Successional Changes in the Hydrology, Water Quality,

Primary Production, and Growth of Juvenile Arctic

Grayling of Blocked Tanana River Sloughs, Alaska

By

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ABSTRACT

A comparative stream study was conducted to assess the influence of development and blockage on the hydrology, water quality, primary production, and Arctic grayling of Badger Slough, Alaska. Data collected showed that Badger Slough exhibited stable, clear flows throughout the summer, and higher total and total dissolved phosphorus, orthophosphate, alkalinity, pH, conductivity, and average temperatures, and lower winter dissolved oxygen concentrations than both Piledriver and 23-Mile Sloughs. Mean algal biomass (3.3 mg m^{-3}) and primary production (6.9 g O_2 m^{-2} d^{-1}) are greater than that recorded for any other interior Alaska streams and percent fines in riffle substrates have increased. However, growth of age-0 grayling remains high. Badger Slough has eutrophied due to increased nutrients and stable flows, and the quality of rearing habitat for age-0 fish remains good. However, an annual flushing flow of 8.0 m^3 s^{-1} is recommended for controlling accumulations of fines and maintenance of grayling habitat.

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INTRODUCTION

Blockage and development of lotic systems can affect the physical and chemical characteristics of these systems and ultimately affect the fish habitat (Hynes 1970, Ellis et al. 1979, Skulberg 1982, Welch 1992). The blockage of Tanana River sloughs, Alaska has created highly suitable habitat for Arctic grayling (*Thymallus arcticus*) populations; however it appears that urbanization of a slough's catchment may accelerate eutrophication, resulting in the development of unanesthetic aquatic vegetation, and depressed Arctic grayling populations. The impetus for this study was to demonstrate how blockage and development of Tanana River sloughs may influence the succession of a slough and its fish habitat, thereby providing a basis for the protection and management of desirable Arctic grayling habitat.

Badger Slough (previously part of Chena Slough) is a groundwater drainage that flows for about 27 km toward the northwest, between North Pole and Fairbanks. Prior to 1940, Chena Slough was one of several side channels of the Tanana River that carried large volumes of glacial water to the Chena River 35 km from its mouth (Figure 1). In 1933 it was estimated that 70% (100 m^3/sec) of the Chena River flow at Fairbanks was inflow from the Tanana River, and during the 1937 summer flood an estimated 50% of the 620 m^3/s peak flow at Fairbanks was due to overflow from the Tanana River (U.S. Congress 1938). Flooding problems attributed to Chena Slough resulted in the construction of several river engineering projects. In 1943, Chena Slough was bisected by the construction of Moose Creek Dike, which diverted the waters back into the Tanana

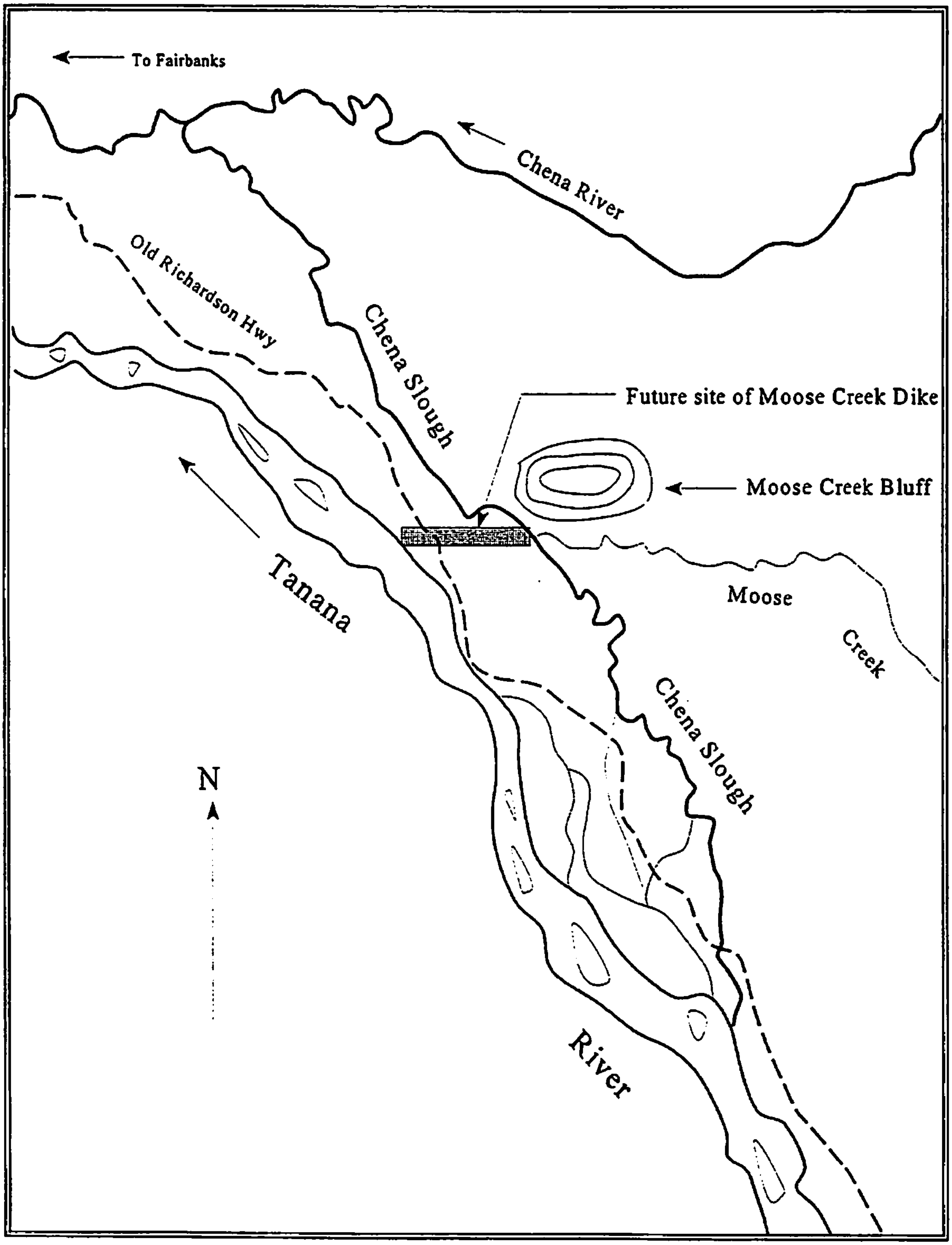


Figure 1. Chena Slough prior to construction of flood control projects, 1940.

and created both Badger (lower section of Chena Slough) and Piledriver (upper section) Sloughs (Figures 2 and 3). Subsequently, Badger Slough and the lower Chena River changed from glacial to clearwater streams. The Tanana River continued to flow into Piledriver Slough until the construction of the Chena River Flood Control Project when dikes were placed at the entrance of Piledriver Slough in 1976, blocking inputs of silty, glacial water from the Tanana River. These river engineering projects have turned Badger and Piledriver Sloughs into groundwater systems fed by up wellings from the Tanana River Aquifer.

The blockage of Badger Slough has significantly enhanced the recreational value of this system by creating new habitat for several species of fish and the establishment of an Arctic grayling fishery. The springs and seepage of Badger Slough are sufficient to keep portions of it open throughout the winter (Tack 1976). This results in Badger Slough being ice free by mid-April before the ice in the Chena River breaks up. Arctic grayling (hereafter referred to as grayling) enter Badger Slough in early spring to spawn and a majority of these fish return to the Chena River during late May and early June with a few grayling of all sizes remaining in the slough until freeze-up (Tack 1976, Hughes 1986). Consequently, Badger Slough has one of the earliest grayling fisheries in the Fairbanks area and has historically provided one of the highest angling success rates in the state of Alaska (Roguski and Winslow 1969). For the period 1968-1977, the annual harvest of grayling was estimated at 9,540 (Walker 1983). Badger Slough provides spawning and rearing habitat for the Chena River population, and grayling reared in Badger Slough are thought to make a large contribution to the Chena River fishery (Tack 1976; Walker

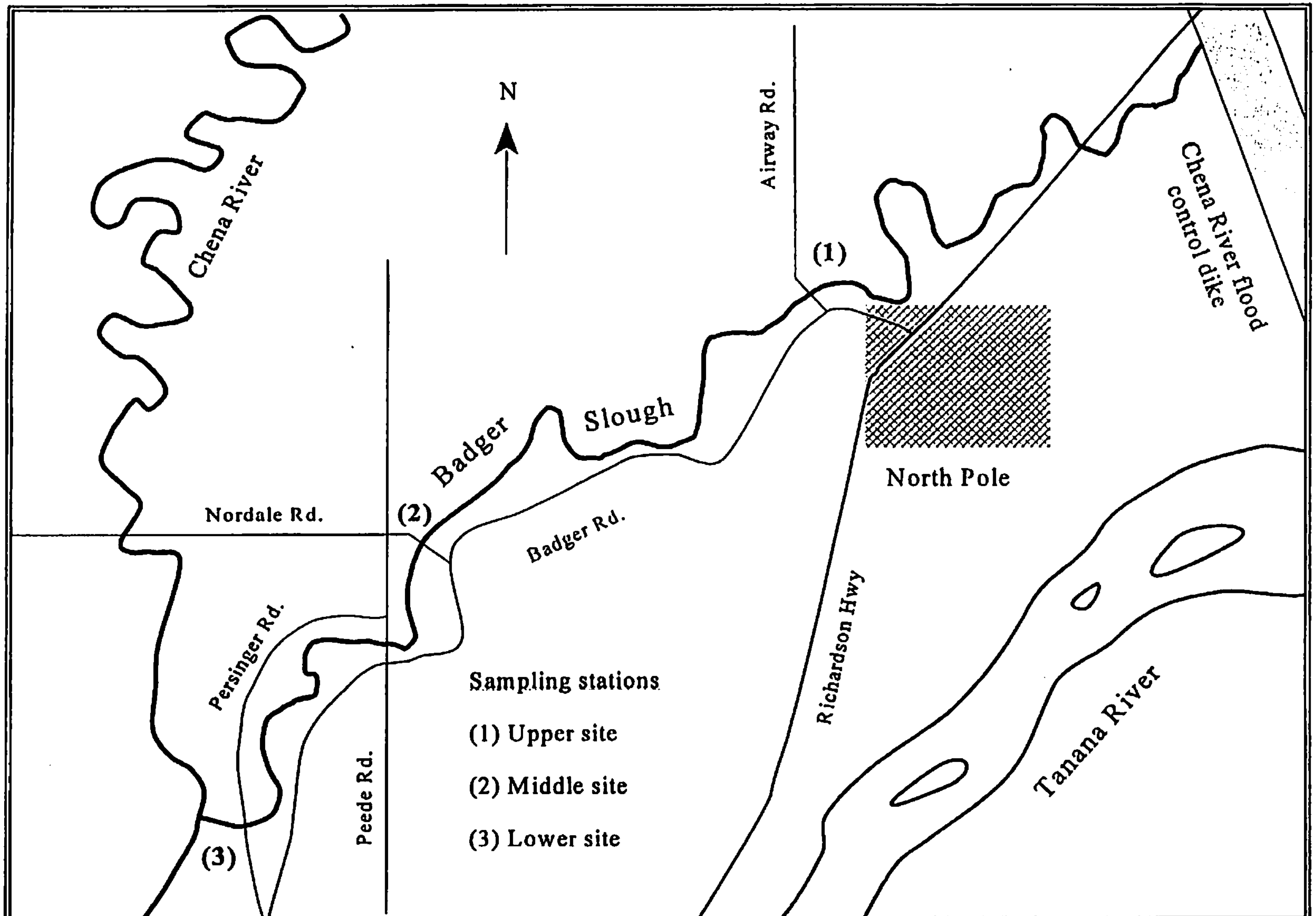


Figure 2. Location of sampling stations at Badger Slough, 1996.

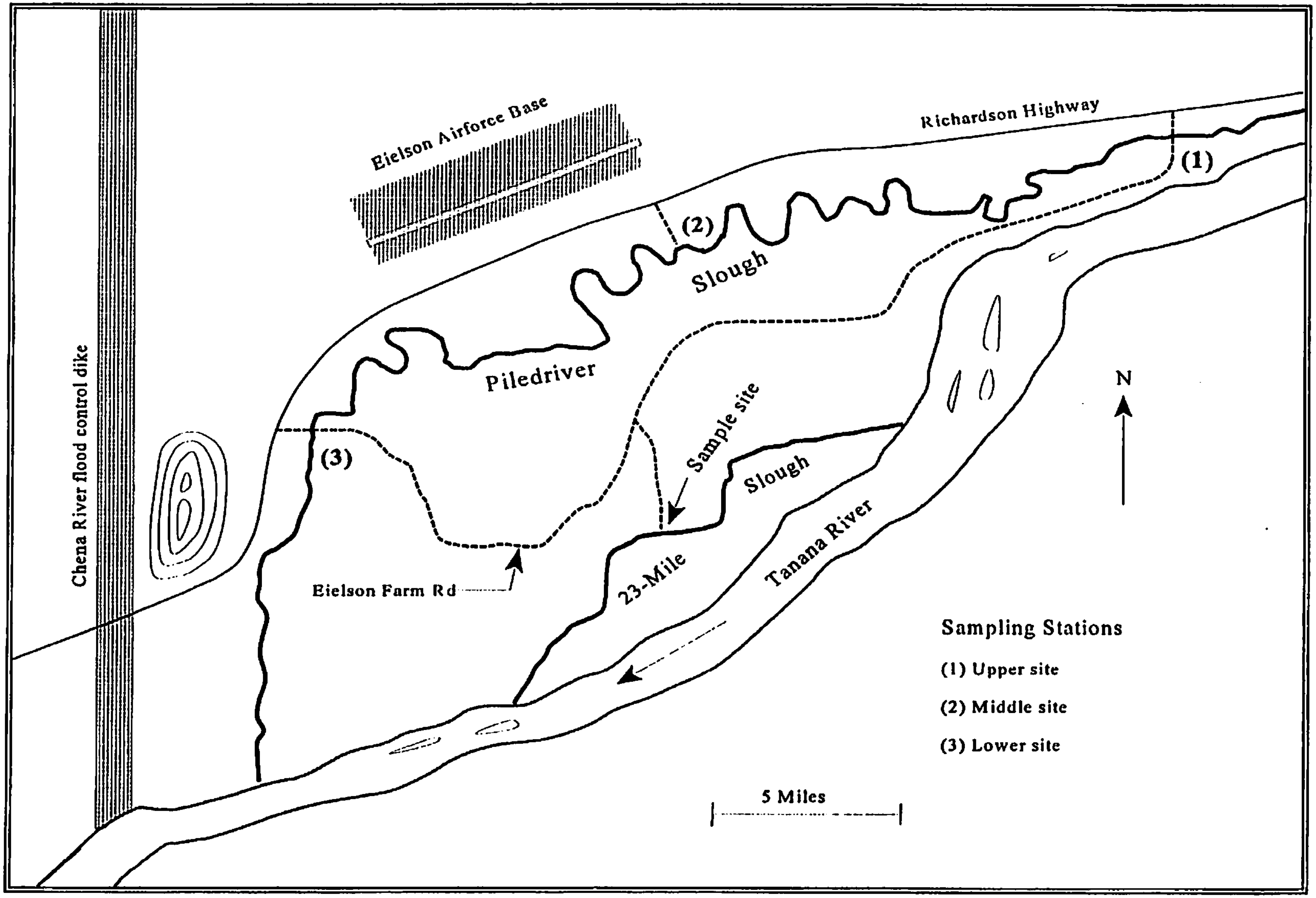


Figure 3. Location of sampling locations at Piledriver Slough, 1996.

1983). Using scale analysis, Walker (1983) estimated 30 to 50% of Chena River grayling originated from Badger Slough, and a mark-recapture study showed that the Badger Slough grayling represented an estimated 35% of the potential spawners of the lower 152 km of the Chena River (Fleming 1997).

The establishment of a grayling fishery in Badger Slough has coincided with the development of residential and commercial areas within Badger Slough's catchment and along its shore. In conjunction with this development of Badger Slough, the Alaska Department of Fish and Game, Sport Fish Division, has expressed concern over the apparent decline in numbers of grayling. Catch data suggest that the Badger Slough grayling fishery has declined from 11,064 grayling harvested in 1973 to an estimated 1,102 fish in 1990 (Tack 1974, Mills 1991). After 1990, catch-and-release regulations were established in Badger Slough. In addition to the decline of the grayling fishery, a growing concern among the residents of Badger Slough has developed about the aesthetic qualities and apparent eutrophication of the slough. In summer, Badger Slough supports substantial growths of aquatic vegetation (attached algae and rooted macrophytes) (Hughes 1986). It has been suspected that the urbanization of the drainage basin has resulted in cultural eutrophication of the slough and may ultimately impact the grayling population.

Although Badger Slough represents a unique situation in regards to its history, it shares common problems with other streams that have been impacted by humans such as flow regulation and urban pollution (i.e., sewage and urban runoff). Badger Slough is representative of a regulated river in that it no longer experiences periodic high-water or flushing events that are necessary for channel maintenance (particularly for the removal of fine sediments from gravel), riparian habitat maintenance, prevention of vegetation encroachment, and the maintenance or enhancement of fishery habitat (Reiser et al. 1989). Stream regulation can cause sedimentation problems which can negatively affect the stream biota (Milhous 1982, Waters 1995) and cause changes in physical and chemical factors (Welch 1992).

Stream sediments are known to influence the composition, abundance, density, biomass, and distribution of stream invertebrates (Cordone and Kelly 1961, Erman and Erman 1984, Minshall 1984,). Loss in macroinvertebrate habitat due to sedimentation may lead to a decline in the food base of salmonids, resulting in decreased biomass and abundance (Alexander and Hansen 1986, Gore 1989), decreased production (Waters 1982), and ultimately in reduced growth of juvenile salmonids (Crouse et al. 1981, Murphy et al. 1981). Intrusion of fines into the gravel substrates of streams can further impact salmonid embryos by decreasing redd permeability, and thereby decreasing dissolved oxygen (DO) concentrations within the redd (McNiel and Anhnell 1964, USEPA 1987, Chapman 1988).

Changes in water quality as a result of stream regulation (increased light penetration, reduced flows, increased temperature) (Milhous 1982, Reiser et al. 1989), and additions of limiting nutrients (nitrogen, phosphorous, carbon) can influence the biota of a stream (Hynes 1970, Deegan and Peterson 1992, Welch 1992). One influence often implicated is the over-development of algae. Nutrient enrichment experiments have demonstrated that nitrogen, phosphorus, or carbon additions can stimulate algal growth in streams (Grimm and Fisher 1986, Jones et al. 1984, Peterson et al. 1986, Dickman 1973). Positive correlations between periphyton biomass and ambient total nitrogen (TN) and total phosphorous (TP) concentrations have been established in the contiguous United States and Alaska (LaPerriere et al. 1989, Lohman et al. 1991, Van Nieuwenhuyse and Jones 1996). In addition to nutrient levels, light, temperature (Van Nieuwenhuyse and LaPerriere 1986), substratum, and particularly flood frequency can act to control algal production (Bushong and Bachmann 1989, Lohman et al. 1991). The synergistic effects of a regulated stream, characterized by stable, low flows, increased light penetration, and warmer temperatures, and nutrient enrichment can result in the accrual of undesirable, nuisance levels of attached algae (100-150 mg chlorophyll a m^{-2}) (Welch et al. 1988) and rooted plants (Hynes 1970, Welch 1992). In streams, beds of macrophytes can profoundly reduce and change the velocity profiles of a cross-section resulting in the deposition of organic and inorganic fines, accelerating eutrophication of a stream (Petts 1989). Hence, primary production can be further stimulated by greater nutrient availability at the sediment/water interface due to greater retention and processing of organic matter in the hyporheic zone (Coleman and Dahm 1990, Valett et al. 1994).

