FISH USE OF UPWELLINGS

An Annotated Bibliography
(Annotations Primarily Author Abstracts)

Compiled for the
Region III Forest Practices Riparian Management Committee

by
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SUMMARY

Several water bodies in the Tanana River Basin exhibit areas of upwelling—localized or widespread areas where water flows from the bed up into the water column. These upwelling areas can appear as gravel-bedded springs, pockmarked areas in sandy or silty areas, or generalized flow up through gravel substrate. More than one water source feeds upwelling areas. Some waters are hyporheic, part of the river or stream water column that moves down into and rises up out of porous bed materials. These flows have chemical characteristics very close to those of the surface flow. Other upwellings are true groundwater, which has been subsurface for extended time (years to millennia), and has have conductivity and very low dissolved oxygen (DO) relative to surface flows. Recent field work along the Tanana River suggests that a third water source may also supply upwelling areas, with a subsurface time of perhaps months to a few years, exhibiting similar chemical and DO characteristics to that of hyporheic flow but being relatively independent of channel flow stage or season. This literature review was undertaken to better understand fish use of upwelling areas, and to assist with evaluating potential risks to such use by land use activities including timber harvest and access road construction.

Preferential use by fish of upwelling areas has been widely reported. Baxter and McPhail (1999) found that bull trout females preferentially spawned in upwelling locations, which had warmer water temperatures. Garrett et al. (1998) found that kokanee (landlocked sockeye salmon) preferred to spawn in upwelling areas in the North Fork Payette River, Idaho, and that the warmer water temperatures accelerated development, protected eggs from freezing, and perhaps increased survival. Lorenz and Eiler (1989) examined sockeye salmon spawning areas in the glacial Taku River near Juneau, and its tributaries. They found that upwelling groundwater was an important component of spawning habitat in the main stem of the Taku, and that redd characteristics were different in such areas. Kogl (1965) looked at the interactions of groundwater and chum salmon spawning in the mid-Chena River, and noted the complex interplay between overwinter water temperatures, DO, spawning sites, and upwelling areas. Barton's (1992) radiotelemetry work in 1989 catalyzed much of the ADF&G interest in upwelling areas by documenting fall chum spawning in the main stem of the glacial Tanana River, and similar patterns have been observed during subsequent annual aerial surveys of spawning chum salmon in the area. ADF&G Division of Sport Fisheries biologists have noted use of upwelling areas by spawning fall chum salmon in the Nenana River basin as well.

The key attributes of fish habitat in upwelling areas are warmer winter water temperatures, and increased or consistent intergravel flow. The warmer water provides thermal units needed for hatching and prevents freezing of eggs. The flow provides oxygen and carries away waste products and may prevent freezing. Fish preferentially use areas with warm upwelling sources that contain adequate DO or that have been oxygenated by mixing with air or with cooler water that contains abundant DO. Fish survival may also benefit from the stability of environmental conditions in groundwater upwelling areas; these areas tend to have more stable temperatures, water levels, and intergravel flow rates.

In general, authors were concerned that the importance of upwelling areas to maintenance of healthy fish populations has not been fully appreciated by fisheries and land managers. Barton (1992, page 15) notes that the relatively numerous and small spawning areas in the main stem of the Tanana River cumulatively contribute significantly to the total available spawning area for Tanana Basin fall chum salmon. Garrett et al. (1998, page 929) agree that use of upwelling areas by fish can have population level effects, and suggest that managers consider affording special consideration to upwelling areas used by spawning salmonids. However, no studies were found that provided data on linkage between upwelling areas used by fish and potential effects from land use activities. Before it can be determined whether or not dispersed timber harvest and road building activities, or cumulative effects of more regional harvesting efforts, could affect upwelling areas and the fish species that use them, we need a better understanding of where the upwelling water is coming from; why upwellings, as such, occur where they do; and what the fish use of the upwellings areas is. First steps could include (1) monitoring the temperature and water chemistry of upwellings and winter open water areas, and (2) documenting the year-round presence and abundance of fish, by species and life stage, in these upwelling areas.

