WATER RESOURCES AND SURFICIAL GEOLOGY OF THE MENDENHALL VALLEY, ALASKA

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INTRODUCTION

The Mendenhall Valley, about 10 miles northwest of the city of Juneau, is part of the Greater Juneau Borough in southeast Alaska (Index map). Average yearly rainfall measured at the Juneau Airport is 54.9 inches. Average temperature in January is 25°F, and in July 56°F. The 20-mile square study area includes a low-lying glacial valley bordered by steep mountain slopes and the narrow hilly Mendenhall Peninsula that extends 2 miles southward into the tidewater of Gastineau Channel. The peninsula is underlain by Bedrock, the valley by alluvial fill. The peninsula and valley are among the most promising large areas available for future development in the borough.

Residential areas are rapidly developing in the valley and on the peninsula. The urban population of Juneau has remained at approximately 7,000 since 1960; the rural population has increased from 1,900 in 1960 to 5,100 in the spring of 1966. Most of this population growth has been in the Mendenhall Valley, which had a population of 2,940 in the spring of 1966.

There is no central water-supply system in the valley. Water is obtained from wells, from small surface-catchment systems, and from rain. One of the larger tract developments and several of the trailer parks in the area have installed ground-water supply systems.

The accelerated growth of the area has focused attention on the need for information as to the location, development, and management of water resources. Present water use in the study area is estimated at 882,000 gpd (gallons per day), based on a 300 gpd per capita rate in the city of Juneau. Projections based on the population growth rate suggest that water use in the study area may approach 1,500,000 gpd by 1970.

This study is part of an overall cooperative investigation of the water resources of the Greater Juneau Borough. The Mendenhall Valley was chosen as a starting point in the study because of the particlarly rapid growth of population and the consequent urgent need for water information. Fieldwork for this report began in July 1965 and ended in May 1966.

Acknowledgments.—Appreciation is expressed to the many individuals and organizations who contributed to this report, including the State of Alaska, the U.S. Public Health Service, the U.S. Forest Service, the Greater Juneau Borough, the U.S. Fish and Wildlife Service, and many residents of the Juneau area. The authors also wish to express appreciation to their colleagues in the U.S. Geological Survey.

AVAILABILITY OF SURFACE WATER

The main source of the Mendenhall River is melt water from Mendenhall Glacier. Another source is runoff from Nugget, Steep, and Montana Creeks. A large part of the streamflow in Nugget Creek is glacial melt water from Nugget Creek Glacier. Other streams in the valley are Duck, Jordan, Lake, and Auke Creeks. Duck and Jordan Creeks on the eastern side of the valley flow from steep forested mountains to the flat valley floor, discharging into Gastineau Channel. Lake Creek flows to Auke Lake from heavily timbered moderately rugged mountains on the western valley slopes. Water from Auke Lake is discharged to Auke Bay through Auke Creek.