Whether excessive benthic algae exerts a negative influence on salmonid growth is uncertain. Decomposition of algal vegetation can deplete oxygen, resulting in impaired growth and the displacement or the killing of fish (Hynes 1970, Skulberg 1982, Warren 1971), and dense mats of filamentous algae can reduce habitat for benthic animals (Welch

1992). Conversely, increased primary production from physical and chemical changes can result in increased fish production and juvenile growth rates from the increased food availability of invertebrates (Warren et al. 1964, Deegan and Peterson 1992, Welch 1992, Bilby and Bisson 1992).

The purpose of this study was to characterize the successional state, hydrology, water quality, primary production, invertebrate drift, and growth of young of the year Arctic grayling in Badger Slough. This study was done in order to address the issue of how development has impacted Badger Slough and its grayling population, and to recommend possible remedial action. Because virtually no historical water quality data exist for Badger Slough, a comparative stream study using Badger, Piledriver, and 23-Mile Sloughs was conducted to assess the influences of development on Badger Slough. It was assumed that each of these sloughs represents a particular successional state of a blocked slough of the Tanana River. Badger Slough was blocked off in 1941 and is developed. Piledriver Slough was blocked off in 1976, has experienced some agricultural and residential development, and is probably representative of Badger Slough in the 1960s. Twenty-three-mile Slough is in the process of naturally being blocked, runs clear from early fall to spring, and is probably representative of Badger Slough immediately after blockage.

STUDY AREA

The area encompassing Badger, Piledriver, and 23-Mile Sloughs occupies part of the alluvial plain (approximately 244 m) in depth) of the Tanana River and is underlain by localized areas of permafrost (Collins 1990). The boreal, riparian vegetation is characterized by stands of white *Picea glauca* and black *Picea mariana* spruce, larch *Larix laricina*, cottonwood *Populus tacamahacca*, and overhanging alder *Alnus* spp. and willow *Salix* spp. The water table in the high-transmissivity aquifer that underlies the area is generally shallower than 4.6 m and fluctuates seasonally about 0.6 m , and slopes northwesterly (0.75 m km^{-1}), the principal direction of groundwater flow (Krumhardt 1982). The Tanana Basin has a continental climate of long, cold winters and short, warm summers. The average annual temperature in Fairbanks is -3°C (26°F) with record extremes of 37°C (99°F) and -54°C (-66°F) (ACRC 1997). Precipitation averages 27.7 cm (10.9 in) of water equivalent per year with 180 cm (71 inches) of snow (ACRC 1997).

Badger Slough drains a relatively flat (mean channel slope = 0.00063 m km^{-1}) area of approximately 68 km^2 and enters the main Chena River 34.6 km above the confluence of the Tanana and Chena Rivers. Badger Sloughs lies almost entirely within the municipality of North Pole, Alaska (population approx. 24,400) with most of its banks developed into residential areas. The groundwater in the area of Badger Slough, which has no piped sewage system, is contaminated by seepage from septic tanks (Krumhardt 1982). Homeowners bury their septic systems (including leach fields) 10 to 15 ft below the surface to avoid seasonal frost conditions, and in many areas, this places the system below or at the water table, thereby nutrifying the groundwater (Krumhardt 1982). For Badger Slough, only limited water quality data exist from 1949-51.

The groundwater springs and seepage of Badger (and Piledriver) Slough are sufficient to maintain open leads throughout the winter (Tack 1976), though long portions may be frozen to the substrate. Because of the slightly warmed temperatures, the ice melts out before ice in the Chena River breaks up, and Badger Slough tends to be ice-free from mid-April to late October. Discharge measurements made in Badger Slough during the ice-free season between 1948 - 1952, in the 1970s, and in 1982 averaged 3.4, 2.0, and 1.4 $m^3 s^{-1}$, respectively (USGS 1951, Walker 1983) with the higher discharges during 1948-52 being attributed to seepage from Piledriver Slough through the earthen Moose Creek Dike (Burrows 1995). The relatively stable Badger and Piledriver discharges are related to the level of the aquifer which fluctuates with the height of the Tanana River, rising during the summer months and falling during the winter (Krumhardt 1982).

Since the construction of Moose Creek Dike, Badger Slough has atrophied considerably over the years and is now much smaller and shallower (Collins 1990). Most of Badger Slough has a wide (20-30 m), fairly shallow channel with a thick layer of organic mud on the bottom (Hughes 1986). The flow in these sections is sluggish and the channel is being narrowed as rushes, alders, and willows colonize the banks. Few natural riffle areas exist and a majority of the riffle areas result from the constriction of flow through a culvert at one of several road crossings. In summer, the slough supports a thick growth of aquatic macrophytes (*Hippuris* sp., *Potomageton vaginitus*, *Sparganium* sp., *Vallisneria* sp., and *Ranunculus* sp.) and algae (diatoms, *Nostoc* sp., and filamentous algae).

Piledriver Slough is a 34-km-long (mean channel slope = 0.00077 m km^{-1}) groundwater system fed by the Tanana River aquifer draining an area of approximately 75 km^2 (Figure 3). The name Piledriver Slough originates from the logging industry in the early 1900s when piles were driven into the Tanana River to divert water down Chena Slough in order to float timber to downtown Fairbanks. In 1976, with the construction of the Chena River flood control project, dikes were placed at the top of Piledriver Slough, blocking the inputs of glacial Tanana River water, and Piledriver Slough was changed from a periodic Tanana River side-channel to a clearwater slough. Periodically, as in 1993, the Tanana River has overflowed its banks and drained into Piledriver Slough. Currently, Piledriver Slough consists of a series of long pools and shallow riffles. The bottom of the upper half of Piledriver is characterized by sandy pools and gravel riffles with little or no rooted aquatic vegetation. Further downstream, pools are layered with organic fines covered by mosses, and riffles support a sparse development of rooted macrophytes and algal mats.

Grayling have become established in Piledriver Slough at higher densities than other assessed populations in the Tanana River drainage (Fleming 1995). A substantial grayling fishery has developed and has provided as much as 20% of the drainage total catches in 1990 and 1991 (Mills 1991, 1992). Although popular among anglers, Piledriver

Slough has remained undeveloped, aside from some farms and a few residential houses at the beginning of the slough, because it mostly lies within the Eielson Air Force Base Reservation.

Twenty-three-mile Slough is a 10-km side-channel of the glacial Tanana River paralleling Piledriver Slough to the south (Figure 3). The slough runs clear from mid-September until late May when the rising Tanana River spills into the slough. Twenty-three-mile Slough is fed by the Tanana River aquifer and remains ice-free throughout the winter with shore-to-shore ice developing only during extreme cold (-40°C). The slough channel is composed of gravels and glacial sands free of aquatic macrophytes with periphyton colonizing the substrates when the slough is running clear. This slough is free of development and access to the slough is restricted by private property.

Samples for this study were collected from three locations along both Badger and Piledriver Sloughs to elucidate any upstream-downstream changes in the sloughs. Badger Slough samples were collected from the Persinger Road crossing (lower site), Nordale Road crossing (middle site), and Airway Road crossing (upper site) (Figure 2). Piledriver Slough samples were collected from Eielson Farm Road crossing (lower site), the old Bailey Bridge site (middle site), and the Stringer Road crossing (upper site) (Figure 3). Due to the restricted access of 23-Mile Slough only one sample location was selected, which was located on private land at the end of Crick Road, at its approximate mid-point.

METHODS AND MATERIALS

Discharge

Discharge was monitored in all sloughs for the duration of the ice-free season. Discharge was measured at the middle monitoring station for Badger Slough, at the lower monitoring station for Piledriver Slough, and at the sole monitoring station for 23-Mile Slough. The mid-section method was used to estimate discharge by measuring water depth and current velocities at 0.6 of water depth at 10-20 even-distance intervals across the stream perpendicular to the flow (Gorden et al. 1992). Current velocities were measured using a Marsh-McBirney model 201 portable water current meter. Staff gauges were placed at the monitoring stations and water levels were recorded opportunistically. A stage-discharge relationship was established and stream flows not measured directly were estimated using this relationship.

Water quality

Grab samples were collected 2-3 times per month (usually around noon) from May through August at each of the monitoring sites. All samples were taken in triplicate and samples not analyzed in the field were collected in labeled, acid pre-cleaned polyethylene bottles and transferred back to a lab for later processing. Slough temperatures (^{0}C) were recorded every 3 hours at monitoring sites during the field season using StowAway temperature data loggers. Specific conductivity ($\mu S\ cm^{-1}$) and pH were measured with a calibrated Checkmate digital pH/conductivity/DO meter. Total alkalinity ($mg\ L^{-1}$ as

$CaCO_3$), orthophosphate (mg L^{-1}), nitrate-N (mg L^{-1}), and ammonium-N (mg L^{-1}) were measured with a HACH Chemical Company field test kit containing a 2000 DR spectrophotometer. Turbidity (NTU) was measured with a HACH hand-held 2100P turbidimeter. Water samples for total nitrogen (µg L^{-1}) and for total and total dissolved phosphorous (µg L^{-1}) were sent to the University of Missouri at Columbia for analysis. Nitrogen concentrations were determined by using the second derivative UV scan after persulfate oxidation method (Crumpton et al. 1992). Phosphorous concentrations were determined using ascorbic acid color development after persulfate digestion (APHA et al. 1985). Dissolved oxygen (DO) (mg L^{-1}) was monitored from March 1996 to March 1997 using a YSI model 57 oxygen monitor, and during cold conditions HACH Accuvac DO ampules in conjunction with a HACH DR100 dissolved oxygen colorimeter were used.

Algal biomass

Summer benthic algal standing crops were indexed by measuring sestonic chlorophyll *a* concentrations (Swanson and Bachmann 1976). Sestonic algae refers to the fraction of benthic algae that is scoured off the substratum and is suspended in the water column. Sestonic chlorophyll *a* samples were taken in triplicate in conjunction with water quality sampling. Grab samples of suspended algae (1-2 L) were collected and filtered through a 0.3-μm glass fiber filter and frozen over desiccant until processing. All filters were ground with 90% acetone and allowed to extract for 24 hours in a refrigerator. Samples were centrifuged for 30 minutes at half speed and immediately analyzed for chlorophyll *a* content by the fluorometric method using a Turner Designs fluorometer calibrated against spectrophotometric readings of diluted standards (APHA 1985). When chlorophyll concentrations were at permissible concentrations, the trichromatic method was used to determine chlorophyll *a* concentrations using a Shimadzu UV-1601 spectrophotometer (APHA 1985).

Primary productivity

Primary productivity was estimated using the standard (APHA 1985) freewater single-station diel oxygen curve method of Odum (1956) as modified by Van Nieuwenhuyse and LaPerriere (1986). A YSI Model 56 dissolved oxygen monitor continuously recorded DO concentrations and temperature (^{0}C). Temperature and DO readings at 1-hour intervals were manually transferred from the strip charts to a data file. Changes in DO concentrations were plotted against time (hours) and corrected for diffusion. Tables from Mortimer (1981) were used to calculate oxygen saturation, and the formula of O'Conner and Dobbins (1956) was used to derive the reaeration coefficient. The reaeration coefficient was corrected for temperature according to Elmore and West (1961). From the DO vs. time plot, gross primary productivity was calculated using the trapezoid rule. Daytime respiration was quantified by connecting the pre-dawn and post-sunset minimums as suggested by Hall and Moll (1975). Accrual of oxygen other than from production and diffusion was considered negligible. Atmospheric pressure was calculated from altitude according to Goltermann (1969).

The DO monitor was always placed in a smooth-flowing stretch, usually at the end of a glide approximately 30 cm below the water surface. The DO probe was secured with a clamp to a section of a steel rod driven into the substrate. At all times a stirrer was engaged to ensure adequate flow across the membrane surface. Measurements were taken over 5-10 day intervals and the DO monitor was periodically calibrated against a YSI Model 57 dissolved oxygen meter. Observed means depths were used to adjust production estimates from g-O_2 m^{-3} d^{-1} to g-O_2 m^{-2} d^{-1}.

Invertebrate drift

Invertebrate drift samples were collected to obtain an index of invertebrate biomass (number of invertebrates m^{-3} hr^{-1}). Waters (1961) determined that the amount of drift in the water column is proportional to the production of invertebrates in riffles. Duplicate 2-hour drift samples were collected once in June and once in July near the three sampling locations in both clearwater sloughs. Standard drift nets were deployed during the same time on consecutive days until sampling was completed. A pair of nets was placed near the downstream end of each riffle, perpendicular to the stream flow, equidistant from the banks, with the bottom edge of the net at the substrate surface. The nets were secured to steel rods driven into the stream bed. Discharge measurements were made before and after the sampling period. Water velocity was measured at the center of the net mouth using a Marsh-McBirney model 201 portable water current meter. Samples were placed into and preserved in a labeled wide-mouthed bottle containing 95% ethanol solution and stored until laboratory analysis.

Juvenile Arctic grayling growth

Age-0 Arctic grayling were collected on four sampling occasions from July through September from both Piledriver and Badger Sloughs and measured to the nearest mm (fork length). Differences in growth (length) between sloughs and comparisons with historical growth patterns (Walker 1983) were used to indicate a change in the quality of rearing conditions in Badger Slough. In fish, growth is very labile, influenced by abiotic and biotic factors. Water temperature, velocity, hardness, and pH, as well as food supply and competition, may be jointly or individually important in determining fish growth along a stream's gradient (Hynes 1970). Age-0 grayling were selected as opposed to age-1+ fish because of the migratory behavior of the grayling in Badger Slough.

Using minnow seines (4.6 m long x 1.2 m wide with 1.6 mm mesh, and 6.1 m x 1.2 m with 3.1 mm mesh) age-0 grayling were collected within three reaches located in the upper, middle, and lower segments of both Badger and Piledriver Sloughs. A minimum of 100 fish per sampling reach were collected and all age-0 grayling captured were measured and recorded to the nearest mm. Due to the active nature of juvenile fish, grayling were anesthetized by immersing them in a dilute solution of tricaine methanesulfonate (MS-222) for 3 minutes. Fish were held in temporary gravel pools dug out of the bank until sampling was completed to ensure that fish were not recaptured and were fully recovered.

Substrate

Bed materials from riffle areas were collected from areas near each of the monitoring sites for each slough. These riffles were selected because that they appeared representative and were unaffected by man-made structures such as culverts. Eight to ten randomly selected substrate samples were collected from each riffle using a cylindrical substrate corer with a minimum of 5 kg of material being removed. The sediment corer was 27 cm in height by 18 cm in diameter and essentially represented an opened, one-pound coffee can. Samples were collected by driving the corer into the substrate, digging the bed material away from the downstream edge of the corer, slipping a metal plate underneath, and lifting out the sample. The top 20 cm of the stream substrate was placed into a labeled sampling bag and transported back to the lab for dry sieving. Samples were oven dried (48 hr at 150° C) and passed through a series of 12 US Tyler sieves following a geometric progression. Sieve sizes used were 128, 64, 32, 16, 8, 4, 2, 1, 0.5, 0.25, 0.125, and 0.633 mm. Substrate sizes and percent fines were analyzed by plotting a cumulative frequency curve (% mass), the X-axis being the particle size (mm) and the Y-axis being percentage finer (cumulative) (Gorden et al. 1992).

Flushing flows

Duration and magnitude of flushing flows were estimated using the incipient motion methodology based on the Shield entrainment function (Reiser et al. 1989). This method was selected because of the lack of extensive flow records often needed for assessing flushing flow requirements and the inability to conduct test flow releases.

The incipient motion methodology provides an estimate of discharge expressed as discharge per unit stream width for flushing fines from bed sediments. In this method, critical unit discharges for bed mobilization are a function of grain size and channel slope (Reiser et al. 1989). The relationship is derived from the Shields entrainment function. This relationship can be expressed as:

$$q = 47k^{5/3}\left(d_{50}^{3/2} / S^{7/6}\right)$$

where q = unit discharge (cms/m), S = the channel slope (m/m), k = estimated Shields parameter, and d_{50} = the median grain size where half of the sample based on mass is larger or smaller (Reiser et al. 1989). There are several values for k that might be selected based on the condition of the stream bed. Milhous (1986) recommends a k-value of 0.03 for movement of the amour layer and "deep" flushing of trapped fines in riffle segments of a stream and it was therefore used. The duration of the estimated flushing flows was approximated using the travel time - median bed grain size relationship as described by Reiser et al. (1987). Median grain sizes were obtained from the analysis of the slough substrates as previously described. Stream widths were measured with a 100 m tape measure and channel slope was measured utilizing a level and graduated staff as described by Gorden et al. (1992).

Statistics

A one-way analysis of variance was performed to determine significant differences ($P<0.05$) between means of measured variables (Neter et al. 1990). Tukey analysis was then used to make pairwise comparisons of a variable within and among sloughs. For water quality data and sestonic algae data, averages from May 14 - September 1 were calculated and tested for significant differences among sampling stations within a slough and for differences between sloughs. The average lengths of age-0 grayling from one sampling event were tested for significant differences between sampling sites within a slough, and when no differences were found, data sets were pooled and differences in mean lengths between Piledriver and Badger Sloughs were tested. For percent fines, samples for a particular size class from a slough were averaged, and then these averages were tested for significant differences between sloughs.

RESULTS

Discharge

Flows in Badger, Piledriver and 23-Mile Sloughs averaged 1.23 (1.01 - 1.50), 1.65 (1.45 - 2.10), and 3.34 (0.85 - 6.12) $m^3 s^{-1}$, respectively (Appendix Table 6). Flows for Piledriver and Badger Sloughs tended to remain relatively stable, and excluding precipitation events, fluctuated slightly with the flow in the Tanana River (Figure 4). Excluding the early July storm event, maximum flows in all three sloughs occurred in early August when the Tanana River was at its maximum flow. Minimum discharge for all sloughs was recorded in late May and early June, a period of time between breakup and the increase in discharge in the Tanana River due to glacial melt.