Annotations in this review are typically author's abstracts. Citations and annotations came from a variety of sources, including an online search of the Water Resources Abstracts, Fish and Fisheries Worldwide, and Arctic and Antarctic Regions databases (key word "upwelling"), reviewers' personal libraries, and the annotated bibliography in ADF&G Technical Report No. 97-1.

REFERENCES

Barton, L. H. 1992. Tanana River, Alaska, fall chum salmon radio telemetry study. Alaska Department of Fish and Game. Fisheries Research Bulletin No. 92-01. Juneau.

A total of 210 Tanana River fall chum salmon was radio tagged in fall 1989 about 11 km below Fairbanks. Previous surveys documented fall chum spawning areas only in those areas where visual surveys could be conducted.

Specific spawning areas were identified for 131 fish. Ninety-seven (74%) of these fish spawned in the floodplain of the Tanana River between upper Salchaket Slough and the mouth of the Little Gerstle River. Six different spawning areas were identified in the mainstem Tanana River between upper Salchaket Slough and the Little Delta River. Specific spawning sites were observed in mainstem channels or sloughs near Salchaket Slough, the mouths of the Little Salcha and Salcha Rivers, Flag Hill, Silver Fox Lodge, and about 5 km below the Little Delta River. Four spawning areas were found between the Little Delta River and Delta Creek.

About 18% of the 131 fish for which spawning areas were determined used the Delta River for spawning. Only three tagged fish (2%) were believed to have spawned above the Gerstle River. The furthest upstream spawner was near the mouth of George Creek. Overall, about 82% of the spawners were tracked to areas upstream of the Little Delta River.

In Barton's concluding remarks he states that at least in some years, the numerous and relatively smaller spawning areas in the mainstem Tanana River, when taken collectively, contribute more substantially to total Tanana River fall chum salmon spawning escapement than previously realized.

Baxter, J. S., and J. D. McPhail. 1999. The influence of redd site selection, groundwater upwelling, and over-winter incubation temperature on survival of bull trout (*Salvelinus confluentus*) from egg to alevin. Canadian Journal of Zoology 77:1233-1239.

Bull trout females generally selected spawning areas of groundwater discharge that had higher water temperatures during the incubation period. Fertilized eggs were placed in locations selected and not selected by females for redds. Eggs in selected areas had significantly higher, and less variable, survival rates that eggs in nonselected areas, although alevin lengths did not significantly differ. The authors suggest that preferred redd locations may be limiting in bull trout systems.

Clark, R. A., and W. P. Ridder. 1987. Abundance and length composition of selected grayling stocks in the Tanana Drainage during 1986. Alaska Department of Fish and Game, Division of Sport Fish. Fishery Data Series No. 26. Juneau.

This report describes field studies conducted during 1986 on stocks of Arctic grayling in the Delta Clearwater, Richardson Clearwater, Goodpaster, Chena, Chatanika, and Salcha rivers, One Mile Slough, Caribou and Shaw creeks, and Fielding and Tangle lakes.

Sampling in the Richardson Clearwater River was conducted between 21 and 30 July. The Arctic grayling population was estimated to be 1,418 fish larger than 150 mm. Twenty seven of the Arctic grayling sampled in the Richardson Clearwater River were tagged previously in other waterbodies in other years (24 from Caribou Creek, 1 from Rapids Creek, and 2 from the Goodpaster River).

The post-spawning migration of Arctic grayling out of Caribou Creek was sampled with a weir from 2 to 18 June. A total of 817 Arctic grayling, of which 320 were considered adults, was captured.

Dingman, S. L., H. R. Samide, D. L. Saboe, M. J. Lynch, and C. W. Slaughter. 1971. Hydrologic reconnaissance of the Delta River and its drainage basin, Alaska. Cold Regions Research and Engineering Laboratory, Research Report v. 262, Hanover, NH.

