table aquifers at Anchorage respond directly to recharge from rainfall, snowmelt, streams, or diversions and to discharge of water by pumping or drainage. (See figs. 2, 4, and 5.) The water levels in shallow wells and those of most of the lakes in the area fluctuate with the water table. Decreased recharge or increased discharge may dry up shallow wells and lower the level of lakes. Such effects have apparently not resulted from the major pumping which began in 1958 nor from the small continuous diversion from Ship Creek.

ARTESIAN AQUIFERS

In artesian aquifers, water-level changes due to recharge and discharge are more pronounced than changes in water-table aquifers. The artesian aquifer, being under pressure, responds to both minor and major loss or gain of head through appreciable distances.

Pumping of a well tapping an artesian system causes a cone-shaped depression to form in the piezometric surface around the well. The cone of depression expands as pumping continues, until it intercepts a source of recharge which equals the discharge of the well. If the discharge from a well or group of wells exceeds the total available recharge, the water level will continue to decline so long as the discharge continues. A composite cone of depression is formed when several wells are pumped in an area and may extend over a much larger area than the area encompassed by the wells. Water levels in other artesian wells within this area will be lowered by this cone of depression and will adjust to a new equilibrium if the intercepted recharge source is ample to meet the larger demand.

The lowering of the water level, therefore, is an inevitable result of pumping from an aquifer. In artesian aquifers, the lowering of the piezometric level may be very noticeable at great distances. The lowering of the piezometric level does not dewater an artesian aquifier if the water level is not lowered below the base of the confining layer, but usually causes a water-level decline in the recharge area permitting more recharge. Upon cessation of pumping, the piezometric surface may or may not recover to its former level, depending upon the effect of pumping on stored water in the recharge area.

Water-level measurements in wells in the Anchorage area were made to determine the effect at the beginning of major ground-water pumpage. Figure 8 shows the water-level fluctuations in two wells in the area in relation to the first pumpage of the city wells for the water year ending September 30, 1958. The relation of water level to pump-

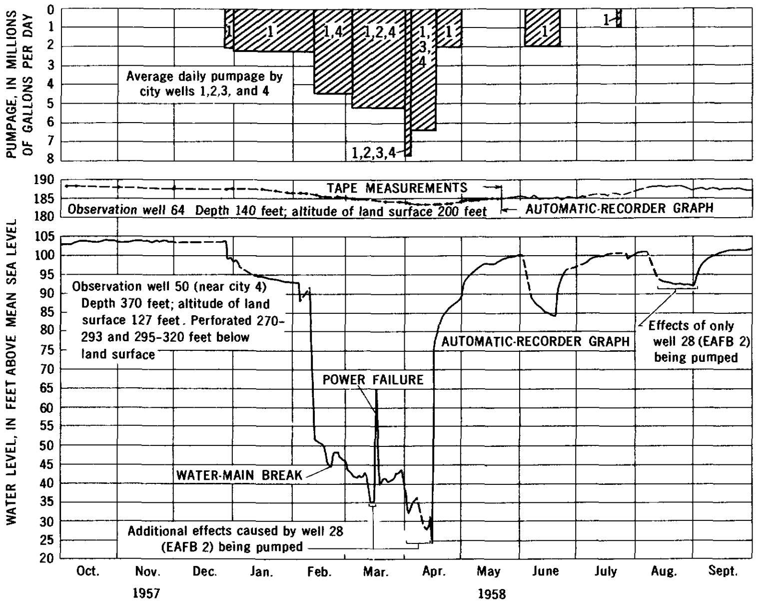


FIGURE 8.—Relation of city pumpage to artesian water levels during the 1958 water year, Anchorage area, Alaska.

age is evident from the comparison of the hydrograph of observation well 50, adjacent to city well 4 within the area of major pumpage (pl. 1). The continual lowering of the water level in April, after city well 2 was shut down, was due to pumping by well 28 (Elmendorf Air Force Base, well 2) after a temporary shutdown of about 2 weeks. The airbase well also was pumped during August, as is reflected on the hydrograph of well 50. Termination of major pumping in mid-April resulted in a sharp recovery of the water level in well 50.