Water quality

Average temperatures (^{0}C) from May 14 - August 27 were 1.5 degrees warmer in Badger Slough than in Piledriver Slough. Due to vandalization of the data logger at the upper Badger Slough site, only the lower and middle monitoring stations were used from Badger and Piledriver Sloughs. Maximum recorded temperatures for Badger, Piledriver, and 23-Mile Sloughs were 20.7, 18.5, and 17.3, respectively, and minimum temperatures were 2.6, 2.1, and 0.6. (Appendix Tables 7 - 9). During May and into mid-June water temperatures in the lower reaches of Piledriver Slough were depressed until the dissipation of extensive shelf ice in early June (Figure 5). By mid-October, both Piledriver and

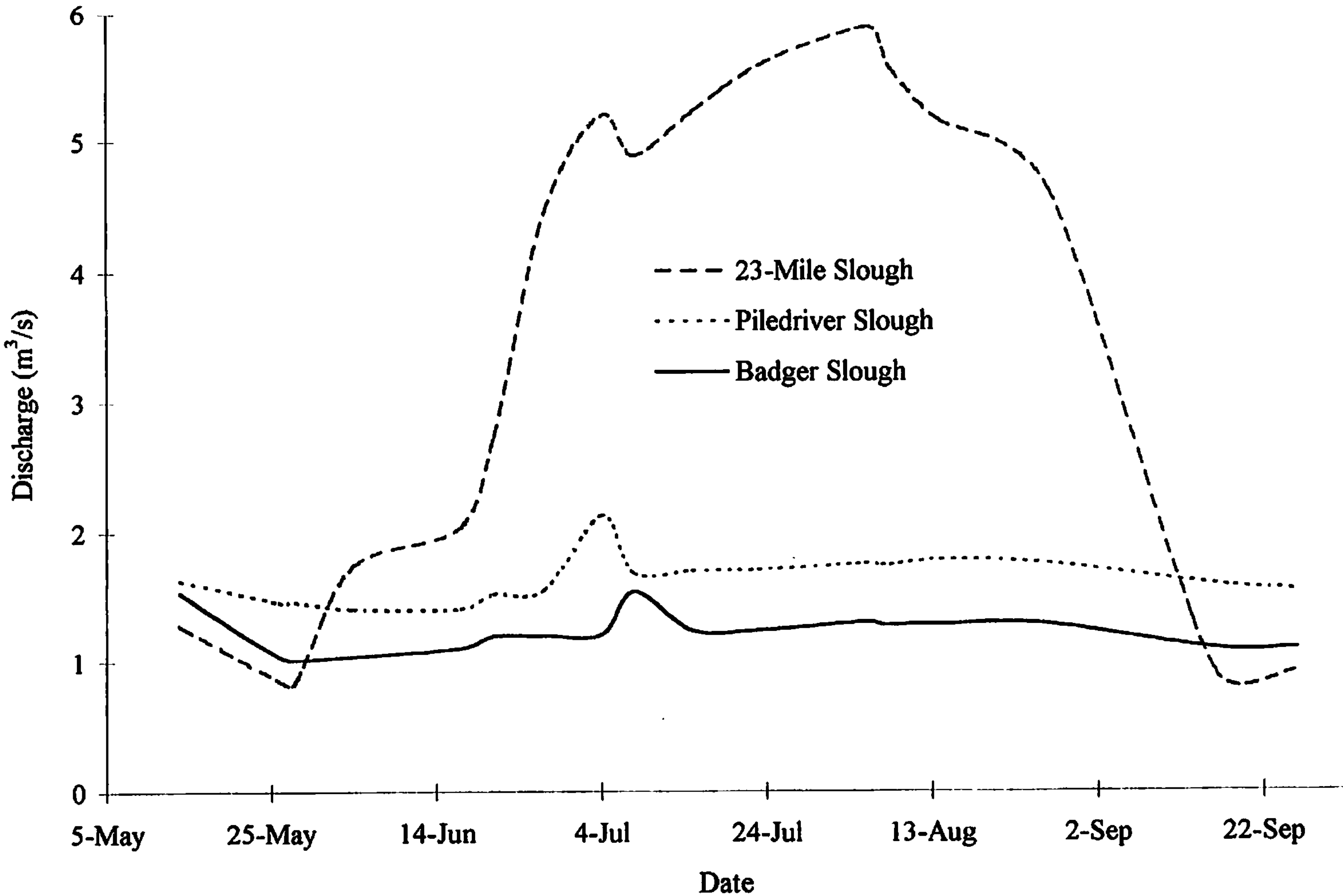


Figure 4. Discharges for Badger, Piledriver, and 23-Mile Sloughs, 1996.

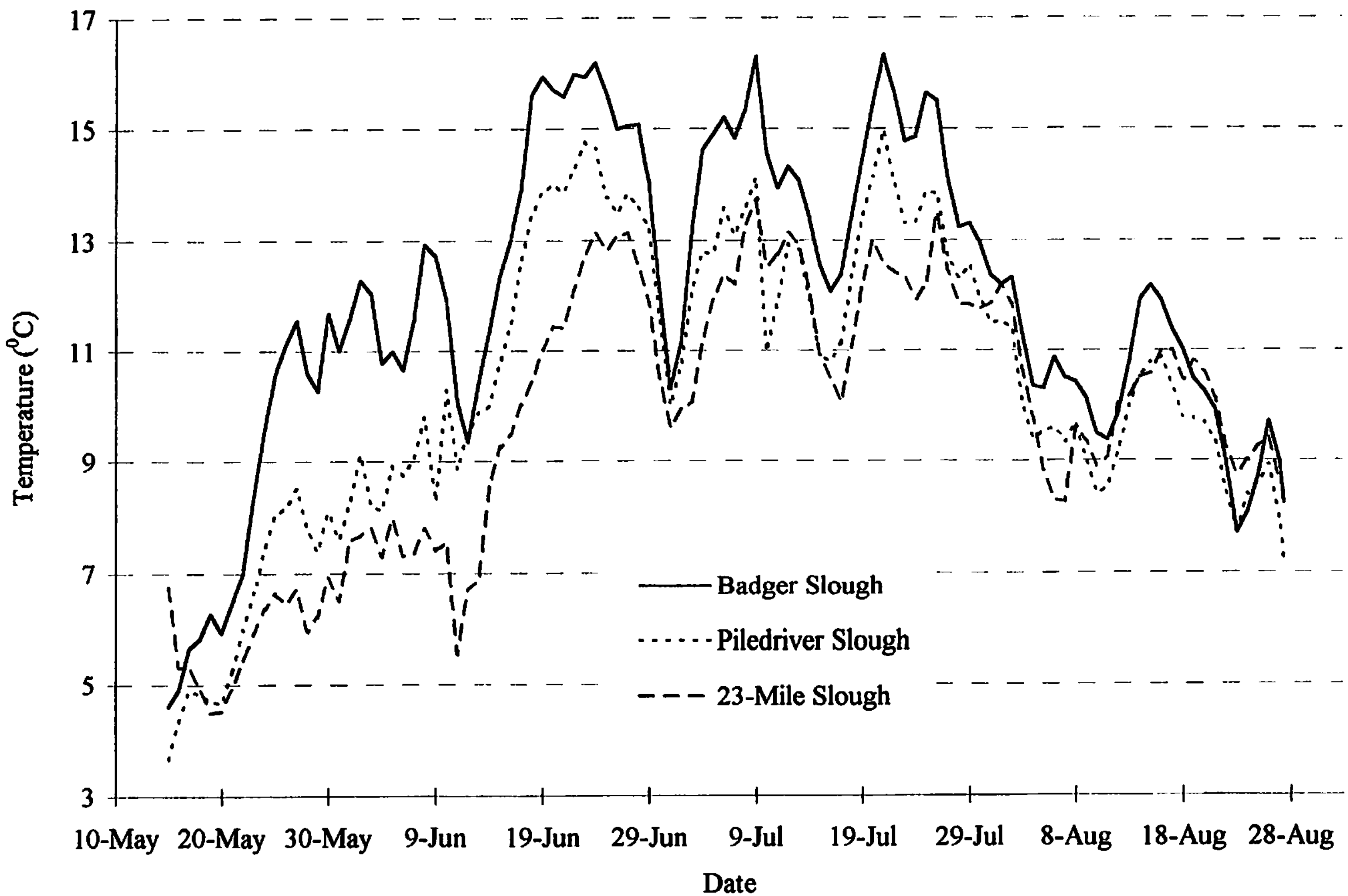


Figure 5. Average daily temperatures for Badger, Piledriver, and 23-Mile Sloughs, 1996.

Piledriver and Badger Sloughs were mostly ice covered with water temperatures at 0^0 C. After ice-up, temperatures remained at 0^0C until the last sampling date on February 3, 1997.

From May 14 to September 1, Badger Slough consistently displayed significantly higher values for pH, alkalinity (Figure 6), and conductivity than Piledriver and 23-Mile Sloughs ($P<0.001$) (Table 1). Prior to intrusion of the Tanana River water into 23-Mile Slough in early June, there were no significant differences in alkalinity, pH, turbidity, and conductivity between Piledriver and 23-Mile Sloughs. Intrusion of Tanana River water into 23-Mile Slough resulted in decreased conductivity, alkalinity, and pH, and turbidity increased as discharge increased. Turbidity was significantly different among sloughs (23-Mile > Badger > Piledriver) ($P<0.001$) (Figure 7).

Ammonium-N and Nitrate-N levels were consistently below detection limits, 1.0 and 0.8 mg L^{-1}, respectively. No significant differences were found for TN and TDN among sloughs. Processing error may have occurred for TN and TDN samples and the values are therefore suspect.

Mean orthophosphate-P values were significantly different among sloughs (Badger > Piledriver and 23-Mile), as well as among sampling stations within Badger and Piledriver Slough (upper site > middle and lower sites) ($P < 0.01$) (Table 1). Mean TP was significantly different among sloughs (23-Mile > Badger > Piledriver), as well as among sampling stations within Badger and Piledriver Sloughs (upper site > middle and lower sites) ($P < 0.01$). No differences were found in TDP between Piledriver and 23-Mile Sloughs, and TDP was significantly greater in Badger than both Piledriver and

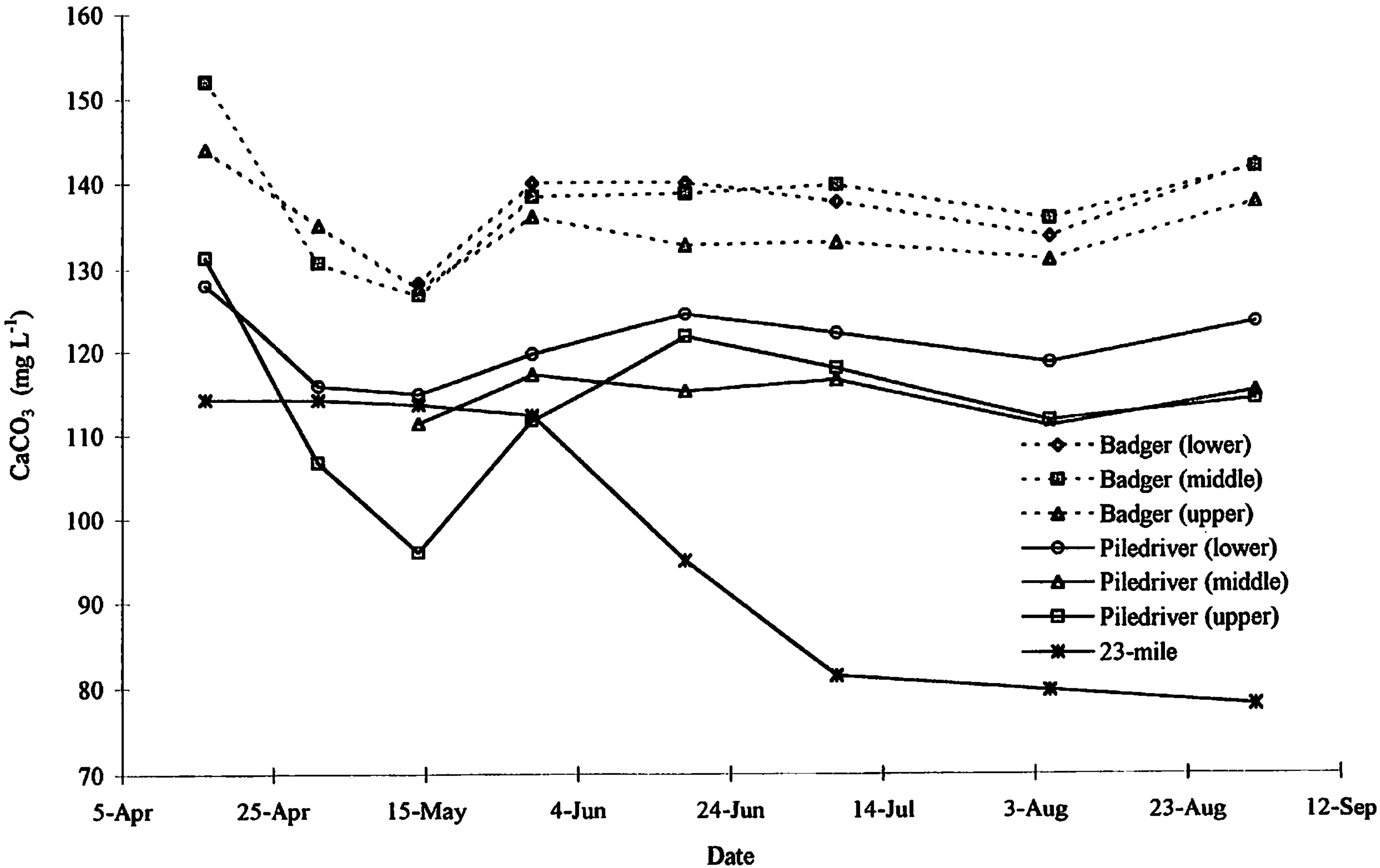
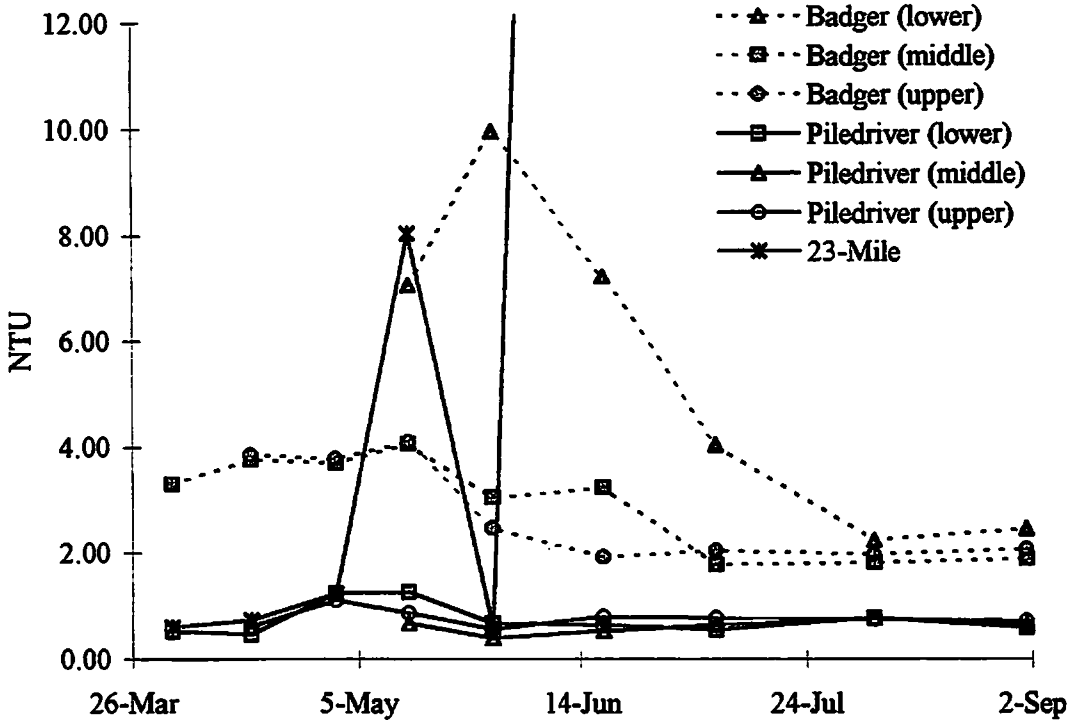


Figure 6. Alkalinity (as $CaCO_3$) at monitoring stations for Badger, Piledriver, and 23-Mile Sloughs, 1996.

Table 1. Water quality data (paired means ± SD) at water monitoring stations for sloughs, May 14 to September 1, 1996.

Sample location	Alkalinity ($CaCO^3$ mg/L)	pH	conductivity (µS/cm)	Turbidity (NTU)	TP (µg/L)	TDP (µg/L)	Orthophophate-P (µg/L)	TN (mg/L)	DN (mg/L)
Badger									
Upper	133 ± 4	7.7 ± 0.4	327 ± 12	5.5 ± 2.9	66 ± 29	34 ± 7	32 ± 21	1.59 ± 1.56	1.10 ± 1.22
Middle	137 ± 5	7.8 ± 0.4	328 ± 12	2.6 ± 0.9	38 ± 9	23 ± 5	20 ± 5	1.14 ± 1.31	1.14 ± 1.46
Lower	137 ± 5	7.9 ± 0.4	326 ± 12	2.4 ± 0.8	33 ± 8	21 ± 4	20 ± 9	0.83 ± 1.18	0.76 ± 1.09
Mean	136 ± 5	7.8 ± 0.4	327 ± 12	3.5 ± 2.3	45 ± 23	27 ± 8	24 ± 20	1.13 ± 1.39	0.96 ± 1.26
Piledriver									
Upper	112 ± 8	7.4 ± 0.4	303 ± 14	0.7 ± 0.1	18 ± 3	15 ± 4	7 ± 5	1.18 ± 1.54	1.01 ± 1.28
Middle	115 ± 3	7.5 ± 0.4	293 ± 20	0.6 ± 0.2	10 ± 2	8 ± 3	1 ± 1	1.31 ± 1.47	1.07 ± 1.21
Lower	121 ± 3	7.4 ± 0.3	303 ± 16	0.7 ± 0.3	9 ± 3	8 ± 3	0 ± 0	1.06 ± 1.40	1.16 ± 1.33
Mean	116 ± 6	7.4 ± 0.4	300 ± 8	0.7 ± 0.2	12 ± 7	11± 5	3 ± 5	1.29 ± 1.48	1.12 ± 1.25
23-Mile									
Middle	96 ± 6	6.8 ± 0.1	269 ± 34	362 ± 369	203 ± 216	13 ± 8	2 ± 3	1.02 ± 1.16	0.82 ± 0.81



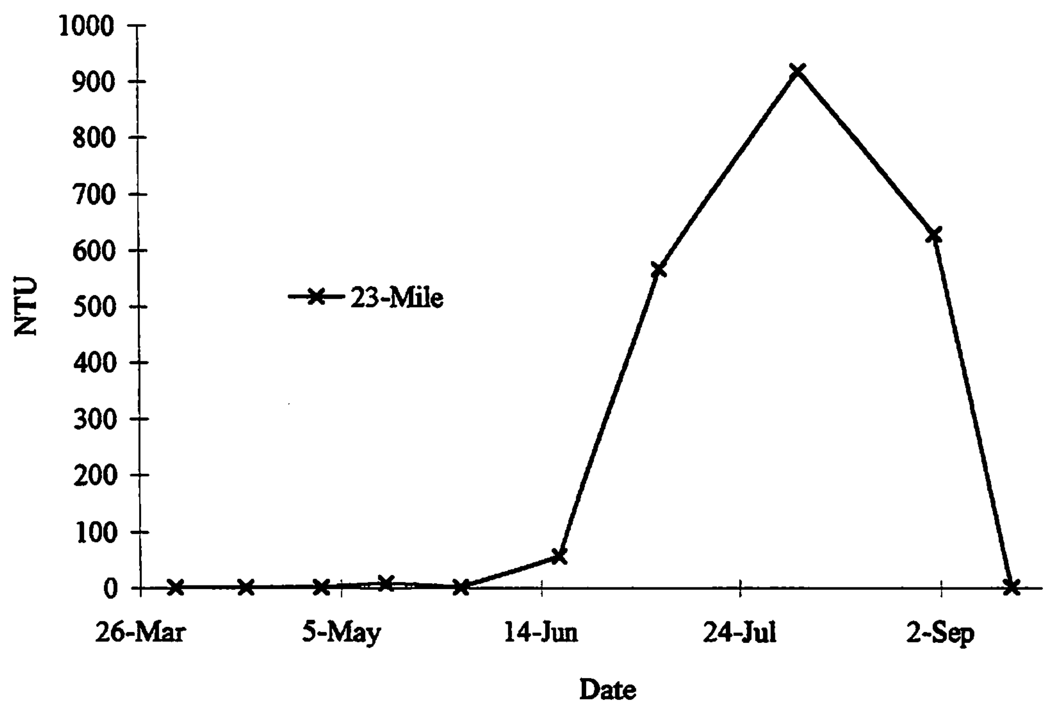


Figure 7. Turbidity at monitoring stations for sloughs (upper chart), and on an expanded scale, 23-Mile Slough (lower chart), 1996.

23-Mile Sloughs. The highest total phosphorus concentrations tended to occur in May and June (Figure 8). Orthophosphate and TDP also followed this pattern. A significant relationship ($P < 0.001$) was found between TP and turbidity in 23-Mile Slough (Figure 9).

