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UNITED STATES
DEPARTMENT OF THE INTERIOR
GEOLOGICAL SURVEY
WASHINGTON 25, D. C.

WATER RESOURCES APPRAISAL

OF THE

ANCHORAGE AREA, ALASKA

-Water Conservation through Conjunctive Use-

by

David A. Sommers

and

Melvin V. Marcher

U. S. Geological Survey
Open-file Report
1965

☆ U.S. GOVERNMENT PRINTING OFFICE: 1962—O-632210

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ABSTRACT

At the present, water use in the Anchorage area amounts to about 21 mgd (million gallons per day); of this amount ground water accounts for about 10 mgd. By 1980, 60 mgd may be required to meet the demand.

The greatest potential problem is overpumping the ground-water reservoir resulting in excessive declines in water levels, which, in turn, might lead to salt-water intrusion. A well-laid plan for conjunctive use of surface and ground water seems to be the most promising means of supplying the expected need of 60 mgd, and of preventing salt-water intrusion of the aquifers.

Total inflow into the Anchorage hydrologic system amounts to about 180 mgd. Of this amount Ship and South Fork Campbell Creeks contribute about 130 mgd, North Fork Campbell Creek and other streams contribute an estimated 24 mgd, and precipitation and ground-water inflow contribute an estimated 26 mgd.

Of the total outflow, which must be equivalent to the inflow, Ship and Chester Creeks contribute about 94 mgd, Campbell Creek about 25 mgd, and ground-water pumpage contributes an assumed amount of approximately 10 mgd. The difference of 50 mgd between inflow and outflow presumably is accounted for by submarine discharge beneath Cook Inlet and evapotranspiration.

Surface and subsurface storage of excess stream discharge during periods of high flow can overcome the problem of water shortages during periods of greatest demand. Surface storage can be accomplished by construction of an additional dam on Ship Creek. Natural

ground-water storage can be supplemented by spreading techniques to increase the amount of ground-water recharge. Additional recharge can be provided by returning air-conditioning water to the aquifer through recharge wells. Recharge along the coastline would be a means of maintaining a fresh-water barrier against salt-water intrusion.

The area with the greatest potential for ground-water development is along Ship Creek east and north of Mountain View. The alluvial fan east of Mountain View seems favorable for installation of deep wells; and withdrawal of ground water in this area is not likely to result in salt-water intrusion. Similar favorable conditions exist in the alluvial fan areas of North and South Forks Campbell Creek. Infiltration galleries in alluvial deposits along Ship Creek are a relatively inexpensive and convenient means of withdrawing water.

To plan for orderly and economical development of the Anchorage area's water resources, geologic and hydrologic studies are needed. An expanded network of stream-gaging stations and observation wells is needed. Deep wells near the coastline are needed to monitor any changes in chemical quality of ground water that would indicate impending salt-water intrusion. Borehole geophysical studies and pumping tests are needed to define the boundaries and hydraulic characteristics of the aquifers. The primary goal of these and other supplementing studies would be to provide the information needed to construct an electric-analog model of the Anchorage hydrologic system. Such a model would provide a means of assessing quantitatively alternative methods of water development.

INTRODUCTION

Scope and Purpose of Report

As part of a cooperative program between the U. S. Geological Survey and the City of Anchorage, the Survey was requested to evaluate the available hydrologic data to provide guidelines for development of additional water supplies for the City. This report presents the results of that evaluation.

Published reports by Cederstrom, Trainer, and Waller, (1964) and Waller, (1964) as well as recently collected basic data have been utilized in the preparation of this report. Hydraulic characteristics of the aquifers and boundaries of the aquifer system are practically unknown and detailed ground-water pumpage records are nonexistent. Because records of surface water flow are of relatively short duration they provide only a tentative basis for long-term predictions. Until such information is available, a thorough quantitative hydrological analysis of the area is not possible.

Continued growth of the metropolitan Anchorage area and the associated population increase will impose greater demands for water of good quality. Consequently, the problem of most immediate concern is the formulation of an adequate water-resources development plan to accommodate the increased use. The questions of where to locate additional surface and ground-water supplies, where to reserve areas of the watershed or aquifers for municipal use, and where and how to employ conservation measures are of primary interest.

The water situation in the Greater Anchorage Area

Water use and projected demands

By 1980, the water demands of the Anchorage area will, it is predicted, be nearly three times the present use and to meet this demand wise development of the area's water resources will be necessary. Conjunctive use of both surface and ground water should provide an adequate supply of potable water to meet the expected demand. Present average daily use of water in the Anchorage area is 21 mgd (million gallons per day). The daily use of surface and ground water in the Anchorage area, including the military, from 1954 to 1964, is shown in Figure 1. Ground-water use, in particular, has risen sharply since 1960. By 1980 the Greater Anchorage area is expected to have 250,000 inhabitants (Wilsey, Ham, and Blair, 1961, p. 150) and may require 60 mgd of potable water.

Water problems - present and potential

Failure to devise and follow an appropriate plan for water-resources development may result in areas of overdraft, excessive declines in ground-water levels, salt-water encroachment, and contamination of considerable portions of the aquifer system. These difficulties can be effectively prevented by conjunctive use of surface water and ground water, through efficient management of all available water resources.

Declining water levels, owing to heavy withdrawals, are inevitable as ground-water use increases, and may even have a salutary effect by inducing additional recharge in favorable areas. Declining water

