Overview of Environmental and Hydrogeologic Conditions Near Big Delta, Alaska

By Gordon L. Nelson

U.S. GEOLOGICAL SURVEY

Open-File Report 95-180

Prepared in cooperation with the

FEDERAL AVIATION ADMINISTRATION

Anchorage, Alaska
1995

U.S. DEPARTMENT OF THE INTERIOR
BRUCE BABBITT, Secretary

U.S. GEOLOGICAL SURVEY
Gordon P. Eaton, Director

For additional information write to:

District Chief
U.S. Geological Survey
4230 University Drive, Suite 201
Anchorage, AK 99508-4664

Copies of this report may be purchased from:

U.S. Geological Survey
Earth Science Information Center
Open-File Reports Section
Box 25286, MS 517
Federal Center
Denver, CO 80225-0425

CONTENTS

FIGURE

TABLES

CONVERSION FACTORS AND VERTICAL DATUM

Multiply	By	To obtain
millimeter (mm)	0.03937	inch
meter (m)	3.281	foot
kilometer (km)	0.6214	mile
square kilometer (km^2)	0.3861	square mile
liter per second (L/s)	15.85	gallon per minute
cubic meter per second (m^3/s)	35.31	cubic foot per second
meter squared per day (m^2/d)	10.76	foot squared per day
liter per second per meter [(L/s)/m]	4.83	gallon per minute per foot
degree Celsius (°C)	°F = 1.8 x °C + 32	degree Fahrenheit (°F)

Sea level:

In this report "sea level" refers to the National Geodetic Vertical Datum of 1929--a geodetic datum derived from a general adjustment of the first-order level nets of both the United States and Canada, formerly called Sea Level Datum of 1929.

Overview of Environmental and Hydrogeologic Conditions Near Big Delta, Alaska

by Gordon L. Nelson

ABSTRACT

The Big Delta Federal Aviation Administration facility is located at Allen Airfield, part of the Fort Greely Army Testing and Training Center in east-central Alaska. The facility is underlain by an alluvial fan complex containing abundant ground water. A review of well records, maps, and existing literature indicated that a highly transmissive alluvial aquifer receives recharge from direct infiltration of precipitation and from infiltration of streams along the north front of the Alaska Range. In general, ground water flows toward the northeast where it discharges into streams, wetlands, and lakes along the north boundary of the aquifer. Clearwater Lake, Clearwater Creek, and the Tanana River constitute this discharge boundary. Discontinuous permafrost does not extend to depths as great as the water table. The hydrologic effects of several moraines underlying the area have not been quantified.

INTRODUCTION

The Federal Aviation Administration (FAA) owns and (or) operates airway support and navigational facilities throughout Alaska. At many of these sites, fuels and potentially hazardous materials such as solvents, PCB's, and pesticides may have been utilized. To determine if environmentally hazardous materials have been spilled or disposed of at the sites, the FAA is conducting environmental studies mandated by the Comprehensive Environmental Response, Compensation, and Liability Act and the Resource Conservation and Recovery Act. To complete these more comprehensive environmental studies, the FAA requires information on the hydrology and geology of areas surrounding the sites. This report, the product of compilation, review, and summary of existing hydrologic and geologic data by the U.S. Geological Survey provides a summary of such supplemental information for the Big Delta FAA facility and nearby areas. Also presented in this report are descriptions of the history, socioeco-nomics and physical setting of the Big Delta area.

BACKGROUND

Location

The Big Delta FAA facility is in east-central Alaska at approximate lat 64°02' N., long 145° 43' W. It is along the Richardson Highway approximately 190 km southeast of Fairbanks and 160 km north of Glennallen near the junction of the Delta River and Jarvis Creek (fig. 1). The area is in the eastern reaches of the Tanana-Kuskokwim Lowland, a broad depression bordering the Alaska Range on the north (Wahrhaftig, 1965). The FAA facilities are concentrated at Allen Airfield, approximately 5 km south of the city of Delta Junction and approximately 20 km south of the village of Big Delta.