Minimum DO concentrations (mg L^{-1}) were observed in March 1996 in all three sloughs (Table 2). From May 15 to October 4, DO concentrations remained above 9.0. After the development of ice cover, DO decreased more rapidly at all three sampling stations in Badger Slough than in Piledriver Slough. Extensive open leads above the lower sampling station during a warming trend in early February coincided with the rebound of DO concentrations at the lower monitoring station of Badger Slough. In 23-Mile Slough, DO levels remained >8.0 as it tends to remain ice free throughout winter.

Algal biomass

Suspended chlorophyll a concentrations (May 15 to September 1) collected from Badger, Piledriver, and 23-Mile Sloughs averaged 3.29 ± 2.35, 0.71 ± 0.47, and 2.53 ± 1.47 mg m^{-3}, respectively (Appendix Table 10). Average sestonic chlorophyll a concentrations in Badger and 23-Mile Sloughs were not significantly different from each other but both were significantly greater than Piledriver Slough ($P < 0.01$). Additionally, there were significant differences ($P < 0.05$) between stations within Badger Slough (lower>middle>upper) as well as within Piledriver Slough (lower>both middle and upper) (Figure 10). Maximum concentrations in all sloughs were found during June and minimum concentrations occurred at the end of summer. Maximum chlorophyll a

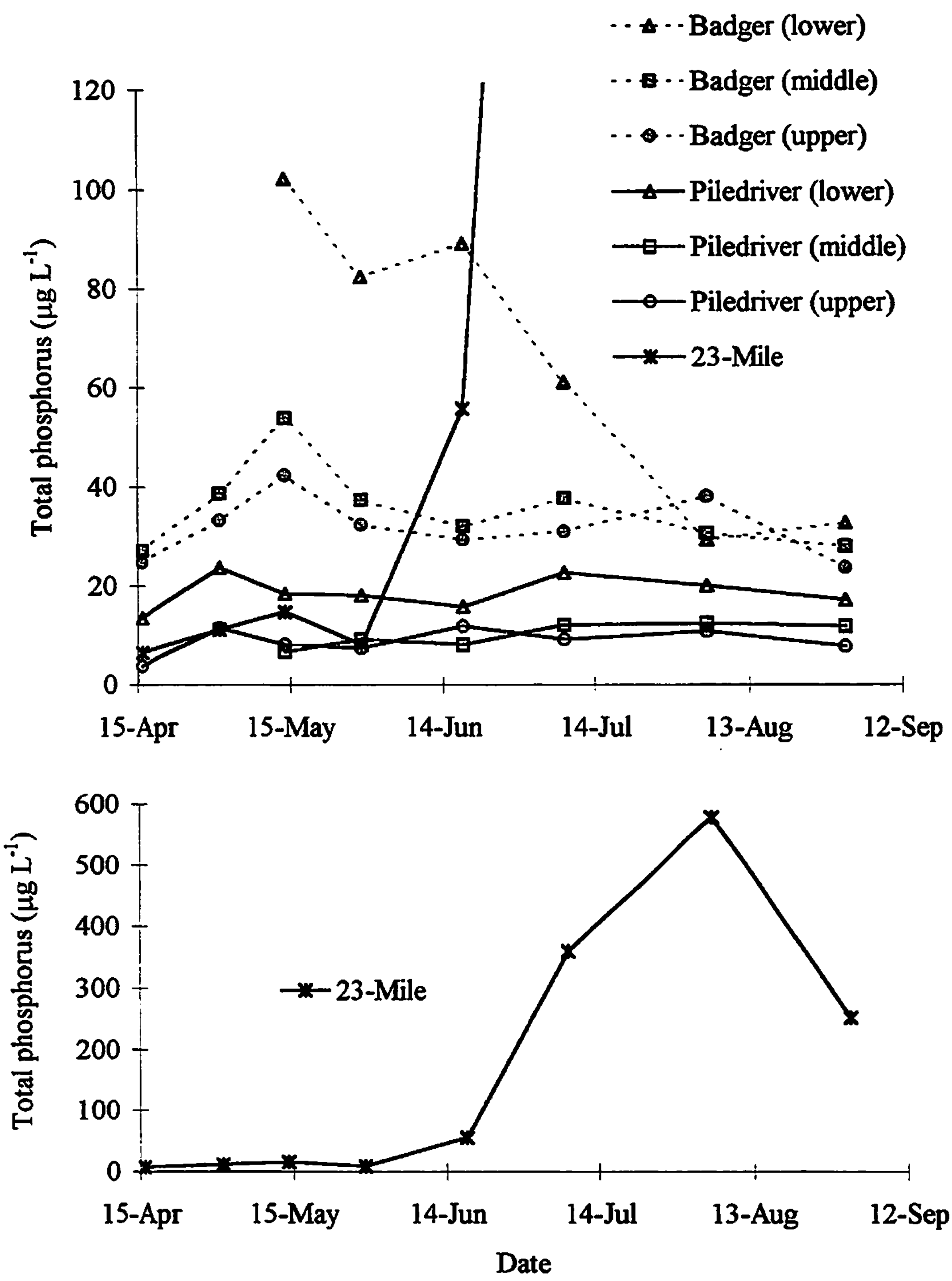


Figure 8. Total phosphorus at monitoring stations for sloughs upper chart), and on an expanded scale, 23-Mile Slough (lower chart), 1996.

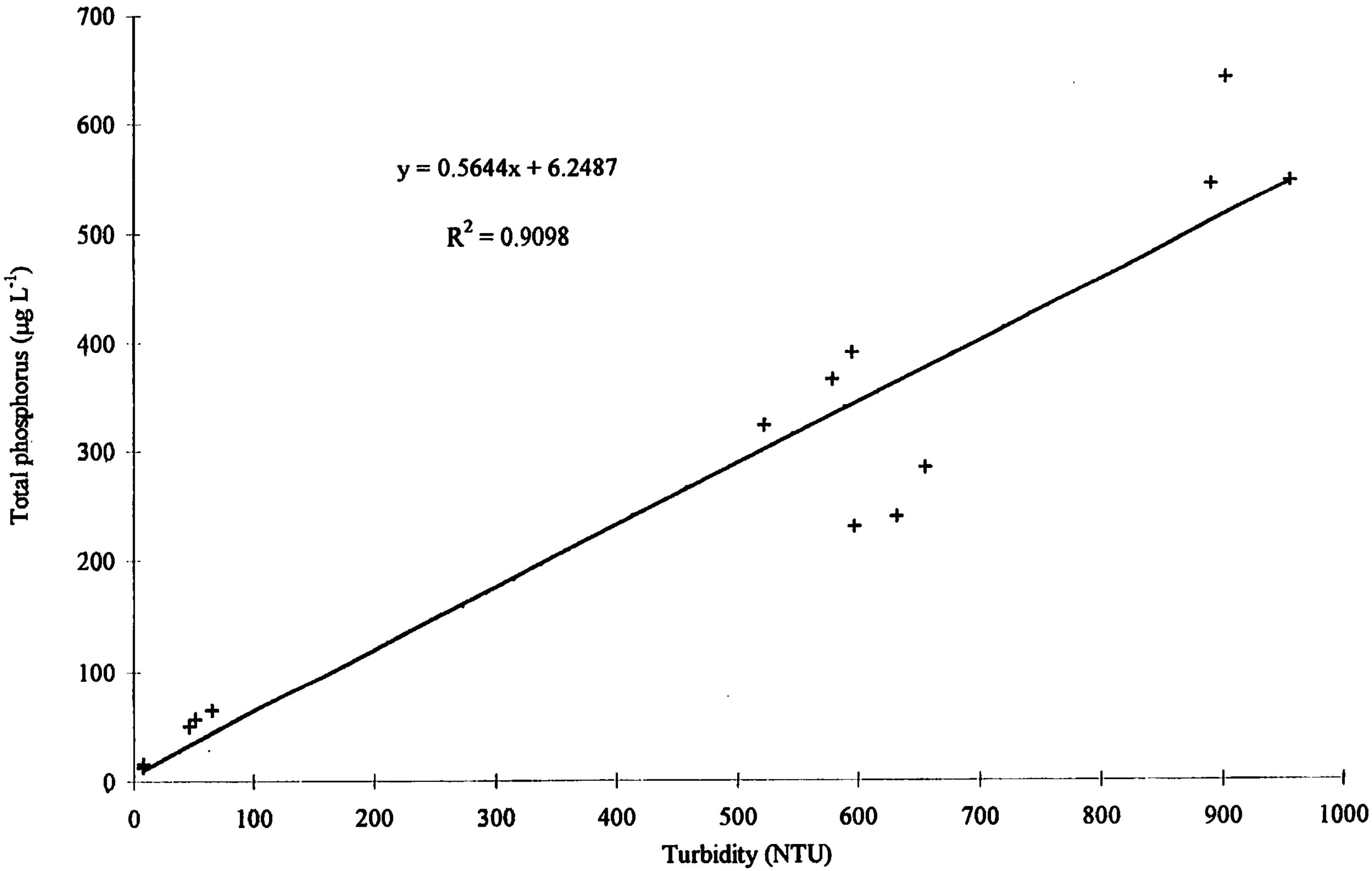


Figure 9. Relationship between turbidity and total phosphorus concentrations in 23-Mile Slough, 1996.

Table 2. Dissolved oxygen concentrations (mg L^{-1}) at slough sampling stations, March 15, 1996 to February 4, 1997.

Date	Badger			Piledriver			23-Mile
	lower	middle	upper	lower	middle	upper	
15-Mar	--	1.4	0.85	2.25	--	2.5	8.08
2-Apr	--	1	3.3	4.1	--	2.9	8.5
10-May	8.8	6	6	7.2	--	7.8	>9.0
1-Jun	>9.0	>9.0	>9.0	>9.0	>9.0	>9.0	>9.0
1-Sept	>9.0	>9.0	>9.0	>9.0	>9.0	>9.0	>9.0
4-Oct	--	7.8	--	9	--	--	8.8
6-Nov	3.2	1.4	3.5	5	6	5.5	8.6
13-Dec	3	0.9	2.3	4.25	6.7	3	8.5
4-Feb	6	1.3	2.0	4.3	5	2.7	7.8

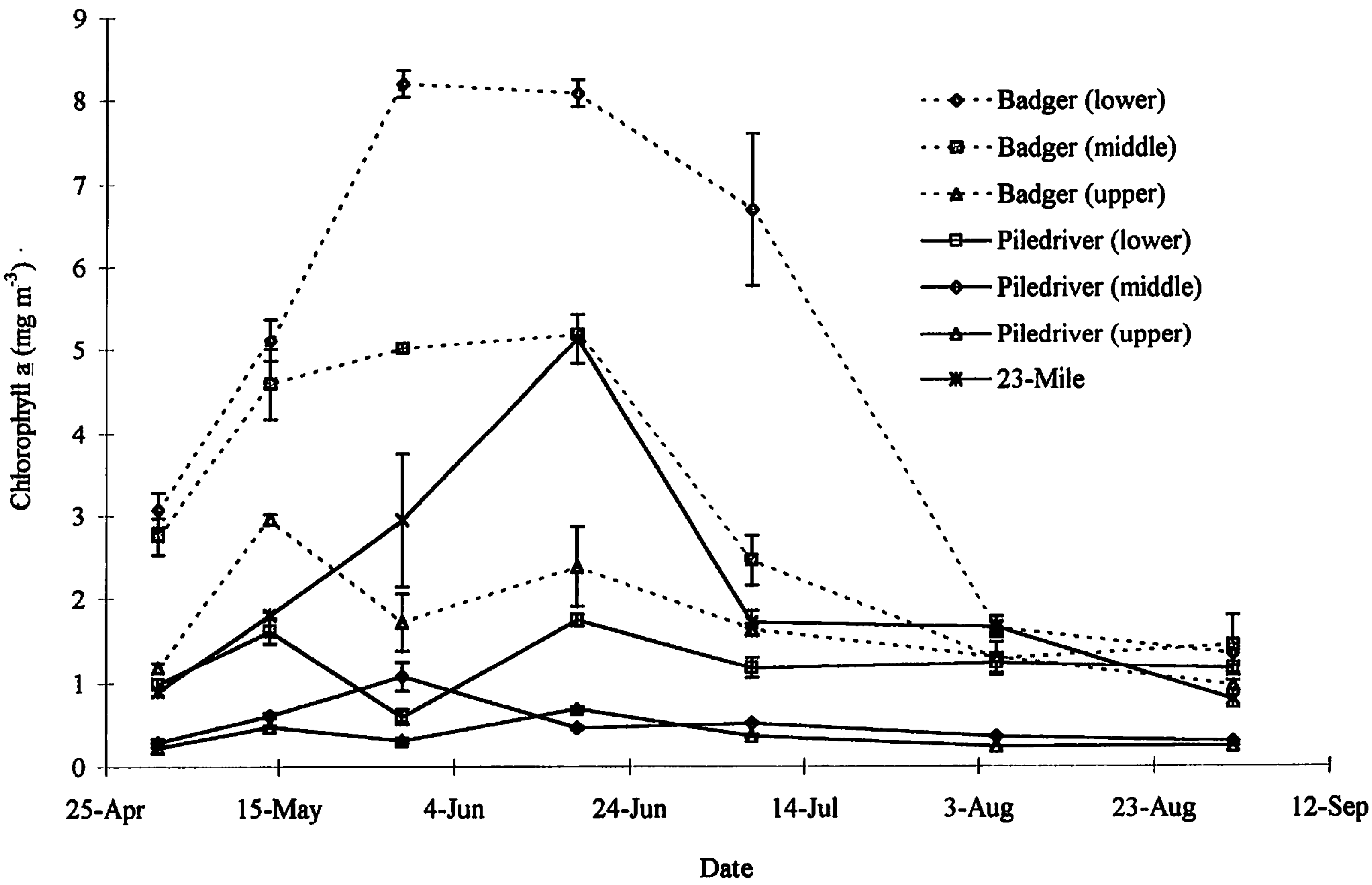


Figure 10. Average (± SD) sestonic chlorophyll a concentrations in sloughs at water quality monitoring stations, 1996.

concentrations in 23-Mile Slough coincided with the intrusion of the Tanana River resulting in increased scouring of attached algae. A positive relationship ($P < 0.001$) was found between TP and sestonic chlorophyll a (Figure 11).

Primary productivity

Simultaneous comparisons of gross primary productivity (g-O_2 m^{-1} d^{-1}) between the upper, middle, and lower sampling stations of Badger and Piledriver Sloughs were not possible due to the failure of a DO probe. However, some general comparisons were still possible.

Gross primary productivity (GPP) rapidly decreased below detection limits (0.2 g-O^2 m^{-1} d^{-1}) in 23-Mile Slough as turbidity increased from the intrusion of glacial Tanana River water (Figure 12). After June 24, GPP was no longer measurable in 23-Mile Slough. In Badger Slough (middle site), GPP estimates ranged from a maximum of 6.9 in early July to a low of 0.63 in fall (Appendix Tables 11 - 13). In Piledriver Slough, productivity attained maximum value of 4.0 during mid-August at the lower sampling station and a low of 1.1 during mid-July at the middle sampling station.

July productivity estimates at the middle sampling station in Badger Slough were five times greater than the middle sampling station in Piledriver Slough and almost twice that of the lower Piledriver station. Even upper Badger Slough displayed greater productivity than did lower Piledriver Slough. These comparisons are notable because the highest observed productivity estimates tended to occur farthest downstream during mid-summer. This pattern of increasing primary production estimates is consistent with

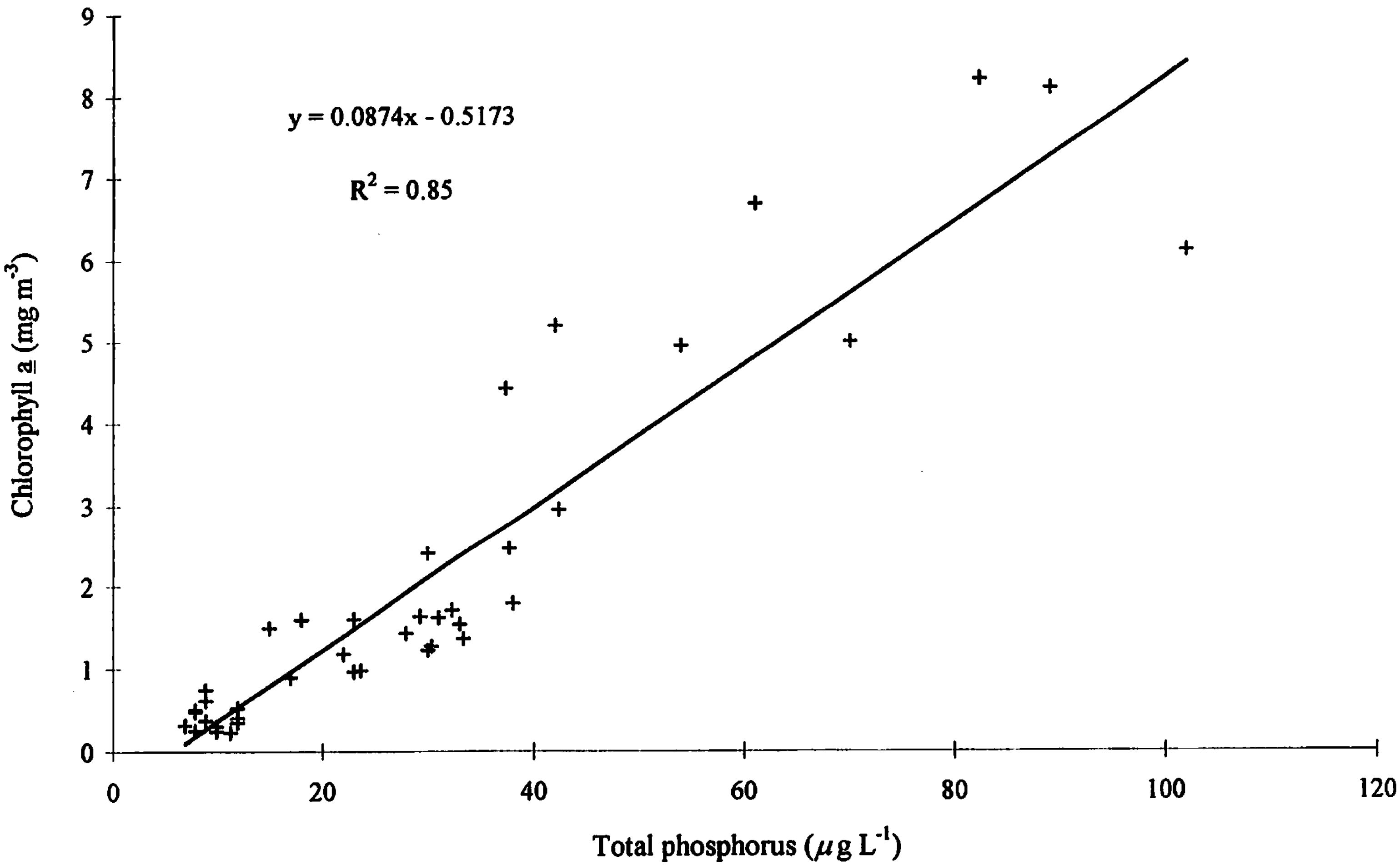


Figure 11. Relationship between total phosphorus and sestonic chlorophyll a concentrations among sampling stations within Badger and Piledriver Sloughs, 1996.