A one-year reconnaissance study was made of a large braided glacial river and its drainage basin (drainage area 1665 m2; elevation range 1000 - 10,000 ft) for which a minimum of hydrometric and meterologic data existed. The report includes estimates of the water balance, flow-duration curves, and sediment characteristics, and descriptions of stream response to glacial melt and rain, channel geometry and channel processes. Mean annual basin precipitation is estimated at 40.4 in. and mean annual loss of permanent glacial storage is about 1 in. About 30% of this leaves the basin as evapotranspiration, 50% as stream flow, and 20% as groundwater flow. Characteristics of response to glacial melt are outlined. Flow peaks near the mouth occur with 24 hours of rainfall greater than 0.5 in./day at foothills meterological stations; rains of less than that amount do not generally produce discernible stream response. Stream channel geometry is described in detail. Most channels on the lower floodplain are asymmetrical and are roughly triangular or parabolic, and have high width/depth ratios. At-a-station hydraulic geometry is described. Surveys and ground and aerial photography are used to describe channel changes.

Eiler, J. H., B. D. Nelson, and R. F. Bradshaw. 1992. Riverine spawning by sockeye salmon in the Taku River, Alaska and British Columbia. Transactions of the American Fisheries Society 121:701-708.

Radio telemetry was used to determine the distribution of sockeye salmon *Oncorhynchus nerka* returning to spawn in the glacial Taku River in 1984 and 1986, and to locate and characterize spawning areas used by this species. During the study, 253 sockeye salmon were tracked as they moved upriver; 204 of these were followed to spawning areas. Only 37% of the 204 fish traveled to areas associated with lakes; the remaining 63% returned to "riverine" areas—river areas without lakes (42% to the Taku River main stem, 17% to the Nakina River, and 4% to other rivers). Sockeye salmon spawning in riverine areas used a variety of habitat types, including main-river channels, side channels, tributary streams, and upland sloughs. Most (55%) of the radio-tagged fish that returned to the Taku River main stem were tracked to side-channel spawning areas. Half of the 471 adult sockeye salmon sampled in the main-stem spawning areas had migrated to sea as juveniles before their first winter. This study showed that many sockeye salmon returning to the Taku River do not depend on lakes, and that riverine sockeye salmon make up a major portion of the run in some river systems.

Francisco, K., and W. B. Dinneford. 1977. Fourth interim report of the commercial fish - technical evaluation study: Tanana and Delta Rivers. Joint State/Federal Fish and Wildlife Advisory Team. Special Report No. 19.

This paper reports the results of studies conducted from September 1976 through May 1977. The distribution and abundance of chum and coho salmon were determined through test gillnet fishing, aerial surveys and ground surveys. Carcass sampling was used to determine the age and sex composition of chum and coho salmon. Early life history information and the timing of smolt outmigration was recorded for chum salmon in the Delta River.

An estimated 39 to 43 chum salmon spawned in 1976 in the Tanana River next to riprap installed as part of the Trans-Alaska Pipeline crossing. In 1974, before construction, an estimated 247 chum salmon spawned in the area. Fish distribution in 1974 and 1976 was similar, and the estimated escapement for the area was higher in 1976 than in 1974.

Delta River chum salmon hatched after about 122 days of incubation (October 7 to February 3). The first emerged fry were seen on April 6, which indicates about 185 days from spawning to emergence. Outmigration peaked in the two weeks from April 8 to April 21. Water chemistry data are presented for the Delta River chum salmon spawning area for April through May 1977.

Garrett, J. W., D. H. Bennett, F. O. Frost, and R. F. Thurow. 1998. Enhanced incubation success for kokanee spawning in groundwater upwelling sites in a small Idaho stream. North American Journal of Fisheries Management 18:925-930.