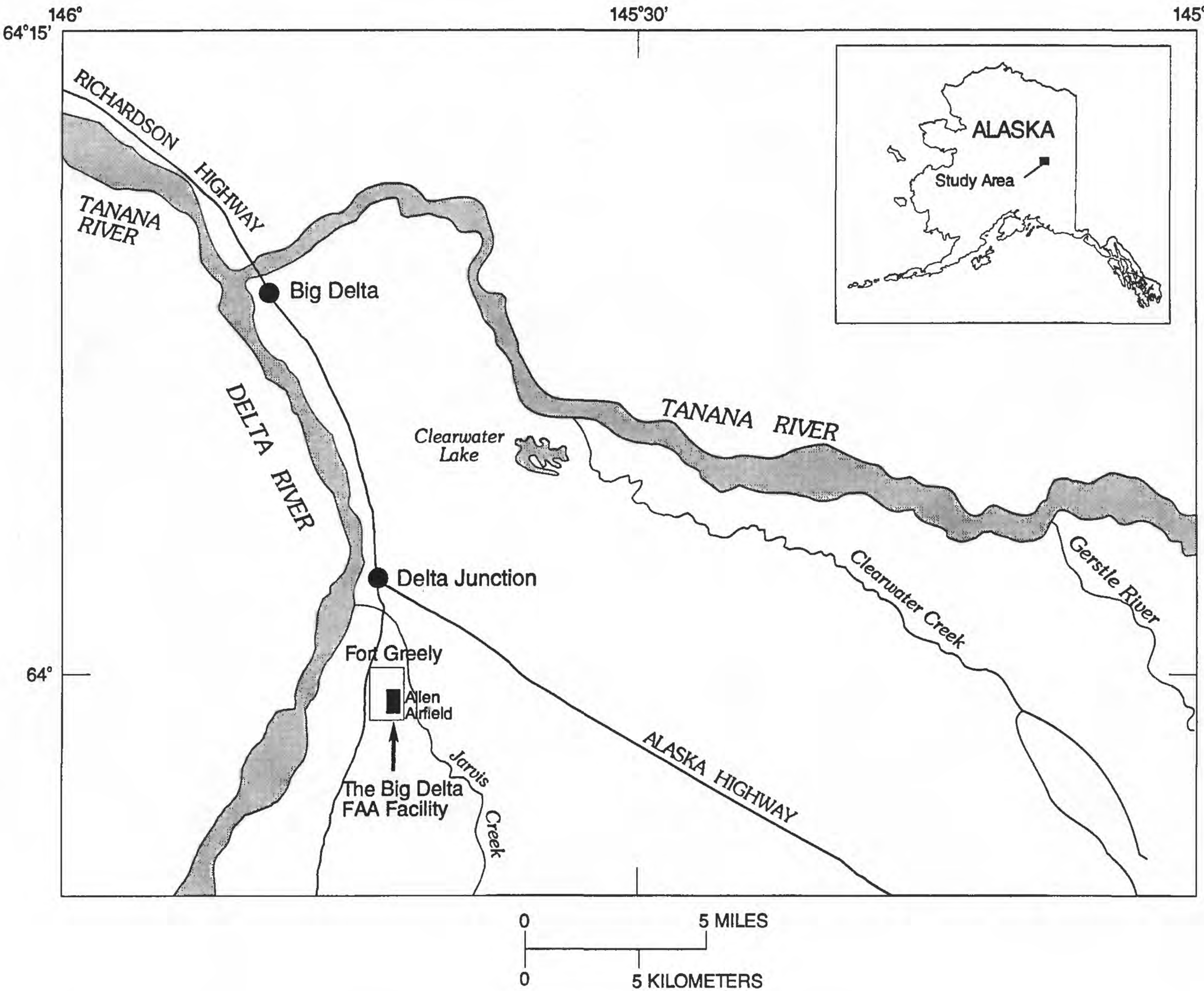

Figure 1. Location of Federal Aviation Administration facility near Big Delta, Alaska.

History and Socioeconomics

Big Delta was established as the McCarthy Telegraph station by the U.S. Army in 1904. It was situated on one of the earliest roads in Alaska, the route from the port of Valdez to the gold camps near Fairbanks and Circle. The community of Delta Junction was established as a road construction camp along the Richardson Highway in 1919. During World War II, the Alaska Highway was built through Canada and connected to the Richardson Highway at Delta Junction (Selkregg, 1976).