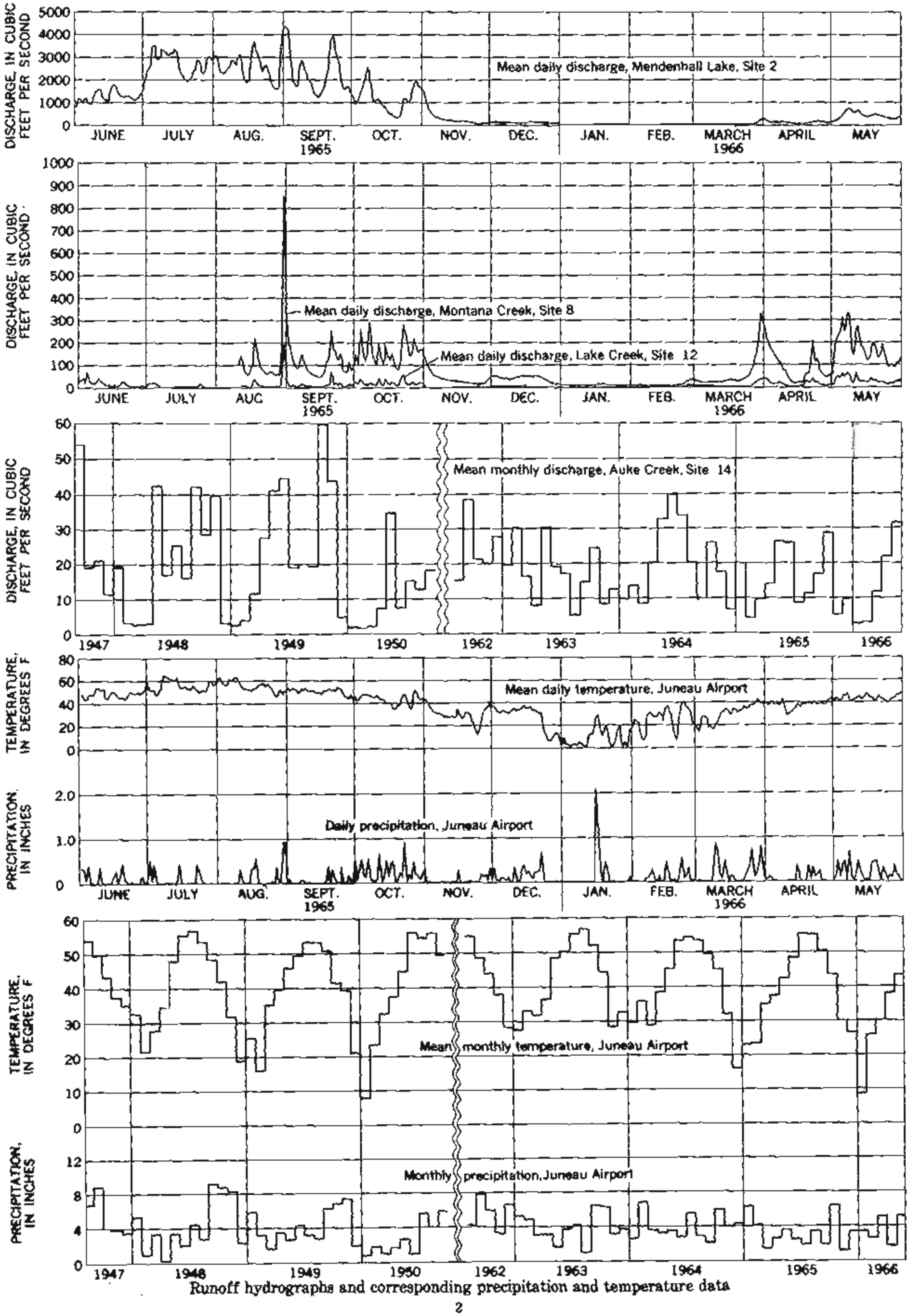
Stream-gaging stations provided information for runoff hydrographs for Mendenhall Lake and Montana, Lake, and Auke Creeks. Hydrographs for Montana and Lake Creeks are shown on one graph to illustrate the similarity of the flow patterns of the two creeks due to similar drainage basin characteristics. The flows react readily to rainfall, as can be seen by comparison of the rainfall and streamflow graphs. The effects of temperature and rainfall on streamflow in the valley are shown by graphs of monthly means of temperature and rainfall at the Juneau Airport and monthly average flows on Auke Creek. The Mendenhall River is influenced primarily by the temperature patterns.

Minimum flow from Mendenhall Lake, which is the most critical factor in determining the adequacy of a surface-water supply, was 31 cfs (cubic feet per second) during the 1965-66 winter period. Nugget Creek and Montana Creek had, at all observations, flows in excess of 5 cfs; Duck, Jordan, Steep, Lake, and Auke Creeks had observed flows of less than 1.5 cfs. Most of the low flows occurred during the winter months. Very low flows have been reported on the smaller streams during dry summer periods.