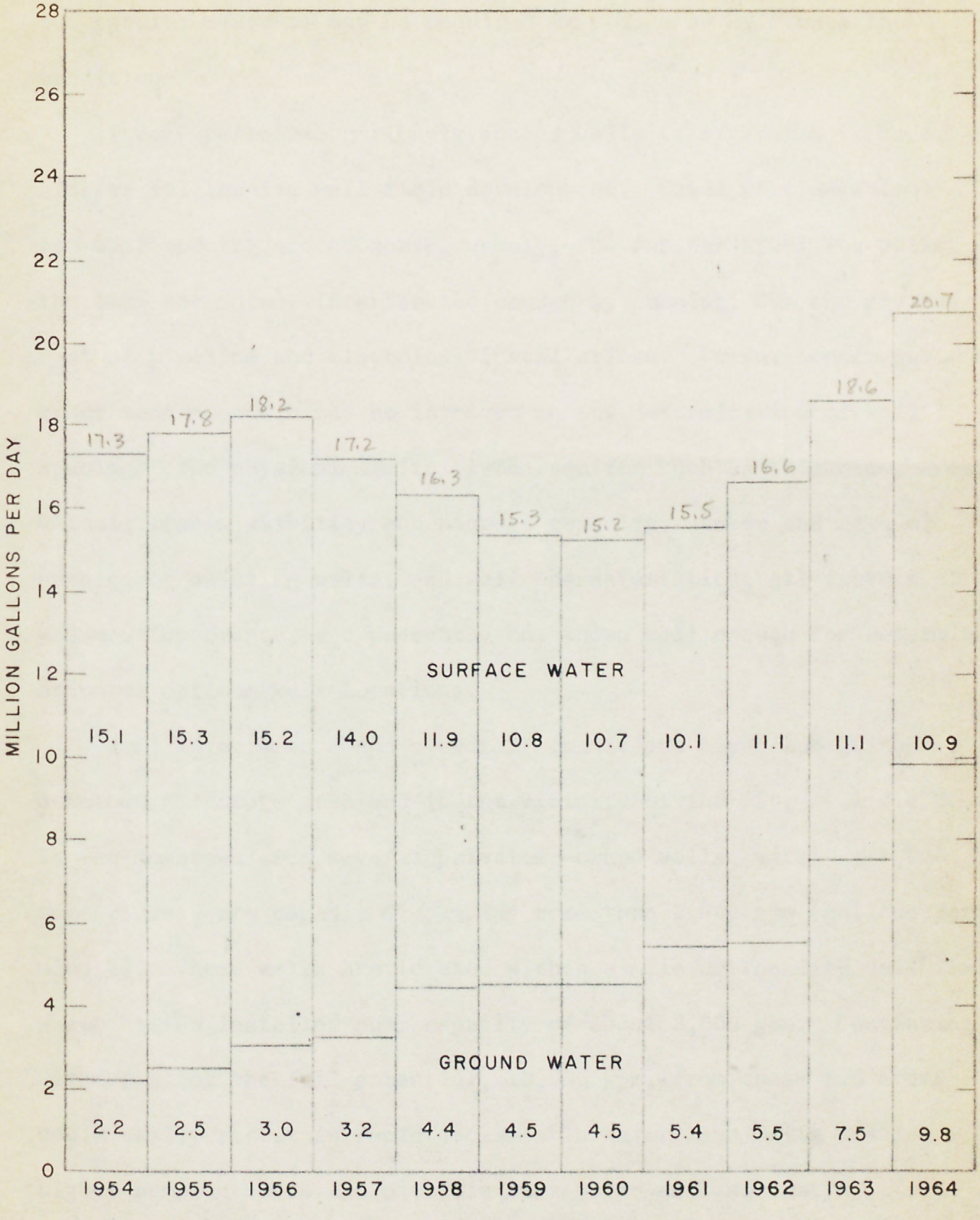

Figure 1.--Estimated average daily water use in the Anchorage area, Alaska

levels, interference between wells, and regions of overdraft are closely related to the potential problem of salt-water encroachment; and special measures may be required to reduce or eliminate these conditions.

Interference among closely spaced wells is a problem to be considered in planning well-field development. Usual considerations for well spacing are economic, namely, the farther apart the wells, the less the mutual interference caused by pumping, but the greater the cost of pipeline and electrical installations. Often, considerations other than economic may be involved in the determination of well spacing. The physical limits of the aquifer such as thickness, areal extent, transmissibility and storage capacity, number and rate of pumping of existing wells, and well characteristics, all factors of primary importance, are presently not known well enough for determination of optimum well locations.

Well interference and overdraft conditions may occur in the downtown Anchorage area and in the vicinity of the City well field. In the downtown area several privately-owned wells, within a 1,000 foot radius, are capable of pumping more than 2,000 gpm (gallons per minute). These wells are located within a mile of the City well field, which has an installed pump capacity of about 8,000 gpm. Continuing withdrawal of the full potential, 10,000 gpm, from these two areas could easily result in rapid declines in water level with ensuing higher pumping costs and possible salt-water encroachment.

In coastal areas such as Anchorage, the danger of salt-water intrusion into the aquifer system is always present, especially when large quantities of ground water are withdrawn from the aquifer system close to the coastline. Continued unrestricted development of ground water can disturb the natural balance of the ground-water reservoir which in turn will alter the position of the salt-fresh water interface allowing salt water to move landward.

Contamination of the aquifer system from local unrestricted waste disposal and accidental release of toxic liquids is a potential hazard for water-supply development in some areas near Anchorage. According to local authorities, this situation will gradually be alleviated by expansion of municipal water-supply and waste-disposal systems.

HYDROLOGIC SYSTEM OF THE ANCHORAGE AREA

General setting

Effective utilization and management of the available water supply in the Anchorage area require recognition of the complex interchange of water between the atmosphere and the earth and its distribution and movement on the earth. Inter-related factors, such as climate, topography, and geology complicate this movement of water. Figure 2 is a generalized hydrologic diagram of the Anchorage area.

Most of the surface water available to the Anchorage area is derived directly from precipitation, namely, the inflow of Ship Creek, Campbell Creek, and other minor creeks. Chester Creek and a few small streams are supported largely by seepage of ground water. Most of the lakes and swamps in the lowland area are supplied from surface runoff or direct precipitation and their levels are maintained by seepage of ground water.

Most of the surface water is discharged from the area by Ship Creek, Campbell Creek, and Chester Creek into Cook Inlet. A large amount of water from Ship Creek is diverted for the water supply system to the military and the City of Anchorage. A considerable percentage of this diverted water is later released via storm drains and sewer outfalls into Cook Inlet. The amount of surface water lost through evaporation from open water surfaces is unknown. The remainder of the surface water infiltrates into the ground and is either retained as soil moisture or seeps downward into the ground-water reservoir.