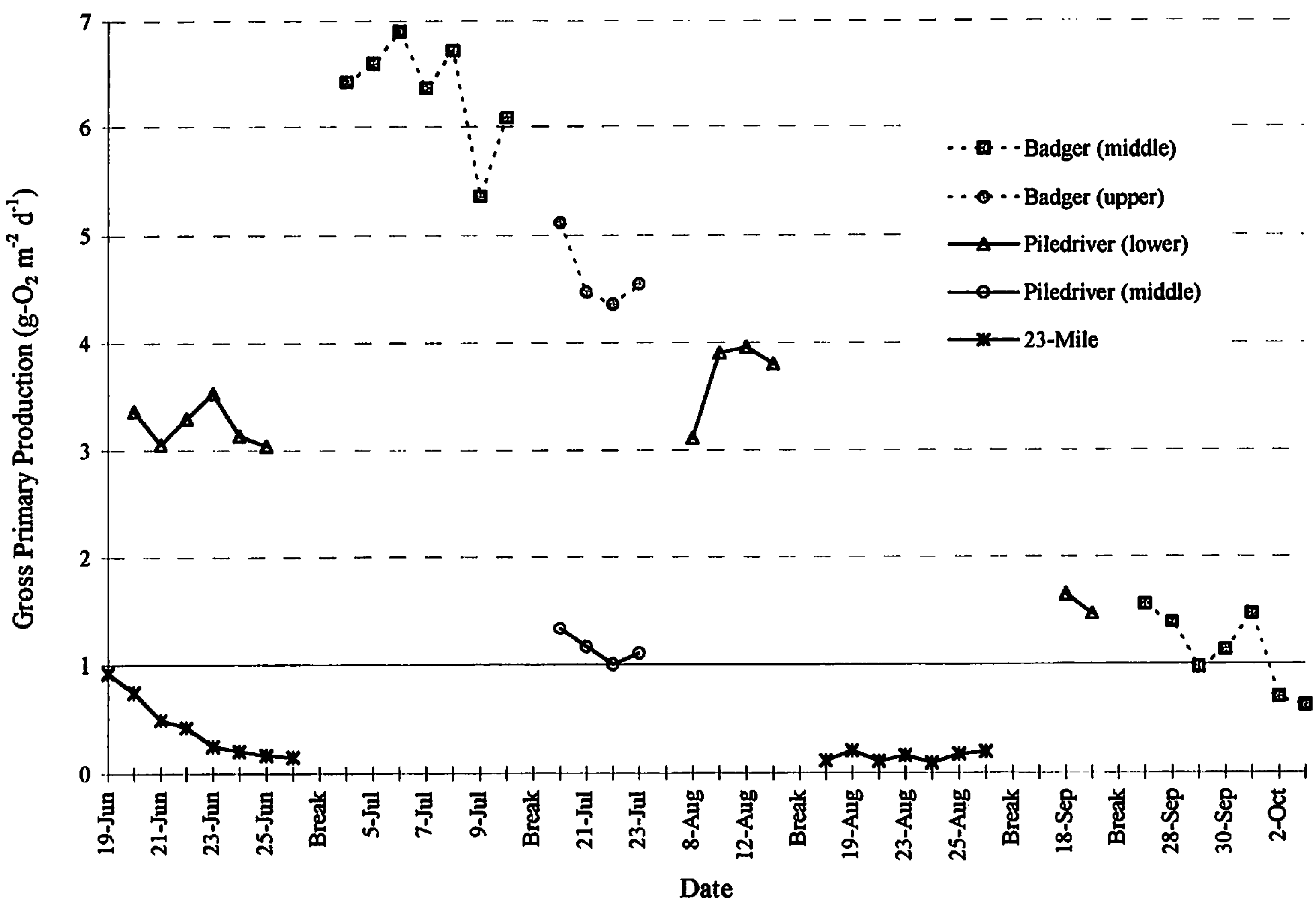


Figure 12. Gross primary production in Badger, Piledriver, and 23-Mile Sloughs, 1996.

the pattern of chlorophyll a concentrations observed. In Badger and Piledriver Sloughs, the chl a values also tended to increase as one moved downstream with the maximum concentrations occurring during the month of June.

Invertebrate drift

Unfortunately, copious amounts of filamentous algae and seston clogged the drift nets in Badger Slough, which negated any accurate measure of drift and made the separation of the invertebrates from the seston a formidable task. Therefore, the drift samples were used only for qualitative assessments.

Especially notable were the large numbers of planktonic organisms (mainly chydorids, copepods, and daphnids) that tended to dominate the drift samples, as well as large numbers of ostracods. Visual inspection revealed that drift samples also contained Ephemoptera, Plecoptera, Tricoptera (EPT taxa), and Diptera in both Badger and Piledriver Sloughs. Visually, the densities of the planktonic organisms appeared equivalent between Badger and Piledriver Sloughs. Drift samples from 23-Mile Slough (collected in mid-July after intrusion of the Tanana River) also contained EPT taxa and Diptera, however, in far fewer numbers than Badger and Piledriver Sloughs, and no planktonic organisms were found. During the July 4 sampling period, large numbers of caddis flies were observed hatching from 23-Mile Slough.

Juvenile Arctic grayling growth

No Arctic grayling were captured in 23-Mile Slough. Seine hauls made in 23-Mile Slough in July and August did capture juvenile round whitefish *Prosopium cylindraceum*, juvenile coho salmon *Oncorhynchus kisutch*, and slimy sculpin *Cottus cognatus*. Numbers and sizes were not noted. In April, a large school (approximately 100 fish) of 150-250 mm grayling were observed feeding within pools near overhanging vegetation above the sampling station. A local landowner also has reported seeing schools of coho salmon spawning annually in late fall within 23-Mile Slough and its tributaries.

No significant differences were found between sampling areas within a slough; therefore, samples from a slough were pooled for data analysis. The average length of age-0 grayling was significantly greater in Badger Slough than in Piledriver Slough (Figure 13) at each sampling event ($P < 0.001$). By September 30, mean lengths (± SE) of age-0 grayling in Badger and Piledriver Sloughs were 82.3 (0.7) mm and 78.5 (0.6) mm, respectively (Appendix Table 14). The patterns of growth (length) of age-0 grayling in both sloughs appear to parallel one another. Due to the low number of sampling dates, growth rates were not analyzed; however, the pattern of growth does suggest that growth rates in Badger Slough age-0 grayling are similar to that of Piledriver Slough age-0 grayling.

It should be noted that there was an absence of age-0 grayling after August 9 (no age-0 grayling captured) at the upper and middle reaches of Piledriver Slough. A similar pattern occurred in Badger Slough with no fish being captured at the upper sampling site on September 30. Consequently, additional riffle sections were sampled at the lower

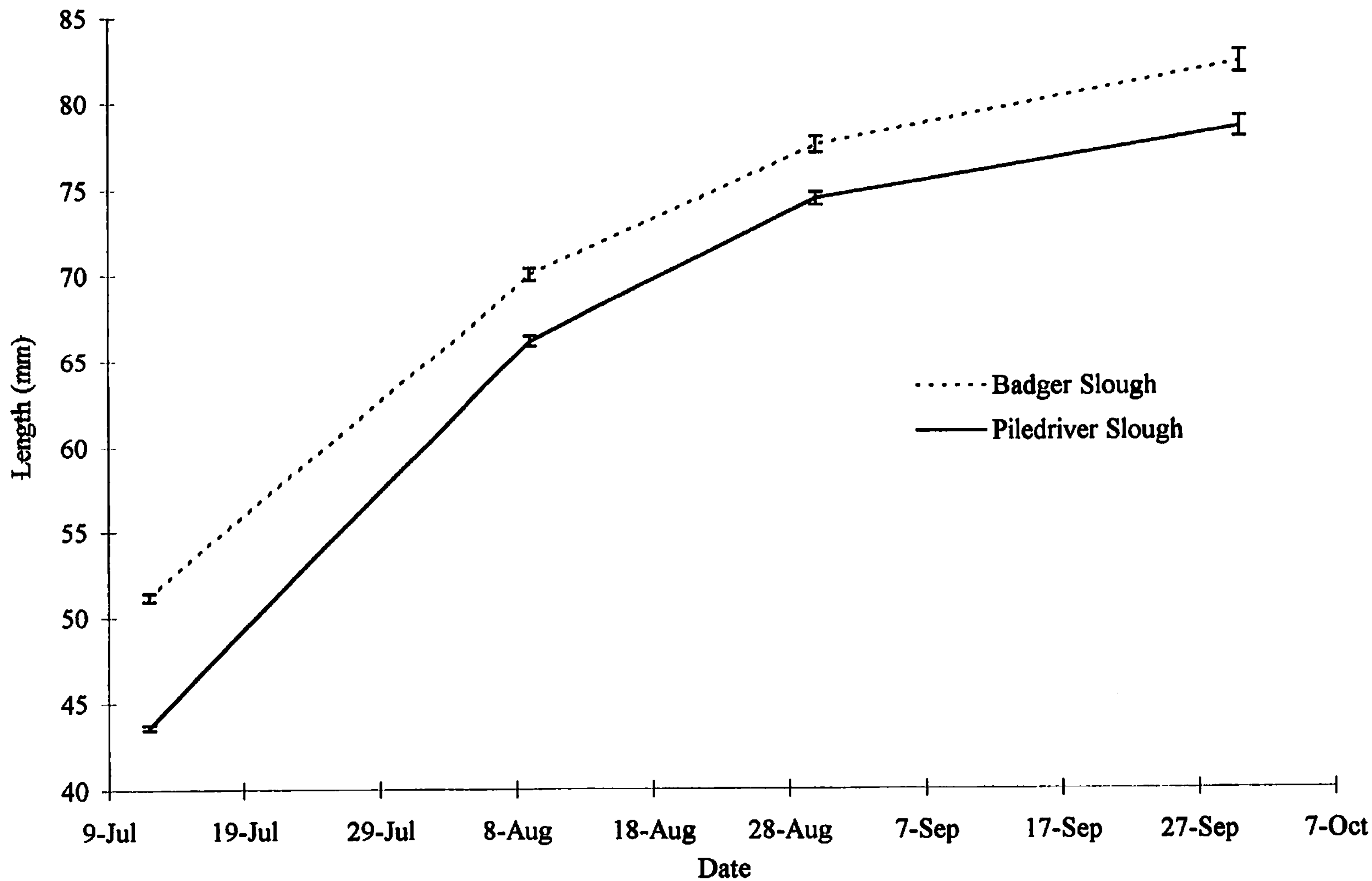


Figure 13. Average fork lengths (± SE) of age-0 Arctic grayling in Badger and Piledriver Sloughs, 1996.

sampling sites at each slough to ensure an adequate number (a representative sample) of fish were collected.

Substrate

Piledriver Slough had significantly less ($P<0.01$) percent fines for each size category (4.0, 2.0, 1.0, and 0.5 mm) than Badger and 23-Mile Sloughs. No significant differences were found between Badger and 23-Mile Sloughs (Table 3). The median grain size (d_{50}) and the grain size of which 90% is finer by weight (d_{90}) were significantly different among all three sloughs ($P< 0.01$). Particle sizes were consistently smaller in Badger Slough across all size categories than in both Piledriver and 23-Mile Sloughs (Figure 14). Twenty-three-mile Slough had a greater fraction of larger particles (>64 mm) than did Piledriver Slough (Appendix Table 15). Visual inspection of substrates showed that the organic content of the fines (< 2 mm) was considerably greater in Badger Slough than in Piledriver and 23-Mile Sloughs (Frank Wuttig, geological engineer, personal communication, 1996). The fines sampled from Badger Slough appeared dark brown in coloration, whereas the fines in Piledriver and 23-Mile Sloughs were the color of glacial flour (gray).

Flushing flows

A Shields parameter of 0.03 was utilized to estimate unit discharge ($m^3\ s^{-1}\ m^{-1}$) recommended for the release of trapped fines (Gordon 1992). Unit discharges for Badger, Piledriver, and 23-Mile Sloughs were calculated as 0.53, 0.81, and 0.46 $m^3\ s^{-1}\ m^{-1}$,

Table 3. Percent fines by weight of riffle substrates in Badger, Piledriver, and 23-Mile Sloughs. Given are sample size (N), average, standard deviation (SD), median grain size by weight (d_{50}), and grain size of which 90% is finer by weight (d_{90}).

Slough	N	Particle size (mm)	Percent Mean	Percent SD	d_{50} (mm)	d_{90} (mm)
Badger	24	<4	17.5	4.5	14.7	49.6
		<2	12.4	4.2		
		<1	10.8	4.2		
		<0.5	9.4	3.9		
Piledriver	24	<4	10.4	5.7	25.8	66.9
		<2	6.8	4.1		
		<1	5.6	3.4		
		<0.5	4.7	2.8		
23-Mile	10	<4	17.1	4.3	19.7	73.7
		<2	11.7	3.2		
		<1	10	2.9		
		<0.5	8.4	2.5		

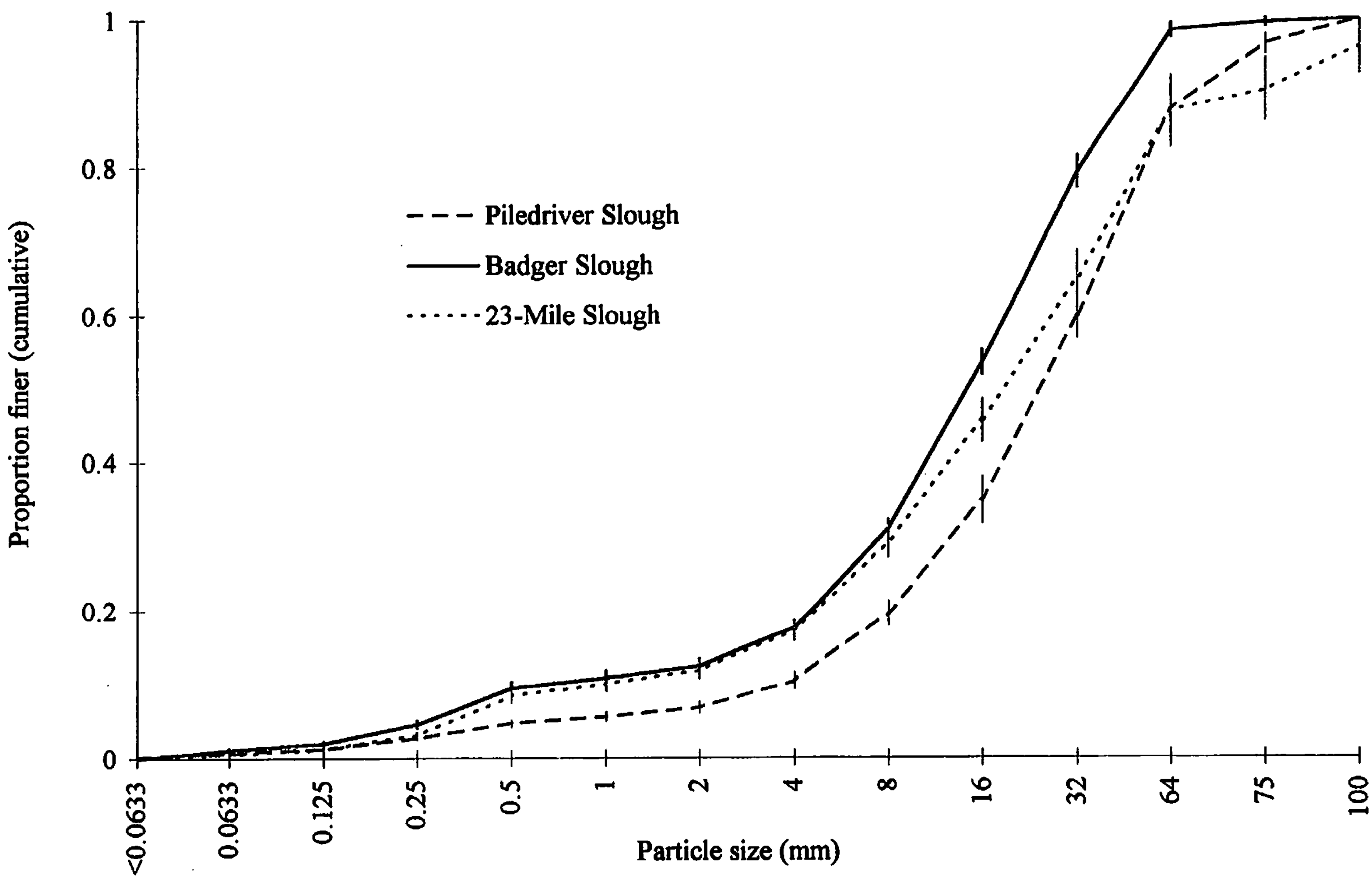


Figure 14. Substrate particle size distributions (± SE), by mass, for Badger, Piledriver, and 23-Mile Sloughs, 1996.

respectively. By multiplying the mean width of riffle areas measured, a rough estimate of a required flushing flow was obtained. Flushing flows for Badger, Piledriver, and 23-Mile Sloughs were estimated as 7.95, 10.5, and 11.4 m^{-3} s^{-1}, respectively. Utilizing a conservative bed load travel time of 0.03 h km^{-1} (Reiser et al. 1987), the needed duration of a flushing flow in Badger and Piledriver Sloughs would be approximately 83 hours.

DISCUSSION

Water quality

My results indicate that there are significant differences in water quality between Badger, Piledriver, and 23-Mile Sloughs. Water in Badger Slough shows pH values near neutrality. Although greater than Piledriver Slough, Badger Slough turbidity values were still very low. Badger Slough alkalinity values are high when compared to other streams in interior Alaska. Alkalinity in Badger Slough is twice that found in the Chena River; only the Delta Clearwater River, also a groundwater tributary to the Tanana River has similar values (LaPerriere et al. 1989). Alkalinity levels in Piledriver Slough and 23-Mile Slough (prior to intrusion of the Tanana River) are also some of the highest recorded for clearwater streams in interior Alaska.

Mean TP values recorded for Badger Slough are greater than any other found for clearwater streams of interior Alaska (3.2 to 26 mg m^{-3}) and in the Kuparuk River on the North Slope (1.5 - 16 mg m^{-3}) as reported by LaPerriere et al. (1989), and Peterson et al. (1986), respectively. However, in comparison with 115 north temperate streams (Van Nieuwenhuyse and Jones 1996), Badger Slough ranks near the lower 25^{th} percentile (48 mg m^{-3}) and would be classified as moderately enriched (Lohman et al. 1991). The range of TP values is consistent with values associated with mixed land uses in the eastern United States (Brooks et al. 1991) and with rural areas of Norway (Skulberg 1982).

might be interpreted as evidence of sewage inputs; however, a similar pattern was observed in Piledriver Slough which had a 100% TP and a 57% increase in TDP. However, in Badger Slough TP increased 30 μg/L as compared to only 9 μg/L in Piledriver Slough, and orthophosphate concentrations in Badger Slough were 9 times that found in 23-Mile and Piledriver Sloughs, suggesting the influence of septic systems in Badger Slough. It has been shown that urbanization results in increases in the amount of phosphorus discharged to surface waters is in approximately direct proportion to population densities (Wetzel 1983).

During the ice-free season, dissolved oxygen remained above levels considered strongly suitable for overwintering salmonids (Merritt 1992). With the onset of icing, DO rapidly decreased in Badger Slough, and within one month, concentrations had dropped to levels considered strongly unsuitable for salmonids. In contrast, areas within Piledriver Slough maintained areas of suitable levels of oxygen throughout winter as did 23-Mile Slough which tends to remain ice free. However, unsuitable DO were found in portions of Piledriver Slough in 1991 (Merritt 1992). Although considered unsuitable for salmonids, Arctic grayling can tolerate DO levels below 2.0 mg L^{-1} at 0°C (Schallock 1980), and grayling have been shown to overwinter in lakes where DO levels reached 1.0 mg L^{-1} (Rogoski and Tack 1970).