Peak flows have often occurred during late summer as a result of heavy rains. The maximum known high water on Mendenhall River was in late summer 1961, when the flow was approximately 27,000 cfs at the river mouth. Excessive flows in the nonglacial streams could occur during the fall to spring months when heavy rains fall on frozen ground. The runoff and response to temperature changes and rainfall patterns can be seen on the stream hydrographs.

Average flow on Mendenhall River is estimated to be 1,000 cfs. Measurements taken at the various sites on Montana Creek and Mendenhall River indicate that part of the flow in these streams is contributed from ground-water inflow during most of the year.

Lakes.—The two large lakes in the valley are Mendenhall and Auke. Mendenhall Lake, formed by Mendenhall Glacier, has a maximum depth of 200 feet and covers a surface area of about 1.12 square miles. Its maximum volume is about 40,500 acre-feet and is normally high in summer and low in the winter. The water contains a large amount of glacial flour at all times. Auke Lake, fed by Lake Creek, had depths of as much as 113 feet and a volume of about 6,500 acre-feet. The lake elevation fluctuates only slightly, being normally higher in the spring and summer than in the winter.



Runoff hydrographs and corresponding precipitation and temperature data

Streamflow measurements in cubic feet per second

Site 1 Date	Site 1 Discharge	Site 2 Date	Site 2 Discharge	Site 3 Date	Site 3 Discharge	Site 4 Date	Site 4 Discharge	Site 5 Date	Site 5 Discharge	Site 6 Date	Site 6 Discharge	Site 7 Date	Site 7 Discharge
1965		1965		1965		1965		1965		1965		1965	
Aug. 6	246	June 29	1240	Aug. 6	4.69	July 30	2930	July 29	2760	July 29	103	July 30	96.3
Sept. 8	329	July 30	3060	Aug. 30	40	Aug. 4	2050	Aug. 5	2180	Aug. 2	80	Aug. 3	70.2
Sept. 25	237	Aug. 4	2180	Sept. 25	8.11	Aug. 30	3405	Aug. 30	3600	Sept. 27	46.9	Sept. 29	62.3
Oct. 27	480	Aug. 30	3230	Oct. 27	23.2	Oct. 1	1220	Oct. 1	1160	Oct. 26	125	Oct. 26	130
Dec. 30	16.5	Oct. 1	1150	Dec. 29	1.46	Oct. 28	2000	Oct. 28	1960	Dec. 28	28.4	Dec. 28	15.1
1966		Oct. 28	1930	1966		Dec. 29	77.3	Dec. 29	86.8	1966		1966	
Feb. 25	14.8	Dec. 29	71.6	Feb. 16	1.27	1966		1966		Feb. 7	7.78	Feb. 7	7.19
Apr. 5	27.8	1966		Mar. 31	5.50	Feb. 15	32.3	Feb. 16	38.6	Mar. 28	66.8		
May 2	93.24	Feb. 15	31.1	May 31	12.7	May 3	272.09	Mar. 30	267	Mar. 30	110		
May 27	50.2	Mar. 30	240			May 25	289	May 3	271	May 5	314		
June 11	307	May 5	363					May 25	326	May 26	81.9		
		May 25	306										
		June 9	1740										