As early as the 1950's, the area around Big Delta was undergoing agricultural development and by the late 1970's and early 1980's, the State of Alaska had placed a major agricultural development plan into operation. As part of this plan, more than 280 km^2 of land was cleared, tilled, and planted, and much of that acreage is still under cultivation today.

Delta Junction is a second-class city having approximately 1,000 residents within its limits. About five times that many people live in the greater Delta Junction area. The local economy relies on military and government spending, highway-related work, agriculture, the service industry, and tourism. More than 50 percent of employment is with the Federal, State, and local governments (Alaska Department of Community and Regional Affairs, 1984). Employment, however, is limited and many residents depend on supplemental public assistance and subsistence activities (Selkregg, 1976).

The Big Delta FAA facility was established in 1941 when an air navigation site was constructed (Ecology and Environment, Inc., 1992). Present facilities include a very high frequency omnidirectional range tactical air navigation/directional finder (VORTAC/DF), a remote center air ground (RCAG) facility, and a non-directional beacon (NDB) facility. A detailed list of FAA facilities at Big Delta and a list of potential sources of contamination can be found in a report by Ecology and Environment, Inc. (1992).

PHYSICAL SETTING

Climate

The Big Delta area has a continental climate characterized by significant diurnal and annual temperature variations, low precipitation, and low humidity (Hartman and Johnson, 1984). This accounts for its long, cold winters and relatively short, warm summers. The mean annual temperature is -2.4° C, but temperature ranges from a July mean maximum of 20.6° C to a January mean minimum of -24.1° C (Leslie, 1989). Mean annual precipitation is about 290 mm and most rainfall occurs in July and August. Approximately 1,000 mm of snow falls annually. Mean monthly temperature, precipitation, and snowfall are summarized in table 1 (Leslie, 1989).

Table 1. Mean monthly temperature, precipitation, and snowfall for the period 1942 to 1987, Big Delta.
[Modified from Leslie (1989);°C, degree Celsius; mm, millimeter]

	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.	Annual
Temperature (°C)													
Mean maximum	-16.0	-11.7	4.6	4.2	13.7	19.2	20.6	17.9	11.3	-0.1	-10.1	-15.6	2.4
	(Record maximum 33.3 °C, July 1969)												
Mean minimum	-24.1	-21.4	16.9	6.9	2.7	8.4	10.2	7.6	1.9	-7.6	-17.9	-23.5	-7.3
	(Record minimum -52.8 °C, January 1947)												
Mean	-20.1	-16.6	10.8	1.3	8.2	13.8	15.4	12.8	6.7	-3.8	-13.9	-19.6	-2.4
Precipitation (mm of moisture)													
	8.4	6.9	7.6	61.5	21.6	30.7	68.8	49.0	27.9	14.7	10.4	9.4	292.1
Snowfall (mm)													
	142.2	109.2	111.8	78.7	12.7	0.0	0.0	0.0	40.6	221.0	185.4	149.9	1049.0

Vegetation

Vegetation along the Delta and Tanana Rivers and Jarvis Creek near Big Delta and the FAA facilities consists primarily of lowland spruce-hardwood forests. Expanses of low-brush, treeless bog are to the east and west and alpine tundra occupies the northern flanks of the Alaska Range (Viereck and Little, 1972). Forested areas are characterized by an overstory of black and white spruce interspersed with paper birch, willows, and poplar trees, with an understory of Labrador tea, grasses, and sedges. Bog vegetation, common where conditions are too wet for tree growth, are made up of sphagnum moss and a variety of sedges and grasses. Alpine vegetation is composed of mountain hemlock, low mat-forming shrubs, deer cabbage, heather, lichen, berries, and willow.

Geology

Granodiorites and quartz monzonites are exposed in the southern part of the Delta-Clearwater area (Holmes and Péwé, 1965). These rocks are in intrusive contact with pelitic schist to the south and west (Holmes and Péwé, 1965). The crystalline bedrock in most of the area is overlain by thick surficial sediments. No bedrock exposures are near the FAA facility.