The pattern of oxygen depletion observed in the sloughs during winter corresponds with the levels of aquatic vegetation that developed. Algal biomass is one of the principal effects of eutrophication, and the respiratory demands from decaying organic matter can rapidly deplete the supply of oxygen (Welch 1992). As noted, DO rapidly declined in

Badger Slough, with DO remaining depressed throughout much of the winter. In the upper reaches of Piledriver Slough, where little vegetation develops, DO remained relatively high. At the lower sampling station of Piledriver, with a greater development of algae, unsuitable DO levels were attained, but, not until February.

Algal biomass

Use of sestonic chlorophyll a concentrations to compare algal production can be criticized because of the variation of physical parameters found among streams (Jones et al. 1984). However, comparisons between Badger and Piledriver Sloughs are allowable because both sloughs are similar in terms of stream flow, catchment size, and substrate. Comparisons with 23-Mile Slough are not valid due to its physical characteristics after intrusion of the Tanana River. When 23-Mile Slough is running clear, benthic algae develops on a thin layer of glacial silt coating the substrates that is easily sloughed off, and any algae collected after intrusion of the Tanana River is likely due to the silt coating being scoured off and to catchment effects (inputs from tributary streams of the Tanana River).

Based upon suspended chlorophyll a concentrations, Badger Slough had more than twice the amount of benthic algal biomass than Piledriver Slough. Maximum concentrations were recorded in mid-June when solar radiation and slough temperatures were at their maximums. The month of August was the coolest in 27 years and September was the second coldest on record; both months were relatively cloudy (ACRC 1997). The resulting decline in water temperature and light in conjunction with declining phosphorus levels could have caused a decline in algal production as reflected by the sestonic chlorophyll a concentrations (Welch 1992).

Average summer sestonic chlorophyll a concentrations measured in Badger are greater than any previously recorded (0.31 ± 0.18 - 1.12 ± 0.84 mg m^{-3}) in the interior of Alaska (LaPerriere et al.1989). Piledriver Slough concentrations are within the ranges of values reported from other interior Alaskan streams. As with TP, Badger Slough sestonic chlorophyll a concentrations rank near the 25^{th} percentile (4.9 mg m^{-3}) in comparison with 115 north temperate streams, Badger Slough (Van Nieuwenhuyse and Jones 1996).

A nuisance level of algae has been established when benthic algal biomass exceeds 100-150 mg chl a m^{-2}, a level at which filamentous algae covers approximately 20% of the stream bottom (Welch et al. 1988). By assuming a certain fraction of the algae is scoured off and transported downstream (daily export rate), benthic algal biomass can be estimated and compared against the nuisance standard. In Missouri Ozark streams Jones et al. (1984) estimated that daily export rates of chlorophyll a ranged from 0.25% to 2.9% of the mean benthic standing crop. If a conservative export rate of 2% is used, nuisance levels of algal biomass would be reached when sestonic chlorophyll a concentrations exceed a threshold level of 2.0 mg L^{-1} (Table 4). In May, June, and July calculated nuisance levels were attained in Badger Slough, primarily at the middle and upper sampling stations, and were never exceeded in Piledriver Slough. The nuisance levels estimated are consistent with personal observations. In Piledriver Slough, scattered algal mats were only observed in the lower reaches. At the upper site of Badger Slough there was a noticeable absence of the extensive growths of benthic algae (filamentous algal

Table 4. Estimated benthic chlorophyll a concentrations (mg m^{-2}) at monitoring stations for Badger, Piledriver, and 23-Mile Sloughs, 1996. A 2.0% daily export rate was assumed and sestonic chlorophyll a was measured.

	Badger			Piledriver			23 - Mile
Date	upper	middle	lower	upper	middle	lower	
1-May	59	138	--	11	--	49	--
14-May	148	247	256	24	30	80	90
29-May	86	251	410	15	54	30	147
18-Jun	119	259	404	34	23	87	257
8-Jul	81	123	334	18	26	59	86
5-Aug	65	64	82	12	17	61	83
1-Sep	48	72	67	12	15	58	55
Mean	112.50	185.50	297.50	21.00	30.00	63.50	132.50

mats) that developed at the middle and lower sampling sites. Near Peede Road, located between the upper and lower sampling stations, the entire width of Badger Slough was covered with filamentous algae, well in excess of the 20% considered a nuisance.

It is evident that Badger Slough has developed excessive growths of benthic algae, although the exact cause of this development is not clear. Several factors can regulate algal growth in streams: light, temperature, flood frequency, substrata, and nutrients (Welch 1992). Of these factors, periodic high-water events that scour the substratum and turbidity, which decreases light penetration, are often the major determinants of periphyton biomass (Van Nieuwenhuyse 1983, Lohman et al. 1991). In Badger Slough, the absence of flooding and turbidity has certainly promoted the development of algae.

However, similar hydrologic conditions existed in Piledriver Slough without the same level of periphyton developing. Observed differences in phosphorus, alkalinity, and temperature may help account for the differences in periphyton biomass. A significant relationship was observed in Interior streams between sestonic algae and alkalinity (LaPerriere et al. 1989). Using this relation, predicted versus observed chl a concentrations were 0.72 versus 3.29 in Badger Slough and 0.64 versus 0.71 in Piledriver Slough suggesting, something else besides alkalinity may be stimulating algal growth in Badger Slough. Using the sestonic algae and TP relation established for northern temperate streams (Van Nieuwenhuyse and Jones 1996), predicted vs. observed chl a concentrations for TP were 5.01 versus 3.29 for Badger Slough, and 1.30 versus 0.71 for Piledriver Slough, respectively. The closeness of these predictions and the significant relationship found between chl a and TP among sampling stations within Badger and

Piledriver Sloughs suggest that phosphorus may be acting as a limiting nutrient, and that any additions of phosphorus are stimulating algal production. Likewise, the neighboring Chena River had been found to be phosphorus limited based on the 50 - 220:1 inorganic nitrogen to inorganic phosphorus ratios measured (Frey et al. 1970). However, more data from experimental additions of nutrients or conclusive TN:TP ratios would be needed to establish primary productivity and nutrient relationships.

The elevated levels of periphyton are most likely a result of additional nutrients. It has been suggested by many residents of Badger Slough that contaminated groundwater from septic systems (Krumhardt 1982) may be entering Badger Slough. However, it would be difficult to address the sources of the elevated phosphorus (and possibly nitrogen) levels without a comprehensive water quality monitoring program. It is possible that the eutrophication of Badger Slough is a function of internal nutrient loading and recycling. The deposition of organic fines on and within the substratum of Badger Slough could result in increased release of nutrients from the processing of organic matter within the hyporheos (substratum) (Pringle 1987, Valett et al. 1994). Thus, the retentive action of the culverts and beaver dams may in fact be increasing nutrient availability as demonstrated by Coleman and Dahm (1990).

Primary productivity

It is evident that there is greater algal production in Badger Slough than in Piledriver and 23-Mile Sloughs, and this conclusion is confirmed by the GPP estimates. Although direct comparisons between corresponding sampling stations of Badger and

Piledriver Sloughs at the same times could not be made, my data do show that GPP tends to be more than 2-5 times greater in Badger Slough than in Piledriver Slough. Compared with the range of values (0.2 - 2.9 g O_2 m^{-2} d^{-1}) observed in other interior streams of Alaska (LaPerriere et al. 1989), Badger Slough far exceeds this range, and values of GPP for Piledriver and 23-Mile Sloughs fall within this range.

The results from 23-Slough show turbidity disrupting production and underscore the importance of light in regulating productivity (Van Nieuwenhuyse and LaPerriere 1986). Throughout the entire ice-free season, turbidity in both Badger and Piledriver sloughs was very low, allowing for maximum solar radiation.

Juvenile Arctic grayling growth

Assuming that the growth of individual age-0 Arctic grayling reflects the quality of rearing habitat, there appears to be no decline in the quality of rearing habitat in Badger Slough. Comparisons between Badger and Piledriver Slough show that, in fact, rearing habitat in Badger Slough may be better than in Piledriver Slough. Moreover, comparison with growth data collected from Walker (1983) also indicates that there appears to be no decline in the quality of rearing habitat in Badger Slough. No significant decreases in age-0 grayling growth (maximum average lengths attained at end of summer season) were found between Walker's (1983) data and mine in 1996 (Table 5). It may be that growth in Piledriver Slough has increased; however, Walker's 1982 Piledriver data are suspect due to a biased sample. His data show the average length of age-0 grayling decreasing during the month of September.

Table 5. Maximum lengths of age-0 Arctic grayling attained at the end of September for Badger and Piledriver Sloughs, 1996. Given are mean lengths, standard deviations (SD), ranges, and sample sizes (N). Data from 1981 and 1982 are from Walker (1983).

			Fork length (mm)		
Location	Year	N	Mean	SD	Range
Badger	1981	80	86.3	8.7	57 - 111
	1982	35	83.6	5.1	72-90
	1996	288	84.3	9.0	65-111
Piledriver	1982	28	63.0	7.6	47-85
	1996	288	78.5	8.2	59-98

In Badger Slough age-0 grayling have continued to exhibit high growth. This growth can be attributed to the absence of high-water events that can be detrimental to the early life history of Arctic grayling. Clark (1992) found that recruitment of grayling in the Chena River, Alaska is influenced by stream flows during the initial weeks of life of a grayling, namely during spawning, emergence, and the larval stage. High flows may dislodge eggs from the shallow nests of grayling (Elwood and Waters 1969) or flush the weak swimming larval fish downstream into unfavorable rearing habitat (Creeco and Savoy 1984). Recently hatched larval fish have poorly developed fins and require shallow, calm backwater areas or side channels with little flow (Sempeski and Gaudin 1995). Water temperatures are typically depressed by high flows and can affect growth by delaying the initiation of spawning, delaying emergence, and the slowing of metabolic processes (Walker 1983). Turbidity from high water decreases water clarity, lowering feeding effectiveness and resulting in decreased growth (Schmidt and O'Brien 1982, McLeay et al. 1987). As witnessed in 1981, 1982, and 1996, Badger Slough has acted as a refuge from high waters, creating favorable rearing conditions characterized by stable flows with calm backwater areas, low turbidity, and warmer waters. In fact, in both Badger and Piledriver Sloughs, average temperatures fluctuated within the optimal thermal tolerances (8-14°C) for young Baikal grayling (Tugarina and Ryzhova 1969).

It could be argued that any decreases in rearing habitat in Badger Slough were offset by an abnormally warm summer in 1996, resulting in increased growth. However, the summer (June, July, and August) of 1996 was the coolest on record since 1984, cooler than 1982, and slightly warmer than 1981 (ACRC 1997). The smaller mean lengths of

Piledriver Slough age-0 grayling may be a function of cooler water and not a function of less suitable habitat. When viewing the parallel growth curves (Figure 8), it appears that the depressed water temperatures (Figure 4) in Piledriver Slough may have delayed spawning and/or emergence, causing age-0 grayling growth in Piledriver Slough to lag behind that of Badger Slough. During the month of May when fish are spawning and incubating, water temperatures for the last two weeks were 2°C cooler on average in Piledriver Slough. Additionally, from May 14 to August 27, Badger Slough had 170 more cumulative degree days than did Piledriver Slough. The lower water temperatures in Piledriver Slough appear to be from the melting of extensive *aufeis*, and the sharp increase in water temperatures corresponds with the dissipation of *aufeis*. However, growth of age-0 grayling in Piledriver Slough was still considered robust for interior Alaska streams (Walker 1983).

The growth of grayling in Badger and Piledriver Sloughs may also be attributed to food availability. During the 1960s, it was speculated that nutrient enrichment from the sewage facilities could have increased invertebrate densities in the lower Chena River and, thereby, accounting for the elevated grayling populations in the lower river (Tack 1971). In comparison to Arctic grayling from other areas of the Chena River watershed, Badger Slough fish feed on a greater taxonomic diversity of food items not found in Chena River (Tipulidae, Culiciadae, Ephemoptera, and Arachnia), and more frequent ostracods and copepods (Walker 1983). Drift samples confirmed an abundant supply of zooplankton, particularly, ostracods, copepods, and daphnia. In addition, out of 20 age-0 grayling stomach contents examined, a high proportion (60%) of age-0 grayling were feeding on leeches.

Temperature may be influencing the migration of age-0 grayling. As the sampling season progressed there was a notable absence of fish from the upper and middle reaches of Badger and Piledriver Sloughs as the temperatures dropped in August and September, which were the second coldest on record when averaged together (ACRC 1997). By the end of September, fish were only found at the lower sampling stations of each slough. Hughes (1986) began capturing out-migrating age-0 grayling in September 1985 at the middle Badger Slough sampling location. The out migration of grayling may be crucial for overwinter survival due to the unsuitable oxygen conditions that develop quickly after the formation of ice in Badger Slough. Overwintering habitat was found to be suitable during 1996-1997 in reaches of Piledriver Slough with DO concentrations remaining at or above 4.0 mg L^{-1}.

Based on the growth of age-0 grayling, it appears as if the quality of rearing habitat in Badger Slough is still very suitable for young grayling; however, growth doesn't indicate whether there may be a decrease in the quantity of habitat available. In Badger and Piledriver Sloughs, age-0 grayling > 40 mm were observed mostly feeding within riffles and glides over exposed (gravel) substrates. Preference for this habitat type is consistent with other findings that show age-0 grayling feeding within the channel over exposed gravel substrates (Lucko 1992). In Badger Slough, areas of exposed gravels tend to occur only in natural riffles or riffles below culverts as identified on a habitat map by Hughes (1986). One particular culvert riffle located below Nordale Road crossing was used as a weir site by Hughes (1986) and for the collection of age-0 grayling by Walker (1983). This particular riffle was described as having exposed substrates and a high density of age-0 grayling that were easily seined. In 1996, this riffle had been largely covered by rooted macrophytes and algal mats; only one age-0 grayling was observed and none were captured by a seine. This is in stark contrast to the exposed riffles from which I captured large numbers (>200) of age-0 grayling with a single seine haul in other parts of Badger Slough in 1996. Similar seine haul successes occurred within Piledriver Slough's unvegetated riffles.

Foot surveys and test fishing revealed that higher densities of age-0 grayling tended to occur in natural riffles as opposed to culvert riffles. A goal of Hughes (1986) was to identify areas of critical habitat, and it should be stressed that the natural riffle areas, particularly those above Peede Road and below Plack Road should be protected.

Substrate

The substrate data show that Badger Slough riffle substrates contain almost twice the amount of fines (<2.0 mm) and have a smaller geometric mean particle size than Piledriver Slough. When compared to 23-Mile Slough, no significant differences were found in percent fines, however Badger Slough did have a smaller d_{50}. This suggests that the riffles of Badger Slough are accumulating organic and inorganic fines and have reached levels similar to that of 23-Mile Slough, which carries large volumes of glacial sands and silts.

The increased fines in riffle substrates can directly or indirectly affect juvenile salmonids. Intrusions of fines into riffle substrates can decrease redd permeability, smothering developing embryos (Chapman 1988), and the resulting loss of invertebrate habitat can indirectly affect salmonid production, causing a decline in the food base (Alexander and Hansen 1986). However, it does not appear that the spawning success or the food base of Badger Slough grayling is affected. Although Interior grayling usually spawn over pea-sized gravel, grayling have been observed spawning over a variety of substrates such as vegetated organic mud and rubble (Armstrong 1986). The ability of grayling to use a variety of substrates and the high catches per seine haul indicates that spawning success has not been affected, and the high growth of age-0 grayling indicates that the food base is adequate. The percent fines in Badger Slough are below the 15-30% level at which salmonid reproduction and invertebrate densities become affected (Chapman 1988, Waters 1995).

The percent fines in Badger Slough are likely underestimated. Riffles were selected only if exposed gravel substrates were observed; and some of the riffle habitat described by Hughes (1986) has since developed a layer of organic fines with thick mats of aquatic vegetation and was subsequently not sampled, as was the case with the riffle located below Nordale Road.

Flushing flows

A flushing flow (approximately 8.0 $m^3 s^{-1}$ for 80 hr) in Badger Slough is recommended for the maintenance of Arctic grayling habitat and the encroachment of riparian vegetation. Such a flow would help to remove fines from the substrate, deposits of organically enriched fines that have accumulated, rooted aquatic macrophytes, and attached algae. Clearly, the incipient method used is an oversimplification, and the most effective methods are those that can predict bankfull discharges from extensive flow records or from test flows (Reiser et al. 1987). However, the 8.0 $m^3 s^{-1}$ recommendation is supported by its close approximation to the maximum flows observed in 23-Mile Slough during 1995 and 1996. During these flows, bedload movement was felt during discharge measurements, however the substrates aren't cleansed due to the substantial amount of suspended sediments in the Tanana River water that is redeposited.

The release of a flushing flow in Badger Slough presents several obstacles: a water source, hydrologic constraints, funding, and biological parameters. A water source would be required and the Chena River and Piledriver Slough are the closest alternatives. Existing culvert crossings would have to be modified to allow for increased flow, and potential flooding of residential areas could limit the size of the flow. The flow would have to occur with ice out before adult grayling have spawned or during the late summer and fall rains after age-0 grayling have adequately developed. Clearly, such a project would be costly and funding would be a formidable obstacle. A flushing flow is highly recommended; however, such an undertaking would be best handled by certified hydrologists.

CONCLUSIONS AND RECOMMENDATIONS

The differences in water quality and algal production shown between Badger Slough and Piledriver and 23-Mile Sloughs indicate that blockage and development have accelerated the eutrophication of Badger Slough. It can be argued that the eutrophic state of Badger Slough is due to natural succession because groundwater-fed systems of the Tanana River tend to be productive. However, it is unlikely that a slough, such as Piledriver Slough, would eutrophy to the same extent as did Badger Slough in just 25 years without developmental influences. Natural succession may be partially the case as the lower sections of Piledriver Slough have eutrophied some when compared to the upper reaches. However, the strong relationship between TP and chlorophyll found among sampling stations and the elevated phosphorus levels in Badger Slough are convincing evidence of culturally accelerated eutrophication.

The eutrophication of Badger Slough is a contentious issue among residents of Badger Slough and they are quick to blame the unaesthetic growths of algae on faulty septic systems. However, more conclusive data from the experimental additions of nutrients or irrefutable TN:TP ratios would be needed to establish primary production and nutrient relationships. In addition, a thorough and comprehensive water quality monitoring program would be required to determine any potential nutrient sources.

Clearly, Badger Slough is valuable in terms of spawning and rearing habitat for Arctic grayling and for Chena River recruitment. Currently, there appears to be no degradation in the quality of rearing habitat for age-0 grayling in Badger Slough; however, there are indications that the quantity of suitable habitat may be decreasing. Accumulations of organic fines in pools and riffles and the development of rooted aquatic plants and nuisance levels of periphyton may eventually constrict the available rearing and spawning habitat.

Without intervention, the aesthetic value of Badger Slough to its residents, the recreational value of Badger Slough as a fishery, and the quantity and quality of rearing habitat for age-0 grayling in Badger Slough will all most likely decline. The blockage and development of Badger Slough have created an open channel with stable, clear, nutrient-rich flows that promote autochthonous production as well as rearing Arctic grayling. However, a lack of high-water events has allowed for the development of aquatic macrophytes and attached algae; accumulations of nutrients, organic fines, and inorganic fines; and the encroachment of riparian vegetation to go unchecked. Therefore, annual flushing flows in fall are strongly recommended in Badger Slough for channel maintenance, the prevention of vegetation encroachment, and the maintenance or enhancement of fishery habitat. Such flushing flows are also recommended for Piledriver Slough, which has begun to show indications of eutrophication in its lower reaches.

LITERATURE CITED

Alaska Climate Research Center (ACRC). 1997. Geophysical Institute. University of Alaska-Fairbanks. Webmaster@climate.gi.alaska.edu.

