# HYDROMETEOROLOGICAL LITERATURE REVIEW FOR THE DELTA-CLEARWATER CREEK AREA

Hydrometeoroloigical Literature Review for the Delta-Clearwater Creek Area
John D. Fox

Completion Report
State of Alaska
Department of Natural Resources
Reimbursable Service Agreement
Dated August 19, 1977

by

John D. Fox
Assistant Professor of
Land Resources

Institute of Water Resources
University of Alaska
Fairbanks, Alaska 99701

IWR No. 92

June, 1978

ACKNOWLEDGMENT

The author wishes to express appreciation to Margo Paine of the Alaska Division of Lands for her cooperation and patience; D. Wilcox and Gordon Nelson of the U. S. Geological Survey for their cooperation and informative conversations; Robert Van Veldhuizen who helped wade through the computer printouts.

This project and report were supported through a contract from the State of Alaska, Department of Natural Resources.

TABLE OF CONTENTS

## LIST OF FIGURES



## LIST OF TABLES

# INTRODUCTION

Phase One of this study consists of a search for existing hydrometeorological data or other information relevant to environmental baseline studies of the Delta-Clearwater Creek agricultural development project. A general summary of this literature search is presented below; a detailed annotated bibliography immediately follows the summary.

Phase Two consists initially of a preliminary analysis, based on existing information, of the local water budget, the groundwater regime, and the potential for transport of agricultural chemicals into the water system. Finally, evaluation and comments on the adequacy or sufficiency of existing data and recommendation for future work are made. Selected charts, diagrams, or tables of data have been included in the text where such information is relevant, but not voluminous.

# SECTION 1
# LITERATURE SEARCH

## BRIEF SUMMARY OF LITERATURE SEARCH

### Meteorological/Climatological Data

The search for hydrometeorological data for the Delta-Clearwater area revealed considerably more data than were expected with respect to meteorological or climatological parameters. Thirty-seven years (1942-present) of daily precipitation and maximum-minimum temperatures are available for the Big Delta airport-Fort Greely area. For seven years previous to this record (1935-1942), data were recorded at Richardson, some 25 miles north of Delta Junction near Banner Creek. In addition, since August of 1958, daily precipitation and maximum-minimum temperatures have been recorded in the immediate vicinity of Clearwater Creek.

Hourly weather observations are also available for the Fort Greely area, both from the Big Delta (FAA) site and the Fort Greely Central Meteorological Observatory for 1968 and 1967 respectively to the present. Data collected at the latter station include that on precipitation, station pressure, temperature, wind direction and speed, snow/soil temperatures, temperature gradients, and solar and net radiation. Data collected at the former station include information on sky cover and dew-point temperatures, and, except for years 1968-1972 are in an unpublished format. Data from the Fort Greely CMO are much more readable and convenient to use.

In addition to these regularly published or recorded data compilations, several summaries analyses have been published (Bilello, 1974; dePercin et al., 1955; Ehrlich, 1953; Feyerhern et al, n.d.; Mitchell, 1956; TVIST, 1972; Sands et al., 1972). Of particular interest is the report by Feyerhern et al. which presents the probabilities of sequence of wet and dry days in Alaska for the Big Delta station.

### Hydrologic Data--Surface Quality and Quantity

The abundance of information on the input to the hydrologic system in the Delta area unfortunately is not matched by data on surface outputs. Other than regular streamflow measurements on the Tanana and irregular measurements for the Delta, Gerstle, and Tanana Rivers (Hulsing, 1978) few actual measurements have been made on the Clearwater and its apparent tributaries. Pearse (1974) reports a discharge measurement of 710 ft$^3$/sec on the Clearwater in June, 1973. Recently, USGS personnel has been measuring gage height and making periodic discharge measurements (Hulsing, 1978; Wilcox, 1978, personal communication). The more recent measurements fall within a range of 600-700 ft$^3$/sec.

Reports on the occurrence or nonoccurrence of small streams shown as tributaries to Clearwater Creek on USGS topographic maps (1:63000) document the difficulty of establishing the regime of influent, intermittent, or ephemeral streams. Hulsing (1978) reports observing these streams leaving the Alaska Range at less than 10 ft$^3$/sec and disappearing into the alluvial fan deposits a short distance beyond the base of the mountain. Several geologic reports of this region allude to this phenomenon as characteristic. Yarborough (1975) refers to these streams in the vicinity of the Alaska Highway as having flooded in past years and states that photographs exist showing water in these channels at the highway. Long's (1977) field reconnaissance of the area north of the Alaska Highway indicates no indications whatsoever of channels flowing to the Clearwater with the exception of Sawmill Creek. Although the channel was evident, no water was flowing at the time of Long's observations.

Appended to Hulsing's report is a summary of field data collected in August and September of 1977 giving measured flows for Sawmill Creek, 3.0 mi and 0.2 mi above Granite Creek, at 50 cfs (3.0 mi) and 208 cfs (0.2 mi) respectively; Granite Creek 0.1 mi above Sawmill Creek at 51 cfs; and Clearwater Creek 0.1 mi above Sawmill Creek and at gage, at 135 cfs and 753 cfs respectively. Discharge at the outlet of Clearwater Lake was measured at 463 cfs.

Water-quality data for the area streams is also sparse. Some data exist for the larger rivers and are published by the USGS. Little specific information exists for the Clearwater Creek itself on the influent streams of the Granite Mountains. Lotspeich (1978) and Pearse (1974) present some limited data which indicate the Clearwater to have a relatively high pH (8.5) and conductivity (300-350 μmhos). Data collected by USGS in the late summer of 1977 included Sawmill Creek, at two locations above Granite Creek; Granite Creek, above confluence with

Sawmill; Clearwater Creek; and Clearwater Lake outlet. The data for Clearwater Creek appear comparable to those of Lotspeich except pH readings are generally lower (ie. 7.4-7.7).

Sands (1971) states that chemical testing took place at the Gerstle River Test Site. This 19,000-acre site includes portions of Sawmill Creek and surrounding land. To date, no specific information on chemical tests has been found. Conversations with past personnel at Fort Greely imply that such information, if it existed, would be classified.

Hydrologic Data--Groundwater

Few actual measurements relevant to the groundwater regime in this area have been found. Reports by Waller and Tolen (1962a and b) include some water-level data and well-log information, and some discussion and interpretation of these data are available. Additional relevant information is currently being obtained by the local USGS staff. There is preliminary evidence that recharge to the Clearwater aquifer may come from the Delta River to the west and the Tanana-Gerstle Rivers to the north and east (Waller and Tolen, 1962a and b; Wilcox, 1978, personal communication) as well as from the influent stream of the Granite Mountains.

Hulsing (1978) reports sinusoidal fluctuation in the static water level as demonstrated in a well at Fort Greely which reaches a low in spring and a peak in fall with overall fluctuation in the range of 18 ft.

Well logs of three wells drilled recently by the Alaska Division of Lands in the vicinity of the 2000-acre test clearing site indicate possible locally confined conditions. Data currently being taken by the USGS staff also indicate possible confined conditions (Wilcox, 1978, personal communication).

Williams (1970) has analyzed well data and permafrost occurrence in the Fort Greely area and concludes that permafrost in that area does not represent a confining layer for the aquifer.

Péwé (1955) refers to the general depth of the water table increasing at a rate of 15 feet per mile upslope from Big Delta.

## ANNOTATED BIBLIOGRAPHY

Anderson, G. S. 1970. Hydrologic reconnaissance of the Tanana Basin, Central Alaska. USGS Hydrologic Investigations Atlas, HA-319.

Series of large maps and diagrams depicting the general setting, hydrology, and water quality of the Tanana River basin as determined from available records. Accompanying text provides a good general description of the hydrology of the Tanana basin; however, it is too general for site-specific purposes.

Balding, G. O. 1976. Alaska water assessment: Water availability, quality, and use in Alaska. Open file report 76-513, USGS, 236 pp.

Includes compilation and summary of surface and groundwater availability and quality in the Tanana subarea of the Yukon subregion of Alaska. Data presented on area-wide maps. Resolution is poor; provides little site-specific information.

Benson, C. S. 1972. Physical properties of the snow cover in the Ft. Greely area, Alaska. U. S. Army Corps of Engineers, CRREL, Special Report 178, Hanover, New Hampshire. 25 pp.

Report of measurements of physical properties of snow including snow depth, density, temperature with depth, structure and texture classification by depth, and gain hardness. The wide variety of snow types found in the Ft. Greely area is noted and interpretations with respect to trafficability are made.

Berwick, V. K. 1964. Magnitude and frequency of floods in Alaska, south of the Yukon River. USGS circular 493. 15 pp.

Report is concerned with a method of evaluating the magnitude and frequency of floods on the basis of flood record analysis. The magnitude of the mean annual flood is related to drainage area size. Little direct relevance except for Tanana River at Big Delta. Maximum stage is reported as 23.57 feet (62,800 cfs) July 29, 1959. Mean annual flood flow is 43,500 cfs.

Bilello, M. A. 1974. Air masses, fronts, and winter precipitation in central Alaska. U. S. Army Corps of Engineers, CRREL Research Report 319, Hanover, New Hampshire. 51 pp.

Discusses the physical, meteorological, and climatological aspects of freezing precipitation in the Tanana River Basin. Winter periods of inclement weather are evaluated with respect to frequency and duration, together with concurrent temperature, wind, atmospheric pressure, and visibility conditions. Hourly data from the Big Delta airport were used in this study.

Childers, J. M. 1970. Flood frequency in Alaska. USGS open-file report, Alaska district. 30 pp.

Results of regional flood frequency analysis for Alaska based on regional regressions. Standard errors of estimates are 53-80%

de Percin, F., S. Falkowski, R. C. Miller. 1955. Handbook of Big Delta, Alaska, Environment. Headquarters Quartermaster Research and Development Command, U. S. Army, Environmental Protection Div., Technical Report EP-5. 57 pp.

Interesting summary and analysis of early meteorological observation in the Big Delta area. Data on extreme temperature frequencies by month; precipitation regime and frequency by month; snowfall, sky cover, percentage occurrence of wind speed by groups, wind chill, temperature, windspeed, and surface wind roses by month.

Dingman, S. L., H. R. Sarnide, D. C. Saboe, M. J. Linch, and C. W. Slaughter. 1971. Hydrologic reconnaissance of the Delta River and its drainage basin, Alaska. U. S. Army CRREL, Research Report 262. 83 pp.

Discussions of regional setting, climate, and water balance are relevant to the Delta-Clearwater study area. An estimation is made of hydraulic conductivity of aquifer and groundwater contributions

to winter flow of the Tanana. Precipitation versus elevation data are presented as well as an estimation of the water balance for the Delta River drainage basin.

Ehrlich, A. 1953. Note on local winds near Big Delta, Alaska. Bulletin Amer. Meteorological Soc. 34(4):181-182.

Reports on the occurrence of surface "jet stream"-like pattern of strong winds in the Big Delta area sweeping across the Tanana lowlands south of Fairbanks in the direction of Nenana. The author classifies strong winds at Big Delta as either east-southeast winds or south-southeast winds. The former are frequent during the fall, winter, and spring. Air reconnaissance during a period of winds gusting up to 75 knots at Big Delta revealed that over Big Delta the strong wind current did not exceed 5 miles in width nor 3000 ft. in height. South-southeast winds occur during any season but especially during spring, summer, and fall. Winds are not as strong as previous case, seldom exceeding 50 knots.

Feyerherm, A. M., L. D. Bark, and W. C. Burrows (n.d.) Probabilities of sequences of wet and dry days in Alaska. North Central Regional Research Pub. 161; Kansas Tech. Bull. 139c. Agricultural Experiment Station, Kansas State Univ. of Agricultural and Applied Science. Manhattan, Kansas. 55 pp.