Coalescing alluvial fans composed of moderately well-sorted silt, sand, and gravel are the principal surficial deposits in the Big Delta area. The thickness of the unconsolidated materials is estimated to be as much as 760 m (Wilcox, 1980). Not all of this thickness is alluvium, however, because alluvial deposits are typically not deposited below sea level. It is likely that deep sediments in the area are poorly sorted lacustrine, glacial, or marine sediments of low permeability. The area was glaciated in at least three episodes, as evidenced by the presence of terminal moraines in the Delta and Gerstle River valleys and in the valleys of several small creeks draining the north face of the Alaska Range (Péwé and Holmes, 1964).

Soils

Schoephorster (1973) mapped the soils of the Big Delta area. Although the area of his mapping ends a few kilometers north and east of the FAA facilities near Fort Greely, existing air photos could, if necessary, be used to extend soil units into the area of the FAA facilities. Five major soil types exist in the Big Delta area: Salchaket, Jarvis, Nenana, Chena, and Tanana. Salchaket is a deep, somewhat poorly drained, fine sandy loam soil and is typically found on the alluvial plains and terraces of the Delta River. This soil forms in the overbank deposits of flowing water and is underlain by a stratum of gravelly cobble. Jarvis is also a very fine sandy silt loam. It is moderately deep (0.5 to 1.0 m) and is stratified over a gravelly substrate. This soil is found along Jarvis Creek and includes both loess and overbank flood deposits. Nenana silt loam is a sandy soil that typically forms in sand dunes occupying the site of former flood plains. Chena is a very fine soil occurring as a thin mantle of silt loam overlying a substratum of gravelly sand. This type of soil occupies nearly level terrain near Big Delta and is well drained. Tanana is a silt loam formed in local alluvial sediments and is poorly drained. This soil typically occurs in vegetated areas in the presence of permafrost.

The Big Delta FAA facility lies in the discontinuous permafrost zone (Ferrians, 1965). Near Fort Greely, 5 out of 14 wells reached permafrost (Wilcox, 1980). The depth of permafrost ranged from immediately below seasonally frozen ground to as much as 66 m below land surface (Wilcox, 1980). There is a noticeable absence of permafrost directly adjacent to and beneath the Delta and Gerstle Rivers and Jarvis Creek (Ferrians, 1965).

HYDROLOGY

Péwé (1955) discussed springs near Big Delta and the configuration of the water table beneath the outwash plain of the Delta River. Holmes and Benninghoff (1957) prepared a terrain study of the Army test area at Fort Greely, which included data on permafrost, ground water, climate, and streamflow of Jarvis Creek. Additional data on ground water, surface water, and water quality were published as part of an evaluation of the suitability of Fort Greely for disposal of radioactive waste (U.S. Army, Corps of Engineers, 1959). Waller and others (1961) mapped the potentiometric surface at Fort Greely, and Waller and Tolen (1962a, 1962b) reported data on springs along the Alaska and Richardson Highways. Péwé and Holmes (1964) published a geologic map of the Mount Hayes D-4 quadrangle that included some well data. The U.S. Geological Survey inventoried wells in the Big Delta, Delta Junction, and surrounding areas in 1965, and the data were used in part to describe hydrologic conditions in the Tanana River basin (Anderson, 1970).

Williams (1970) summarized ground-water and permafrost conditions in the area, and Dingman and others (1971) summarized the hydrology of the Delta River basin. A report on the irrigation potential of the Tanana River basin (Tanana Valley Irrigation Study Team, 1972) included information on ground-water in the Delta/Fort Greely area. Pearse (1974) reported on aspects of water quality and discharge of Clearwater Creek, a discharge boundary of the aquifer underlying Fort Greely and Delta Junction. Wilcox (1980) evaluated natural ground-water quality and defined the boundaries of the aquifer.

Surface Water

The Delta River and Jarvis Creek, the principal freshwater bodies near the FAA facilities at Big Delta, are glacier fed and have broad, braided channels. Both streams flow over permeable alluvial-fan deposits that permit a large quantity of the streamflow to infiltrate, resulting in decreasing streamflow in a downstream direction. Jarvis Creek ceases to flow at the Richardson Highway during the winter, although flow may persist throughout the winter farther upstream (Wilcox, 1980). U.S. Geological Survey stream-gaging stations have never been installed on Jarvis Creek and the Delta River; however, discharge measurements have been taken on numerous occasions and the results are summarized in table 2.