Kokanee (*Oncorhynchus nerka* lacustrine sockeye salmon) spawned in groundwater upwelling in the North Fork of the Payette River, Idaho. Intragravel water temperatures in groundwater-influenced redds exceeded surface flow water temperature by 2.4-2.6°C. In redds without groundwater influence, intragravel and water column temperatures did not differ by more than 0.2°C. Although redds constructed in upwelling sites contained significantly more fine sediments (<0.83 mm) and were constructed in areas of significantly lower surface water velocities than redds not influenced by upwelling, preemergent survival of fry from redds in upwelling sites (84%) significantly exceeded that from redds in other areas (66%). Higher incubation temperatures at upwelling sites accelerated rates of development, protected embryos from freezing, and my increase survival of fry recruiting to Payette Lake.

Kogl, D. R. 1965. Springs and ground-water as factors affecting survival of chum salmon spawn in a sub-arctic stream. Master's thesis. University of Alaska, Fairbanks.

The distribution of spawning chum salmon in relation to springs and ground-water seepage, and the survival of chum salmon eggs in these areas, was studied in the Chena River in 1963-1965. The study area was located on the Chena River, about 64 miles upstream from its mouth and immediately upstream of the mouth of Horner Creek. Temperature and water quality information (dissolved oxygen concentrations, pH, iron, alkalinity, and hardness) were recorded. Plastic standpipes were used to obtain in-river groundwater temperature and water quality measurements. Egg survival, and survival and growth of embryos were recorded.

All seepage water analyzed during the summer and winter had (1) a pH of 6.5, (2) a temperature lower than the main river in summer and higher in winter, (3) an iron content of about 0.1 to 0.3 mg/l, and (4) a lower dissolved oxygen content than surface waters of the main river. Intragravel water temperatures generally were 1 to 2°C higher than the study area surface water. Surface dissolved oxygen concentration was 5.7 mg/l in late October and declined to about 2.0 mg/l by March. Average dissolved oxygen concentrations of intragravel water at the estimated time of egg hatching (December 1) was about 3.8 mg/l. Intragravel water dissolved oxygen concentrations were usually lower than that of the surface, but in those cases where temperatures were lower, dissolved oxygen was higher. Intragravel water hardness increased from about 86 mg/l during incubation to about 103 mg/l about one month after hatching began. Alkalinity initially was 69 mg/l and increased to 86 mg/l during the same period.

Chum salmon chose well defined spawning sites that were directly or indirectly affected by groundwater seepages. Chum salmon spawned at depths ranging from 0.05 to 1.2 m and in water velocities of 0.0 to 0.6 mps. Chinook salmon spawned at water depths of 1.2 to 1.8 m and velocities of 0.5 to 0.8 mps. Average survival of eggs was 84.2%. Alevins hatching from eggs incubated at higher dissolved oxygen concentrations were larger in size (dry weight) than those incubated at lower dissolved oxygen concentrations.

Lorenz, J. M., and J. H. Eiler. 1989. Spawning habitat and redd characteristics of sockeye salmon in the glacial Taku River, British Columbia and Alaska. Transactions of the American Fisheries Society 118:495-502.

Spawning habitats of sockeye salmon (Oncorhynchus nerka) in the Taku River and its tributaries in British Columbia and Alaska were studied to determine habitat use and redd characteristics in a glacial river stream. Radiotelemetry was used to track adult sockeye salmon to 26 spawning reaches, and 63 spawning sites were sampled for habitat characteristics. Over 40% of the salmon in the sampling area had a freshwater age of zero, and most of these spawned in main channels or off-channel areas. The availability of upwelling groundwater influenced habitat use in the main stem of the river; upwelling groundwater was detected in nearly 60% of the sites sampled in main-stem areas. Spawning sites with upwelling groundwater had lower water velocities and more variable substrate compositions than sites without upwelling groundwater. Redds had 2-4 times more fine sediment than previously reported. The probability of use was greatest when substrate had less than 15% fine sediment, water velocity was between 10-15 cm/s, and intragravel temperature was between 4.5 and 6.0 C. (Author 's abstract)

Murphy, M. L., J. Heifetz, J. F. Thedinga, S. W. Johnson, and K V. Koski. 1989. Habitat utilization by juvenile Pacific salmon (*Oncorhynchus*) in the glacial Taku River, southeast Alaska. Canadian Journal of Fisheries and Aquatic Science 46:1677-1685.