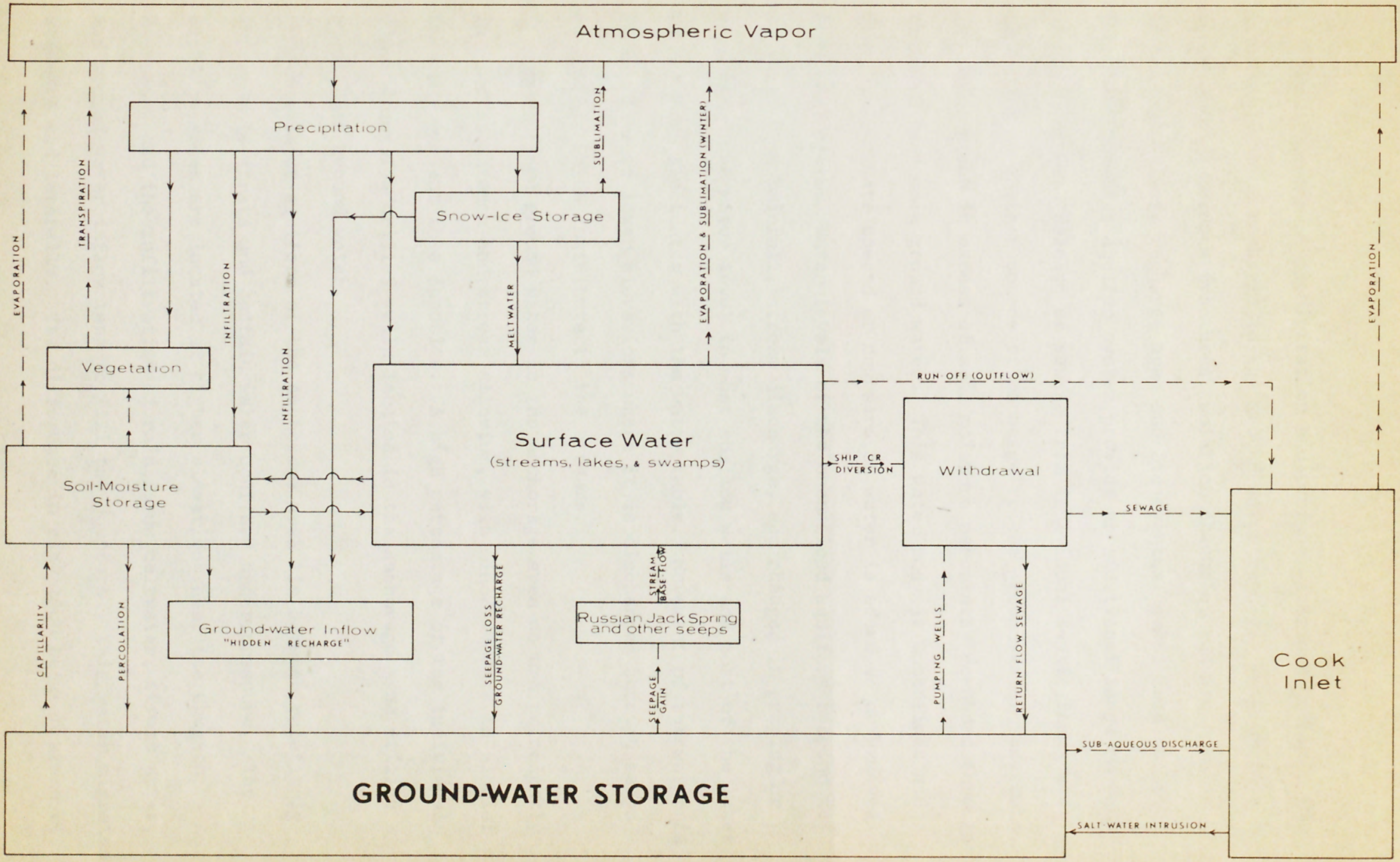

Figure 2. Generalized hydrologic diagram of Anchorage area, Alaska, showing movement of water.

Infiltration of precipitation and surface water are probably the major sources of recharge to the ground-water supply. Infiltration of water through bedrock fractures, solution channels, and fault zones in the mountainous recharge area and its eventual subsurface release into the Anchorage aquifer system provide an additional large amount of fresh water. Release of sewage from individual septic tanks and cesspools is another source of recharge to the ground-water reservoir.

That water in excess of soil moisture percolates downward through the soil to become ground water. This water body is unconfined and free to fluctuate upward or downward as water is added to or removed from the system. Water levels of the unconfined aquifers respond to recharge from rainfall, stream discharge, and changes in pumping or drainage. The water level in most shallow wells and most of the lakes in the area fluctuates with the water table. Movement of the water is from higher to lower elevations where it is discharged through seeps or springs which contribute to the streams.

Unconfined ground water in the Anchorage area occurs principally in glacial outwash and stream alluvium, with minor amounts in glacial fill and ancient lake deposits. A high percentage of the individual dug and shallow drilled wells located in the Anchorage area utilize unconfined ground water.

The major aquifers of the Anchorage area lie between relatively impermeable strata and contain water confined under pressure. The recharge areas are located at higher elevations near the Chugach Mountains and the infiltration of rain, snow meltwater, stream water, and ground-water inflow tend to fill the aquifers. This water migrates downward and laterally. The difference in elevation between areas of

recharge and discharge and the impermeable boundaries causes the water to be confined under pressure.

The artesian aquifer system shows much more pronounced water-level changes due to discharge-recharge relationships than does the unconfined system. Pumping of wells which penetrate the artesian system creates cone-shaped depressions in the piezometric surface. A composite cone of depression is formed when several adjacent wells are pumped simultaneously and the drawdown at any point is equal to the sum of the individual drawdowns. During a period of heavy pumping from December 1957 to April 1958 a cone of depression nearly 2 1/2 miles wide extending to within three-quarters of a mile of Knik Arm was developed. The water level in the apex of the cone of depression was very near sea level (Waller, 1964, p. 30 and pl. 2).

Salt-water intrusion may occur if the water level is lowered below sea level for extended periods. The balance between submarine fresh water discharge and salt-water intrusion easily can be influenced by changes in equilibrium conditions within the aquifer system. Continued unrestricted development of ground water in the downtown section of Anchorage can further disturb the natural balance of the ground-water reservoir and possibly allow the position of the salt-fresh water interface to shift landward. At present, the geographic position and the geometric configuration of the fresh-salt water interface are unknown. The extent of intrusion of sea water will be a significant factor in determining the use of ground water in the area along the coast.

The hydrologic system in the Anchorage area can conveniently be considered in three parts: 1) inflow of water into the system,

2) movement and storage of water within the system, and, 3) outflow of water from the system. The relation between inflow-outflow and change in storage is expressed in terms of a water budget. The discussion of the water budget of the Anchorage area is based on actual measurements, estimates, and assumptions. Therefore, there is a wide range of accuracy, but the figures given are probably in the correct order of magnitude.

Inflow

Precipitation

The average annual precipitation measured at the Anchorage International Airport, representing a 34-year record, is 14.84 inches. Assuming that the 105 square miles of area surrounding Anchorage receives the same amount of precipitation and assuming that 30 percent enters the soil, then 14.2 mgd is available during the year for soil moisture and possible ground-water recharge. The remaining 70 percent of the precipitation contributes to stream runoff and evapotranspiration. A general index of the relative amounts of precipitation available for ground-water recharge may be indicated by the monthly average precipitation in inches listed below. However, the ground surface is normally frozen from December through March, and hence water falling on the ground surface cannot freely percolate to the aquifer system.

Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sep.	Oct.	Nov.	Dec.
.88	.73	.56	.46	.51	.95	1.85	2.59	2.55	1.87	.97	.92

Ground-water inflow

Another source of ground water in the Anchorage area is subsurface inflow from the Chugach Mountains. An unknown amount of precipitation and snow-melt water at high elevations seeps downward along joints and fracture systems in the highly fractured bedrock of the Chugach Mountains. A portion emerges as seeps along the base of the mountains, and the remainder continues to percolate downward to considerable depth and provides subsurface ("hidden") recharge to the Anchorage aquifer system. This concept is supported by the existence of large amounts of ground water in fractures deep beneath the Chugach Mountains. During construction of the Eklutna tunnel, a few miles northeast of Anchorage, fault zones, joints, and shear zones commonly yielded 300 gpm and a few large fault zones produced nearly 10,000 gpm. Recharge to the aquifer system by ground-water inflow is estimated to be 12 mgd by assuming that 13 miles of the mountain front is capable of discharging into the underlying aquifer system at a rate of 1,000 acre-feet per year per mile of mountain front (a value determined from studies of similar terranes in Utah).

Return flow

According to local health officials, approximately 4 mgd of waste water from individual septic tanks and cesspools is returned to the ground-water reservoir in the areas which do not have a central sewer system. Part of this water is shallow runoff, part is lost by evapotranspiration, and part becomes ground-water recharge; the relative proportions of each cannot be determined from the available data.

Streamflow

The flow of Ship Creek is derived mostly from direct runoff of precipitation, including meltwater of snow and ice, in its watershed which includes an area of 90 square miles upstream from the diversion dam. Discharge measurements and gage-height records have been obtained since October 1946. Figure 3 shows that the discharge after diversion from 1946 to 1964 has been, on the average, equal to or greater than 17 cfs (cubic feet per second), or 11 mgd, 90 percent of the time. The maximum discharge, measured at the diversion dam, was 1,860 cfs; the records show that at times there has been no stream flow.

Figure 4 is a hydrograph of the monthly mean discharge of Ship Creek and the corresponding amounts of diversion of water from 1947 to 1964. The 1946-1964 average monthly mean flow of Ship Creek before diversion is listed below in millions of gallons per day:

Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sep.	Oct.	Nov.	Dec.
32.4	25.5	22.0	25.8	118.6	316.2	216.9	158.1	154.1	103.3	60.7	41.9

The yearly average of the monthly mean flow before diversion is 104.6 mgd.

Discharge records for the South Fork Campbell Creek, which has a drainage area of 30 square miles above the gaging station, show an average mean daily discharge of 40.7 cfs (26.3 mgd) from July 1947 to 1964. The maximum discharge recorded is 891 cfs; a short period of no-flow when temporary storage occurred upstream from the gaging station has been recorded. A flow-duration curve of the South Fork Campbell Creek, Figure 5, shows that the base flow is 5 cfs (3.2 mgd) and that, on the average, a flow of 8.5 cfs (5.5 mgd) has been

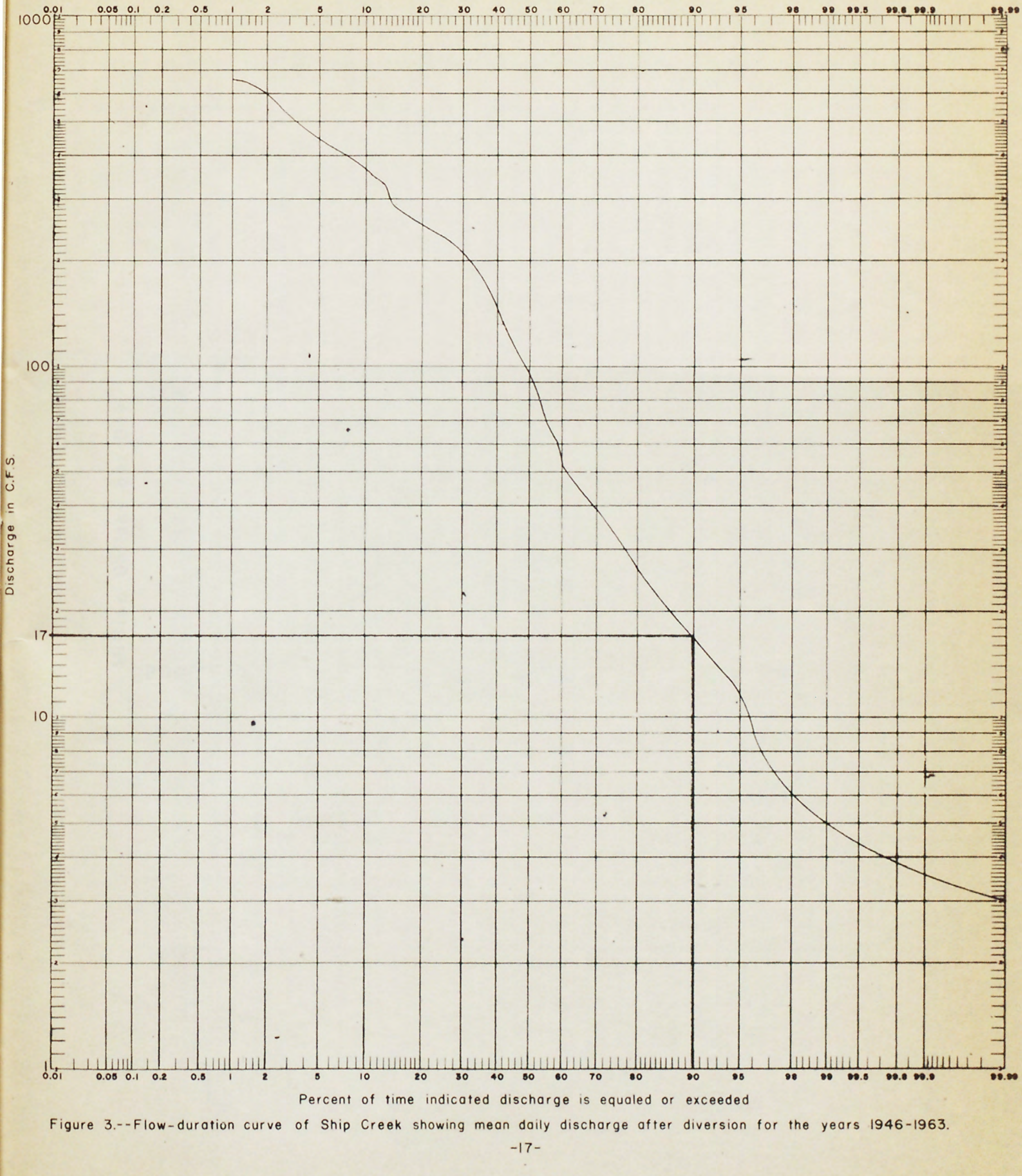

Figure 3.--Flow-duration curve of Ship Creek showing mean daily discharge after diversion for the years 1946-1963.