Table 2. Discharge measurements for the Delta River and Jarvis Creek near Delta Junction
[m^3/s, cubic meters per second]

Station	Date	Discharge (m^3/s)	Station	Date	Discharge (m^3/s)
Jarvis Creek at the Richardson Highway	07-23-48	16.0	Delta River, 3.0 km south of Big Delta	08-24-66	145.3
	09-18-48	3.2		10-19-66	0.7
	07-07-49	21.2		05-17-67	18.7
	05-21-55	4.9		06-14-67	220.3
	05-24-55	5.5		07-18-67	281.2
	06-07-55	8.1		09-14-67	79.9
	06-16-55	7.5			
	06-20-55	16.4			
	06-23-55	8.0			
	08-03-55	19.3			
	08-26-55	8.5			
	09-30-55	1.8			
	11-04-55	0			
	01-31-56	0			
	03-02-56	0			
	05-09-56	9.1			
	06-13-56	7.5			
	07-21-56	25.0			
	08-25-66	7.2			
	09-16-66	3.9			
	06-15-67	22.2			
	06-27-67	13.9			

Flooding

The Delta River occupies a broad flood plain containing numerous shallow, braided channels. The east bank of the river is higher than the west bank. The great expanse of flood plain and the low west bank create very low probabilities of overbank flooding to the east, where the Big Delta FAA facilities are situated. The principal risk to local communities is not from river flooding, but from lateral erosion of the east bank of the Delta River. The Federal Emergency Management Agency (FEMA) reported that numerous groins and bank-protection structures have been installed to prevent bank erosion in areas where homes, other structures, and roads may be threatened (FEMA, 1982). According to studies performed by the Alaska District Army Corps of Engineers, the 500-year flood would not flood the communities on the east side of the Delta River (FEMA, 1982).

Jarvis Creek flows out of the Granite Mountains to the south and has flooded local communities in years past. According to long-term residents of the area, past floodwaters entered an old stream channel approximately 9 km above the junction of Jarvis Creek and the Delta River. This old channel meanders through the community of Delta Junction and enters the Delta River approximately 3 km downstream from the mouth of Jarvis Creek. The U.S. Army placed a barrier at the overflow location after the flood of 1967, and since then, flooding along this old channel has not occurred (FEMA, 1982). Expected flood discharges from the Delta River and Jarvis Creek at Delta Junction are given in table 3 (FEMA, 1982).

Table 3. Expected flood discharges from streams at Delta Junction

Stream	Drainage area (square kilometers)	Expected flood discharge (cubic meters per second)			
		10 years	50 years	100 years	500 years
Delta River	4,242	480	935	1,200	1,900
Jarvis Creek	642	180	340	435	680

Flooding in the Big Delta area may also be caused by debris flows in the mountains, sudden failures of debris-flow dams, or spring breakup ice-jamming in local streams and rivers. However, it is not possible to attach probabilities to these types of flooding. Heavy precipitation and subsequent runoff commonly create local flooding, but a greater source of flooding in the Big Delta area is associated with winter overflow icings. In 1974, satellite images were used to identify an abandoned stream channel about 3 km east of Delta Junction (W.J. Stringer, T.H. George, and R.M. Bell, University of Alaska, Geophysical Institute, written commun., undated). This channel carried winter overflow water from a point on Jarvis Creek, about 18 km south of the Fort Greely airport, to an area 1.5 km west of Clearwater Lake.

Ground Water

The principal aquifer in the Big Delta area consists of the saturated parts of coalescing alluvial fans near the Delta and Gerstle Rivers, Jarvis Creek, and several smaller streams flowing from the Granite Mountain area, about 20 km southeast of the FAA facility (fig. 1). The aquifer is bounded on the south by crystalline bedrock of the Alaska Range, about 20 km south of the facility, and on the north by the Yukon-Tanana Upland, about 35 km north of the facility.

Ground water discharges into the lower Delta River, Tanana River, Clearwater Creek, and Clearwater Lake (fig. 1). The effects of local moraines, which are generally less permeable than alluvium, on ground-water flow is unknown. Previous water-table maps of Fort Greely indicate flow to the northeast (Waller and Feulner, 1959; Péwé, 1955). If this northeasterly flow persists throughout the year, then the moraines do not significantly impede the flow of ground water. During the summer, the water table rises more than 6 m in response to abundant recharge through the beds of Jarvis Creek, Sawmill Creek, Delta River, and other small tributaries. As these creeks cease to flow during the winter, the recharge ceases and the water table falls (Wilcox, 1980).