Presents probabilities that a given day will be wet or dry at Big Delta and the probability that a given wet (or dry) day will be followed by a wet (or dry) day. Tables are presented for "wet days" of at least .01 in, .10 in, .20 in, and .50 inches of precipitation. From such tables, the following information can be obtained: 1) probability a given day of the year will be dry (wet); 2) probability a given sequence of wet and/or dry days will occur at a particular time of year; 3) probability that a given number of days will be wet (dry) in a particular sequence of days. Authors suggest relevance of such information to: 1) field drying of hay; 2) germination of seeds; 3) disease susceptibility in periods of plant growth; 4) applying fertilizer; 5) applying

insecticides and herbicides; 6) time necessary to complete construction projects; 7) planning outdoor community activities. Some examples are provided. This report is available in the University of Alaska library.

Holmes, G. W. 1965. Geologic reconnaissance along the Alaska Highway, Delta River to Tok Junction, Alaska. USGS Bulletin 1181-H. 19 pp.

Contains reconnaissance information on surficial geology and geologic history of the Delta Clearwater area adjacent to the Alaska Highway. An excellent map accompanies the report showing the proposed agricultural area as composed of fan-apron and alluvial-fan gravel deposits from the highway to 2-4 miles north toward Clearwater Creek. These deposits are succeeded northward to Clearwater Creek by Pleistocene and recent stream terrace deposits of mostly silt and sand.

Hulsing, H. 1977. A letter report to Margo Payne, ADL, of hydrologic information collected in the Delta Clearwater study area prior to October 1, 1977. Dated October 7, 1977.

Refers to measured flows in Jarvis Creek, Tanana River, Delta River and the Gerstle River. Of particular interest are aerial observations of Rhoads, Hajdukovich, Sawmill, Granite, and two unnamed creeks flowing from the Alaska Range in August of 1977. Flows were estimated at less than 10 cfs in each stream. These streams were observed to be influent, losing all of their flow a short distance from the base of the Granite Mountains. No flow was observed crossing the Alaska Highway. The letter also reports a gradual gage-height rise of 0.2 ft in Clearwater Creek over a period from May to September 1977. Periodic heavy rains during the summer had little effect on the gage-height reading. In July 1977, a discharge of 727 $ft^3$/sec was measured while in September 753 $ft^3$/sec was measured. This increase in flow represents an increase in gage-height of 0.07 feet. The USGS also has record of static water level in an observation well at Fort Greely from 1965-1975. The record shows a yearly sinusoidal rise and fall of approximately 18 ft/yr. The level is lowest in June and highest in fall.

Long, W. 1977. Channels and water in Delta agricultural area. Alaska Department of Natural Resources, Division of Geological and Geophysical Surveys. Memorandum, August 24, 1977.

This is a report of field investigations of small channels indicated on topographic maps as tributary to Clearwater Creek. Channel and stream studies were primarily conducted in the area northeast of the Alaska Highway and southwest of Clearwater Creek. The author states "traverses through the area across the mapped stream courses failed to show any topographical, erosional, depositional, or other evidence of the presence of a stream." Mr. Long concludes that the only stream within the agricultural area is Sawmill Creek and that other small streams shown on the USGS map of the area are not present. He notes that the map was not field checked.

Lotspeich, F. B. 1978. Interaction of proposed agricultural development with Delta Clearwater Creek, Alaska. Manuscript submitted to Alaska Division of Lands for review. 12 pp.

This paper presents a preliminary analysis of possible interactions between agricultural development and the Delta-Clearwater Creek. Of particular significance is the inclusion of previously unpublished water quality information gathered by the author during July, 1970. Higher conductivity and lower pH distinguished this spring-fed stream from two mountain-fed streams of the Tanana uplands. Water quality of the Richardson Clearwater Creek was found comparable to the Delta Clearwater Creek and the author suggests using the former as a reference control stream as agricultural development progresses. General description of the soil resource is given and a discussion of possible problems associated with excessive fertilization and irrigation. The average available water capacity of the soils is cited as 0.21 in/in or 2.52 in/ft.

Using values of 400 cfs for flow in Clearwater Creek, 1 ac-ft for irrigation, and 73,000 acres, the author calculates the annual flow of the Clearwater might be reduced by 25%. If a more realistic figure of 4 ac/in of irrigation is used, only 8% of the Clearwater flow would be needed. Finally, assuming 60 #/ac of nitrogen is applied and diluted by the total volume of discharge from Clearwater Creek, Lotspeich calculates a concentration of 5.4 ppm of nitrogen in the stream. This is assuming all nitrogen reaches the stream which would certainly not be the case. The author states that under "well-established, accepted practics, no nitrogen from fertilizers should reach the aquifer."

Mitchell, J. M., Jr. 1956. Strong surface winds at Big Delta, Alaska. Monthly Weather Review, Jan., 1956. pp. 15-24.

This report is a good follow-up to Ehrlich, 1953. Strong surface winds at Big Delta, Alaska, were studied with respect to cause, characteristics, and local effects. A distinction between the strong winter east-southeast winds and strong south winds experienced year around is made. An extreme case of the characteristically persistent east-southeast winds is described in which gusts in excess of 40 mph continued for 7½ days (January 20-28, 1952). Monthly wind roses for Big Delta based on records from July 1942 to August 1948 are presented. The author comments that the southerly wind current seldom passes directly over Big Delta, but moves out into the Tanana Plains at a point lying to the west of Big Delta. The author hypothesizes that the recorded strong southerly winds at Big Delta are caused by föhn-type flow of air directly over the Alaska Range "along with or instead of, the current of air passing through the Delta River Valley." Histograms of duration of strong winds at Big Delta during the period October-March are presented.

Moffit, F. H. 1942. Geology of the Gerstle River District, Alaska. USGS Bulletin 926-B. U. S. Government Printing Office, Washington. pp. 107-160.

The study area lies between the Alaska Range Crest and the Tanana River, extending eastward from Delta River to the Johnson River. Three topographical districts are distinguished: high rugged mountains; highland areas, smooth topped hills, and gently sloping surfaces deeply trenched by valleys of glacial streams; and lowlands of Tanana Valley, flat country, no relief, and "underlain by outwash gravel from the glaciers and by stream deposits."

Patric, J. H., and P. E. Black. 1968. Potential evapotranspiration and climate in Alaska by Thornthwaites classification. USDA, Forest Serivce Research Report PNW-71.

Calculates potential evapotransiration by the Thornthwaite method for a number of locations throughout Alaska. Calculations based on Thornthwaite's and Penman's methods are compared to monthly pan evaporation at Fairbanks.

Pease, G. A. 1974. A study of a typical spring-fed stream of interior Alaska. Alaska Department of Fish and Game, Fed. Aid in Fish. Rest. Study G-111, Job G-111-G, F-9-6.

This report on fisheries contains some water quality data for the period October 1972 to November 1973. He gives 350 $mi^2$ as the drainage area of Delta Clearwater and reports a discharge of 710 cfs in June of 1973.

Péwé, T. L. 1951. An observation on wind-blown silt. Jour. Geol. 59:399-401.

This is a report of an observation of silt being picked up from the Tanana River floodplain, raised some 4000 ft above the ground, and suspended over an area of about 300 sq. mi. These observations were made on the afternoon of August 20, 1949, under a southeast 30 mph wind. Particle size analysis of silt from Big Delta, Alaska, is included in the report.

Péwé, T. L. 1975. Middle Tanana Valley. IN: Shorter Contributions to General Geology; Permafrost and Ground Water in Alaska. USGS Professional Paper 264-F. pp. 126-130.

In general discussion of groundwater in gravel outwash plains of the Tanana Valley the author refers to ground water springs at the north end of the outwash plain near Big Delta. "Depth to water increases upslope at a rate of 15 feet per mile to as much as 200 feet, halfway up the outwash plain...."

Reiger, D. 1978. Personal Communication.

Mr. Reiger is a geologist-geomorphologist with the Alaska Geological and Geophysical Survey division of the Department of Natural Resources. He has reviewed detailed geophysical information for the Mt. Hayes A-4 quadrangle and was able to provide estimates of the bedrock surface depth and configurations. Information provided is presented in the appendix to this report.

Sands, R. D., H. L. Ohman, and F. J. Sanger. 1971. Environmental guide for arctic testing activities at Fort Greely, Alaska. U. S. Army Technical Report 70-54-ES, series ES-69, Earth Science Lab., Natick, Mass. 83 pp.

The physical environment of the Fort Greely area is discussed and evaluated with special reference to U. S. Army testing activities. The report is in some respect an update of the one prepared by de Percin et al., 1955. However, some data analyses are included that were not presented in the earlier report. One such analysis involves departures in winter temperatures at 23 temperature stations from that of the reference station at Ft. Greely. Two figures are

presented depicting surface wind patterns in the vicinity of Fort Greely. One illustrates the influence of terrain on surface wind direction while the other is a combined surface wind rose for Big Delta, Alaska, for the months of December, January, and February. During this period, winds from the east-southeast persist 36% of the time. Although the Clearwater area is not mentioned in the test, the diagram of terrain effects on wind indicate a probable easterly flow in that area. Diagrams are reproduced in appendix. Of additional significance, this report depicts the location and size of the Gerstle River chemical test site. Sawmill Creek, the major, yet intermittent, tributary to Clearwater Creek, flows directly through the test area. The location map is included in the appendix. This site was used "to conduct tests of chemical equipment and material, including incendiaries and demolitions. The 19,000-acre area includes a gas chamber, toxic agent yard, and four cleared grid stages."

Searby, H. S., and C. I. Branton. 1973. Climatic conditions in agricultural areas in Alaska. IN: Weller and Bowling (eds.) Climate of the Arctic, 24th Ak. Sci. Conf., Geophysical Institute, Fairbanks, Alaska. pp 281-292.

This is a rather general report which includes information on freedom from frost, growing degree-days, and length of growing season for various locations including the Clearwater area. Of interest is the comment that there are discrepencies in the Big Delta temperature data reducing the number of days of summer frost. The authors conclude that the Clearwater data are more representative. Based on temperature data, the Clearwater was found to be the area least suitable for crop growth of those studied in the Tanana Valley.

Stringer, W. J., T. H. George, R. M. Bell. 1978. Identification of flood hazard resulting from aufeis formation in an interior Alaskan stream. Report prepared for U. S. Soil Conservation Service. 7 pp., illustrated.

This publication reports use of LANDSAT data to document flooding due to aufeis formation on Jarvis Creek near Delta Junction, Alaska. Flooding was mapped by color reconstruction of multispectral imagery and transferred to standard USGS inch-to-the-mile map. The flood channel flowed northwest along the west side of a ridge (moraine) separating the Clearwater Creek topographic drainage area from that of Jarvis Creek and the Delta River. Although the processed image in this report includes little of the proposed agricultural area, it appears feasible that such imagery, if available for a number of years, might be very useful in isolating ponded water and runoff channels from fields and roads during spring breakup or heavy rainfall. Although the existence and location of flooded fields may be obvious to the farm operator, the scale of the imagery would serve state and local interests in tracing the fate of agricultural runoff with reference to Clearwater Creek. Since adequate photo coverage is not ensured by satellite, I would suggest looking into the feasibility of contracting for aerial photos during the peak of spring breakup using near-infrared and/or standard films.

Tanana Valley Irrigation Study Team. 1972. Irrigation potentials, Tanana River Valley, Alaska. Report of a federal-state study team to the Fairbanks North Star Borough. 102 pp.

This study, performed by joint federal-state-university study team, includes detailed description of Clearwater Creek area. Report discusses topics including: economy of Tanana Valley; agricultural potential; land and water resources (section specifically relevant to Delta-Clearwater); irrigation and drainage needs; sample irrigation plans and cost estimate; OHM, Inc. case study; economics and financial analysis. Details are given as a "supporting report."

U. S. Army Electronics Command. 1977. Atmospheric Sciences Laboratory Meteorological Team Data, Fort Greely, Alaska. Central Meteorological Observatory. Meteorological Support Technical Area, White Sands Missile Range, New Mexico.

These are monthly compilations of meteorological data taken at Fort Greely, Alaska. Included are tabulations of hourly precipitation, station pressure, temperature, wind direction and speed, snow/soil temperature, temperature gradient, ozone, radiation (vertical Eppley, net, and total hemispheric). In addition, wind roses, hourly averages for the month for all of the above, and a monthly period from 1967 to July 1977 at the University of Alaska Geophysical Institute library. Additional locations are included in the report distribution list.