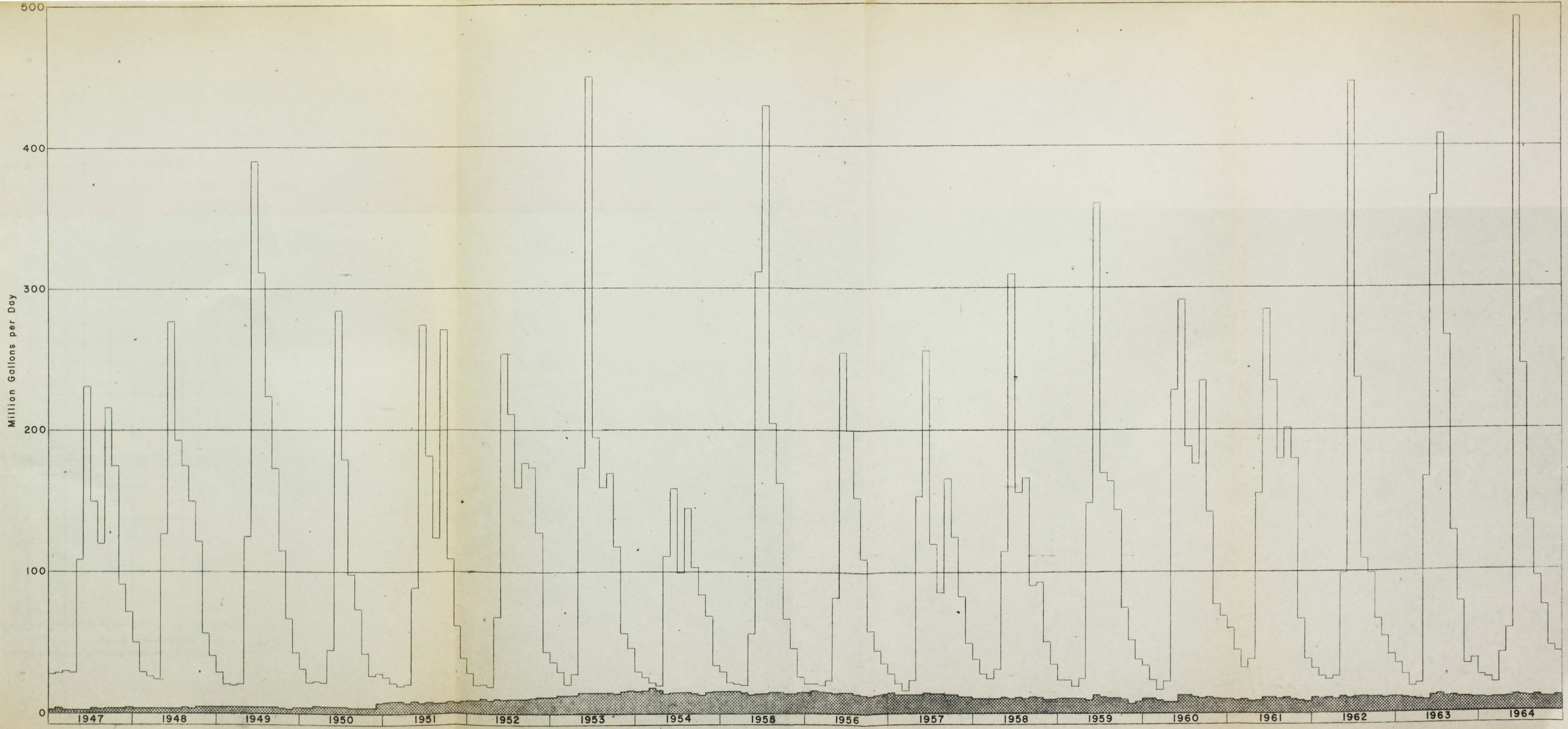

Figure 4. Hydrograph of monthly mean discharge of Ship Creek and corresponding amount of diversion of water.