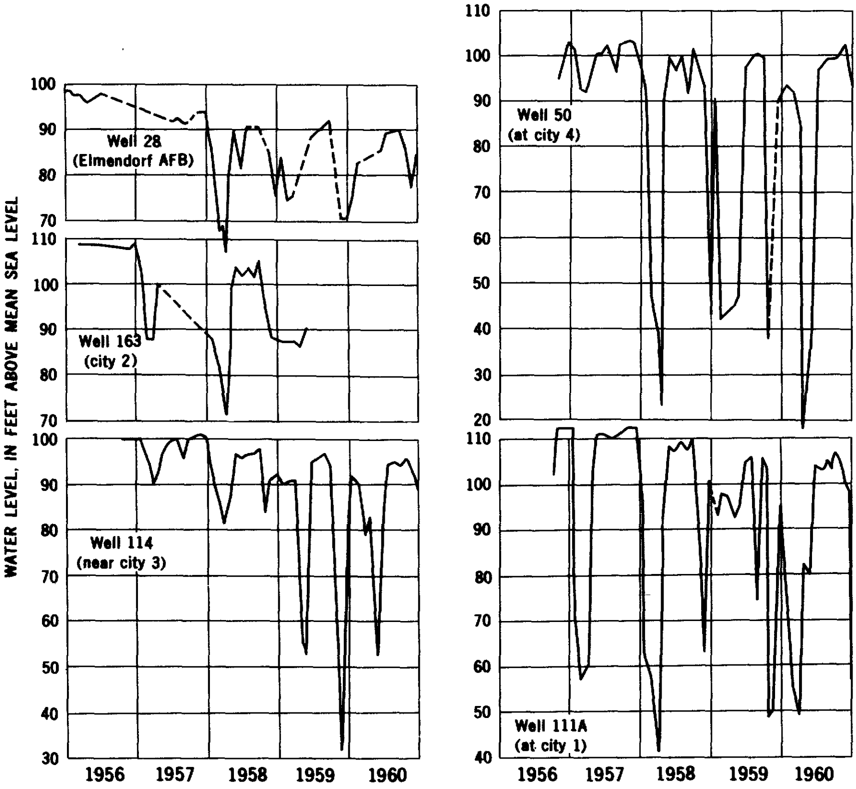
The hydrograph for well 64, almost 2 miles from the city well field (pl. 1), is presented to show the water-level fluctuation near the outer perimeter of the area of influence of major pumping. Well 64 is about on the "pumping divide" of the areas of influence between the Fort Richardson well field and the Anchorage well field. (See pl. 2.) To date, the drawdown due to pumping by the Fort Richardson wells is more noticeable than the drawdown due to pumping by the city wells, even though it amounts to only a foot or so.

Figure 8 shows that when maximum drawdown by pumping occurred the water level in observation well 50 approached sea level and the water level in the pumping well (city well 4) was undoubtedly below sea level. The downward trend was still continuing in mid-April at the time city wells 3 and 4 were shut down. It is evident that mutual interference between all wells in the vicinity creates additional drawdown in the pumping wells.

Hydrographs of water-level fluctuations in observation wells adjacent to large-production wells are shown in figure 9. The hydrographs show the effects of well-field pumping. A slight downward trend in the piezometric surface is apparent from the last 5 years of record and is expected to continue so long as aquifer development continues.

Figure 10 shows water-level fluctuations in four wells within the area of influence of the public-supply wells. A slight downward trend in piezometric levels is also noted in these hydrographs. Well 590 is probably affected by the four large-production city wells, but it is possible that the well is affected by the two wells (316A and 398 on pl. 1) to the north instead. Because the water level in well 590 is usually above the level of the land surface, freezing during winter has resulted in serious gaps in the record of this well.