U. S. Department of Commerce. (Published Monthly). Local Climatological Data for Big Delta. National Oceanic and Atmospheric Administration, Environmental Data Service, National Climatic Center, Asheville, NC.

These monthly reports contain hourly weather observations for particular stations and are available for Big Delta from 1968-1972. These can be obtained from AEIDC in Anchorage on microfiche or paper copies at cost or directly from the National Climatic Data Center, Asheville, NC. Hourly surface weather observations have been taken at Big Delta since 1942 and are available for the period 1942 to present from the National Climatic Data Center, Asheville, North Carolina.

U. S. Department of Commerce. (Published Monthly). Climatological Data for Alaska. National Oceanic and Atmospheric Administration, Environmental Data Service, National Climatic Center, Asheville, NC.

Each monthly report contains daily data for several locations in Alaska. Two stations currently report in the Delta-Clearwater area and another was discontinued. Big Delta FAA Station ([index No. 0781] lat. 64°00', long. 145°44', elevation =1268 feet.) was started in 1942 and is currently active. Clearwater Station ([index No. 2019] lat. 64°03', long. 145°31', elevation =1100 feet) was started in August of 1958. Loretta Nistler is the observer (currently active). Richardson Station (lat. 64°17', long. 146°21', elevation =875 feet) started November, 1935, and ended September, 1942. Data reported for these stations include daily precipitation and daily max-min temperatures. Supplemental data on average wind speed and direction and relative humidity are available for some periods and are included in the monthly reports. These data are readily available in most libraries, including University of Alaska Fairbanks, or from the National Climatic Center at Asheville, NC.

Waller, R. M., and D. A. Tolen. 1962a. Data on wells along the Alaska Highway (State 2), Alaska. State of Alaska, Department of Health and Welfare, Report AS 18. 25 pp.

A tabulation of 70 wells gives data on location, topographic situation, depth and diameter of wells, water levels, and use of each well. Thirty-five well logs and eight chemical analyses of well water are given. Data on three to five wells reported may be relevent to the Clearwater area. One chemical analysis of a well at Clearwater Ranch.

Waller, R. M., and D. A. Tolen. 1962b. Data on wells and springs along the Richardson Highway (State 4) Alaska. State of Alaska, Department of Health and Welfare, Report No. 16. 32 pp.

Tabulation of 110 wells, test holes, and springs gives data on depth and channels of wells, water levels, and use of groundwater. Thirty well logs and twenty chemical analyses of well and spring water are given. Approximately 43 entries in the tables are potentially relevant to the Delta area.

Wallis, A. L. 1977. Comparative Climatic Data through 1976. U. S. Department of Commerce, NOAA-EDS, Asheville, NC.

Presents tables of meteorological elements at approximately 300 locations across the United States. Included are data for Big Delta, Alaska, by month, for highest and lowest temperature of record; mean number of days with minimum temperature ≤32°F; mean number of days with precipitation ≥0.01 inch; average total snowfall in inches; average wind speed (mph); maximum wind speed (mph) and direction of maximum speed; mean cloudiness number of days clear, partly cloudy, cloudy; average % relative humidity morning and afternoon; normal daily maximum, minimum, and mean temperatures; normal heating degree days; normal cooling degree days; normal inches precipitation.

Williams, J. R. 1970. Ground water in the permafrost regions of Alaska. USGS Professional Paper 696. U. S. Government Printing Office, Washington. 83 pp.

Extensive report of the relationship between groundwater and permafrost in Alaska. Discusses definition, origin, distribution, and local configuration of permafrost; effects of permafrost on recharge, movement, discharge, and storage of ground water; and regional occurrence of groundwater in Alaska. Discussions of groundwater occurrence in alluvial fans of the Tanana River Valley are particularly relevant. Specific reference to the Fort Greely-Delta Junction-Clearwater area is made. Details are discussed in the text of this report.

Yarborough, L. F. 1975. Flood history of the Delta study area. A report prepared for USDA Soil Conservation Service. 14 pp. plus appendix.

Interesting report based on interviews with local residents, historic records, and personal observation of the author. Unfortunately, it is difficult to identify the source of specific bits of information as presented in the report. A number of observations mentioned in the report have direct bearing on the hydrologic interpretation of the area. Of particular note is mention of the Goodpaster Flats are becoming "marshier than usual" when the Tanana is high "...even to the extent that fish may enter Voknar Lake

from the Tanana...." Also of interest is mention of drainage flowing into Clearwater Lake and Clearwater Creek, frequently causing an overflow during periods of heavy rain. The author mentions that pictures are available of the small creeks shown on USGS maps "when they have been flowing and flooding." The author also reports taking pictures of flow in Sawmill Creek on August 29, 1975, at the Alcan Highway. Discussion of "Granite Creek" and "Rhoads Creek" indicates historic flooding (years not specified) of possibly poorly defined channels.

## APPENDIX TO SECTION 1

### Report of Personal Communication with Richard Reiger, May 1978

A survey of detailed geophysical information for Mt. Hayes A-4 quadrangle provides estimates of the bedrock surface depth and configuration:

1. Gravity study indicates that Bluff Cabin ridge is joined by a buried ridge to Fourmile Hill, and a buried ridge continues westward from Fourmile Hill bending northwest.
2. Immediately south of the TAPS crossing of the Tanana River, weathered bedrock was obtained in a boring at 72 feet. In section 21 (T9S, R10E) bedrock was not encountered to depths of slightly over 50 feet.
3. Depth estimates to magnetic sources (bedrock) are probably accurate to ±20%.

   Beneath the Goodpaster Flats the depth of bedrock is about 1500 feet.

   Between the Delta River and Clearwater Lake the depth is 2600±200 feet.

   South of Clearwater Lake area the thickness of sediments is consistently about 2500 feet.

   Two relatively shallow areas of buried bedrock are:

   a. North of Sections 22 and 14 (T9S, R10E) 800'-1000'
   b. Section 8 (T9S, R10E) 600'

## SECTION 2
## PRELIMINARY ANALYSES

### LOCAL WATER BALANCE

Two types of water-balance calculations were made as part of this analysis. The first was a basin-wide water balance for the topographic watershed of Clearwater Creek. The second was a water balance of a hypothetical crop grown in the vicinity of Clearwater Creek.

#### Watershed Water Balance

The topographic watershed of Clearwater Creek was subdivided into four elevation zones with calculations performed for each zone to allow for decreasing temperature and increasing precipitation with elevation (Dingman et al., 1971). Two years of data were used to simulate conditions of a relatively "dry" growing season. Daily precipitation and maximum-minimum temperatures from the Clearwater station for water year 1973 (October 1972-September 1973) were used as the "normal year." Similar data from the Big Delta (FAA) station for water year 1958 were used as the "dry" year. The technique used is a computerized water accounting model described in detail by Fox (1976). A general flow diagram of the processes included in the model is presented in Figure 1. Major descriptive parameters of each elevation zone, including area, slope, elevation, azimuth, and per cent forest cover, were estimated from topographic maps of the area, while estimates of soil properties were obtained from the Salcha-Big Delta area soil survey (Schoephorster, 1973). Daily potential evapotranspiration was calculated by the model using estimates of net radiation.

Initial results using this approach resulted in excessive seasonal fluctuations of the total basin outflow. This occurred because the model simply adds channel flow from each elevation zone to obtain total basin outflow. Thus, there is no opportunity for water flowing out of the upper elevation zones to reinfiltrate as it flows through the lower elevation zones as is the case in the Clearwater basin. This problem was overcome by treating the upper two elevation zones (i.e. above 1500 ft. elevation) and the lower two elevation zones as separate watersheds.

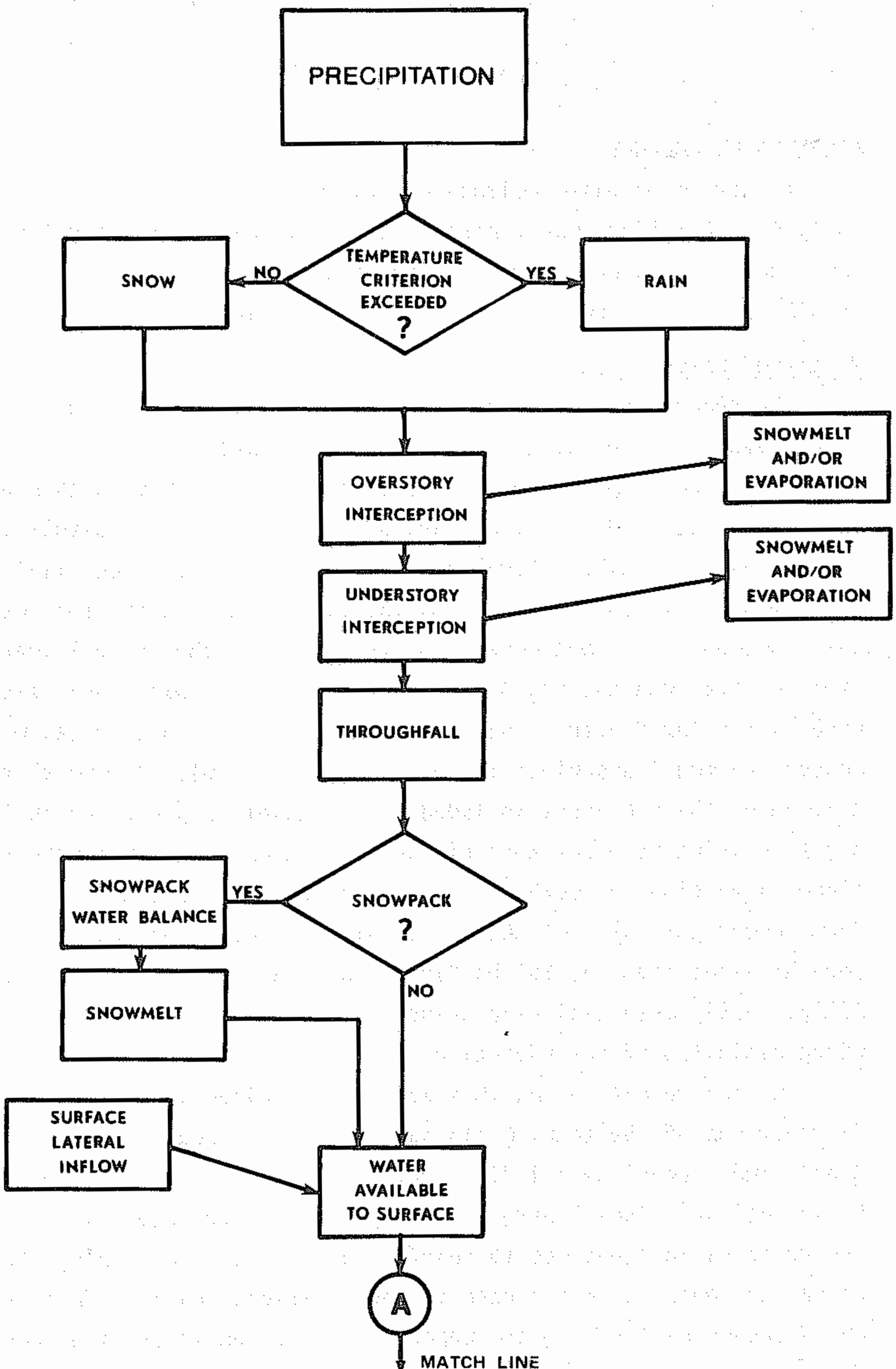
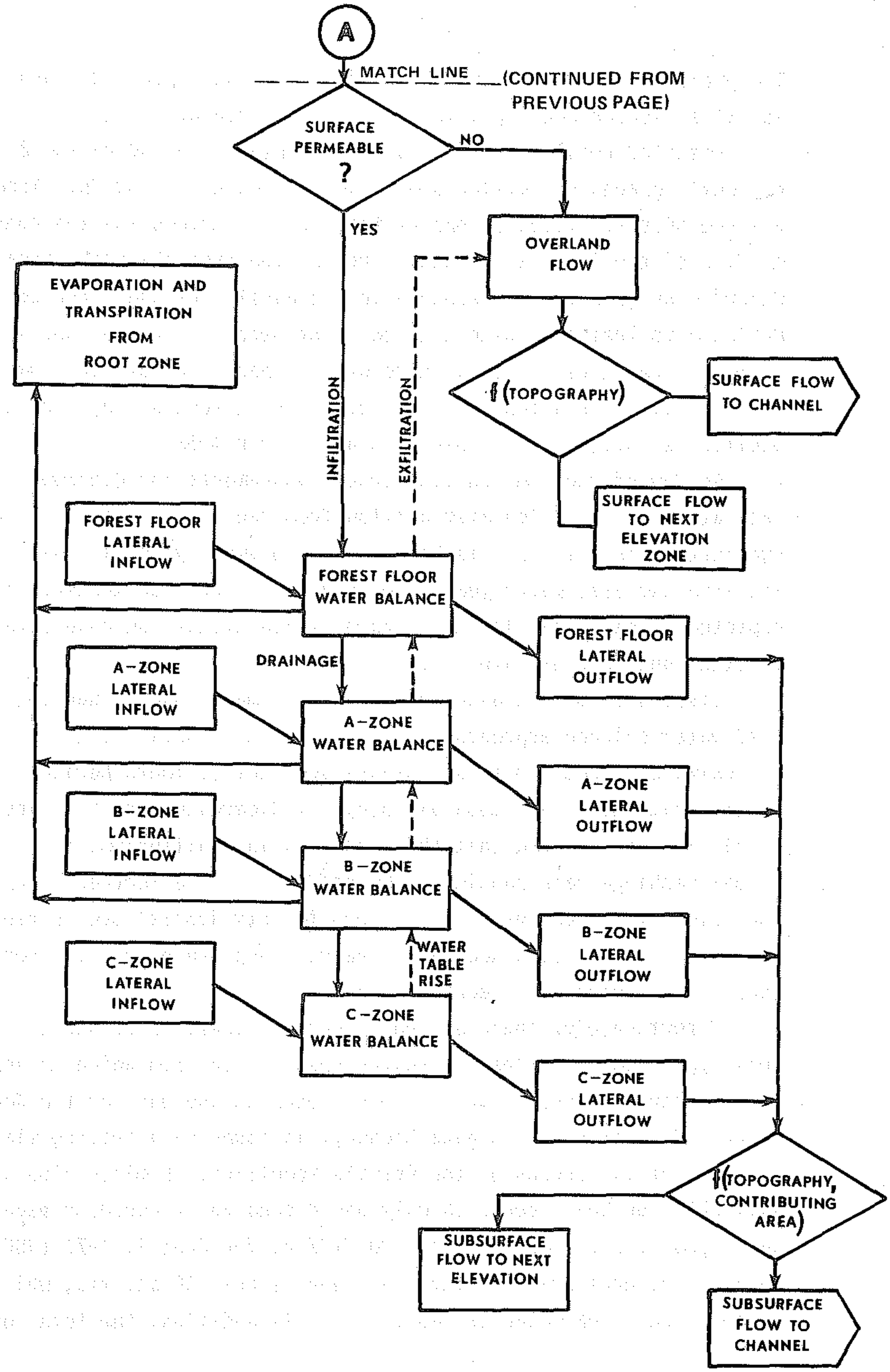