Alexander, G. R., and E. A. Hansen. 1986. Sand bed load in a brook trout stream. North American Journal of Fisheries Management 6:9-23.

American Public Health Association (APHA). 1985. Standard methods for the treatment of water and wastewater 16th Ed. American Public Health Association, Washington D. C. 1193 pp.

Armstrong, R. H. 1986. A review of Arctic grayling studies in Alaska, 1952-1982. Biological Papers of the University of Alaska 23:3-17.

Bilby, R. E. and P. A. Bisson. 1992. Allocthonous versus Autocthonous organic matter contributions to the trophic support of fish populations in clear-cut and old growth forested streams. Canadian Journal of Fisheries and Aquatic Sciences 49:540-551.

Brooks, K. N., P. F. Folliot, H. M. Greegersen, J. L. Thames. 1991. Hydrology and the Management of Watersheds. Iowa State University Press, Ames, Iowa.

Burrows, B. 1995. Written communication. U.S. Geological Survey, Water resources Division, Fairbanks, Alaska.

Bushong S. J. and R. W. Bachman. 1989. In situ nutrient enrichment experiments with periphyton in agricultural streams. Hydrobiologia 178:1-10.

Chapman, W. D. 1988. Critical review of the variables used to define effects of fines in redds of large salmonids. Transactions of the North American Fisheries Society 117:1-21.

Clark, R. A. 1992. Influence of stream flows and stock size on recruitment of Arctic grayling (*Thymallus arcticus*) in the Chena River, Alaska. Canadian Journal of Fisheries and aquatic Sciences 49:1027-1034.

Coleman, R. L. and C. N. Dahm. 1990. Stream geomorphology: effects on periphyton standing crop and primary production. Journal of the North American Benthological Society 13:468-478.

Collins, C. M., 1990. Morphometric Analyses of recent changes on the Tanana River in the vicinity of Fairbanks, Alaska. U.S. Army Corps of Engineers, Cold Regions Research & Engineering Laboratory CREEL report 90-4.

Cordone, A. J., and D. W. Kelly. 1961. The influences of inorganic sediment on the aquatic life of streams. California Fish and Game 47:189-228.

Crecco V. A., and T. Savoy. 1984. Effects of hydrographic fluctuations on year-class strength of American shad (*Alosa sapidissima*) in the Connecticut River. Canadian Journal of Fisheries and Aquatic Sciences 41:1216-1223.

Crouse, M. R., C. A. Callahan, K. W. Malueg, and S. E. Dominguez. 1981. Effects of fine sediments on growth of juvenile coho salmon in laboratory streams. Transactions of the American Fisheries Society 110:281-286.

Crumpton, W. G., T. M. Isenhardt, and P. D. Mitchell. 1992. Nitrate and organic N analyses with second derivative spectroscopy. Limnology and Oceanography 27:907-913.

Deegan, L. A. and B. J. Peterson. 1992. Whole river fertilization stimulates fish production in an Arctic tundra river. Canadian Journal of Fisheries and Aquatic Sciences 49:1890-1901.

Dickman, M. 1973. Changes in periphytic algae following bicarbonate additions to a small stream. Journal of the Fisheries Research Board of Canada 30:1882-1885.

Ellis, J. M., G. B. Farabe, and J. B. Reynolds. 1979. Fish communities in three successional stages of side channels in the upper Mississippi River. Transactions of the Missouri Acadamy of Science 13:5-20.

Elmore, H. L. and W. F. West. 1961 Effect of water temperature on stream reaeration. Journal of the Sanitary Engineering, ASCE SA6:59-71.

Erman, D. C., and N. A. Erman. 1984. The response of stream macroinvertebrates to substrate size and heterogeneity. Hydrobiologia 108:75-82.

Elwood, J. W., and T. F. Waters. 1969. Effects of floods on food consumption and production rates of a stream brook trout population. Transactions of the American Fisheries Society 98:253-262.

Fleming, D. F. 1995. Stock assessment of Arctic grayling in Piledriver Slough during 1994. Alaska Department of Fish and Game, Fishery Data Report Series No. 95-15, Anchorage.

Fleming, D. F. 1997. Unpublished Data. Alaska Department of Fish and Game, Sport Fish Division, Fairbanks, Alaska.

Frey, P. J., E. W. Mueller, and E. C. Berry. 1970. The Chena River-the study of a subarctic stream. Federal Water Pollution Control Administration, Northwest Region, Alaska Water Laboratory.

Goltermann, H. L. 1969. Methods for chemical analysis of freshwaters: International Biological Programme Handbook No. 8. Blackwell Scientific Publications, Oxford and Edinburg.

Gorden, N. D., T. A. McMahon, and B. L. Finlayson. 1992. Stream hydrology: an introduction for ecologists. John Wiley & Sons, New York.

Gore, J. A. 1989. Models for predicting benthic macroinvertebrate habitat suitability under regulated flows. Pages 253-263 *in* J. A. Gore and G. E. Petts, editors. Alternatives in Regulated River Management. CRC Press, Inc., Bacta Roton, Florida.

Grimm, N. G. and S. G. Fisher. 1986. Nitrogen limitation in a Sonoran Desert stream. Journal of the North American Benthological Society 5:2-15.

Hall , C. A. and R. Moll. 1975. Methods of assessing primary productivity. Pages 26-33 *in* H. Leith and R. H. Whitttaker, editors. Primary Productivity of the Biosphere. Springer-Verlag, New York.

Hughes, N. 1986. Fish and aquatic habitat of Badger Slough, Chena River, Alaska. Unit Contribution Number 22, Alaska Cooperative Fishery Research Unit, University of Alaska, Fairbanks.

Hynes, H. B. 1970. Ecology of running waters. University of Toronto Press, Toronto.

Jones, J. R., M. M. Smart, and J. N. Burroughs. 1984. Factors related to algal biomass in Missouri Ozark streams. Verhandlungen der Internationalen Vereinigung fuer Theoretische und Angewandt Limnologie 22:1867-1875.

Krumhardt, A. P. 1982. Hydrological information for land use planning, Badger Road area, Fairbanks, Alaska. U.S. Geological Survey Water Resources Investigations 82-4097. Anchorage, Alaska.

Krumhardt, A. P. 1982. Hydrological information for land use planning, Badger Road area, Fairbanks, Alaska. U.S. Geological Survey Water Resources Investigations 82-4097. Anchorage, Alaska.

LaPerriere, J. D., E. E. Van Nieuwenhuyse, and P. R. Anderson. 1989. Benthic algal biomass and productivity in high subarctic streams, Alaska. Hydrobiologia 172:63-75.

Lohman, K., J. R. Jones, and B. Perkins. 1991. Effects of nutrient enrichment and flood frequency on periphyton biomass in northern Ozark streams. Canadian Journal of Fisheries and Aquatic Sciences 49:1199-1205.

Lucko, B. 1992. Distribution of young of the year Arctic grayling in the Swan River drainage. Alberta Forestry, Lands Wildlife, Fish and Wildlife Division, Peace River, Alberta.

McLeay, D. J., I. K. Birkwell, and G. L. Ennis. 1987. Responses of Arctic grayling of prolonged exposures to Yukon placer mining sediment. Canadian Journal of Fisheries and Aquatic Sciences 44:658-673.

McNiel, W. J. and W. H. Ahnell. 1964. Success of pink salmon spawning relative to size of spawning bed materials. U.S. Fish and Wildlife Service Special Scientific Report - Fisheries 469.

Merritt, M. F. 1993. Ranking selected streams in Interior Alaska on the basis of suitability for sustaining an introduced rainbow trout population. Alaska Department of Fish and Game, Division of Sport Fish. Memorandum.

Milhous, R. T. 1982. Effect of sediment transport and flow regulation on the ecology of gravel-bed rivers. Pages 819-842 *in* R. D. Hey, J. C. Bathurst, and C. R. Thorne, editors. Gravel Bed Rivers. John Wiley & Sons LTD, New York.

Milhous, R. T. 1986. Physical habitat simulation and the moveable bed. Pages 1976-1983 *in* M. Karamoz, G. R. Baumli, and W. J. Brick, editors. Water World Issues in Evolution, Proceedings of Water World 1986, American Society of Civil Engineers, New York.

Mills, M. J. 1991. Harvest, catch, and participation in Alaska sport fisheries during 1990. Alaska Department of Fish and Game, Fisheries Data Series No. 91-58, Anchorage.

Mills, M. J. 1992. Harvest, catch, and participation in Alaska sport fisheries during 1991. Alaska Department of Fish and Game, Fisheries Data Series No. 92-40, Anchorage.

Minshall, G. W. 1984. Aquatic insect-substratum relationships. Pages 358-400 *in* V. H. Resh, and D. M. Rosenberg, editors. The ecology of aquatic insects. Preager Scientific, New York.

Mortimer, C. H. 1981. The oxygen content of air-saturated fresh waters over ranges of temperature and atmospheric pressure of limnological interest. Mitteilungen der Internationalen Vereinigung fuer Theoretische und Angewandt Limnologie 22:23.

Murphy, M. L., C. H. Hawkins, and N. H. Anderson. 1981. Effects of canopy modification and accumulated sediment on stream communities. Transactions of the American Fisheries Society 110:469-487.

Neter, J., W. Wasserman, and M. Kutner. 1990. Applied linear statistical models. Richard D. Irwin Inc., Boston.

O'Conner, E. P. and W. Dobbins. 1956. The mechanism of reaeration in natural streams. Journal of the Sanitary Engineering Division ASCE, Proc., 82, SA6 1115(1) - 115(30).

Odum, H. T. 1956. Primary productivity of flowing waters. Limnology and Oceanography 2:85-97.

Peterson, B. J., J. Hobbie, and T. Corliss. 1986. A continuous-flow bioassay: Test of nutrient limitation in a tundra stream. Limnology and Oceanography 28(3): 583-591.

Petts, G. E. 1989. Perspectives for ecological management of regulated rivers. Pages 3-26 *in* J. A. Gore and G.E. Petts, editors. Alternatives in Regulated River Management. CRC Press, Inc., Bacta Roton, Florida.

Pringle, C. M. 1987. Effects of water and substratum nutrient supplies on lotic periphyton growth: an integrated bioassay. Canadian Journal of Fisheries and Aquatic Sciences 44(619-629).

Reiser D. W., M. P. Ramey, and T. R. Lambert. 1987. Considerations in assessing flushing flow needs in regulated stream systems. *in* J. Craig and J. Kemper, editors. Regulated Streams: Advances in Ecology. Plenum Press, New York.

Reiser, D. W., M. P. Ramey, and T. A. Wesche. 1989. Flushing flows. Pages 92-129 *in* J. A. Gore and G.E. Petts, editors. Alternatives in Regulated River Management. CRC Press, Inc., Bacta Roton, Florida.

Roguski, E. A., and P. C. Winslow. 1969. Investigations of the Tanana River and Tangle Lakes grayling fisheries: migratory and population study. Alaska Department of Fish and Game. Federal Aid in Fish Restoration, Annual Report of Progress 1968-1969, Project F-9-1, 10:333-351.

Roguski, E. A., and S. L. Tack. 1970. Investigations of the Tanana River and Tangle Lakes grayling fisheries: migratory and population study. Alaska Department of Fish and Game. Federal Aid in Fish Restoration, Annual Report of Progress 1969-1970, Project F-9-2, 11(16-B):303-319.

Schmidt, D. and W. J. O'Brien. 1982. Planktivorous feeding ecology of Arctic grayling (Thymalus arcticus). Canadian Journal of Fisheries and Aquatic Sciences 39:475-482.

Sempiski, P. and P. Gaudin. 1995. Size-related changes in diel distribution of young grayling (Thymallus thymallus). Canadian Journal of Fisheries and Aquatic Sciences 52:1842-1848.

Schallock, E. 1980. Investigations dealing with probable grayling movement in relationship to water development projects. U.S. Fish and Wildlife Research Unit, Branch of the River Basin Studies, Contract Number 14-17-005-36.

Skulberg, O. M. 1982. Effects of stream regulation on algal vegetation. *in* A. Lillehammer and S. Saltveit, editors. Regulated Rivers. Universitetsforlaget AS, Oslo.

Swanson, C. D., and R. W. Bachmann. 1976. A model of algal exports in some Iowa streams. Ecology 57:1076-1080.

Tack, S. L. 1971. Distribution, abundance and natural history of the Arctic grayling in the Tanana River. Alaska Department of Fish and Game. Federal Aid in Fish Restoration, Annual Report of Progress, 1970-1971, Project F-9-3, 12(R-I).

Tack, S. L. 1974. Distribution, abundance and natural history of the Arctic grayling in the Tanana River. Alaska Department of Fish and Game. Federal Aid in Fish Restoration, Annual Report of Progress, 1975-1976, Project F-9-6, 15(R-I).

Tack, S. L. 1976. Distribution, abundance, and natural history of the Arctic grayling in the Tanana River. Alaska Department of Fish and Game. Federal Aid in Fish Restoration, Annual Report of Progress, 1975-1976, Project F-9-8, 17(R-I).

Tugarina, P. and L. Ryzhova. 1969. An ecological and physiological description of the Baikal black grayling. Hydrobiologia 5:46-50.

U.S. Congress. 1938. Tanana River and Chena Slough, Alaska. Letter from the Secretary of War, 75th Congress, 3rd Session, House Document No. 137.

U.S. Environmental Protection Agency (USEPA). 1987. Development of criteria for fine sediment in the northern Rockies ecoregion. EPA, Report 910/9-87-162, Washington D. C.

U.S. Geological Survey (USGS). 1951. Water resource data for Alaska, Water Year 1950. Water Data Report.

Valett, H. M., S. G. Fisher, N. B. Grimm, and P Camill. 1994. Vertical hydrologic exchange and ecological stability of a desert stream ecosystem. Ecology 75: 548-560.

Van Nieuwenhuyse, E. E., 1983. Effects of placer mining on the primary productivity in interior Alaska Streams. Unpublished masters thesis. University of Alaska, Fairbanks, Alaska. 120pp.

Van Nieuwenhuyse, E. E. and J. D. LaPerriere. 1986. Effects of placer gold mining on primary production in subarctic streams of Alaska. Water Resources Bulletin 22:91-99.

Van Nieuwenhuyse, E. E., and J. R. Jones. 1996. Phosphorus-chlorophyll relationship in temperate streams and its variation with stream catchment area. Canadian Journal of Fisheries and Aquatic Sciences 53:99-105.

Walker, R. J. 1983. Growth of the Young -of -the year salmonids in the Chena River. Unpublished M.S. thesis. University of Alaska, Fairbanks, Fairbanks, Alaska.

Warren, C. E. 1971. Biology and Water Pollution Control. W. B. Sanders, Philadelphia.

Warren, C. E., J. H. Wales, and G. E. Davis. 1964. Trout production in an experimental stream enriched with sucrose. Journal of Wildlife Management 28:617-660.

Waters, T. F. 1961. Standing crop and drift of stream bottom organisms. Ecology 42:532 - 537.

Waters, T. F. 1982. Annual food production by *Gammarus pseudolimnaeus* among substrate types in Valley Creek, Minnesota. American Mid. Naturalist 112:95-102.

Waters, T. F. 1995. Sediment in streams: Sources, biological effects, and control. American Fisheries Society. Bethesda, Maryland.

Welch, E. B., J. M. Jacoby, R. R. Horner, and M. R. Seely. 1988. Nuisance biomass levels of periphytic algae in streams. Hydrobiologia:157:161-168.

Welch, E. B. 1992. Ecological Effects of Wastewater: Applied Limnology and Pollution Effects. Chapman and Hall, New York.

Wetzel, R. G. 1983. Limnology. Sanders College Publishing, New York.

Wuttig, F. J. 1996. Written communication, Shannon and Wilson Inc., Fairbanks, Alaska.

APPENDIX

Table 6. Discharges ($m^3 s^{-1}$) for Badger, Piledriver, and 23-Mile Sloughs, 1996.

Date	23-Mile Slough	Piledriver Slough	Badger Slough
14-May	1.29	1.61	1.52
26-May	--	1.45	1.04
28-May	0.84	1.45	1.01
4-Jun	1.73	1.40	1.04
17-Jun	2.04	1.40	1.11
21-Jun	2.73	1.51	1.20
27-Jun	4.45	1.54	1.20
4-Jul	5.20	2.13	1.21
8-Jul	4.88	1.67	1.52
15-Jul	5.23	1.69	1.24
23-Jul	5.57	1.70	1.24
5-Aug	5.88	1.75	1.30
7-Aug	5.70	1.74	1.28
8-Aug	--	1.74	1.28
14-Aug	5.16	1.78	1.29
27-Aug	4.62	1.75	1.29
16-Sep	0.93	1.58	1.10
26-Sep	0.92	1.54	1.10

Table 7. Mean daily temperatures of sloughs at monitoring stations, 1996.

	Badger		Piledriver			23-Mile
Date	lower	middle	lower	middle	upper	middle
5/14/96	5.1	4.0	2.9	4.4	2.9	6.7
5/15/96	5.6	4.2	4.1	4.5	3.5	5.3
5/16/96	6.1	5.2	5.0	4.7	3.8	5.3
5/17/96	6.3	5.3	4.8	4.9	4.7	4.9
5/18/96	6.6	5.9	4.8	4.6	4.5	4.5
5/19/96	6.2	5.6	4.5	4.7	5.6	4.5
5/20/96	6.7	6.1	5.4	5.1	5.7	4.9
5/21/96	7.3	6.7	5.9	6.0	7.8	5.4
5/22/96	8.8	8.0	6.5	6.7	8.6	5.9
5/23/96	10.0	9.2	7.6	7.4	9.4	6.3
5/24/96	11.0	10.2	8.1	8.0	10.0	6.6
5/25/96	11.5	10.8	8.4	8.0	10.0	6.4
5/26/96	11.9	11.2	8.5	8.5	10.7	6.7
5/27/96	11.0	10.2	7.6	7.9	9.3	5.9
5/28/96	10.7	9.9	6.1	8.7	9.9	6.2
5/29/96	12.2	11.2	6.4	9.7	11.3	6.9
5/30/96	11.3	10.7	6.3	8.9	10.8	6.5
5/31/96	12.0	11.2	6.4	10.1	12.1	7.6
6/1/96	12.6	11.9	7.7	10.5	12.1	7.7
6/2/96	12.3	11.8	5.8	10.5	11.1	7.8
6/3/96	11.2	10.4	6.8	9.4	10.2	7.3
6/4/96	11.3	10.7	8.1	9.7	10.5	8.0
6/5/96	10.9	10.4	8.2	9.3	9.7	7.3
6/6/96	11.8	11.3	7.8	10.3	10.8	7.4
6/7/96	12.9	12.9	8.1	11.4	12.3	7.8
6/8/96	12.9	12.6	5.1	11.5	11.8	7.4
6/9/96	12.2	11.7	9.4	11.2	11.8	7.6
6/10/96	10.3	9.9	8.9	8.8	9.5	5.5
6/11/96	9.6	9.1	9.4	9.7	9.8	6.7
6/12/96	10.2	10.7	10.3	9.5	10.2	6.9
6/13/96	11.2	11.5	10.4	9.7	10.2	8.5
6/14/96	12.5	12.3	11.1	10.5	11.3	9.3
6/15/96	13.0	13.0	11.8	11.1	11.9	9.5
6/16/96	13.7	14.1	12.9	12.4	12.8	10.0
6/17/96	15.8	15.4	13.8	13.1	13.5	10.4
6/18/96	16.3	15.6	14.2	13.5	14.1	11.0
6/19/96	16.0	15.4	14.5	13.5	14.3	11.4
6/20/96	15.8	15.3	14.2	13.5	14.2	11.4
6/21/96	16.3	15.7	14.5	14.1	14.6	12.1
6/22/96	16.1	15.8	15.0	14.5	14.7	12.7
6/23/96	16.6	15.9	14.8	14.5	14.2	13.1
6/24/96	15.8	15.5	14.1	13.4	13.0	12.8
6/25/96	15.5	14.5	13.7	13.3	13.6	13.1
6/26/96	15.5	14.7	14.1	13.6	13.2	13.1
6/27/96	15.5	14.6	13.9	13.3	12.7	12.6

Table 7. Continued.