Water-level measurements in the aforementioned wells and in others in the Anchorage area were also used to construct contour maps of the piezometric surface just before and near the end of the 1958 pumping season and at the end of 1960 for comparison with conditions at the end of 1957. The movement of ground water is similar to that of surface water—the water moves by gravity from points of high head to



WELL DESCRIPTION

Well	Depth in feet	Altitude of land surface, in feet above mean sea level	Perforated or screened, in feet below land surface
28	530	140	------
163	338	94	286 - 338
114	230	129	160 - 182 190 - 201
50	370	148	270 - 293
111A	470	107	165 - 180 190 - 201

FIGURE 9.—Water-level fluctuations showing drawdown effects of adjacent large-production wells.

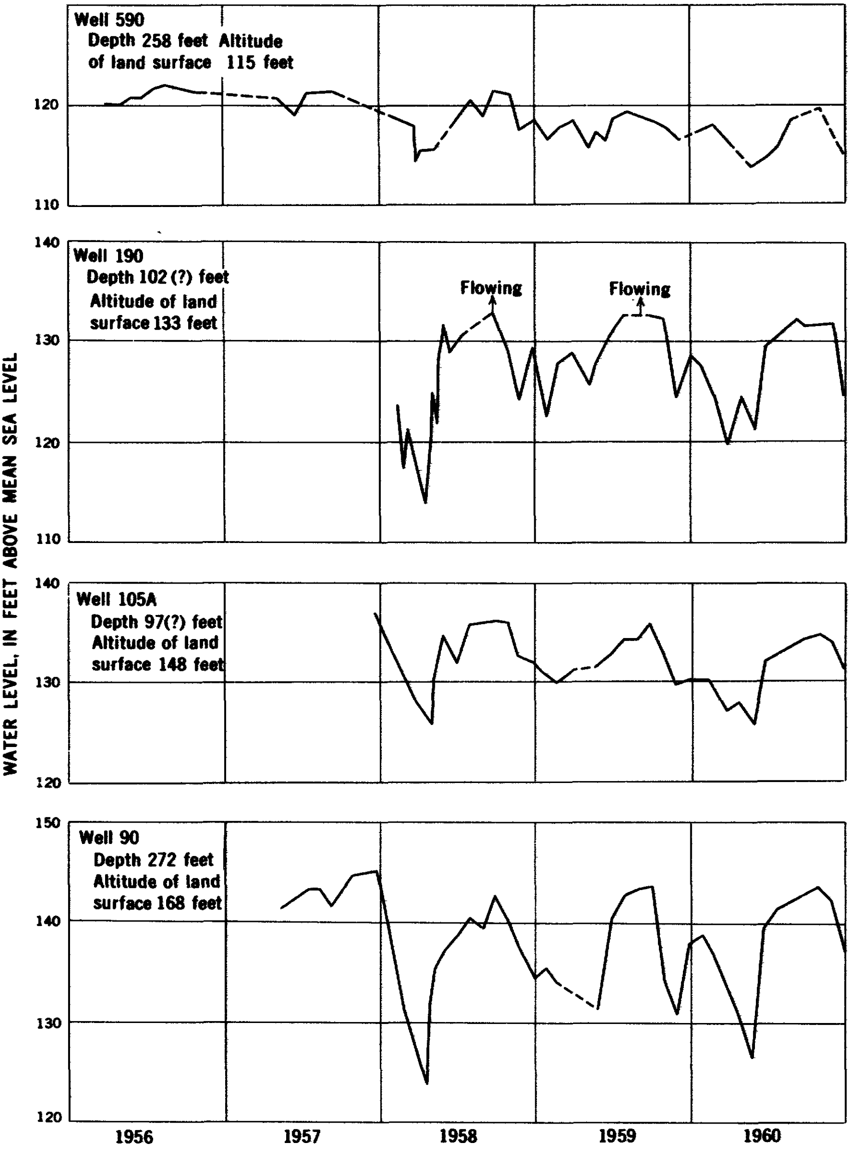


FIGURE 10.—Water-level fluctuations in wells near the Anchorage well field.

points of low head in response to the hydraulic gradient. A contour map of the piezometric surface indicates this hydraulic gradient. The contours of the piezometric surface in the Anchorage area have been generalized because artesian pressures vary in accordance with the depth of the wells. The observation wells used have been completed with well screens or open-end casing at different depths below the surface. However, the contours show the general configuration of the artesian-aquifer pressure level and the direction of flow in the Anchorage area.