FIGURE 1: FLOW CHART OF PROCESSES CONSIDERED BY THE WATER BALANCE MODEL USED IN THIS STUDY. (AFTER FOX, 1976)


A
MATCH LINE
(CONTINUED FROM PREVIOUS PAGE)
SURFACE PERMEABLE ?
NO
YES
OVERLAND FLOW
EVAPORATION AND TRANSPIRATION FROM ROOT ZONE
f (TOPOGRAPHY)
SURFACE FLOW TO CHANNEL
INFILTRATION
EXFILTRATION
SURFACE FLOW TO NEXT ELEVATION ZONE
FOREST FLOOR LATERAL INFLOW
FOREST FLOOR WATER BALANCE
FOREST FLOOR LATERAL OUTFLOW
DRAINAGE
A-ZONE LATERAL INFLOW
A-ZONE WATER BALANCE
A-ZONE LATERAL OUTFLOW
B-ZONE LATERAL INFLOW
B-ZONE WATER BALANCE
B-ZONE LATERAL OUTFLOW
WATER TABLE RISE
C-ZONE LATERAL INFLOW
C-ZONE WATER BALANCE
C-ZONE LATERAL OUTFLOW
f (TOPOGRAPHY, CONTRIBUTING AREA)
SUBSURFACE FLOW TO NEXT ELEVATION
SUBSURFACE FLOW TO CHANNEL

The procedure was to obtain the outflow for the upper watershed and then add it as subsurface input to the lower watershed.

Detailed results are presented in Tables 1 (a and b) and 2 (a and b), while graphs of outflow are found in Figures 2a and 2b. Note the extreme seasonal fluctuations of the upper watershed and the constant outflow of the lower watershed. The outflow from the upper area can be regarded as groundwater recharge to the aquifer of the lower zone. Notice also that even with a 23 per cent decrease in the annual recharge from the mountains in 1958, there was no change in outflow from the lower zone. This situation must result in a decrease in storage in the aquifer as indicated in Table 1 (a and b) for 1958.

Review of the limited-discharge measurements for Clearwater Creek indicate that the calculated outflow from the lower watershed probably underestimates the mean discharge by approximately 200 $ft^3$/sec. In both the 1958 and 1973 water years, monthly flows were constant--as might be expected. Again, available discharge measurements indicate some minor fluctuations in Clearwater Creek.

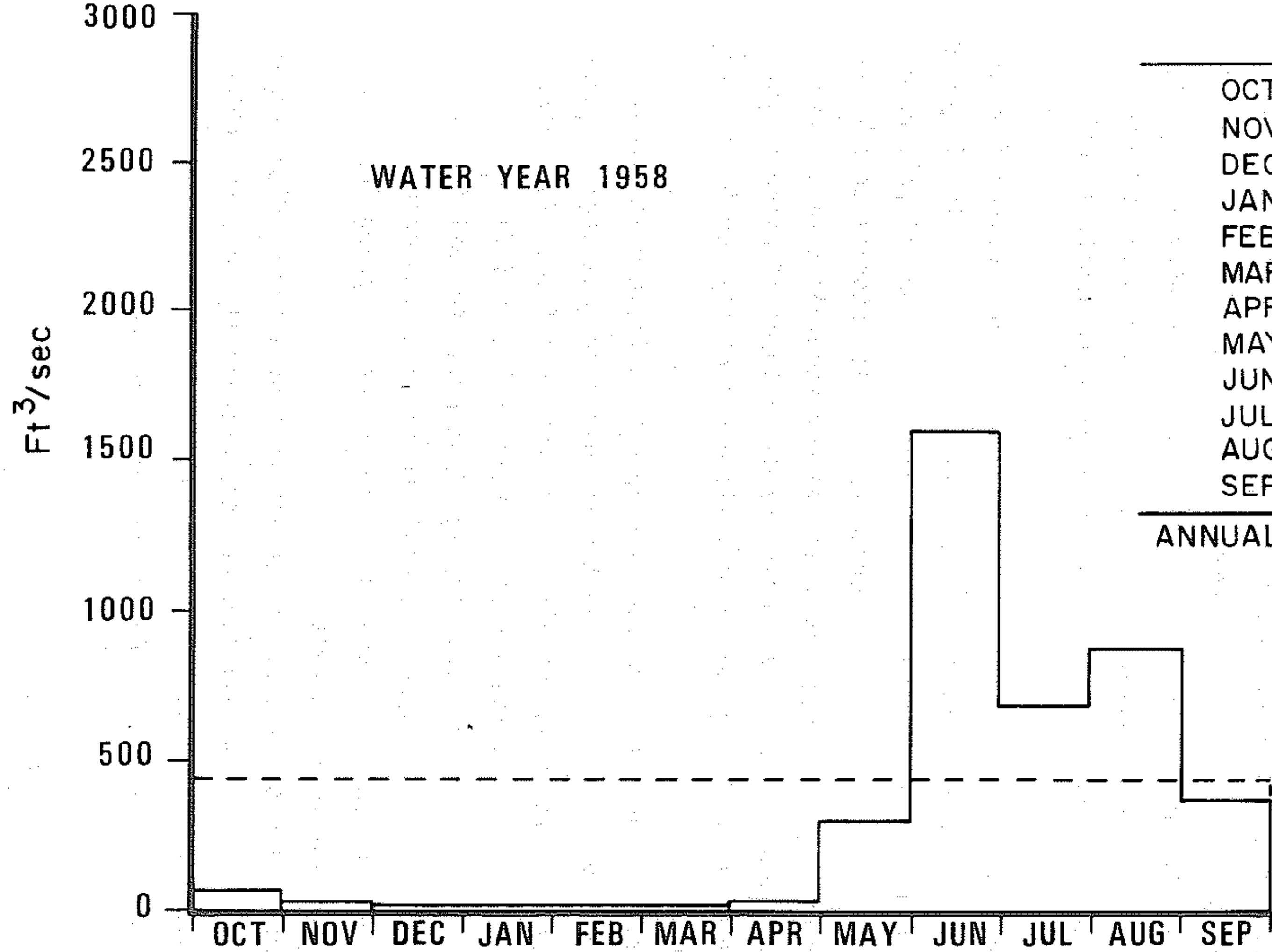
Discussion of the discrepancy in flow magnitude is warranted. The 1973 water balance approaches an equilibrium situation with total inputs approximately equal to total outputs over the 12-month period. If we assume that the actual mean discharge of Clearwater Creek is approximately 700 $ft^3$/sec and that the system is in equilibrium, then the actual recharge rate should be 700 $ft^3$/sec. If we further assume that the calculated recharge rate of approximately 425 $ft^3$/sec is representative of the influent mountain streams, then there must be another source of recharge to Clearwater Creek.

Unfortunately, there are no direct measurements of streamflow in this upper region of the Clearwater Creek basin from which to verify this recharge figure. However, Dry Creek, to the east of the Johnson River and south of the Alaska Highway, is found in a setting similar to those of the creeks of the Granite Mountains. Limited flow data are available for Dry Creek with only one discharge measurement made in water-year 1973. The value is 690 $ft^3$/sec for June 9, 1973 (USGS, 1973). The drainage area for Dry Creek is only 58 sq. mi., while that of the upper Clearwater is 140 sq. mi. In addition, the total outflow from the upper zone of the model includes water passing directly across the 1500-foot contour to the lower zone, before flowing to a channel. Adjusting for these factors, the comparable flow based on Dry Creek data is approximately 1840 $ft^3$/sec; considerably less than the 2900 $ft^3$/sec, obtained for June in the water-balance calculations. The discrepancy may be due to 1) overestimation of snowfall in the Granite Mountains for 1973; 2) error in the monthly timing of snowmelt; 3) a difference in the general amount of snowfall on Granite Mountain and Macomb Plateau; or 4) a difference in the timing of snowmelt between the broader, flatter Macomb Plateau and Granite Mountain. If, in fact, the water-balance calculations overestimate recharge from the Granite Mountain streams, the conclusion that there must be another recharge mechanism is only reinforced.

Another point worth discussing is the lack of any overland flow in either year as calculated for the lower zone of the model. The occurrence of overland flow depends on the intensity of snowmelt or rainfall relative to the soil infiltration and surface-depression storage capacities. However, the model uses daily precipitation and snowmelt totals. Overland flow can occur in this model when the daily input of water to the soil profile exceeds the available soil storage capacity, or if an area is designated as impervious.