Site 8 Date	Site 8 Discharge	Site 9 Date	Site 9 Discharge	Site 10 Date	Site 10 Discharge	Site 11 Date	Site 11 Discharge	Site 12 Date	Site 12 Discharge	Site 13 Date	Site 13 Discharge	Site 14 Date	Site 14 Discharge
1965		1965		1965		1965		1965		1965		1965	
July 29	90	July 29	94	July 29	3170	Aug. 2	0.69	Aug. 3	11.1	June 29	3.46	June 30	8.52
Aug. 3	78.8	Aug. 5	67	Aug. 2	3360	Aug. 30	7.63	Aug. 30	27.5	July 26	.3	July 23	1.72
Aug. 30	878	Aug. 30	8.34	Aug. 30	5020	Sept. 25	3.56	Sept. 25	4.86	Aug. 30	165	Aug. 31	114
Sept. 29	70.9	Sept. 29	68.8	Oct. 1	1380	Oct. 27	8.88	Oct. 27	23.8	Sept. 28	17.9	Sept. 28	16.1
Oct. 26	155	Oct. 26	166	Oct. 28	2060	Dec. 30	.44	Dec. 30	1.04	Oct. 27	18.4	Oct. 27	32.7
Nov. 23	15.4	Dec. 29	17.7	Dec. 30	96.2	1966		1966		Nov. 23	.68	Nov. 23	1.31
Dec. 28	16.8	1966		1966		Feb. 17	Dry	Feb. 17	.2	Dec. 28	.88	1966	
1966		Feb. 16	5.92	Feb. 23	83.6	Mar. 31	19	May 27	16.4	1966		Jan. 1	2.11
Feb. 16	8.70	May 5	218			May 27	6.19			Feb. 23	3.35	Feb. 23	2.60
April 8	83.4	May 25	90.9							Mar. 30	35.4	Mar. 28	23.3
May 5	399									Apr. 11	5.36	Mar. 30	56.2
May 26	92.6									May 4	38.4	May 5	62.6
June 8	223									May 26	14.5	May 26	21.7

QUALITY OF WATER

The chemical quality of water in Mendenhall Valley varies with source and location. In general, surface water is soft and of good chemical quality, but often contains objectionable amounts of glacial silt. Chemical analyses of water from six streams are shown by diagrams to illustrate the quality of surface water in the valley (quality of water map). Compared to surface water, ground water is of poor quality, is moderately hard, and contains iron. The temperature of ground water ranges from 42°F. to 52°F. The chemical properties of most of the water in the area, as shown on the table of selected chemical analyses of water samples, are dominated by alkaline earths and weak acids except for the Mendenhall Peninsula area which has alkali carbonate water according to Piper (1944).

Selected chemical analyses of water samples

Well number	Date of collection	Depth of well (feet)	Temperature (° F)	Silica (SiO_2)	Iron (Fe)	Calcium (Ca)	Magnesium (Mg)	Sodium (Na)	Potassium (K)	Bicarbonate (HCO_3)	Sulfate (SO_4)	Chloride (Cl)	Fluoride (F)	Nitrate (NO_3)	Dissolved solids Calculated	Hardness as $CaCO_3$: Calcium, magnesium	Hardness as $CaCO_3$: Noncarbonate	Specific conductance (micromhos at 25° C)	pH	Color
Wells which produce from sediments																				
5	Sept. 1, 1965	80	43	19	2.31	14.0	12.0	5.7	3.4	101	9.6	2.8	0.1	0.1	119	84	1	188	7.1	5
6	Sept. 3, 1965	60	49	11	.88	10.0	16.0	1.2	3.1	106	11.0	0	.3	.3	106	91	4	189	7.1	5
31	Sept. 9, 1965	43	51	17	.22	21.0	3.8	7.8	2.0	97	4.8	3.5	0	0	108	68	0	161	7	5
43	Sept. 17, 1965	42	46	19	.48	16.0	5.1	22.0	1.2	120	9.1	4.6	.1	.2	204	61	0	204	7.2	-
44	-----do-----	89	--	16	.06	29.0	9.4	7.2	2.7	137	13.0	1.8	.1	.2	147	106	0	233	7.3	-
132	Sept. 3, 1965	38	50	21	2.19	8.8	64.0	6.5	8.1	274	66.0	5.3	.1	1.4	318	285	60	559	7.5	5
Wells which produce from bedrock																				
8	Sept. 3, 1965	131	52	14	0.13	0.8	1.4	124	6.9	262	29.0	5	1.1	0.1	329	8	0	535	8.8	4
103	Sept. 10, 1965	120	49	24	.31	34.0	12.0	45	4.3	254	3.3	7	0	.7	---	134	0	428	7.7	-
Surface water																				
Jordan Creek (12)	Sept. 1, 1965	--	49	2.1	0.68	12	0.5	0.8	0	36	2.4	0	0.1	0	87	32	2	77	6.5	5
Lake Creek (13)	-----do-----	--	--	1.3	.18	0	3.4	.5	0	11	3.8	.4	.1	0	15	14	5	29	6.4	-
Mendenhall R.	-----do-----	--	39	.6	.40	2.4	.6	.4	0.4	8	2.4	.4	.1	0	12	8	2	18	6.5	5
Montana Creek (6)	-----do-----	--	--	2.9	.23	6.8	.7	1.0	0	19	.5	1.4	.3	0	23	20	4	44	7.1	10
Nugget Creek (1)	Sept. 8, 1965	--	42	1	.13	4.0	1.0	.6	0	15	1.4	.4	0	0	16	14	2	33	6.8	6
Steep Creek (3)	Sept. 1, 1965	--	48	1.8	.05	8.4	.7	.5	0.4	28	2.4	.4	0	.1	29	24	1	53	6.7	5