This research paper reports the results of field studies conducted to determine juvenile salmon use of the lower Taku River in southeast Alaska during summer 1986. Sockeye, coho, and chinook salmon were present within the study area. Chinook salmon were predominantly age 0 (99%) and ranged from 40 to 93 mm FL. Seining was used to estimate fish density.

Habitat was classified into two broad categories: river habitats -- main channels, backwaters, braids, channel edges, and sloughs within the active river; and off-channel habitats -- beaver ponds, terrace tributaries, tributary mouths, and upland sloughs on the valley floor.

Mean water velocity was lowest (0-5 cm/s) in sloughs, backwaters, tributary mouths, upland sloughs, and beaver ponds; intermediate (10-21 cm/s) in braids, channel edges, and terrace tributaries; and highest (102 cm/s) in main channels. Main channels, except for channel edges, were assumed too swift (mean, 102 cm/s) to contain rearing salmon. Mean depth ranged from 0.3 m in braids to 1.0 m in beaver ponds and 2.9 m in main channels. Typically, river habitats were turbid (means, 240-400 JTU), whereas off-channel habitats were clear or humic (means, 20-208 JTU). Water temperatures were 2-4°C higher in beaver ponds and upland sloughs than in channel edges, braids, and terrace tributaries.

The distribution of salmon was most closely related to water velocity, and turbidity had a secondary influence. Sockeye and coho densities were highest in still or slow water (<11 cm/s), whereas chinook density was highest in slow-to-moderate current (1 to 20 cm/s). All species were virtually absent from areas with currents greater than 30 cm/s. Differences in water velocity may have masked effects of turbidity. Chinook density was similar in areas of different turbidity.

In the active channel of the lower Taku River, substrate is mostly compacted gravel, sand, and mud, providing little cover from the turbulent flow, and the only suitable habitat occurs along the channel edge. Other studies have shown juvenile chinook salmon can inhabit areas with current as fast as 70 cm/s where coarse substrate (20-40 cm diameter) provided cover from the fast current.

Mean salmon density in the habitat types corresponded to water velocity but also differed between the river and off-channel areas. Chinook primarily were in river habitats with mean velocities of 3 to 15 cm/s, particularly sloughs and channel edges (means, 6-8 fish/100 m^2), and off-channel terrace tributaries and tributary mouths (means, 5-8 fish/100 m^2). Chinook were virtually absent from beaver ponds and upland sloughs (<1 fish/100 m^2).

Pearse, G. A. 1974. A study of a typical spring fed stream of interior Alaska. Annual report of progress. Alaska Department of Fish and Game, Federal Aid in Fisheries Restoration, Volume 15. Project F-9-6, Job G-III-G.

This paper reports the results of field work conducted on the Delta and Richardson Clearwater rivers in 1972 and 1973 examining the distribution, movements, abundance, life history information, and food habits of Arctic grayling and round whitefish, and certain aspects of coho salmon life history. Water quality values for temperature, pH, alkalinity, hardness, dissolved oxygen, and carbon dioxide are presented.

Smaller (<300 mm) Arctic grayling entered the Delta Clearwater in early April, with larger Arctic grayling entering the river in mid May and June. Most of the fish moved downstream in fall; a few remained through mid winter. All were absent in March 1973. No ripe pre-spawning Arctic grayling were collected in the Delta Clearwater; however, nine young-of-the-year were captured in the lower river in late July 1973, indicating a few Arctic grayling do spawn in the system. Rearing grayling emigrate from spawning rivers such as the Goodpaster River and Shaw Creek, and migrate to summer feeding areas such as the Delta and Richardson Clearwater rivers.