Plate 2 shows the approximate altitude of water levels in wells in the artesian aquifers on December 27, 1957, before the beginning of large-scale pumpage. By early April the eight city and military wells had pumped more than 350 million gallons. The approximate shape of the water-level surface on April 11, 1958, at the time of maximum lowering is shown on plate 3. Only Elmendorf Air Force Base well 28 and city wells 1, 3, and 4 were pumping at this time.

The contours show that the cone of influence of the pumping wells extends outward at least 3 to 4 miles. The irregularities in the contours east of the pumping depression are probably due to differences in the permeability of the aquifer, to slow leakage from an aquifer not in direct hydraulic contact with the principal aquifers tapped, or to sluggish response of partially plugged observation wells. The contours also show mutual interference among the production wells, which are spaced approximately 1 mile apart. A drawdown of as much as 80 feet was observed in adjacent observation wells, and a drawdown of about 20 feet occurred 1 mile to the southwest. However, the conditions shown on plate 3 do not represent a state of equilibrium at the maintained pumping rate. The hydrograph of well 50 (fig. 8) indicated that the cone of influence had not as yet become stabilized by mid-April, at which time most of the wells were turned off.

Plate 4 shows the approximate water-level contours at the end of calendar year 1960. Comparison of the nonpumping conditions (except for local drawdown at city well 1) with nonpumping conditions 3 years earlier shows that the water level has declined slightly in the area. This trend agrees with similar trends of the water-level hydrographs presented previously.

The contour maps also show that the general movement of ground water in the Anchorage area is in the direction away from the alluvial-fan areas of Ship and Campbell Creeks—the areas of stream loss, or ground-water recharge, as referred to in an earlier section. Where municipal pumping operations have created cones of depression, the direction of movement of ground water is diverted toward the wells.

Under extended pumping conditions or increasing use of ground water in the future, it can be expected that the area of influence will extend to areas where recharge takes place. Inducing recharge by lowering the piezometric level in favorable areas, such as the stream-recharge areas of Ship Creek, could be considered. Furthermore, the upward leakage of artesian water might be curtailed by this lowering of the piezometric level, and thus the acreage of swampy lowlands in the area could be reduced. It is also realized that such a lowering of the piezometric level might reduce spring flow and dry up some lakes that are fed principally from ground water.

Figure 11 shows the long-term trend of the piezometric level in observation well 441 southwest of Anchorage and observation well 52 near the city well field and the estimated ground-water use for the last 7 years. The trend of well 441 indicates the effects of progressively increasing ground-water use in the area. The fluctuations gradually became erratic about 1955 as more wells were constructed and began pumping in the area. Well 52 reflects more obviously the pumpage in the city well field.