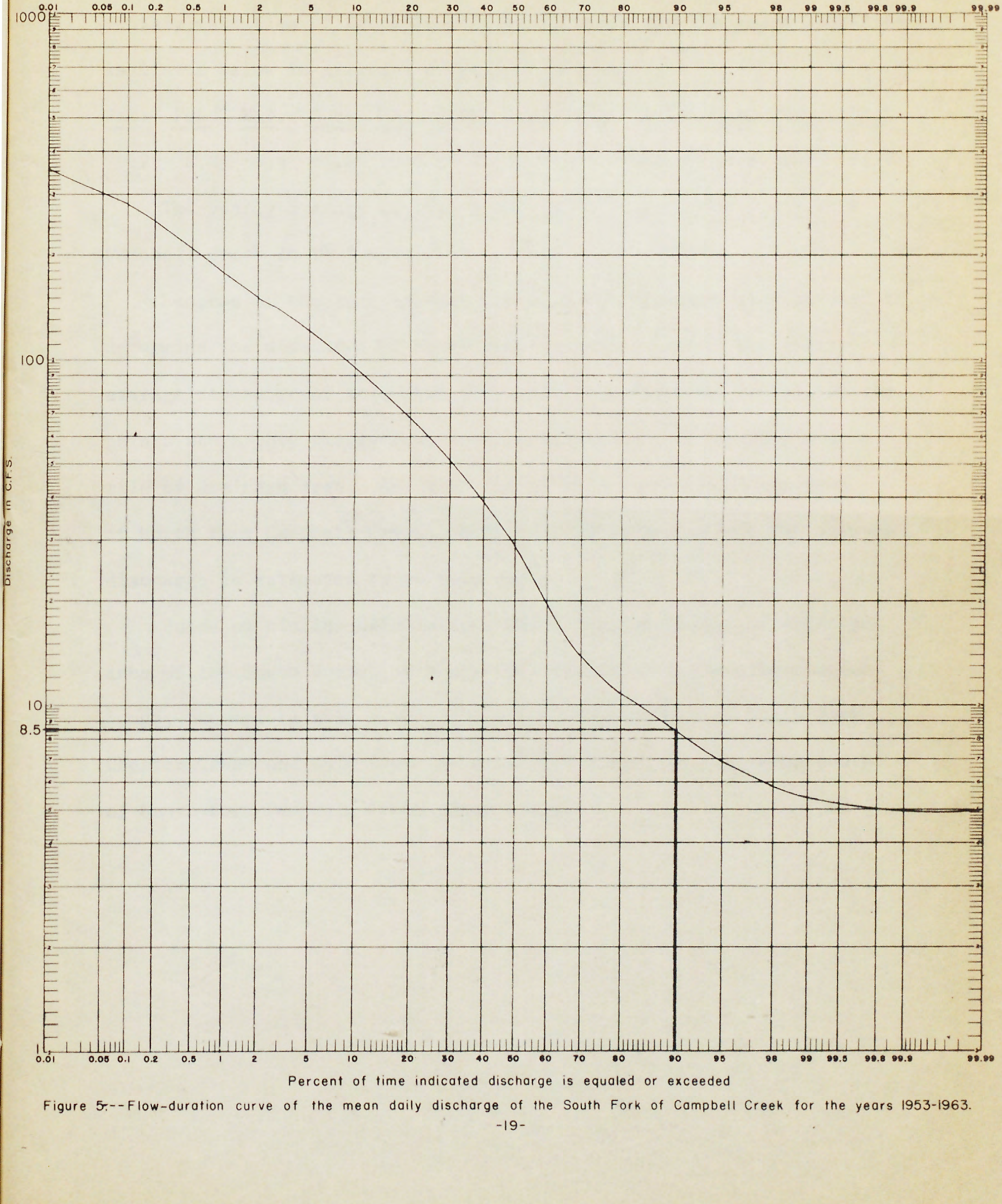

Figure 5.--Flow-duration curve of the mean daily discharge of the South Fork of Campbell Creek for the years 1953-1963.

maintained at the gaging station 90 percent of the time. The average monthly mean flow of South Fork Campbell Creek for the years 1947-1964 is listed below in millions of gallons per day:

Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sep.	Oct.	Nov.	Dec.
9.2	6.7	5.4	5.8	29.4	66.2	51.7	41.4	41.3	28.9	18.1	11.6

The yearly average of the monthly mean flow of the South Fork Campbell Creek is 25.9 mgd.

Because of the lack of data, an indirect approach must be used to determine the discharge of North Fork Campbell Creek. The yearly average discharge of both Ship and South Fork Campbell Creeks, to the points where they emerge from the mountains, is 1.16 mgd per square mile of drainage area. Applying this factor to the drainage area of North Fork Campbell Creek, which is 12.2 square miles, the average discharge is estimated to be 11.0 mgd.

Based on similar calculations the 3.9 square miles of drainage area of the South Branch of South Fork Chester Creek provides about 5 mgd, the mountainous area between the South Branch of South Fork Chester Creek and Ship Creek an estimated 3 mgd, and the area south of South Fork Campbell Creek about 5 mgd.

Total inflow

The average annual inflow of water to the Anchorage area with the indicated degree of accuracy is given below:

Source	MGD (Yearly average)		
	Measured	Calculated by analogy	Estimated
Streamflow			
Ship Creek	104.6		
South Fork Campbell Creek	25.9		
North Fork Campbell Creek		11	
South Branch, South Fork Chester Creek		5	
Other mountain front area		8	
Precipitation			14
Ground-water inflow			12
	130.5	24	26
Total (rounded)		180	

Movement and storage of water

Streamflow

Water from Ship Creek is diverted at a small concrete dam located on bedrock where Ship Creek emerges from the Chugach Mountains. The reservoir has a capacity of 12 million gallons. Occasionally, when a period of peak demand coincides with a period of low-flow, virtually all flow in Ship Creek is stopped at the diversion dam. The diversion of Ship Creek for the last three years, 1961-1964, has averaged 11.1 mgd, with occasional monthly mean diversions greater than 12 mgd. After diversion, the excess water flows over the dam spillway and continues down Ship Creek where some of the flow furnishes recharge to the ground-water reservoir and the remainder continues to Cook Inlet.

A second gaging station on Ship Creek at Elmendorf Air Force Base was placed in operation in May 1963. The drainage area above this station is 113 square miles. Maximum discharge measured was 490 mgd and the minimum discharge was 1.3 mgd. Records indicate that a loss of flow occurs between the gaging stations at the diversion dam and Elmendorf Air Force Base. This loss represents recharge to the ground-water system and takes place where Ship Creek flows across the alluvial-fan deposits of sand, silt, and gravel. The average mean daily loss during the low-flow period, October through May, was 8.7 mgd. During the high-flow period, June through September, the average daily mean recorded water loss was 37 mgd. The maximum recorded surface water loss on Ship Creek for a single 24-hour period was 201 mgd in June 1964. The actual amount of recharge during high-flow periods probably is

considerable greater than the recorded value, because high-flow discharge measurements are made at the Glenn Highway bridge rather than at the diversion dam, thus leaving a two mile stretch of Ship Creek flow unrecorded. The average monthly mean loss for the available period of record is listed below in millions of gallons per day.

Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sep.	Oct.	Nov.	Dec.	Yearly Average
6.5	7.1	5.8	11.0	18.1	65.3	45.9	20.7	15.5	7.8	11.6	12.3	18.4

The yearly average loss of 18.4 mgd, divided by the length of stream channel over which this loss occurs, shows a water loss of 2.9 mgd per linear mile. This figure can be used to estimate recharge from the North Fork and South Fork Campbell Creek as these streams flow across similar alluvial-fan areas. Occasional measurements made at selected points on the South Fork Campbell Creek have demonstrated recharge. Thus, the 2.5 miles of stream channel of the South Fork and 1.4 miles of the North Fork Campbell Creek, which meander over alluvial fans, are estimated to contribute approximately 11 mgd for ground-water recharge.

The total ground-water recharge from Ship Creek and Campbell Creek amounts to approximately 30 mgd. The remaining flow of Ship Creek and Campbell Creek that discharges into Cook Inlet is estimated to be 100 mgd. The estimate of 8 mgd for the other stream areas is assumed to be almost entirely contributed to ground-water recharge. This brings the total recharge from streamflow to nearly 40 mgd.

Ground water

A considerable amount of ground water is in storage in the Anchorage area. Assuming that the average porosity of the aquifer is 20 percent and that the saturated thickness is 200 feet, nearly 10 billion gallons of water is estimated to be stored beneath each square mile of the area. Because the amount of ground water in storage is so large relative to annual use, the ground-water reservoir is an excellent potential regulating body.

Water moving downward through permeable surficial deposits that comprise the water-table aquifers eventually reaches layers of clay or till, which, because of their relatively low permeability, causes most of the water to flow laterally. Sandy zones in the impermeable beds apparently permit water to move upward or downward, but some of the water continues to move laterally until it reaches the surface and is discharged as springs or seeps. The amount of water discharged in this manner is probably considerable. For example, Russian Jack Springs, which has a minimum recorded daily mean flow of 2.56 mgd and a maximum daily mean flow of 5.73 mgd, contributes a yearly average of 3.7 mgd to Chester Creek. Other springs and seeps contribute lesser but significant amounts of water to the lower reaches of all the streams of the area.

The artesian aquifers apparently are recharged mainly from areas along the flank of the Chugach Mountains. From these areas the water migrates downward and laterally. Permeable zones in the overlying confining beds presumably permit water to move upward where the head in the artesian aquifer is greater than that in the water-table aquifer.