Locally, shallow permafrost causes poor drainage and wet soils. On a regional scale, however, permafrost is discontinuous and does not prevent ground-water recharge over significant areas (Ferrians, 1965). Under recharge areas of the alluvial fan complex, downward flow of ground water through multiple aquifers is common. A 167-m-deep well at the Gerstle River Test Site penetrated several aquifers perched on silt layers.

Specific-capacity tests, filed with the U.S. Geological Survey, were used to estimate aquifer transmissivity. These estimates, however, should not be considered definitive of the properties of the entire alluvial- fan aquifer system. The wells may test only small units of the system, in which case, they are not accurate predictors of overall actual transmissivity. Specific capacity tests may also be poor indicators of transmissivity in alluvial fan materials where "delayed drainage" is significant. Delayed drainage, the sluggish release of ground water during a test of an unconfined aquifer, causes drawdown responses that are not consistent with the mathematical assumptions of a typical specific yield. To reduce the effect of well design on specific-capacity data, only data for screened wells are included in table 4. The mean specific capacity for these wells is about 78 (L/s)/m of drawdown, which corresponds to a transmissivity of approximately 4,000 to 5,000 m^2/d.

Table 4. Aquifer-test information from wells on Ft. Greely

[m, meter; L/s, liter per second; (L/s)/m, liter per second per meter]

Ft. Greely well No.	Depth (m)	Length of screen (m)	Pumping rate (L/s)	Drawdown (m)	Specific capacity [(L/s)/m]
MW-64a	121	12	63	0.46	134
MW-8	120	12	63	.42	142
MW-9	83	9	63	.60	134
MW-10	91	9	95	5.49	17
MW-11	101	9	95	9.15	32
MW-12	84	9	95	2.43	190
LW-13	248	30	88	7.01	12
W-15b	50	3	28	.24	108

DRINKING WATER

Present Drinking-Water Sources

Most Big Delta, Delta Junction, and Fort Greely residents obtain their drinking water from wells. Most of the wells are privately owned and serve individual properties. There are no community water systems in Big Delta and Delta Junction. The water-supply system at Fort Greely, which serves both the military and the FAA facility, also obtains ground water from local wells.

Alternative Drinking-Water Sources

Alternative drinking-water sources in the Delta-Clearwater area include nearby surface-water sources and undiscovered aquifers. Surface-water bodies in the Fort Greely area are not viable alternatives. Streams often run dry in the winter and carry a high load of glacial silt during the summer. Treatment costs associated with the removal of glacial silt would likely be high.

The ground-water system near Big Delta has not been mapped in sufficient detail to define individual aquifers and confining units. It is likely that multiple aquifers exist, but the quality and quantity of these aquifers and their vulnerability to contamination is unknown. Some perched aquifers may go dry during the winter when recharge is reduced. Others may be highly permeable and susceptible to contamination during high pumping.

SUMMARY

Big Delta has a local population of 1,000 and a regional population of 5,000. Abundant drinking water exists in an alluvial aquifer underlying the city. The highly permeable alluvium may allow rapid infiltration of contaminants. However, alternative drinking-water sources may be available from nearby surface-water sources, from confined aquifers, or from wells drilled away from contaminated areas.

REFERENCES CITED

Alaska Department of Community and Regional Affairs, 1984, Community profile database—Big Delta, Alaska: Division of Municipal and Regional Assistance, variously paged.

Anderson, G.S., 1970, Hydrologic reconnaissance of the Tanana basin, central Alaska: U.S. Geological Survey Hydrologic Investigations Atlas HA-319, 4 sheets.

Dingman, S.L., Samide, H.R., Soboe, D.L., Lynch, M.J., and Slaughter, C.W., 1971, Hydrologic reconnaissance of the Delta River and its drainage basin, Alaska: U.S. Army Materiel Command Cold Regions Research and Engineering Laboratory Research Report 262, 83 p.