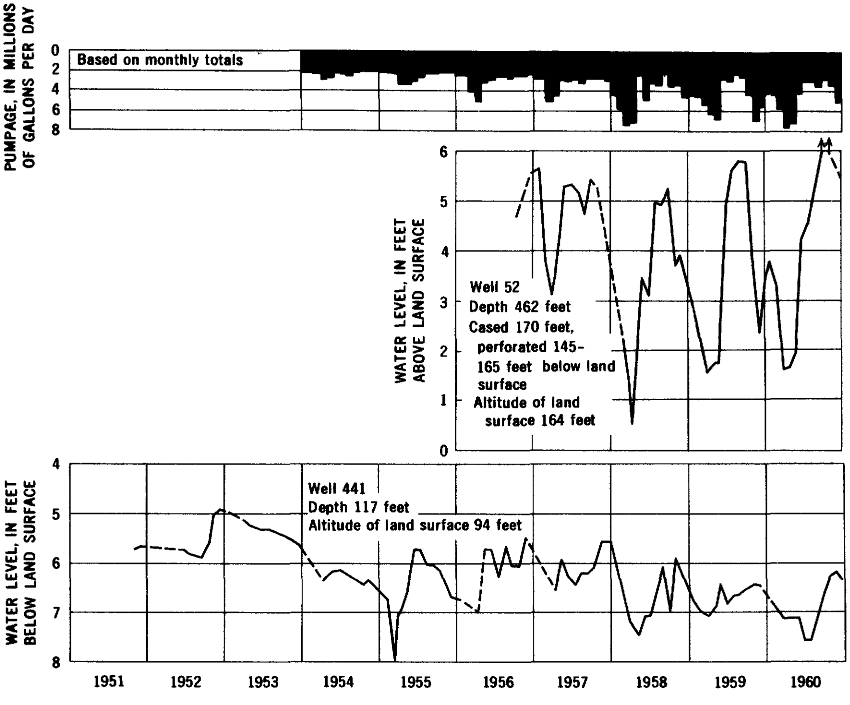


FIGURE 11.—Relation between increasing pumpage and water-level fluctuations in two wells in the Anchorage area.

CHANGES IN STREAMFLOW

A decrease in streamflow near areas of pumping can be related to the aforementioned induced recharge of aquifers. Anchorage area streams are not known to be affected in such a manner by the present pumping schedule. The area of influence (pl. 3) would have to extend further eastward to the recharge area along the creeks. Such a situation may occur in the future as the aquifers are more fully developed. Under these conditions, more water would be salvaged from loss to the ocean. Probably only the military wells, along Ship Creek (pl. 1) in the eastern part of the lowland, are now inducing recharge when they are pumping.

CHEMICAL-QUALITY CHANGES

Pumping large quantities of water from aquifers induces recharge, as mentioned in the previous section, which may cause water of a different character to migrate toward the pumping well. Chemical analyses were made of water samples taken periodically from each of the city wells and are presented in table 3. Water samples from the three newly acquired city wells were also analyzed and are presented along with older analyses from Survey records. Periodic samples of Russian Jack Springs were also taken, and selected analyses are included in the table.

All the waters are generally similar, and no noticeable change in quality of water from a single well was noted for the period of record. Iron-bearing ground water in some areas of Anchorage is known to be troublesome, especially in shallow wells. The water from city well 2 shows sporadic occurrences of increased iron content, which may indicate that poor-quality aquifers or sources of recharge are being tapped. The occurrence of iron even in small quantities is undesirable. The U.S. Public Health Service (1946) recommends 0.3 ppm as a limit for iron and manganese. Because the ground water has a high iron content, an extensive sampling program of the streams was undertaken in an effort to determine where ground water enters the streams. Plate 5 shows the results of a series of stream analyses from samples taken at the stream-gaging sites in October 1960, when discharge was at about a median stage. Chester Creek, which has a greater ground-water increment, has the highest iron content throughout its length. The fact that it has a smaller runoff increment than the other streams at this time of the year results in less dilution of the ground-water inflow. The fact that the iron content of the streams generally increases downstream indicates that the contributions by shallow aquifers and streams increase or they probably contain greater amounts of iron. Note that the highest iron content (0.25 ppm) occurs in the sample from Little Campbell Creek, which drains a lowland.

The chemical quality of the streams would be very susceptible to change if large quantities of water were diverted at the mountain front or if excessive ground-water discharge lowered the water table. Both possibilities should be considered in the future use of Anchorage area streams for public supply or for recreation. If large withdrawals from the deep aquifers causes the water from the shallow aquifers and streams, both containing relatively high iron content, to move into the aquifer system, the quality of the deep water will deteriorate.

SALT-WATER ENCROACHMENT

Salt-water encroachment can occur in fresh-water formations which extend beneath coastal waters under conditions such as those at Anchorage. (See fig. 1.) For example, encroachment will occur if the water level in an aquifer is lowered below sea level for extended periods, a condition favorable to the creation of a hydraulic gradient extending from the sea to the major areas of pumping. Landward migration of salt water can also occur from reduced fresh-water head because of the density differential between salt water and fresh water. Data from existing wells near the coast indicate that salt-water encroachment into the fresh-water formations had not occurred in the Anchorage area as of 1960. However, our present knowledge indicates that as ground-water withdrawals are increased in the future, excessive drawdown of the water level may occur and salt-water encroachment may take place in local areas.