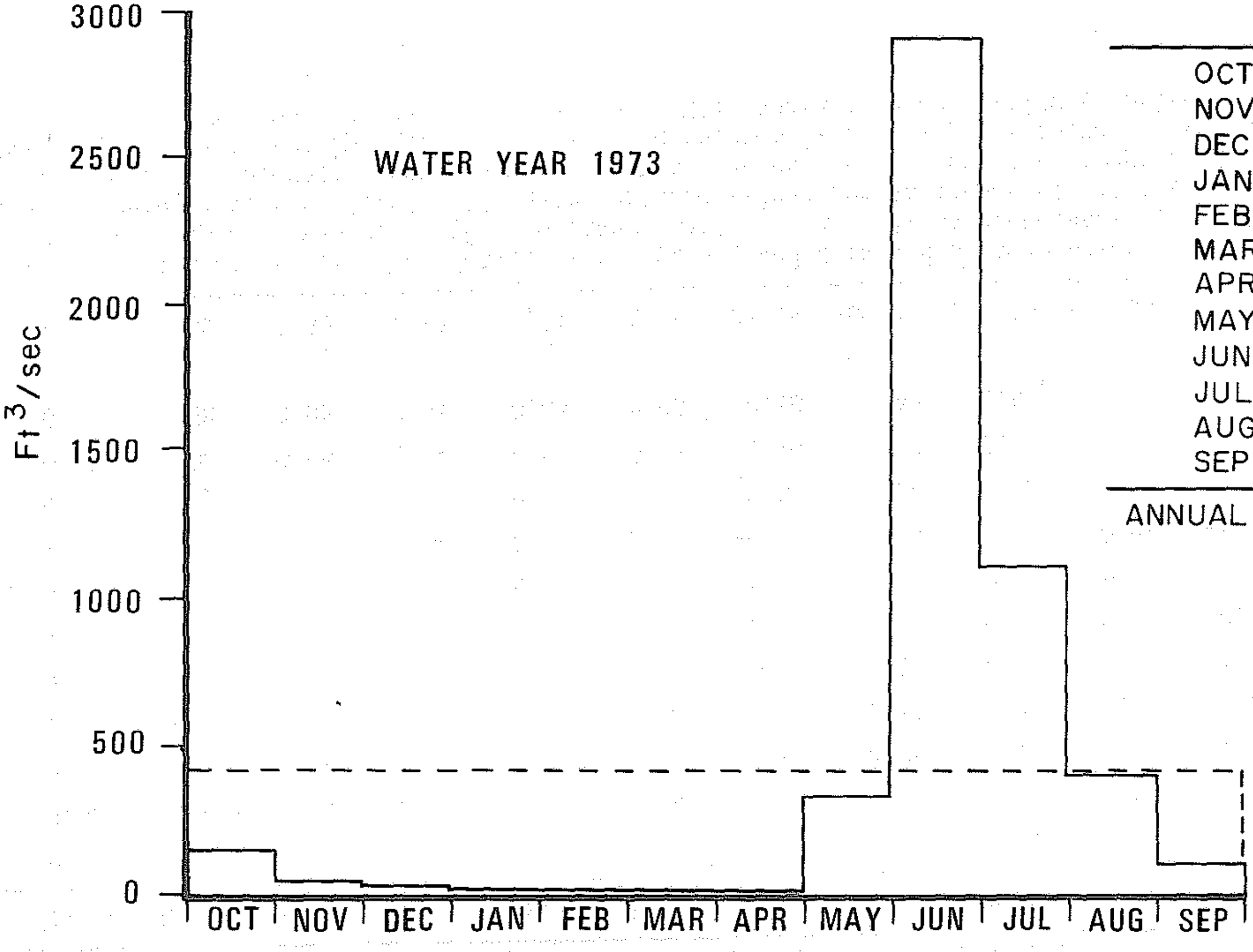
Obviously, a more detailed analysis involving field measurements and hourly precipitation and snowmelt rates would be necessary to investigate the probabilities and conditions for overland flow. The whole process is complicated by the effect of frozen soils on infiltration capacities. If the soil moisture is high just prior to soil freeze-up in fall, infiltration capacities could be reduced considerably. If, however, antecedent soil moisture is low in the fall, spring infiltration could be relatively unaffected.

Considering the small-scale irregularities of a forest floor superimposed on an almost-flat land surface, the probability of a significant amount of overland flow occurring in the lower zone of the Clearwater Creek watershed is low. Some channel extension may occur seasonally.




| | UPPER (———) | LOWER (-----) |
|---|---|---|
| OCT | 43 | 411 |
| NOV | 10 | 410 |
| DEC | 6 | 409 |
| JAN | 5 | 409 |
| FEB | 4 | 410 |
| MAR | 4 | 409 |
| APR | 23 | 410 |
| MAY | 301 | 409 |
| JUN | 1588 | 410 |
| JUL | 684 | 409 |
| AUG | 878 | 411 |
| SEP | 380 | 409 |
| ANNUAL | 328 | 410 |

FIGURE 2a: MEAN DAILY OUTFLOW FROM UPPER AND LOWER SUBAREAS OF CLEARWATER CREEK WATERSHED OBTAINED FROM THE WATER BALANCE MODEL FOR WATER YEAR 1958.




| | UPPER (——) | LOWER (- - - -) |
|---|---|---|
| OCT | 173 | 411 |
| NOV | 33 | 410 |
| DEC | 11 | 409 |
| JAN | 7 | 409 |
| FEB | 5 | 411 |
| MAR | 4 | 409 |
| APR | 8 | 410 |
| MAY | 325 | 409 |
| JUN | 2899 | 411 |
| JUL | 1114 | 411 |
| AUG | 403 | 411 |
| SEP | 111 | 411 |
| ANNUAL | 424 | 411 |

FIGURE 2b: MEAN DAILY OUTFLOW FROM UPPER AND LOWER SUBAREAS OF CLEAR-WATER CREEK WATERSHED OBTAINED FROM THE WATER BALANCE MODEL FOR WATER YEAR 1973.

TABLE 1a

1957-58 WATER BALANCE FOR UPPER CLEARWATER CREEK WATERSHED (140.3 SQ. MILES, AREA ABOVE 1500-FT. CONTOUR)

| | Oct | Nov | Dec | Jan | Feb | Mar | Apr | May | Jun | Jul | Aug | Sep | Total |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Rain | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0.22 | 4.99 | 6.09 | 6.14 | 2.26 | 19.70 |
| Snow | 4.58 | 0.65 | 4.51 | 2.55 | 0.44 | 2.62 | 0.07 | 0.36 | 0.75 | 1.69 | 0.84 | 2.55 | 21.61 |
| PET | 0 | 0 | 0 | 0 | 0 | 0.05 | 1.44 | 2.09 | 3.17 | 2.39 | 1.25 | 0.29 | 10.68 |
| AET | 0 | 0 | 0 | 0 | 0 | 0.03 | 0.03 | 1.14 | 2.95 | 2.23 | 1.24 | 0.29 | 7.91 |
| Trans | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 1.11 | 2.72 | 2.07 | 1.01 | 0.14 | 7.05 |
| Intc | 0 | 0 | 0 | 0 | 0 | 0.03 | 0.03 | 0.03 | 0.23 | 0.17 | 0.23 | 0.15 | 0.85 |
| Evap | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| ΔStorage | 4.24 | 0.58 | 4.46 | 2.50 | 0.41 | 2.56 | -0.14 | -3.00 | -9.92 | 0.01 | -1.46 | 1.50 | 1.74 |
| SWO | 0 | 0 | 0 | 0 | 0 | 0 | 0.08 | 1.34 | 9.86 | 3.48 | 4.45 | 0.74 | 19.95 |
| GWO | 0.35 | 0.08 | 0.05 | 0.04 | 0.03 | 0.03 | 0.10 | 1.13 | 2.76 | 2.14 | 2.76 | 2.28 | 11.75 |
| Total Flow | 0.35 | 0.08 | 0.05 | 0.04 | 0.03 | 0.03 | 0.18 | 2.47 | 12.62 | 5.62 | 7.21 | 3.02 | 31.70 |
| Mean Daily Flow (CFS) | 42.61 | 10.06 | 6.09 | 4.87 | 4.04 | 3.65 | 22.65 | 300.75 | 1587.75 | 684.30 | 877.90 | 379.98 | 327.72 |

NOTE: All water-balance calculations shown on Tables, 1 (a and b), and 2 (a and b) were based on climatological data from either the Clearwater or Big Delta (FAA) weather stations. A daily water-balance accounting was performed using a method developed by Fox (1976). All water-balance values are in inches of water except where indicated otherwise. The following abbreviations are used in these tables: PET: potential evapotranspiration; AET: actual evapotranspiration; Trans: transportation; Intc: Interception loss; Evap: evaporation for ground surface; GWI: ground water inflow; GWO: ground water outflow; SWO: surface water outflow (overland flow)

TABLE 1b

1957-58 WATER BALANCE FOR LOWER CLEARWATER CREEK WATERSHED (211.5 SQ. MILES, AREA BELOW 1500-FT. CONTOUR)

| | Oct | Nov | Dec | Jan | Feb | Mar | Apr | Mar | Jun | Jul | Aug | Sep | Total |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Rain | .02 | 0.0 | 0.0 | 0.0 | 0.0 | 0.02 | 0.0 | 0.19 | 1.87 | 2.54 | 2.28 | 1.13 | 8.05 |
| Snow | 1.47 | 0.21 | 1.47 | 0.83 | 0.14 | 0.83 | 0.02 | 0.0 | 0.0 | 0.0 | 0.0 | 0.43 | 5.40 |
| PET | 0.14 | 0.0 | 0.0 | 0.0 | 0.19 | 0.96 | 3.66 | 4.73 | 5.51 | 3.96 | 2.75 | 1.28 | 23.18 |
| AET | 0.12 | 0.0 | 0.0 | 0.0 | 0.03 | 0.10 | 0.03 | 2.70 | 2.33 | 3.62 | 2.58 | 1.22 | 12.73 |
| Trans | 0.06 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 2.64 | 2.05 | 3.44 | 2.30 | 0.88 | 11.37 |
| Intc | 0.06 | 0.0 | 0.0 | 0.0 | 0.03 | 0.10 | 0.03 | 0.04 | 0.28 | 0.18 | 0.28 | 0.33 | 1.33 |
| Evap. | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.01 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.01 |
| ΔStorage | -.64 | -1.9 | -.73 | -1.37 | -1.89 | -1.46 | -2.05 | -3.1 | 5.75 | .42 | 2.24 | .18 | -4.55 |
| GWI | .23 | .05 | .03 | .03 | .02 | .02 | .12 | 1.64 | 8.37 | 3.73 | 4.78 | 2.00 | 21.02 |
| SWO | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |
| GWO | 2.24 | 2.16 | 2.23 | 2.23 | 2.02 | 2.23 | 2.16 | 2.23 | 2.16 | 2.23 | 2.24 | 2.16 | 26.29 |
| Total Flow | 2.24 | 2.16 | 2.23 | 2.23 | 2.02 | 2.23 | 2.16 | 2.23 | 2.16 | 2.23 | 2.24 | 2.16 | 26.29 |
| Mean Daily Flow (CFS) | 411 | 409.5 | 409.2 | 409.2 | 409.5 | 409.2 | 409.5 | 409.2 | 409.5 | 409 | 411 | 409.2 | 409.9 |

NOTE: See note, Table 1a.