Water-level measurements show that from the recharge areas water in the artesian aquifers is moving seaward. Apparently the water is discharged through submarine springs and seeps but the location of these springs and seeps and the amount of water discharged through them are unknown.

Outflow

Outflow of water from the system is accomplished by surface water discharge into Cook Inlet, withdrawal of ground water by pumpage, submarine discharge into Cook Inlet, ground-water seepage to streamflow through Russian Jack Springs and other seeps, and evapotranspiration. The actual amount of water outflow is extremely difficult to estimate because of the lack of sufficient data.

Analysis of the record of the Elmendorf Air Force Base gaging station on Ship Creek indicates that for the 1964 calendar year the mean daily discharge was 78.5 mgd. The mean daily outflow of Campbell Creek is estimated to be about 25 mgd.

Chester Creek has a recorded mean daily discharge of 15.7 mgd. Of this amount 4.6 mgd is contributed by the drainage area in the Chugach Mountains. The remaining 11.1 mgd, of which 3.7 mgd is derived from Russian Jack Springs alone, is assumed to be seepage from the ground-water reservoir. The amount of water consumed by evapotranspiration and that lost by submarine discharge into Cook Inlet are presently indeterminate. An estimate of the ground-water withdrawal from pumpage is 10 mgd.

The average annual outflow of water from the Anchorage area with the indicated degree of accuracy is listed below:

Source	MGD (Yearly average)	
	Measured	Estimated
Streamflow		
Ship Creek	78.5	
Campbell Creek		25
Chester Creek (including Russian Jack Springs)	15.7	
Pumping		10
	94.2	35
Total (rounded)		130
Submarine discharge plus evapotranspiration (by difference)		50
Total (rounded)		180

The difference of about 50 mgd between inflow, as shown on page 21 and outflow shown above is assumed to be accounted for by submarine discharge and evapotranspiration. The relative proportions of each cannot be estimated on the basis of the available data.

DEVELOPMENT OF WATER RESOURCES

The major problem concerning water management in the Anchorage area is the development of a suitable plan to compensate for the lack of water during periods of greatest demand. This problem can be achieved by conjunctive use of water through surface and subsurface storage, using the excess discharge of streams during periods of high flow to provide water during the periods of low flow.

Two potential reservoir sites on Ship Creek (Black and Veatch, 1953) have a combined estimated capacity of more than four billion gallons. The availability of water to supply these potential surface reservoirs can be determined by conventional engineering methods. In any water development plan, provision should be made to maintain a minimum flow in the stream for quality control, waste management, power plant cooling, and other purposes.

The importance of ground water will increase with time because it provides an economical means of regulating supply to demand and avoids costly treatment plants and distribution facilities. If ground-water use continues as projected, several changes in the pattern of use should be considered.

A logical first step in changing the pattern of use would be to phase out gradually the present city supply wells and replace them with new wells closer to the area of recharge.

The area along Ship Creek east and north of Mountain View has the greatest potential for ground-water development (fig. 6). Large quantities of water are not being withdrawn in this area and because

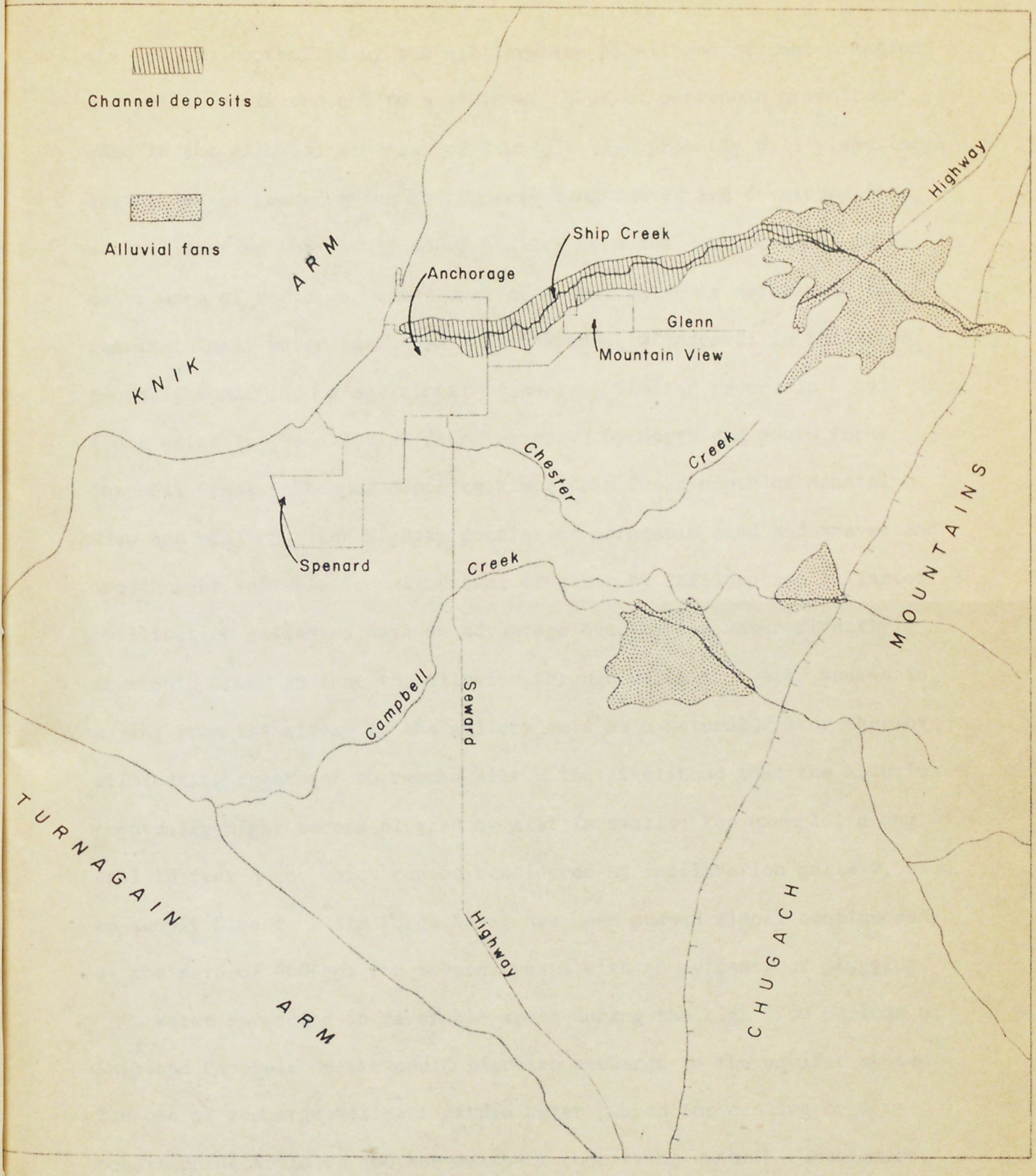

Figure 6.--Sketch map of the Anchorage area showing areas favorable for development of ground-water supplies.