Iron.—Relatively iron-free water enters the valley by precipitation and flow in streams. The iron content increases slightly in the surface streams as the water passes through the valley. The iron content greatly increases when water enters the ground and moves through the sediments. The map shows the distribution of iron in the ground water of the study area. An iron content of more than 0.3 ppm (parts per million) is considered unacceptable for domestic use by U.S. Public Health Service standards. Most of the water in the study area exceeds this limit and causes staining of household fixtures.

The amount of iron taken into solution may be related to the amount of organic material in the sediments and possibly to the length of time during which the water has been moving through the subsurface rocks. Ground water obtained from the northeastern side of the valley contains less iron than water from the central part of the valley. This absence of iron content may be related to the presence of more porous and permeable sands and less organic material. Iron-free water entering the subsurface in this area moves rapidly through coarse sands into silty, fine-grained floodplain, estuarine, and marine sediments, which are less permeable and contain much organic material, which results in the iron content increasing noticeably. Water from bedrock that contains no organic material averages less than 1 ppm iron, even though much of the bedrock is composed of iron-rich volcanic rocks. Organic material is present in large quantities in deltaic and bog deposits along the north shore of Auke Lake where iron content of ground water is high in contrast to water from surrounding bedrock and from surface sources.

Salt-water intrusion.—Salt or brackish water occurs in shallow estuarine deposits in parts of the south end of the Mendenhall Valley and is reported from deep wells in the central part of the valley. Some of the salt water may be connate or may have been left during deposition of the valley-filling sediments. Salt water also occurs in the Mendenhall River as far north as the mouth of Montana Creek, the limit of the tidal effects. In the vicinity of test wells M-5 and M-10, shown on the surficial geologic map, there is some indication that the salt content of ground water increases rapidly with depth. Wells along the western side of the Mendenhall River south of the Glacier Highway have penetrated salt water.

The occurence-of-water-and-ice map shows the approximate location of the salt-water-fresh-water interface in the southern part of the Mendenhall Valley. Although fresh water may occur as lenses in the surficial deposits, all wells drilled south of this line are likely to penetrate salt water at shallow depth. Increased pumping in this area, particularly near the airport, may cause the salt-water interface to move northward causing contamination or increase in chloride content of water in wells.

AVAILABILITY OF GROUND WATER

Ground water in the study area is obtained in Recent unconsolidated sediments and in bedrock fractures. Wells completed in unconsolidated sediments generally produce adequate quantities of water. The average bedrock well will only supply enough water for a single family.

Bedrock.—Most ground water in the Mendenhall Peninsula and Auke Lake areas is obtained from fractures in bedrock of slate and varying amounts of Metamorphosed volcanic agglomerate and breccia. The area of exposed bedrock is shown on the geologic map. Yields, in a sample of 46 wells, range from less than 1 gpm (gallons per minute) to a maximum to 20 gpm and average about 3 gpm.

The availability of water in bedrock is determined by the fracture pattern because primary porosity and permeability are absent. Some secondary fracture porosity and permeability occur in joints, faults, and volcanic breccias and agglomerates. In effect, the openings in the rocks have been increased by compression and uplift.