TABLE 2a

1972-73 WATER BALANCE FOR UPPER CLEARWATER CREEK WATERSHED(140.3 SQ. MILES, AREA ABOVE 1500-FT. CONTOUR)

| | Oct | Nov | Dec | Jan | Feb | Mar | Apr | May | Jun | Jul | Aug | Sep | Total |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Rain | 0.13 | 0 | 0 | 0 | 0 | 0 | 0 | 1.52 | 0.31 | 11.38 | 3.43 | 0.43 | 26.20 |
| Snow | 1.86 | 1.26 | 1.93 | 2.39 | 7.36 | 0.18 | 0.89 | 1.97 | 2.84 | 0 | 0.40 | 0.06 | 21.14 |
| PET | 0 | 0 | 0 | 0 | 0 | 0.07 | 0.91 | 1.73 | 2.27 | 2.63 | 1.06 | 0.60 | 9.27 |
| AET | 0 | 0 | 0 | 0 | 0 | 0.03 | 0.05 | 1.08 | 2.26 | 2.53 | 1.03 | 0.57 | 7.55 |
| Trans | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0.93 | 1.78 | 2.12 | 0.73 | 0.47 | 6.03 |
| Intc | 0 | 0 | 0 | 0 | 0 | 0.03 | 0.05 | 0.15 | 0.48 | 0.41 | 0.31 | 0.09 | 1.52 |
| Evap | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| ΔStorage | 0.60 | 1.00 | 1.83 | 3.18 | 6.49 | 0.13 | 0.86 | -0.26 | -13.15 | -0.29 | -0.51 | -0.96 | -1.14 |
| SWO | 0.27 | 0 | 0 | 0 | 0 | 0 | 0 | 1.31 | 19.25 | 6.10 | 0.85 | 0.10 | 27.88 |
| GWO | 1.14 | 0.26 | 0.09 | 0.06 | 0.04 | 0.03 | 0.03 | 1.37 | 3.78 | 3.05 | 2.46 | 0.78 | 13.09 |
| Total Flow | 1.42 | 1.26 | 0.09 | 0.06 | 0.04 | 0.03 | 0.03 | 2.67 | 23.04 | 9.15 | 3.31 | 0.88 | 40.98 |
| Mean Daily Flow (CFS) | 173 | 33 | 11 | 7.3 | 5.4 | 3.65 | 7.8 | 325 | 2899.0 | 1114. | 403. | 111. | 423.7 |

NOTE: See note, Table 1a.

TABLE 2b

1972-73 WATER BALANCE FOR LOWER CLEARWATER CREEK WATERSHED (211.5 SQ. MILES, AREA BELOW 1500-FT. CONTOUR)

| | Oct | Nov | Dec | Jan | Feb | Mar | Apr | May | Jun | Jul | Aug | Sep | Total |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Rain | .05 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.81 | 3.96 | 3.71 | 1.25 | 0.16 | 9.94 |
| Snow | .60 | .41 | .63 | .78 | 2.40 | 0.06 | 0.29 | 0.33 | 0.0 | 0.0 | 0.0 | 0.0 | 5.50 |
| PET | .06 | 0 | 0 | 0 | 0.21 | 0.94 | 2.53 | 3.57 | 4.22 | 3.86 | 2.16 | 1.94 | 19.49 |
| AET | .05 | 0 | 0 | 0 | 0.03 | 0.03 | 0.06 | 2.37 | 4.00 | 3.67 | 2.06 | 1.73 | 14.00 |
| Trans | 0 | 0 | 0 | 0 | 0 | 0.0 | 0.0 | 2.14 | 3.40 | 3.20 | 1.73 | 1.63 | 12.10 |
| Intc | .05 | 0 | 0 | 0 | 0.03 | 0.03 | 0.06 | 0.22 | 0.59 | 0.46 | 0.33 | 0.10 | 1.87 |
| Evap | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0.01 | 0.01 | 0.01 | 0.01 | 0.0 | 0.04 |
| ΔStorage | -.7 | -1.58 | -1.54 | -1.41 | .38 | -2.18 | -1.91 | -1.69 | 13.08 | 3.87 | -.85 | -3.16 | 3.42 |
| GWI | .94 | .17 | .06 | .04 | .03 | .02 | .02 | 1.77 | 15.28 | 6.07 | 2.2 | .58 | 27.18 |
| SWO | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |
| GWO | 2.24 | 2.16 | 2.23 | 2.23 | 2.02 | 2.23 | 2.16 | 2.23 | 2.16 | 2.24 | 2.24 | 2.17 | 26.31 |
| Total Flow | 2.24 | 2.16 | 2.23 | 2.23 | 2.02 | 2.23 | 2.16 | 2.23 | 2.16 | 2.24 | 2.24 | 2.17 | 26.31 |
| Mean Daily Flow (CFS) | 411 | 409.5 | 409.2 | 409.2 | 410.5 | 409.2 | 409.5 | 409.2 | 409.5 | 411. | 411. | 411.4 | 411 |

NOTE: See note, Table 1a.

TABLE 3a

CALCULATED DRAINAGE FROM THE TOP 6 INCHES OF SOIL UNDER SPECIFIED SURFACE CONDITIONS (IN.)

| | Oct | Nov | Dec | Jan | Feb | Mar | Apr | May | Jun | Jul | Aug | Sep | Total |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Crop | .79 | .01 | 0.0 | 0.0 | .01 | .84 | 3.21 | .05 | 1.45 | .70 | .09 | 0.0 | 7.15 |
| No-Crop | .79 | .01 | 0.0 | 0.0 | .01 | .84 | 3.21 | .05 | 1.23 | 1.03 | .32 | 0.0 | 7.49 |
| Mulch | .80 | .02 | 0.0 | 0.0 | 0.0 | .86 | 3.52 | .55 | 2.86 | 2.59 | .99 | .01 | 12.20 |
| Crop-Crop* | .65 | 0.0 | 0.0 | 0.0 | 0.01 | .91 | 3.24 | 0.0 | 1.41 | .64 | .08 | 0.0 | 6.94 |
| Mulch-Crop* | .65 | .02 | .01 | 0.0 | .01 | .94 | 3.24 | 0.0 | 1.32 | .58 | .04 | 0.0 | 6.81 |

TABLE 3b

CALCULATED DRAINAGE FROM THE TOP 30 INCHES OF SOIL UNDER SPECIFIED SURFACE CONDITIONS (IN.)

| | Oct | Nov | Dec | Jan | Feb | Mar | Apr | May | Jun | Jul | Aug | Sep | Total |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Crop | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | .04 | 3.30 | .20 | .89 | .79 | .45 | 0.0 | 5.67 |
| No-Crop | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | .04 | 3.25 | .20 | .72 | .83 | .73 | 0.01 | 5.78 |
| Mulch | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | .05 | 3.46 | .65 | 2.13 | 2.28 | 1.48 | .23 | 10.28 |
| Crop-Crop* | .43 | .16 | 0.0 | 0.0 | 0.5 | .24 | 3.48 | .10 | 0.90 | .65 | .39 | 0.0 | 6.40 |
| Mulch-Crop* | .50 | .13 | .01 | 0.0 | 0.0 | .29 | 3.33 | .02 | .39 | .09 | .09 | .08 | 4.93 |

*Crop-Crop refers to water-balance calculations for a year of crop cover following a previous year of crop cover. Mulch-Crop refers to water-balance calculations for a year of crop cover following a previous year of mulch.

**The initial moisture contents for the second year of the sequential calculations were the ending moisture values for the respective first-year calculations. Climatological data for 1972-73 were used in all simulations.

Field Water Balance

The second set of water-balance calculations involved a hypothetical field in the vicinity of Clearwater Creek. The following situations were investigated:

1. Crop cover: growing from an initial canopy density and root depth of 0.0 and reaching an ultimate density of 1.0 and a root depth of 4.0 inches.
2. No crop cover: just bare mineral soil.
3. No crop cover with nontranspiring mulch.
4. Crop cover following crop cover: in previous year.
5. Crop cover following mulch: used in previous year.

The objectives of this analysis were to 1) estimate whether water would percolate below the crop root zone, 2) estimate actual evapotranspiration of a growing crop with a final root depth of 4 inches, and 3) estimate whether such evapotranspiration would increase significantly after a "water-conserving" fallow season.

Estimates of leaching. Table 3 (a and b) shows the amount of water leached beyond the top 6 and 30 inches of soil under a variety of situations. First of all, approximately 7 inches of water are leached under cropped conditions. However, only approximately 30 per cent of the total is leached during the growing season. The greatest leaching takes place during the peak of spring snowmelt (April in 1973) and in response to spring rain before the crop has developed fully (i.e. 3.96 in. of rain fell in June 1973 and 3.71 in. of rain fell in July, 1973 yet leaching in July under a more fully developed crop cover was about half that in June).

Leaching from the base soil was only slightly greater than that for a cropped soil since the root depth of the crop was only 4 inches. However, leaching from an uncropped but mulch-covered soil is approximately 5 inches greater than under cropped conditions. This is due to the reduced evapotranspiration of the mulch-covered soil. This also indicates that moisture conserved under the mulch treatment is not being retained in the root zone.

In the above analysis, the possible effect of the mulch on the water-retention properties of the soil were not included. Moreover, the present model does not allow for possible upward movement of soil water into the root zone in response to drying of the soil surface. Although the simulated conditions are proably not descriptive of any particular tillage practice, it does provide a means of looking at the effect of reduced evapotranspiration on soil-moisture conservation. A more detailed study of the possiblity for significant upward water movement to the root zone would be desirable. Also, use of actual measured soil properties would greatly enhance the validity of the foregoing calculations.

Crop Water Use. Model estimates of actual evapotranspiration are given in Table 4. These values represent evaporation from the soil surface, evaporation from water intercepted on the crop canopy, and transpiration of water from the crop. Calculations were based on the assumption that growth was initiated June 1 and continued to reach full ground cover and maximum root depth (4 inches) in 80 days. Thereafter, crop consumptive use was assumed to decrease to the end of the growing season (mid-September) as is often the case after heading in small grains (Jensen, 1968).

Evapotranspiration for all cropped situations was approximately 10 inches while for the bare soil approximately 9 inches were lost. The greatest change in actual evapotranspiration was for the mulch-covered soil with only about 4 inches of evaporative loss.

The soil moisture deficits (potential evapotranspiration minus actual evapotranspiration) calculated by the model were approximately 8 inches for the April-September period. This compares with approximately 7 inches deficit estimated by TVIST (1972). However, the latter study assumes 4 inches of soil water available in 24 inches of soil and uses a monthly calculation period. The present study root depth is assumed to be only 4 inches and used a daily calculation period. The question arises as to whether moisture deficits calculated in this way adequately reflect the moisture-crop interaction. We do know that plants are not simple wicks through which water passes from the soil to the atmosphere. Different species have different water requirements for optimal development and different efficiencies with respect to water use. The relationship between commercial yield of barley and soil moisture needs to be investigated. Taylor and Ashcroft (1972) indicate that small grains such as barley respond to changes in moisture status during the period of vegetative growth. Usually it is unnecessary (and possibly undesirable) to apply further water after such small grains reach the heading stage, providing the soil is filled at about the time heads emerge and begin to blossom.

Finally, if moisture deficits are expected and barley yield is responsive to reduction of these deficits, what are the relative efficiencies (economic and otherwise) of irrigation versus summer fallow to reduce moisture deficits and increase yield?

Water balance calculations. To gain insight into the effectiveness of mulching for water conservation, water-balance calculations were performed using the 1973 data for two consecutive years of crop cover and for a crop cover following a year of mulch-covered soil. The second year in each case started with the ending soil moisture conditions of the cropped and mulched years respectively. Results are shown in Tables 3 (a and b) and 4 for drainage and evapotranspiration respectively.

The reason there is little difference between successive crops and crop following mulch is that moisture conserved by the mulch percolates out of the root zone before the end of the water year (September 30). Thus, from the standpoint of leaching and transpiration, the two situations are quite similar as they both start the second-water year with about 1 inch of soil moisture in 6-inch root zone. Even if moisture under the mulch-covered soil were stored in the root zone, spring snowmelt would recharge the unmulched soil allowing both situations to display approximately equal spring moisture conditions. If frozen soils generally prevent infiltration in this area, then perhaps the mulch treatment would conserve moisture to the following year. Yet, the implication of inhibited infiltration is high soil moisture content in the fall. Unless the winter snowpack is exceptionally light or blown off the fields and spring rains are sparse, it does not appear that moisture will be conserved by the practice of summer fallow. Other reasons for this practice, however, are cited by Lewis and Wooding (1978).