the area is controlled by the military the likelihood of contamination and pollution is reduced to a minimum. Beds of permeable gravel and sand in the alluvial fan east of Mountain View probably will yield large quantities of ground water to properly constructed and developed deep wells. Because the fan is about 5 miles from the coastline and is a major area of recharge, withdrawal of ground water is not likely to result in salt-water intrusion. Furthermore, withdrawal in this area probably would induce additional recharge. Similar favorable conditions exist in the alluvial fans traversed by North and South Forks Campbell Creek. Channel deposits along Ship Creek north of Mountain View and west of Glenn Highway consist of permeable sand and gravel and are thought suitable for withdrawal of water by infiltration galleries. Infiltration galleries have an advantage over taking water directly from Ship Creek in that the alluvium through which the water passes in moving from the stream to the gallery acts as a natural filter thereby eliminating treatment to remove silt. The likelihood that the alluvium eventually might become plugged by silt is small. For example, a dug well 16 feet deep, which can be considered an infiltration gallery, used to supply Elmendorf Air Force Base, has been pumped almost continuously at the rate of 800 gpm for several years with no evidence of plugging.

Water spreading in favorable areas during the high flow periods of Ship and Campbell Creeks could increase recharge to the aquifer system. The use of recharge wells to return water pumped for cooling or air-conditioning would be another means of conserving water. Furthermore, if recharge wells are located along the coastline, the additional recharge would form a fresh water barrier, thus reducing the hazard of salt-water intrusion.

Although recharging through deep wells would locally increase the piezometric pressure in the artesian aquifer, the likelihood that such an increase would have any effect on foundation conditions in the overlying Bootlegger Cove Clay seems doubtful. Measurements made in piezometer tubes installed in the clay by the Corp of Engineers after the Good Friday earthquake and in nearby deep wells show that there is little or no relationship between piezometric pressures in the artesian aquifer and pore pressures in the overlying clay. For example, the water level in a well reported to be 200 feet deep at the west end of the Park Strip (near 9th and N) stands about 70 feet below the surface, whereas the water level in a nearby piezometer tube extending into the clay to a depth of about 90 feet is only about 25 feet below the surface. According to a report by Shannon and Wilson (1964, p. 2) landsliding in the downtown area took place along zones at an elevation of about 40 feet which is about 40 feet below the top of the clay. The clay in this area is about 150 feet thick thus the landslide zones are separated from the underlying artesian aquifer by about 110 feet of essentially impermeable clay. The possibility that a local increase in piezometric pressure would have any effect through 110 feet of clay seems remote. Nevertheless, when artifical recharging is undertaken, observations should be made to determine the effects, if any, the increased pressure would have on foundation conditions.

NEED FOR ADDITIONAL STUDIES

Study of the water resources of the Greater Anchorage Area and the problems resulting from their present development enphasize the need for planning a sound water-resources development program to insure adequate supplies of potable water for the future. Because the military and the borough as well as the city have a large stake in the area's water resources, their cooperation and support of additional hydrologic studies should be sought.

Hydrologic studies needed can be grouped into two general types--basic records and areal studies. Each forms an essential and integral part of the analysis of the entire system. The primary goal of these studies would be to construct an electric analog model which can be used to predict quantitatively the effects of alternative methods of water development.

The present cooperative program between the City of Anchorage and the Geological Survey includes the collection and compilation of data on streamflow, ground-water levels, and chemical quality of ground and surface waters. In addition some information is collected on pumpage, well logs, and well descriptions. This program should be expanded.

An expanded network of stream-gaging stations is needed to provide more definitive information on stream gains and losses which provide a basis for determining the rate and amount of ground-water recharge. Installation of gaging stations at selected points throughout the area should provide more accurate information on the inflow-outflow relationship.

The likelihood of salt-water intrusion is strongly suggested by the sudden increase in chloride content in deep wells on Fire Island. Whether this reflects the effects of the Alaska earthquake of 1964 or an expansion of the cone of influence of the city well field is debatable. At any rate, deep wells near the coastline are needed to monitor changes in chemical quality that would indicate intrusion of salt water. If information provided by the monitoring wells indicates intrusion, immediate investigations can be undertaken to determine the rate and extent of intrusion in order to formulate remedial measures.

In addition to a series of wells along the coastline an expanded network of wells to monitor variations in water levels is needed. Information provided by such a network would be used to determine changes in ground-water storage and to pinpoint areas where water-level declines are or are likely to become excessive.

Accurate quantitative study of the ground-water reservoir is vital to an analysis of the hydrologic system. Because of the complex subsurface geologic conditions, geophysical logging of test holes and wells offers the most practical means of defining aquifer boundaries and important aquifer characteristics. Seismic studies would be useful in defining geohydrologic conditions in some parts of the area where no wells are available for geophysical logging. Pumping tests will provide additional information on aquifer boundaries and characteristics.

Measurements of lake levels, when combined with other data, would provide useful information on changes in ground-water storage and serve as potential indicators of possible approaching water-level declines. Measurements to determine water loss from lakes and swamps would be desirable to further define the inflow-outflow relationship. The

effects of swamp environments on chemical quality of ground water should also be determined.

The extent and effects of the March 27, 1964 earthquake have not been studied in detail. The short term effects were rapid and erratic fluctuations of water levels and varying degrees of damage to wells. Preliminary investigations suggest that compaction of the aquifer system may have occurred as a result of reorientation of material within aquifer units. A study of tide-produced cyclic water-level fluctuations in records from selected observation wells before and after the earthquake suggests a possible change in hydraulic characteristics of the aquifers, but substantiating information is not available. The important implication is that the dynamic equilibrium of the hydrologic system may have been disturbed. Thus, the continuing utility of previously-determined hydrologic data may be questionable. Determination of the long-term effects of the earthquake will require collection and analysis of additional data; the studies outlined in previous paragraphs will provide most of these data.

As previously stated, the goal of the studies outlined is to construct an electric-analog model that will simulate the entire hydrologic system. An electric-analog model is made of electrical resistors that are chosen so as to be proportional to the storage coefficients. Electrical voltage and current are scaled to represent field conditions of hydraulic head and quantity of flow. Such a model provides a rapid means of programming a large number of hydrologic combinations. By proper analysis the analog model can be used to give information as to proper well spacing, water-level drawdowns at any given point, and reaction of the hydrologic system to changing rates and volumes of withdrawal of water.

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