In locating new wells in bedrock, it is necessary to drill into or intersect fractured or brecciated zones. These zones can more easily be found and mapped if the following information is taken into consideration:

1. Many bedrock fractures follow bedding planes that trend in a northwest direction and dip 40 to 60 degrees to the northeast.
2. Zones of brecciated volcanics generally trend northwestward with the bedding.

Much of the bedrock area is overlain by a thin cover of glacial till that produces small quantities of water. Care must be taken in the area to seal the well casing from the surface to the bedrock in order to avoid contamination from iron-bearing ground water that collects along the bedrock-till contact.

Unconsolidated sediments.—Unconsolidated sediments of silt, sand, and gravel are present throughout Mendenhall Valley. Their distribution is shown on the accompanying sheet on geology. These deposits are recharged principally from Mendenhall Lake and from precipitation. As water moves into and from storage, the water table fluctuates showing the stage of storage at any particular time. Water levels dropped in the 1965 summer dry period and during December 1965 and January 1966. They began to rise in February and reached a maximum in early spring 1966. The generalized water-level map shows an approximation of the height of the static water level above MLLW (mean lower low water) during 1965 for selected wells in the valley. Mean lower low water is approximately 7 feet lower than mean sea level in the Juneau area. The water table slopes southwestward at an average gradient of about 15 feet per mile and ranges from 3 to 10 feet below the surface.

The abundance of intermixed glacial silt and clay in the unconsolidated sediments of the valley generally causes lack of permeability. Fine-grained silty detritus is commonly found in glacial sediments. The permeability of sedimentary materials bordering Mendenhall Lake and Mendenhall River is diminished by the deposition of glacial flour. As water flows into the sediments, much of the flour (clay and silt particles) is deposited along the water-sediment interface, or is carried a short distance into the void spaces between sediment grains.

Water moves more readily through deposits of coarse well-sorted washed sands. Coarse sands, which offer the best possibility for developing large supplies of ground water, are in the northeastern part of the valley. The area, marked on the water-level map (occurrence of water and ice map) as favorable for large-capacity wells, appears to be underlain by relatively permeable medium to coarse sands containing water of low iron content. Well 7 in this area supplies most of the water for a 50-unit trailer court. It is estimated that pumping rates on well 7 approach 2,000 gallons per hour without appreciable drawdown. Test hole M-14, 700 feet south of well 7, penetrated 87 feet of permeable sand.

Infiltration galleries.—An infiltration gallery, an artificial tunnel that extends into a zone of saturation, drains water by gravity into a sump or well. Such a gallery might consist of a perforated pipe surrounded by a gravel pack. Deposits of water-saturated sand and gravel in abandoned outwash stream channels suitable for gallery installation occur along the south shore of Mendenhall Lake, as shown on the occurrence of water and ice map.

Two test pits were excavated in these sands in the spring of 1966. Pit No. 1, as shown in the accompanying photograph, is 15 feet by 25 feet in area and about 8 feet deep. The water level in the pit was within 4 feet of ground level shortly after excavation. The permeability of the sand indicates that probably more than 50 gpm could be pumped continuously from a gallery.

There would be many advantages to a gallery located near the lake. It would provide naturally filtered water from a large reservoir of lake water and would require a minimum of pumping to maintain adequate line pressure.

GEOLOGY

The surficial geologic map shows the distribution of rock types in the Mendenhall Valley area. They have been divided generally into bedrock or metamorphic rocks of Mesozoic age and unconsolidated sediments of Quaternary age. The unconsolidated sediments have been subdivided into (a) older marine, estuarine, and alluvial deposits, generally between 6,000 and 18,000 years old, and (b) younger, generally nonmarine deposits. Most of these younger sediments were laid down during the recent advance and retreat of the Mendenhall Glacier. A brief description of the map units and their water-bearing qualities is presented with the geologic map. A more detailed description of their water-bearing qualities will be found in the section on availability of water.