The possibility of salt-water encroachment is suggested by the cone of influence (pl. 4) at the time of concentrated pumping in the Anchorage well field. If city pumping continues indefinitely, or if nearby wells also pump continuously from the same aquifers, the cone of influence might expand westward until salt water moves into the seaward extensions of the aquifers believed to be beyond Fire Island, off Point Campbell (pl. 1), where fresh water is obtained from wells below sea level. A small program of periodic (biannual) sampling and analysis to determine the chloride content was begun in 1954. Wells 282 and 283, close to Knik Arm (pl. 1), were selected for this program. Figure 12 shows the chloride content of water from these wells as of 1960. The chloride content is only 1 to 4 ppm, and no definite trend is apparent.

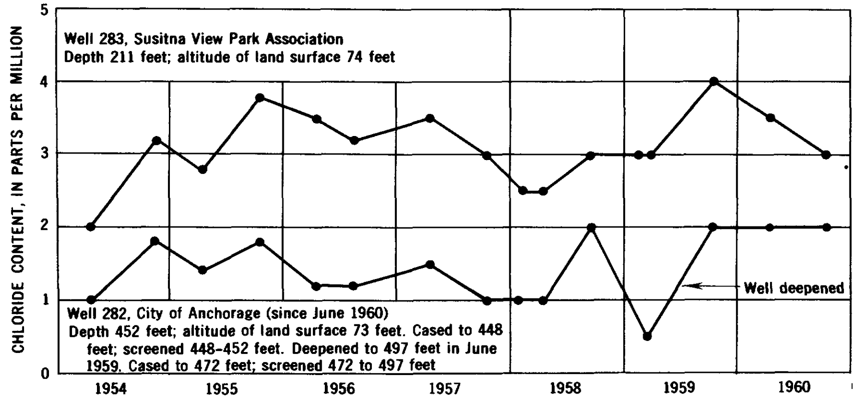


FIGURE 12.—Chloride content of ground water from two wells near Knik Arm, 1954–60.

SUMMARY AND CONCLUSIONS

Major withdrawals of ground water, begun in the Anchorage area in 1958, represent only a small part of the water supply to the area, but they have affected certain aspects of the hydrology. With proper planning, ground- and surface-water supplies should be adequate for any future requirements.

The present major source of supply, Ship Creek, has a yearly mean flow of good quality water of about five times the present average use of water by some 80,000 people. This supply, however, must be supplemented by ground water during the late winter low-flow period and during times of high turbidity. Preliminary data indicate that Ship Creek water is a major source of recharge to the underground aquifers. An estimated average inflow of water by percolation of 5 to 10 mgd occurred in the recharge area in the period 1957–60.

Although Ship Creek is considered as the major source of recharge to the ground-water reservoir, areas where geologic conditions are most favorable for recharge have not been delineated. Such areas should be investigated. The South Fork Campbell Creek area is considered to be comparable to the Ship Creek area, but the recharge, both present and potential, probably is less.

The artesian-aquifer system in the Anchorage area seems to contain an ample source of good quality water to supplement the Ship Creek supply, and could even be developed as the sole source. Yearly average use, which reached 4.5 mgd in 1960, has not caused any appreciable depletion of ground water in storage.

Daily pumpage records indicate that as much as 7 to 8 mgd has been withdrawn from the aquifers at certain times. This withdrawal has caused substantial, but temporary, lowering of the piezometric levels in wells. It is concluded that the present large-production wells, 1,000 gpm or more, are spaced too closely for the most economical operation of wells when they are pumped simultaneously. Water-level observations should be continued in and near the well fields to determine the amount of drawdown caused by pumping. Such information would reveal whether pumpage is exceeding recharge and to what extent the cones of depression in the well fields are expanding.