Arctic grayling tagged in the Goodpaster River in May were recaptured in the Delta Clearwater later in the summer. Arctic grayling tagged in the Goodpaster River in late summer were captured the following year in the Richardson Clearwater and Clearwater Lake. Arctic grayling tagged in the Delta Clearwater in May and June were captured later in the summer in Clearwater Lake and the Goodpaster River.

Round whitefish tagged in the Tanana River between the mouths of the Delta Clearwater and Goodpaster rivers, and near the mouth of the Delta River in late March were recaptured in the Delta Clearwater, Richardson Clearwater, Tanana River, and Clearwater Lake. No young-of-the-year round whitefish were captured in the Delta Clearwater, which suggests spawning does not occur in this system. Few round whitefish were seen in early September in the Delta Clearwater. Two round whitefish tagged in the Delta Clearwater were observed in a large school of pre-spawning round whitefish in the Goodpaster River in mid September.

Pre-spawning coho salmon were first observed in the Delta Clearwater in 1973 on September 24. Peak spawning occurred around mid October. About 350 to 400 coho salmon were observed in the Richardson Clearwater. Coho and chum salmon were observed in the lower seven miles of the Richardson Clearwater. Young-of-the-year and age 1 coho salmon were observed and captured along the stream margins in cover areas during summer. Some also were captured in spring areas. Rearing fish were absent from the stream margins in fall but were captured in greater numbers in spring areas at this time. Springs are the preferred overwintering habitat for these age classes of salmon. The majority of coho smolt had outmigrated before May 25; some were captured in the Tanana River near the mouth of the Delta River in March.

Ridder, W. P. 1994. Arctic grayling investigations in the Tok River drainage during 1993. Alaska Department of Fish and Game. Fishery Data Series No. 94-19. Anchorage.

This study was conducted in April, May, June, and September 1993 to determine the age and size composition of Arctic grayling larger than 149 mm in the Tok Overflow for an initial assessment of the population in this system. Sampling was expanded to include other locations within 21 km of the Tok Overflow when few fish were found in the Tok Overflow. Other areas sampled included the Tok Overflow #2, the Little Tok River, the Tok River, and Mineral Lake Outlet. Stream descriptions and descriptions of each fishery are provided. Length and age composition data are provided.

The Tok River below the Tok Overflow was found to be an overwintering area for Arctic grayling that disperse upstream to at least Mineral Lake Outlet. Water temperatures indicated the Tok Overflow to be the coldest stream in the study area and likely inhospitable as a summer feeding area for Arctic grayling. Daily high stream temperatures ranged from 2.7 to 4.8°C between 15 April and 6 August. Arctic grayling (56 fish between 200 and 300 mm) were found at the mouth of the Tok Overflow only on 22 June (five other surveys were conducted) when the stream temperature at the mouth was 5.9°C.

The Tok River drainage is the only locale in the Tanana River drainage that supports a significant Dolly Varden fishery. Dolly Varden were captured in the Tok Overflow and the Tok Overflow #2. Two Dolly Varden were active on a redd in the Tok Overflow on 13 September. Eighteen Dolly Varden in the Tok Overflow #2 in June averaged 142 mm in length (range = 101 to 191 mm; SD = 20). Five Dolly Varden captured in the Tok Overflow #2 averaged 159 mm (range = 115 to 212 mm; SD = 32).

Schallock, E. 1965. Investigations of the Tanana River grayling fisheries, migratory studies. Annual report of progress. Alaska Department of Fish and Game, Federal Aid in Fisheries Restoration Project No. F-5-R-6, Job 16-B. 12.

This annual report describes results of studies conducted in 1964 of movements, growth rates, and tag loss in Arctic grayling in the Delta Clearwater, Richardson Clearwater, and the Goodpaster River.