Ecology and Environment, Inc., 1992, Environmental compliance investigation report, Big Delta FAA station, Delta Junction, Alaska: [Copy available through the Environmental Compliance Section, AAL-465, Federal Aviation Administration, Alaska Regional Office, Anchorage, Alaska.]

Federal Emergency Management Agency, 1982, Flood insurance study—City of Delta Junction, Alaska: Southeast Fairbanks Division, 18 p.

Ferrians, O.J., Jr., 1965, Permafrost map of Alaska: U.S. Geological Survey Miscellaneous Geologic Investigations Map I-445, (reprinted 1981).

Holmes, G.W., and Benninghoff, W.S., 1957, Terrain study of the Army test area, Fort Greely, Alaska: Prepared by Military Geology Branch, U.S. Geological Survey, for U.S. Army Corps of Engineers, Waterways Experiment Station, Vicksburg, Mississippi, v. 1, 287 p.

Holmes, G.W., and Péwé, T.L., 1965, Geologic map of the Mount Hayes D-3 quadrangle, Alaska: U.S. Geological Survey Geologic Quadrangle Map GQ-366, 1 sheet.

Leslie, L.D., 1989, Alaska climate summaries (2d ed.): University of Alaska Anchorage, Arctic Environmental Information and Data Center, Alaska Climate Center Technical Note 5, variously paged.

Pearse, G.A., 1974, A study of a typical spring-fed stream of Alaska: Alaska Department of Fish and Game, Federal Aid in Fisheries Restoration Study QG-111, Job G-111-G, F-9-6.

Péwé, T.L., 1955, Middle Tanana Valley, *in* Hopkins, D.M., and others, Permafrost and ground water in Alaska: U.S. Geological Survey Professional Paper 264-F, p. 113-146.

Péwé, T.L., and Holmes, G.W., 1964, Geology of the Mount Hayes D-4 quadrangle, Alaska: U.S. Geological Survey Miscellaneous Geologic Investigations Map I-394, 2 sheets.

Selkregg, L., 1976, Alaska regional profiles—Yukon Region: Anchorage, University of Alaska, Arctic Environmental Information and Data Center, 346 p.

Schoephorster, D.B., 1973, Soil survey of Salcha-Big Delta area, Alaska: U.S. Department of Agriculture, Soil Conservation Survey, 51 p., 26 plates.

Tanana Valley Irrigation Study Team, 1972, Irrigation potentials, Tanana River Valley, Alaska: Report of Federal-State Study Team to the Fairbanks North Star Borough, 102 p.

U.S. Army Corps of Engineers, 1959, Evaluation data for liquid radioactive waste disposal -- SM-1A -- Army package power reactor, v. 1 and 2, Big Delta District: Anchorage, U.S. Army Corps of Engineers, Alaska District, variously paged.

Viereck, L.A, and Little, E.L., 1972, Alaska trees and shrubs: U.S. Department of Agriculture, Agriculture Handbook No. 410, 265 p.

Wahrhaftig.C., 1965, Physiographic divisions of Alaska: U.S. Geological Survey Professional Paper 482, 52 p.

Waller, R.M., and Feulner, A.J., 1959, Direction of ground-water movement at Fort Greely, Alaska, Inclusion No. 1 in U.S. Army Corps of Engineers, Evaluation data for liquid radioactive waste disposal -- SM-1A -- Army package power reactor, v. 2: Anchorage, U.S. Army Corps of Engineers, Alaska District.

Waller, R.M., Feulner, A.J., and Tisdel, F.E., 1961, Ground-water movement in the Fort Greely area, Alaska [abs.]: Geological Society of America Special Paper 68, p. 123.

Waller, R.M., and Tolen, D.A., 1962a, Data on wells and springs along the Richardson Highway (State 4), Alaska: U.S. Geological Survey Hydrological Data Report 16, 32 p.

_____1962b, Data on wells along the Alaska Highway (State 2), Alaska: U.S. Geological Survey Hydrological Data Report 18, 26 p.

Wilcox, D.E., 1980, Geohydrology of the Delta-Clearwater area, Alaska: U.S. Geological Survey Water-Resources Investigations 80-92, 26 p.

Williams, J.R., 1970, Ground water in the permafrost regions of Alaska: U.S. Geological Survey Professional Paper 696, 83 p.