The three geologic sections (A-A', B-B', and C-C') illustrate the subsurface geology in the valley. The sections emphasize the presence of a thin cover of Recent nonmarine outwash and alluvial sediments that overlies a relatively thick accumulation of tidal and marine sediments. They show the impermeable envelope of metamorphic rocks that contain water-bearing sediments, the hydrologic setting of Mendenhall and Auke Lakes, and the relation of the lakes to the water-bearing sediments.

GEOLOGIC HISTORY

The bedrock terrane of the area, which was probably laid bare by glacial scouring, is relatively impervious. It is composed of tightly consolidated metasedimentary, igneous, and metamorphic rock that grades from clastic metasedimentary and volcanic rock in the lower end of the valley and in the Mendenhall Peninsula to quartz diorite in the presently glaciated part of the valley near Stroller White Mountain north of the mapped area. The rocks are from 70 to 225 million years old (Knopf, 1912). Typical rocks are slate, graywacke, sandstone, argillite, thin lenses of limestone, extrusive volcanics that have been altered to greenstone, schist, and phyllite. The rocks generally dip steeply to the northeast.

Mendenhall Valley was formed by glaciation during the Pleistocene Epoch. In the vicinity of the valley, the Pleistocene ice sheet was 4,000 to 5,000 feet thick about 18,000 years ago (Coulter and others, 1965). The ice sheet began to melt about 17,000 years ago and by 11,000 to 7,500 years ago the valley was free of glacial ice as far north as the present front of the glacier.

As the ice receded from the area, relatively permeable unconsolidated sediments were deposited in the valley. These unconsolidated sediments are generally younger than 18,000 years (Heusser, 1960, p. 97) and are composed of bedrock detritus in the form of clay, silt, sand, gravel, and boulders, intermixed during deposition by glacial, tidal, wave, and stream action. Individual beds generally cannot be traced over appreciable distances.

The thickness of the sedimentary fill is known at only a few places. The maximum measured depth of Mendenhall Lake is 200 feet. Depth to bedrock in the center of the valley south of the lake is more than 180 feet at well 1 on the Mendenhall Loop Road. Preliminary interpretations of geophysical investigations in part of Mendenhall Valley indicated 500 feet as a probable depth to bedrock near well 82 (R. D. Miller, oral commun., June 19, 1966).

Many dynamic environmental changes have taken place in the report area since the last glacial maximum. During the buildup of the ice sheet, the land surface was loaded and depressed by the weight of the ice and probably subsided at least 700 feet in the Juneau area (Twenhofel, 1952, p. 528; Heusser, 1960, p. 192; Curray, 1965, p. 725, fig. 2). Concurrently, worldwide ice buildup also caused lowering of sea level by approximately 360 feet (Curray, 1965, p. 725, fig. 2). The worldwide melting of glacial ice after the last glacial maximum caused the rise of sea and land levels.

The relative rate of rise of sea level and land surface differed. The land surface, which had been depressed farther, rose at a faster rate, but both rates appear to be directly proportional to the melting rate of the regional ice sheet. The land rise is thought to be not simply related to unloading but also to the regional tectonic framework, probably in a delicate state of balance, so that loading and unloading allowed relatively rapid and great downwarping and consequent rebound of the land mass. Preliminary evidence suggests that by 4,000 B.C. to 5000 B.C., sea and land levels probably were within 15 feet of their present elevations (Heusser, 1960, p. 189-194). The warm climate, which caused the glaciers to recede, began to cool by 1,000 B.C. (Goldthwait, 1963, p. 44; Heusser, 1957, p. 69 and fig. 2). During this period, the Mendenhall Glacier probably receded farther up the valley than its present position and then began to readvance. It reached its farthest modern advance by A.D. 1750 and then receded rapidly (Lawrence, 1950, p. 201 and 219). As the ice sheet retreated, the sedimentary environment in the valley changed from marine to nonmarine. The paleogeographic maps illustrate the sedimentary environment during the advance and retreat of the glaciers.