The Arctic grayling of the Delta Clearwater move upstream during the summer months (June to September) whereas the fish in the Goodpaster River exhibit both upstream and downstream tendencies with the majority of the fish showing no movement. It is suspected the intrastream movement pattern found in the Goodpaster River is the result of the upstream migration occurring earlier in the season and being masked by the high water of breakup. By the time conditions allow sampling, fish generally have established residency and little net change occurs thereafter.

Inter-stream system movement trends that appeared in 1964 were tendencies for Arctic grayling to move from the Goodpaster River and the Clearwater Lake area into the Delta Clearwater. The absence of ripe fish and young-of-the-year in the Delta Clearwater, the presence of these two groups in the Goodpaster River, and a documented emigration of Goodpaster River fish and immigration of fish into the Delta Clearwater, supports the conclusion that the Goodpaster River is supplying the Delta Clearwater with some of its fish.

Adult Arctic grayling probably spawn in the Goodpaster River and some move to the Delta and Richardson Clearwaters. The Goodpaster River then may serve as a rearing area for the offspring of the adults that take summer residency in the Delta and Richardson Clearwaters. Tag recoveries of inter-system moving fish were made in the summer following tagging and suggest fish may congregate in the Tanana River in winter. Information on growth rates is presented for Goodpaster River and Delta Clearwater Arctic grayling.

West, R. L., M. W. Smith, W. E. Barber, J. B. Reynolds, and H. Hop. 1992. Autumn migration and overwintering of Arctic grayling in coastal streams of the Arctic National Wildlife Refuge, Alaska. Transactions of the American Fisheries Society 121:709-715.

During 1984 and 1985, 67 adult Arctic grayling *Thymallus arcticus* with surgically implanted radio transmitters were released at their summer feeding areas in three river systems of the Arctic National Wildlife Refuge, Alaska. We tracked the fish from aircraft to determine patterns of autumn migration to overwintering locations. During August or September in each area, fish left the small tundra streams where they were tagged and migrated into larger streams. Migration rates peaked at 5-6 km/d about 1 September and averaged 1 km/d. Fish in two river systems moved into adjacent rivers after passage through estuarine waters. Migration distances from spawning or summer feeding areas to overwintering sites were as great as 101 km. Potential overwintering areas determined from transmitter relocations included deep pools, spring-fed areas, and lakes. Management problems associated with these extensive seasonal migrations may include the maintenance of the species migratory circuit in a region that may face future development.

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

The Delta Agricultural Project is developing more than 93 square miles of land in the Delta-Clearwater area. Geohydrologic information can help planners, farmers, and environmentalists evaluate ground-water supplies and potential effects of development on ground and surface water.

The alluvial aquifer system underlying the Delta-Clearwater area is composed of lenticular, interbedded deposits of silt, sand, and gravel. Ground water here occurs under both confined and unconfined conditions. The potentiometric surface across the area slopes approximately northward at gradients ranging from about 1 to 25 feet per mile. Well yields are as high as 1,500 gallons per minute from a well at Fort Greely. Water discharges from the alluvial aquifer into the Clearwater Creek network and Clearwater Lake, into the mouth of the Delta River, and into the Tanana River along the northern boundary of the study area. The discharge rate from the aquifer shows little variation; from May 977 to July 1979 flow at a gaging station on spring-fed Clearwater Creek ranged from 650 to 773 cubic feet per second. Average annual ground-water discharge is estimated to be greater than 1,200 cubic feet per second. The aquifer is recharged by seepage through the streambeds of rives and creeks in the area and by infiltration of precipitation. Reaches of many rivers and creeks are perched above the aquifer and lose water to it. Hydrographs from observation wells in the area reflect seasonal recharge pulses.

The following ground-water flow system is hypothesized: Losses from the Gerstle River, losses from several small creeks draining the Alaska Range, and losses from the Tanana River east of Clearwater Creek recharge the sections of the aquifer that discharge at the Clearwater Creek network. Losses from the Delta River and Jarvis Creek are the main sources of recharge to the sections of the aquifer that discharge in the vicinities of Clearwater Lake and Big Delta. Additional work is needed to verify these hypotheses.