These results, as previously stated, are based on estimates of soil properties and on the assumption that no upward movement of soil moisture reaches the root zone. There is no question that moisture can move

TABLE 4
CALCULATED ACTUAL EVAPOTRANSPIRATION UNDER SPECIFIED SURFACE CONDITIONS (IN.)

| | Oct | Nov | Dec | Jan | Feb | Mar | Apr | May | Jun | Jul | Aug | Sep | Total |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Crop | .03 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 1.04 | 1.09 | 2.21 | 2.84 | 1.96 | 1.13 | 10.30 |
| No-Crop | .03 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 1.04 | 1.09 | 2.43 | 2.30 | 1.27 | 0.56 | 8.72 |
| Mulch | .02 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.32 | .62 | .93 | .89 | .53 | .57 | 3.88 |
| Crop-Crop | .03 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 1.06 | 1.14 | 2.23 | 2.86 | 1.96 | 1.13 | 10.41 |
| Mulch-Crop | .03 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 1.08 | 1.19 | 2.24 | 2.89 | 1.98 | 1.14 | 10.55 |

upward in response to evaporative losses at the soil surface. Estimation of the magnitude and significance of this phenomenon in interior Alaska would require modification to the existing model or use of more sophisticated techniques. This would be a key question to answer in refined estimates of leaching, crop water use, and the effectiveness of various tillage practices.

The reader should recognize that these results are only approximations utilizing at times only one year of data. The purpose is to gain some insight into the overall operation of the water balance. The capacity of the computer model to consider several factors in an analysis not only facilitates "generating numbers" but, moreover, allows the "conditional" nature of the results to be appreciated and areas of limited information to be identified.

## GROUNDWATER REGIME

The purpose of this section is to provide a qualitative analysis of the groundwater regime in the Clearwater Creek area based on current information.

### General

Groundwater occurs under both confined and unconfined conditions. Unconfined aquifers are usually found in unconsolidated alluvium in valleys and in fractured, deeply weathered bedrock. Confined or artesian conditions generally occur on the lower slopes where water-bearing deposits are confined by impermeable sedimentary beds or by permafrost.

In the Tanana Valley the most important source of groundwater is seepage from influent streams and direct infiltration of precipitation and snowmelt. Greatest precipitation falls on mountainous areas with shallow soils over bedrock where runoff/precipitation ratios are high. Where these streams leave the mountains and cross alluvial (glaciofluvial) deposits, water rapidly seeps through streambeds to a generally deep water table. In such situations, groundwater mounds may form under the channels at depth, and water flows away from the axis of the stream. The direction of regional groundwater flow generally parallels surface drainage. The major area of recharge is along the south side of the Tanana Valley where major rivers cross alluvial fans (Anderson, 1970).

Clearwater Creek Area

The geology and geomorphology of the Clearwater Creek-Granite Mountain watershed indicate this area is an excellent example of the general pattern mentioned above. Reports by Yarborough (1975), Hulsing (1978), and Long (1977) document the influent nature of the small, nonglacial streams flowing out of the Granite Mountains and crossing glaciofluvial fans. Previously mentioned water-balance studies yield estimates of the magnitude and seasonal distribution of such recharge. However, these studies also indicated that such magnitudes are not sufficient to maintain an equilibrium flow in Clearwater Creek of 700 ft/sec.

In preliminary analysis of the aquifer, USGS hypothesized a minimal role of such mountain streams but rather speculated recharge to the Clearwater system from the Delta River on the west and continuity of the aquifer with the Tanana River to the east expressed as a constant head boundary. Evidence for recharge from the Delta River is found in well data presented and analyzed by Waller and Tolen (1962) and Waller et al. (1961), who stated that groundwater in the vicinity of Fort Greely moves,

> "...in a northeasterly direction...200 feet below the surface... from the Delta River to the west and probably discharges at the land surface to the northeast in the Clearwater Lake area...."
>
> "...the hydraulic gradient was...about 11 feet per mile...."

Williams (1970) discusses and adds to this report that at Fort Greely the Donnelly outwash is above the water table but underlain by till of the Delta Glaciation which in turn lies above an older gravel. Williams states that "the gravel beneath the Delta till contains water that is confined by the relatively impermeable till."

Frozen ground at Fort Greely extends to a maximum recorded depth of 217 feet but it is found in only one third of the wells (Williams, 1970). Williams remarks that in all but one well the base of the permafrost is above the potentiometric surface, and, in that well, the confining layer is still not permafrost. Williams concludes, "at Fort Greely, therefore, the hydrology of the ground water is dependent on the stratigraphy of the Quaternary deposits and is independent of permafrost." Discussing groundwater in the Donnelly flats area, Williams states, "the frozen ground, as at Fort Greely, is thin and sporadic and has little effect on the groundwater hydrology." Whether this relatively impermeable and confining till layer extends eastward into the Clearwater Creek area is unknown. Considering that the moraine located between Jarvis Creek and the proposed agricultural area is of the earlier Delta glaciation, the eastward continuity of the later till is unlikely.

The USGS also has record of static water level in an observation well at Fort Greely from 1965 to 1975. This record shows a yearly sinusoidal rise and fall of approximately 18 ft/yr. The lowest level was in June and the highest in the fall.

Thus, there is evidence that at least the lower portion of Clearwater Creek and Clearwater Lake are influenced by groundwater flow from the Delta River. The extent of this recharge boundary, however, is unknown. Also there is evidence that permafrost may not significantly affect the groundwater regime in this area. Wilcox (personal communication, 1978) reported preliminary analysis of water level fluctuations in a well recently drilled in the 2000-acre test area indicate the possibility of confined or partially confined conditions.

The possibility for recharge from the Tanana-Gerstle Rivers to the east of Clearwater Creek remains to be discussed. Preliminary steady-state groundwater modeling by USGS assumed a constant head boundary condition as the east margin of the aquifer. Dingman et al. (1971) report a study of discharge records for the Tanana River at Big Delta and near Tanacross (Cathedral Rapids), indicating a flow increase of approximately 3000 $ft^3$/sec during the winter months. Working under the assumption that in winter surface flow from the major tributaries is no more than a few per cent of this flow increase, the authors estimate that "virtually all of the flow increase in the Tanana River between Cathedral Rapids and Big Delta is from groundwater flow (much of this reach of river is open throughout the winter due to the influx of groundwater) and amounts to about 3000 $ft^3$/sec (0.6 $ft^3$/sec $mi^2$)." Using a simple groundwater model, Dingman et al. solved for the hydraulic conductivity of the aquifer. Their value of $1.6 \times 10^{-2}$ ft/sec agrees well with values given by Todd (1964) for "clean sands, mixtures of clean sands, and gravels." This texture class conforms with reports of the surficial geology of the area (Holmes, 1965; Moffit, 1942).

Thus, it is likely that the Tanana River is a sink and is not a source of groundwater recharge, at least during the winter months. However, it is not unreasonable to assume that increases in summer river levels of the Tanana due to surface water input upstream from Cathedral Rapids and between Cathedral Rapids and Big Delta may change the river-groundwater relationship such that a flow gradient exists from the Tanana to the aquifer and that it may possibly influence flow in Clearwater Creek. Yarborough (1975) reports observation of an increase in "wetness" of the Goodpastor flats during times when the Tanana is rising. Wilcox (personal communication, 1978) has performed statistical analysis of some water quality data. Tentative interpretation also imply a relationship between the Tanana River and Clearwater Creek. Additional data collection and analysis will be necessary to confirm these findings.

Undoubtedly, further work is needed to define better the lateral boundary conditions of this aquifer and establish more data points for net flow approximations. Also of concern is the thickness of the aquifer. Wells and test borings in the area and general geologic reports provide little evidence of how deep the bedrock might be. However, information obtained in personal communication with Dick Reiger of the Alaska State Geological and Geophysical Surveys Division, was quite helpful. Review of magnetic surveys in the area of Goodpastor flats, Big Delta, and Clearwater Creek indicate possible depth to bedrock of 1500-2500 ft. Details of this information are included in the appendix.

The complexity of the aquifer dynamics coupled with the lack of information render any analysis or conclusions very tentative. If a significant amount of recharge to its Clearwater Creek aquifer is from the Tanana, Gerstle, or Delta River systems, the possibility of drawdown or pollution of the creek due to pumping for irrigation or application of chemical to the soil surface may be reduced.

## POLLUTANT TRANSPORT

The effects of grain development on water quality will be governed by where development takes place, what agricultural practices are implemented, and how these practices are carried out. Issues of concern are basically erosion and transport of sediment to streams, transport of fertilizers and derivatives to streams and wells (particularly nitrogen and phosphorus), and the transport of pesticides to water courses and domestic water supplies (wells). In certain areas, maintenance of the aesthetic quality of streams may also be of concern.

Basically, sediment, nutrient, and pesticides are transported by water flowing over the soil surface or percolating to groundwater bodies which feed streams. The overland flow pathway is significant only where surface infiltration capacities are low in relation to water delivery rates (i.e., rates of rainfall, snowmelt, or irrigation) and where land slope and roughness allow water to move off site. Surface infiltration capacities can be reduced by compaction of the soil due to farm machinery traffic but may be increased by incorporation of organic matter and tillage. High soil moisture content in the fall when the soil freezes can cause a blockage of soil pores during the subsequent spring snowmelt period. Soil which is frozen when dry experiences less of a reduction in infiltration capacities in spring.

Soil profile layering also affects the infiltration regime since saturated percolation rates through the soil profile will be determined by the least permeable layer and its location in relation to the whole profile.

Most identified agricultural land in Alaska is on very gentle slopes or nearly flat land. Accordingly, even if instantaneous infiltration capacities are exceeded by water delivery rates, temporary ponding with subsequent infiltration may be more characteristic than overland flow. The hazard of overland flow may be greatest for poorly designed, undrained road networks associated with agriculture rather than the fields themselves.

With specific reference to the Delta-Clearwater area, overland flow is apparently uncommon from existing fields during spring breakup (Burt Clifford, personal communication). This observation is reinforced by reports of the seasonally stable flows in Clearwater Creek.

The second major pathway for water and associated pollutant movement is subsurface flow or percolation to groundwater aquifers. This pathway is important primarily where precipitation is high in relation to evapotranspiration or, in other words, in groundwater recharge areas. In these areas, the depth to water table and nature of the soil and aquifer are important. In areas not normally considered recharge areas, there is the possibility that water can contribute to groundwater bodies during certain periods of time particularly if precipitation rates are high and water tables are close to the surface.

Previously presented water-balance calculations of leaching from the top six inches of soil (Table 3a) indicate that annual totals may approach 7-12 inches depending upon cropping and tillage practices. Similar values for percolation from the 30-inch top soil layer are also given in Table 3b. These values might be significantly less in drier years. Of particular significance, however, is the occurrence of greatest amounts during the snowmelt period and during months of high rainfall on nonvegetated and mulched soils.

It may seem contradicting that leaching occurs from a root zone whose crop is experiencing water deficits. This apparent contradiction stems from the common practice of assuming no moisture movement below field capacity and from failing to consider the day-to-day variations in potential evapotranspiration and precipitation when calculating water deficits. The procedure used in this study to calculate leaching includes the assumption that the rate of percolation decreases with decreasing moisture contents as long as there exists a gradient in soil moisture tension between the top soil and the subsoil. If the soil moisture tension in the top soil is significantly greater than that of the subsoil, percolation is assumed to be zero. Also, since daily moisture accounting was performed, the problems of using monthly or seasonal data were not encountered.

The significance of these estimates of leaching to estimation of possible pollutant transport depends on the proximity of the water table to the surface, and the nature of materials between the top soil and the water table. Well logs for wells drilled in the 2000-acre test area in the Clearwater Creek area indicate 40-50 feet of frozen sand and gravel under about 5 ft of silt. Below this frozen ground is approximately 60-80 feet of dry sand and gravel. The likelihood of groundwater recharge or chemical transport through this extent of material is low. Such a probability is further reduced if preliminary indications that the aquifer is partially confined are confirmed.

Lotspeich (1978) performed a simple calculation of the relative impact of nitrogen fertilizer application on Clearwater Creek. Assuming that 60 lb/acre of nitrogen are applied to 73,000 acres and diluted by the total volume of discharge from Clearwater Creek, Lotspeich calculates a concentration of 5.4 ppm of nitrogen in the stream.