Marine Phase: 10,000-4500 B.C.—After the retreat of the ice sheet, approximately 10,000 to 12,000 years ago, the valley floor was covered by seas that may have been more than 400 feet deep (Twenhofel, 1952, p. 528, and Curray, 1965, p. 725, fig. 2). Rapid emergence of the area caused water depths to shoal so that by 4500 B.C. the bedrock surface may have been within 35 feet of modern sea level datum (Heusser, 1960, p. 97). The Paleogeographic map shows conditions as they may have existed about 6000 B.C.

Sedimentation during the interval, 10,000 B.C. to 4500 B. C., was marine; the rocks consist of intermixed poorly sorted clay, silt, sand, and boulders. Early in this span some of the sediment probably dropped to the bottom of the valley from the glacier front and from icebergs in the bay. Along the bay shore, deltaic fans of stream-sorted sand were developed; the largest was near the mouth of Montana Creek. Both organic material derived from the sea and fragments of vegetation carried by streams were buried in the accumulating sedimentary fill. This material, as well as salt water, has been penetrated in several areas by deeper wells in the valley (cross section B-B' on the surficial geologic map.)

Estuarine and Nonmarine Phase: 4500 B.C.-A.D. 1750—Between 3500 and 4500 B.C. the relatively rapid rise of sea and land ceased at, or near, modern sea level datum. The paleogeographic map shows conditions as they migh have appeared about 800 B.C. Outwash from the glacier and alluvial detritus from the streams formed a graded plain which advanced southward from the bedrock exposures at the north end of the valley. Estuarine or tidal sediments were deposited in front of the plain, and pioneer forests grew on the plain above tide level. Drainage from Nugget Creek and melt water from Mendenhall Glacier deposited stream-sorted sand and gravel in deltas along the eastern side of the valley. During periodic floods, trees and vegetation were repeatedly buried under alluvial sediments.

As the climate became cool and wet during the Little Ice Age (Matthes, 1942, p. 214), which began about 1000 B. C., the Mendenhall Glacier began to readvance southward. The glacier overrode trees that had been established in the Mendenhall Lake area, probably excavated sediments from the site of Mendenhall Lake, and reached its terminal position sometime before A.D. 1765 (Lawrence, 1950, p. 215). Increased streamflow due to the cool-wet climate during the advance probably caused the burial by sediments of forest growth south of the glacier. The remains of the forest, buried tree trunks and logs, can be seen at localities MWB, MWC, and MWD on the surficial geologic map.

Nonmarine Phase: A.D. 1750 to Present.—The last recession of Mendenhall Glacier about A.D. 1750 (Heusser, 1964, p. 77; Lawrence, 1950, p. 203), changed the physical environment of the valley. The paleogeographic map shows conditions as they might have appeared in A.D. 1750. Since that time, the glacier has retreated at an average rate of 40 feet per year. As the glacier receded, many temporary terminal positions were recorded by concentric morainal ridges of coarse cobbles and boulders deposited on the fine sediments of the earlier outwash-plain or lake deposits. During this stage, melt water from the glacier and Nugget Creek, which flowed over the morainal material, deposited glacial outwash east of Dredge Lake and down the east side of the valley. Extensive deposits of coarse gravel and sand, shown on the surficial geologic map, were deposited by the melt-water stream as far south as well 96.

As the glacier retreated northward, the morainal material formed a dam that impounded Mendenhall Lake. Between A.D. 1750 and 1900 the dam was overtopped near its center, and the overflow of lake and melt water through the morainal material formed the present channel of Mendenhall River, which became the principal drainage of the valley. The river rapidly incised a channel through the flood-plain deposits. The lake became a settling pond for the coarse debris from the glacier and Nugget Creek. The Mendenhall River carried a sediment load principally derived from bank erosion, consisting of fine sand and silt. The sediment presently is being deposited in the delta area near the airport.

Depositional rates and processes have changed over the past 200 to 300 years. The valley area is presently undergoing regional uplift at a calculated rate of 2 centimeters per year (Hicks and Shofnos, 1965, p. 3316), probably as the result of unloading by melting of ice of the Little Ice Age. Consequently, sediments deposited during the glacial advance are now being eroded and transported to tidewater.

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