No detrimental changes in the chemical quality of ground water were noted. The ground water is not as good in quality as the Ship Creek water, but its constant quality and temperature are considered very desirable. Long-range changes in chemical quality may occur through induced recharge of poorer quality water in shallow aquifers or streams and from possible sea-water encroachment. A continuation of periodic water sampling and chemical analysis would provide an opportunity for noting such changes.

Additional construction of large wells and well fields is feasible and should be considered for full development of the aquifers in the area. A program of well inventory and test drilling would enable a better selection of widely spaced locations for new wells. The existing wells should be protected against uneconomical pumping lifts by prohibiting the construction of large-production wells nearby.

REFERENCES CITED

Anchorage City Planning Commission, 1955, Preliminary plan, water for Anchorage: Anchorage City Planning Comm., 28 p.

Cederstrom, D. J., and Trainer, F. W., 1953, Tabulations of well records and logs and chemical analyses of ground waters in the vicinity of Anchorage, Alaska: U. S. Geol. Survey open-file rept. 38 p.

Cederstrom, D. J., Trainer, F. W., and Waller, R. M., 1964, Geology and ground-water resources of the Anchorage area, Alaska: U.S. Geol. Survey Water-Supply Paper 1773. (In press.)

Kerr, J. E., and Cederstrom, D. J., 1951, Records of wells in the Anchorage area, Alaska: U.S. Geol. Survey open-file rept. 6 p.

Lohr, E. W., 1957, Chemical character of public water supplies of the larger cities of Alaska, Hawaii, and Puerto Rico, 1954: U.S. Geol. Survey Water-Supply Paper 1460–A, p. 2–14.

McGuinness, C. L., 1951, The water situation in the United States with special reference to ground water: U.S. Geol. Survey Circ. 114, 127 p.

Meinzer, O. E. 1923, Outline of ground-water hydrology with definitions: U.S. Geol. Survey Water-Supply Paper 494, 68 p.

Miller, R. D., and Dobrovolny, Ernest, 1959 Surficial geology of Anchorage and vicinity, Alaska: U.S. Geol. Survey Bull. 1093, 128 p.

Nyman, F. E., 1959, Well water protects Anchorage water system: Johnson Natl. Driller's Jour., v. 30, no. 1, p. 8–11.

U.S. Bureau of the Census, 1960, U.S. Census of Population: 1960: Number of Inhabitants, Alaska: U.S. Bur. of the Census Final Rept. PC(1)–3A, 11 p.

U.S. Public Health Service, 1946, Drinking water standards: Public Health Repts., v. 61, no. 11, p. 371–384.

Waller R. M., 1961, Water utilization in the Anchorage area, Alaska, 1958–59: U.S. Geol. Survey open-file rept., 49 p., 7 figs., 5 tables. Alaska Dept. of Health and Welfare Water-Hydrological Data 12, 19 p., 7 figs., 5 tables.

——— 1960a, Water for an expanding Anchorage [abs.]: Eleventh Alaskan Sci. Conf. Proc. (In press.)

Wells, J. V. B., and Love, S. K., 1957, Compilation of records of quantity and quality of surface waters of Alaska through September 1950: U.S. Geol. Survey Water-Supply Paper 1372, 262 p.

——— 1958a, Quantity and quality of surface waters of Alaska, October 1950 to September 1953: U.S. Geol. Survey Water-Supply Paper 1466, 243 p.

——— 1958b, Quantity and quality of surface waters of Alaska, October 1953 to September 1956: U.S. Geol. Survey Water-Supply Paper 1486, 229 p.

——— 1960a, Quantity and quality of surface waters of Alaska, October 1956 to September 1957: U.S. Geol. Survey Water-Supply Paper 1500, 100 p.

——— 1960b, Quantity and quality of surface waters of Alaska, 1958: U.S. Geol. Survey Water-Supply Paper 1570, 120 p.

The U.S. Geological Survey Library has cataloged this publication as follows:

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(Continued on next card)

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