The previously cited calculations represent the worst possible case, i.e., all fertilizer reaching the stream. Such simple calculations are interesting but can be misleading. Even under conditions of excessive irrigation and accelerated leaching, all fertilizer would not reach the stream. When dealing with nutrient and organic pesticides, at least three additional features must be considered in addition to the rate and volume of water flow. These are: 1) the adsorption of the chemical onto the organic and mineral soil components, 2) the degradation of the chemical during residence on or in the soil, and 3) the uptake of the chemical by growing plants. All of these factors indicate that movement of the potential pollutant may be less rapid than the movement of water through the soil profile. The interactions involved between soil, plants, microbial activity, and water flow can be very complex and difficult to predict. Letey and Oddson (1972) discuss possible groundwater contaminations by a relatively mobile organic chemical applied to a loam soil. Their theoretical calculations reveal that for a soil moisture content of 30 per cent (by volume) it would take a total of 7.2 feet of water applied to the soil surface to leach any amount of organic chemical below the 4-ft depth in 12 hours. Calculations involving longer times periods would have to consider degradation and uptake as well as the effect of adsorption considered above. Computer models of such interactions exist and theoretically could be used to analyze specific combinations of cropping, tillage, irrigation, and fertilization practices (see Dutt et al., 1972; Elzy et al. 1974).

To comment again on the Delta-Clearwater situation as an example, conditions are those of low precipitation, high demand by crops for both water and nutrients, high adsorptive potential associated with soil organic material and surface residues, and a possibly reduced rate of decomposition or degradation of hazardous materials because of the low Alaskan soil temperatures. Mobile nutrient forms such as nitrate may be more susceptible to leaching under summer fallow conditions than cropped conditions due to reduced plant uptake, increased nitrogen substrate, and increased soil temperatures. However, the probability of significant amounts of chemicals reaching the water table appears low.

## ASSESSMENT AND RECOMMENDATIONS

The criteria for evaluation of existing hydrometeorological data were quantity, quality, availability, and relevancy to consideration of the environmental baseline studies. Various types of data are considered separately, and any recommendations for additional work are included.

### Precipitation and Temperature

There is an abundance of daily and hourly precipitation and temperature data for the Big Delta (FAA) and Fort Greely stations. The quality of the data is considered adequate, with the note that minimum temperatures of record of Big Delta at the FAA Station may be higher than can actually be expected in the surrounding areas due to possible influence of buildings in the vicinity of the station thermometer (Searby and Branton, 1973). There are also daily data in the Clearwater area that are perhaps more representative of the proposed agricultural area.

There are probably enough relevant precipitation and temperature data of sufficient quality and availability to serve most purposes of environmental baseline, impact, and agronomic studies.

### Wind Speed and Direction

There is also a considerable amount of wind speed and direction data available in either published form or original data sheets from Ft. Greely and Big Delta (FAA) Stations. Analyses of early data are also available in a variety of reports and publications.

The basic problem with available wind speed and direction data is the uncertainty as to whether they are representative of the proposed agricultural area. The wind speed and direction recorded at the Big Delta (FAA) Station are known to vary over short distances and time periods, and may be affected by air flow down the Delta River valley. If a few years of wind speed and direction data were available for the Clearwater area (particularly during the snow-free period), some systematic relationship to the Big Delta-Fort Greely data might be established, in which case, the existing historical data could be better utilized.

Recommendations. Recommendations are for the establishment of a wind-speed and direction recording station in the vicinity of the proposed agricultural area. Since possible wind erosion associated with wind speed and direction is the main concern, the station might be located best in an existing clearing or agricultural field, far enough from surrounding obstructions and tall vegetation to avoid local aberration of prevailing wind parameters. An alternative might be to locate the anemometer above the existing forest canopy, under the assumption that the wind profile will be displaced to the ground surface upon agricultural development. May through September would serve as a minimal recording period.

Preliminary analysis of the wind erosion hazard might be based on the assumption that recorded wind speed data at Big Delta-Fort Greely represent the "worst" possible situation. The question of wind direction, however, is more critical for designing shelterbelts and agronomic practices for maximum protection.

Streamflow Quantity and Quality

Streamflow data relevant to the Clearwater area are sparse. Although observations of surface water regime are available, there is a general lack of measured flow data. This situation, however, is currently being improved by the USGS.

Little historical water quality data are available for the smaller streams of the area; however, such information is currently being obtained on a regular basis for Clearwater Creek by the Institute of Water Resources.

Recommendations. Staff gage readings and periodic discharge measurements should be continued with particular attention paid to detecting any seasonal variations in flow in the main channel of Clearwater Creek. Monthly reconnaissance estimates of discharge in the major creeks draining the Granite Mountain during the spring summer and fall would be desirable. Water quality data for Clearwater Creek should continue to be obtained. A sampling program for pesticide residue in soils and/or streams is recommended.

Groundwater

Relevant data on the groundwater regime are currently being obtained by the USGS. Past data on wells and test holes provide only a preliminary basis for speculation.

Recommendations. Continue current work by USGS and further investigate the aquifer depth and boundaries to the east, west, and north perhaps via geophysical methods.

Miscellaneous Data

Additional data exist on solar and net radiation, relative humidity, sky cover, snow, and soil temperature for Fort Greely which can be useful for water-balance calculations, crop growth and evapotranspiration studies, frost hazard, and grain-drying studies.

Recommendations. As a general recommendation, a standard agrometeorological station would be desirable in the development area, which would include wind speed, direction, air temperature (max-min), relative humidity, soil temperature, precipitation, and pan evaporation.

In addition, soil moisture studies would be desirable to estimate the amount and direction of moisture flux in the soil profile. Measures of infiltration capacities, leaching, and chemical analysis of leachate under a variety of tillage, cropping, and chemical applications would also be desirable future work. Spring aerial photographs of existing fields using infrared or color film would be useful in estimating the extent of surface depression storage and overland flow.

General

As indicated above, in many cases further data gathering is probably not necessary, while in other cases even a minimal effort will be of substantial additional benefit to our analytic capabilities. As a general recommendation, I would suggest studies be performed which can be completed in a short time period but which are designed to answer specific questions about environmental impact and agronomic practices. This approach deviates from the mere data-gathering implications of "environmental baseline" studies.

## REFERENCES


Anderson, G. S. 1970. Hydrologic reconnaissance of the Tanana Basin, Central Alaska. USGS Hydrologic Investigations Atlas, HA-319.

Bilello, M. A. 1974. Air masses, fronts, and winter precipitation in central Alaska. U. S. Army Corps of Engineers, CRREL Research Report 319, Hanover, New Hampshire. 51 pp.

Clifford, B. 1977. Soil Conservation Service, USDA, Anchorage, personal communication.

dePercin, F., S. Falkowski, R. C. Miller. 1955. Handbook of Big Delta, Alaska, Environment. Headquarters Quartermaster Research and Development Command, U. S. Army, Environmental Protection Div., Technical Report EP-5. 57 pp.

Dingman, S. L., H. R. Sarnide, D. C. Saboe, M. J. Linch, and C. W. Slaughter. 1971. Hydrologic reconnaissance of the Delta River and its drainage basin, Alaska. U. S. Army CRREL, Research Report 262. 83 pp.

Dutt, G. R., M. J. Shaffer, and W. J. Moore. 1972. Computer simulation model of dynamic bio-physiochemical processes in soils. Tech. Bull. 196, Dept. Soils, Water and Engineering, Agri. Exp. Station, U. of Arizona, Tucson. 101 pp.

Ehrlich, A. 1953. Note on local winds near Big Delta, Alaska. Bulletin Amer. Meteorological Soc. 34(4):181-182.

Elzy, E., T. Lindstrom, L. Boersma, R. Sweet, and P. Wicks. 1974. Analysis of the movement of hazardous waste chemicals in and from a landfill site via a simple vertical-horizontal routing model. Special Report 414, Agri. Exp. Station, Oregon State Univ., Corvalis. 110 pp.

Feyerherm, A. M., L. D. Bark, and W. C. Burrows (n.d.) Probabilities of sequences of wet and dry days in Alaska. North Central Regional Research Pub. 161; Kansas Tech. Bull. 139c. Agricultural Experiment Station, Kansas State Univ. of Agricultural and Applied Science. Manhattan, Kansas. 55 pp.

Fox, J. D. 1976. A forest model of vegetation streamflow relations. Ph.D. dissertation, University of Washington. 275 pp.

Holmes, G. W. 1965. Geologic reconnaissance along the Alaska Highway, Delta River to Tok Junction, Alaska. USGS Bulletin 1181-H. 19 pp.

Hulsing, H. 1977. A letter report to Ms. Margo Payne, ADL, of hydrologic information collected in the Delta Clearwater study area prior to October 1, 1977. Dated October 7, 1977.

Jensen, M. E. 1968. Water consumption by agricultural plants. IN: Kozlowski (ed.) Water Deficits and Plant Growth, Vol. II, Academic Press, NY. pp. 1-22.

Letey, J., and J. K. Oddson. 1972. Mass Transfer. IN: C. A. I. Goring and J. W. Hamaker (Eds.) Organic Chemicals in the soil environment. Vol. 1, Marcel Dekker, Inc., NY. pp. 399-437.

Long, W. 1977. Channels and water in Delta Agricultural Area. Alaska Department of Natural Resources, Division of Geological and Geophysical Surveys. Memorandum, August 24, 1977.

Lotspeich, F. B. 1978. Interaction of proposed agricultural development with Delta Clearwater Creek, Alaska. Manuscript submitted to Alaska Division of Lands for review. 12 pp.

Mitchell, J. M., Jr. 1956. Strong surface winds at Big Delta, Alaska. Monthly Weather Review, Jan, 1956. p. 15-24.

Moffit, F. H. 1942. Geology of the Gerstle River District, Alaska. USGS Bulletin 926-B. U. S. Government Printing Office, Washington. p. 107-160.

Pease, G. A. 1974. A study of a typical spring-fed stream of interior Alaska. Alaska Department of Fish and Game, Fed. Aid in Fish. Rest. Study G-111, Job G-111-G, F-9-6.

Péwé, T. L. 1975. Middle Tanana Valley. IN: Shorter Contributions to General Geology; Permafrost and Ground Water in Alaska. USGS Professional Paper 264-F. p. 126-130.

Reiger, D. 1978. Personal Communication.

Sands, R. D., H. L. Ohman, and F. J. Sanger. 1971. Environmental guide for arctic testing activities at Fort Greely, Alaska. U. S. Army Technical Report 70-54-ES, series ES-69, Earth Science Lab., Notick, Mass. 83 pp.

Schoephorster, D. B. 1973. Soil survey of the Salcha-Big Delta Area, Alaska. Soil Conservation Service, U. S. Department of Agriculture.

Searby, H. S., and C. I. Branton. 1973. Climatic conditions in agricultural areas in Alaska. IN: Weller and Bowling (eds.) Climate of the Arctic, 24th Ak. Sci. Conf., Geophysical Institute, Fairbanks, Alaska. pp 281-292.

Tanana Valley Irrigation Study Team. 1972. Irrigation potentials, Tanana River Valley, Alaska. Report of a federal-state study team to the Fairbanks North Star Borough. 102 pp.

Taylor, S. A., and G. L. Ashcroft. 1972. Physical Edaphology: The Physics of Irrigated and Non-Irrigated Soils. W. H. Freeman & Co., San Francisco. 534 pp.

Todd, D. K. 1964. Groundwater. IN: V. T. Chow (ed.) Handbook of Applied Hydrology. McGraw-Hill, New York. p. 13•1-13•55.

Waller, R. M., and D. A. Tolen. 1962a. Data on wells along the Alaska Highway (state 2), Alaska. State of Alaska, Department of Health and Welfare Report AS 18. 25 pp.

Waller, R. M., and D. A. Tolen. 1962b. Data on wells and springs along the Richardson Highway (State 4) Alaska. State of Alaska, Department of Health and Welfare, Report No. 16. 32 pp.

Wilcox, D. 1978. Water Resource Division, USGS, Fairbanks, personal communication.

Williams, J. R. 1970. Ground water in the permafrost regions of Alaska. USGS Professional Paper 696. U. S. Government Printing Office, Washington. 83 pp.

Yarborough, L. F. 1975. Flood history of the Delta study area. A report prepared for USDA Soil Conservation Service. 14 pp. plus appendix.