Date	Badger		Piledriver			23-Mile
	lower	middle	lower	middle	upper	middle
6/28/96	14.3	13.8	13.3	13.2	12.7	11.9
6/29/96	12.4	11.8	11.6	11.5	10.6	10.5
6/30/96	10.7	9.9	9.9	10.1	8.8	9.6
7/1/96	11.7	10.6	10.8	10.7	9.2	9.9
7/2/96	13.2	13.1	12.7	11.5	9.4	10.1
7/3/96	15.0	14.3	13.5	12.1	9.7	11.2
7/4/96	15.4	14.4	13.3	12.2	10.6	11.9
7/5/96	15.7	14.7	14.0	13.2	11.1	12.4
7/6/96	15.1	14.6	13.6	12.6	10.6	12.2
7/7/96	15.5	15.1	13.8	13.3	11.4	13.3
7/8/96	16.3	16.3	14.5	13.8	11.7	13.7
7/9/96	15.0	14.3	10.2	11.8	9.7	12.5
7/10/96	14.4	13.5	11.3	12.5	10.2	12.7
7/11/96	14.6	14.1	13.4	12.4	10.3	13.1
7/12/96	14.4	13.8	13.4	12.3	10.3	12.9
7/13/96	13.8	13.0	12.2	11.6	9.5	12.1
7/14/96	12.9	12.2	11.1	10.6	8.8	10.9
7/15/96	12.4	11.8	11.0	10.6	8.8	10.5
7/16/96	12.6	12.2	11.6	10.7	8.7	10.1
7/17/96	13.3	13.5	12.8	11.9	9.9	11.1
7/18/96	14.2	14.7	14.1	12.7	10.8	12.2
7/19/96	15.1	15.7	14.4	14.0	12.1	13.0
7/20/96	16.1	16.6	15.7	14.3	12.2	12.6
7/21/96	15.9	15.4	14.5	13.5	11.0	12.4
7/22/96	15.2	14.4	13.8	12.8	10.6	12.3
7/23/96	15.0	14.7	13.8	12.8	10.7	11.9
7/24/96	15.5	15.7	14.5	13.2	11.3	12.2
7/25/96	15.7	15.3	14.5	13.2	10.9	13.5
7/26/96	14.7	13.6	13.2	12.2	10.0	12.4
7/27/96	13.7	12.8	12.7	12.0	10.0	11.8
7/28/96	13.6	13.0	13.0	12.1	10.1	11.8
7/29/96	13.4	12.5	12.6	11.3	9.2	11.8
7/30/96	12.8	11.9	12.0	11.0	8.9	11.9
7/31/96	12.5	11.9	11.9	11.2	8.6	12.2
8/1/96	12.6	12.1	12.1	10.8	8.3	11.8
8/2/96	11.8	10.8	10.5	9.5	7.4	10.6
8/3/96	11.0	9.7	9.6	9.2	7.4	9.8
8/4/96	10.7	9.9	10.1	9.0	7.8	8.8
8/5/96	11.3	10.5	10.1	9.1	7.5	8.3
8/6/96	10.9	10.1	9.7	9.0	7.5	8.3
8/7/96	10.8	10.0	9.9	9.5	8.0	9.6
8/8/96	10.3	9.9	9.6	8.4	7.0	9.4
8/9/96	9.9	9.1	8.7	8.1	6.9	8.9
8/10/96	9.8	8.9	8.7	8.3	7.0	9.1
8/11/96	10.3	9.4	9.5	8.8	7.5	10.0

Table 7. Continued.

Date	Badger lower	Badger middle	Piledriver lower	Piledriver middle	Piledriver upper	23-mi middle
8/12/96	11.2	10.4	10.7	9.3	8.0	10.2
8/13/96	12.4	11.5	11.1	10.0	8.9	10.5
8/14/96	12.5	11.8	11.4	10.1	8.9	10.6
8/15/96	12.2	11.6	11.4	10.3	9.1	11.0
8/16/96	11.8	11.0	10.8	9.9	8.5	11.0
8/17/96	11.4	10.7	10.1	9.5	8.2	10.5
8/18/96	10.9	10.1	9.9	9.6	8.5	10.8
8/19/96	10.6	9.9	10.0	9.4	7.9	10.6
8/20/96	10.3	9.6	9.7	9.0	7.7	10.1
8/21/96	9.3	8.6	8.7	8.2	7.1	9.2
8/22/96	8.0	7.4	7.7	7.7	7.0	8.7
8/23/96	8.4	7.7	8.4	8.4	7.6	9.0
8/24/96	8.9	8.5	8.9	8.3	7.3	9.2
8/25/96	10.0	9.5	9.3	8.5	7.6	9.4
8/26/96	9.3	8.6	8.1	7.7	7.0	8.6
8/27/96	8.6	7.9	7.3	7.0	6.4	

Table 8. Minimum daily temperatures at monitoring stations of sloughs, 1996.

	Badger		Piledriver			23-Mile
Date	lower	middle	lower	middle	upper	middle
5/14/96	3.3	5	1.9	2.0	2.3	0.6
5/15/96	3.1	2.8	2.6	1.7	2.2	0.8
5/16/96	4.5	3.9	4	3.9	3.1	1.5
5/17/96	3.6	2.8	3.6	3.3	2.8	1.7
5/18/96	5.2	3.7	4.2	4.7	3.7	3.4
5/19/96	3.3	2.2	2.6	3.4	2.2	3
5/20/96	4.5	3	4	4.5	3.3	3.3
5/21/96	4.5	3.1	4.4	4.8	3.6	3.7
5/22/96	5	3.1	4.4	5.6	3.7	4.2
5/23/96	6.3	3.1	5.5	6.6	3.9	4.5
5/24/96	7.5	3.7	6.3	7.9	4.8	5.8
5/25/96	7.9	3.7	6.4	8.6	5	5.9
5/26/96	8.7	3.9	6.6	9.2	5.5	6.4
5/27/96	9.5	4.7	7	9.3	6.4	7.6
5/28/96	7	3.4	5.2	7.2	5.3	5.6
5/29/96	8.1	3.7	5	8.7	5.6	6.6
5/30/96	9.7	4.8	5.6	9.8	6.7	8.4
5/31/96	8.6	4.8	5.2	8.9	7	8.6
6/1/96	8.9	4.5	6.3	9.7	6.4	8.2
6/2/96	10.6	6.1	4.5	10.8	8.6	9.5
6/3/96	8.4	4.7	5	8.4	6.7	6.9
6/4/96	8.6	5.5	6.7	8.7	7	7.6
6/5/96	7.3	4.4	6.1	7.9	5.3	5.6
6/6/96	8.1	4.2	4.7	8.9	6.3	6.7
6/7/96	10	5.5	3.9	10.9	8.1	9.2
6/8/96	10.4	5.2	3.1	10.9	8.4	9.2
6/9/96	10	5.3	7.2	10.1	8.4	9.3
6/10/96	9.7	4.8	8.1	8.6	7.5	8.7
6/11/96	7.9	4.7	7.2	7.3	7	7.3
6/12/96	8.2	4.2	8.6	8.9	7	7.9
6/13/96	9.5	6.7	8.4	9.5	7	7.8
6/14/96	10.6	7	9	10.8	7.8	9
6/15/96	10.8	6.9	9.3	10.6	7.9	9.3
6/16/96	11.4	6.7	10	11.4	8.7	9.2
6/17/96	12.6	7.5	11.4	13.1	9	10.6
6/18/96	12.6	8.1	11.5	13.4	9.7	11.1
6/19/96	12.8	8.9	12.1	13.5	10	11.5
6/20/96	13.2	9.2	12.1	13.5	10.4	11.8
6/21/96	13.2	10	12.3	13.7	10.8	11.8
6/22/96	13.8	10.6	13.1	14.5	11.2	12.4
6/23/96	12.9	10.6	10.9	13.8	10.8	11.2
6/24/96	13.5	11.7	13.2	14.5	11.2	11.7
6/25/96	13.4	11.8	12	13.4	11.1	10.9

Table 8. Continued.

	Badger		Piledriver			23-Mile
Date	lower	middle	lower	middle	upper	middle
6/26/96	12.8	11.7	12.3	13.2	11.1	11.2
6/27/96	12.8	11.1	12.1	13.1	10.8	10.3
6/28/96	12.8	10.6	12.1	13.1	10.9	10.1
6/29/96	11.8	9.8	10.6	10.8	10.8	10
6/30/96	10.1	9.2	9.5	9.3	9.3	8.2
7/1/96	9.2	8.9	8.9	8.7	8.9	7.5
7/2/96	10.4	8.9	10.8	11.4	9	7.3
7/3/96	12.8	10.1	11.7	12.9	10.1	7.8
7/4/96	12.4	9.8	11.2	12.4	9.3	7.3
7/5/96	13.5	10.9	11.8	13.5	10.9	8.6
7/6/96	12.9	10.4	12	13.2	10.4	8.4
7/7/96	13.2	11.1	11.4	13.1	10.1	8.1
7/8/96	14.8	12.4	9	14.9	11.5	9.5
7/9/96	14.3	12.1	8.2	12.8	11.2	8.9
7/10/96	13.1	11.5	8.7	11.7	10.1	7.6
7/11/96	13.2	11.7	11.8	12.9	10	7.6
7/12/96	13.2	12.3	12	12.4	10.6	8.2
7/13/96	12.9	11.5	10.9	11.8	10	7.9
7/14/96	12.4	10.6	10.6	11.5	9.8	7.6
7/15/96	11.5	10.1	9.7	10.6	9	7.3
7/16/96	11.7	8.7	10	10.8	8.4	6.4
7/17/96	12.3	9.7	10.9	11.8	9.5	7.3
7/18/96	13.4	10.8	12.6	13.5	10.6	8.6
7/19/96	14.1	11.7	9.5	14.0	10.9	8.9
7/20/96	15.1	11.4	13.8	15.3	11.7	9.5
7/21/96	15.3	11.7	13.8	14.6	11.8	9.3
7/22/96	14.5	11.7	12.9	13.5	11.7	9
7/23/96	14	11.1	12	13.1	10.8	8.4
7/24/96	14.8	11.1	12.6	14.1	10.6	8.6
7/25/96	15.1	12.3	13.2	14.3	11.2	9
7/26/96	14.1	11.7	12.1	12.8	10.4	8.1
7/27/96	13.2	11.1	11.5	12.0	10.4	7.9
7/28/96	13.1	10.9	11.4	11.7	10	7.8
7/29/96	13.1	11.1	11.7	12.0	9.7	7.6
7/30/96	12.4	11.2	11.4	11.4	10	7.6
7/31/96	11.8	11.1	10.4	10.9	9.3	7
8/1/96	12.3	11.2	11.5	11.7	9.7	7.2
8/2/96	11.5	9.8	9.7	10.0	8.9	6.9
8/3/96	10.6	9.3	8.7	9.0	7.9	5.9
8/4/96	10	8.1	8.2	8.4	6.9	5.3
8/5/96	10.4	7.9	9.2	9.7	7.6	5.9
8/6/96	10	7.8	8.7	9.3	7.8	6.1
8/7/96	8.7	7.5	8.2	8.6	7.2	5.3

Table 8. Continued.

Date	Badger		Piledriver			23-Mile
	lower	middle	lower	middle	upper	middle
8/8/96	9.5	8.7	9	9.3	7.3	5.5
8/9/96	9.2	8.6	8.2	8.6	7.6	6.1
8/10/96	8.9	8.2	7.8	8.2	7.2	5.8
8/11/96	8.9	8.9	8.2	8.2	7	5.8
8/12/96	9.7	9.2	9.2	9.3	7.6	6.3
8/13/96	10.8	9.3	9.5	10.3	8.1	6.6
8/14/96	11.2	9.3	10.1	11.1	8.2	7
8/15/96	11.2	10.1	10.6	10.9	8.9	7.2
8/16/96	10.9	10.4	10.3	10.4	8.9	7.3
8/17/96	10.4	9.8	9.3	10.1	8.2	6.6
8/18/96	9.7	9.8	8.7	9.3	7.9	6.6
8/19/96	8.7	9	8.1	8.4	7	5.5
8/20/96	8.6	8.7	8.2	8.4	6.7	5.3
8/21/96	8.2	8.6	7.8	7.8	7	5.6
8/22/96	7	7.9	6.6	6.7	6.4	5.5
8/23/96	6.7	7.5	6.7	6.3	6.3	5.5
8/24/96	7	7.5	7	6.9	5.8	4.8
8/25/96	9	8.9	8.6	8.7	7.6	6.6
8/26/96	8.7	7.8	7.3	7.9	7.2	6.1
8/27/96	6.3		5.3	6.1	5.3	4.7

Table 9. Maximum daily temperatures recorded at monitoring stations of sloughs, 1996.

	Badger		Piledriver			23-Mile
Date	lower	middle	lower	middle	upper	middle
5/14/96	7.3	7.9	4.4	6.1	6.7	5.8
5/15/96	8.9	8.4	6.1	6.9	7.6	8.1
5/16/96	7.8	7	6.3	6.3	6.4	6.4
5/17/96	9.3	7.5	6.4	7.3	7.3	8.2
5/18/96	8.2	5.5	5.5	7.0	5.5	5.8
5/19/96	9.2	6.9	6.3	7.5	7.6	9.5
5/20/96	9.5	7.3	7.3	7.5	7.2	8.6
5/21/96	10.3	7.6	7.9	8.6	8.9	12.8
5/22/96	12.9	9	9	10.0	10.1	12.8
5/23/96	14.1	10	10.1	11.4	11.2	14.5
5/24/96	15.1	9.7	10.1	12.0	11.5	14.6
5/25/96	15.7	9.7	11.2	12.6	11.1	14.9
5/26/96	15.9	10	11.1	13.1	12.1	15.7
5/27/96	13.1	7.9	8.6	11.7	9.3	11.7
5/28/96	14.5	9.5	7.6	12.1	12.6	14.8
5/29/96	16.8	10.4	8.6	13.4	14	17.2
5/30/96	13.1	8.4	7	12.3	11.2	13.2
5/31/96	15.9	10.9	7.8	13.4	13.8	16.4
6/1/96	16.5	11.1	9.8	13.7	14.5	15.9
6/2/96	14.3	10.1	7.2	12.8	12.3	13.7
6/3/96	14.1	10.1	9.5	11.8	12.3	14.3
6/4/96	14.6	11.2	10.1	12.4	12.6	14.6
6/5/96	14.6	10.6	10.8	12.3	13.8	14.1
6/6/96	15.9	10.9	11.8	13.5	14.8	14.9
6/7/96	16.1	11.1	13.4	14.8	14.9	16.1
6/8/96	15.3	10	10.6	14.0	14.6	14.5
6/9/96	14.8	10.3	13.5	13.2	14.3	15.4
6/10/96	12.4	6.3	10	11.7	12.1	12
6/11/96	12	9.8	12.9	11.2	13.1	12.8
6/12/96	11.7	9.5	12	11.8	11.4	11.8
6/13/96	13.1	11.4	13.2	13.4	12.3	12.6
6/14/96	14.6	12.8	13.8	14.3	13.4	13.8
6/15/96	16.2	12.9	14.9	15.4	14.8	14.8
6/16/96	16.5	13.8	16.1	16.4	17.3	17
6/17/96	20.2	14	17	17.6	17.2	17
6/18/96	20.7	14.8	17.3	17.9	18.1	17.5
6/19/96	18.7	14.3	17.2	17.0	17.3	17
6/20/96	18.7	13.8	16.4	17.0	16.5	16.7
6/21/96	19.9	14.9	17.6	17.8	17.9	17.8
6/22/96	18.7	15.3	17.8	17.5	18.1	17.5
6/23/96	20.4	16.1	18.1	17.9	18.7	17.3
6/24/96	17.6	13.8	14.9	16.2	15.7	14.6
6/25/96	17.9	14.8	16.2	15.7	15.7	16.7
6/26/96	18.6	15.6	17	16.7	16.2	15.4

Table 9. Continued.

Date	Badger lower	Badger middle	Piledriver lower	Piledriver middle	Piledriver upper	23-Mile middle
6/27/96	18.4	14.1	15.9	16.1	16.4	14.8
6/28/96	15.9	13.8	14.9	14.5	15.7	15.3
6/29/96	14	11.4	12.6	12.8	13.5	13.1
6/30/96	11.4	10.1	10.3	10.4	10.8	9.5
7/1/96	15.1	11.5	13.4	13.1	13.4	11.5
7/2/96	16.2	11.2	14.5	14.8	14.3	11.4
7/3/96	17.2	12.4	14.8	15.9	14	11.7
7/4/96	18.4	14.3	14.8	15.9	15.1	14.5
7/5/96	17.9	14.5	16.1	16.1	16.2	14.1
7/6/96	17.2	13.8	14.8	15.7	15.1	13.1
7/7/96	18.3	15.7	16.2	17.0	17.3	14.9
7/8/96	17.6	15.6	16.7	17.3	16.2	13.5
7/9/96	16.8	12.9	11.1	16.4	13.1	11.2
7/10/96	16.2	14.5	14.9	15.1	15.4	13.1
7/11/96	15.9	14.8	14.6	15.3	15.1	13.1
7/12/96	15.7	14.1	14.9	14.9	14.6	13.1
7/13/96	15.3	13.2	13.4	13.8	14	11.5
7/14/96	14.1	11.4	11.7	12.9	11.5	10.3
7/15/96	13.4	11.2	12.8	12.9	13.2	10.8
7/16/96	13.5	11.4	13.1	13.4	13.2	11.1
7/17/96	14.8	12.8	14.8	15.4	15.1	12.8
7/18/96	15.6	14.1	16.2	15.9	15.6	13.7
7/19/96	16.7	14.6	17.8	17.6	18.1	16.2
7/20/96	17.2	13.8	17.5	17.8	17.6	14.9
7/21/96	16.8	13.5	15.4	16.5	15.6	12.6
7/22/96	15.9	12.9	14.5	15.1	14.1	12.1
7/23/96	16.2	12.9	16.2	16.2	15.7	13.5
7/24/96	16.5	13.4	16.2	17.2	16.5	14.1
7/25/96	16.5	14.9	15.9	16.1	15.7	12.9
7/26/96	15.7	13.4	14.3	14.5	14.1	11.8
7/27/96	14.3	12.9	13.8	13.8	13.8	12.1
7/28/96	14.3	12.9	14.6	14.1	14.8	12.8
7/29/96	14.1	12.4	13.2	13.2	12.6	10.6
7/30/96	13.4	12.6	12.9	12.6	12.1	10.1
7/31/96	13.2	13.7	13.5	13.1	14.1	11.1
8/1/96	13.2	12.6	12.8	12.4	11.5	9.2
8/2/96	12.4	11.2	11.7	11.7	10.3	8.2
8/3/96	11.4	10.3	10.9	10.6	10.8	9.3
8/4/96	11.7	9.8	12.4	11.4	11.5	10.8
8/5/96	11.8	9	11.4	11.4	10.9	9.3
8/6/96	12	9.2	10.9	10.8	11.2	9.5
8/7/96	13.2	12.1	12.3	11.5	12.9	11.5
8/8/96	12.1	10	10.1	10.6	9.3	8.1
8/9/96	10.6	9.3	9.2	9.7	8.7	7.5

Table 9. Continued.

Date	Badger		Piledriver			23-Mile
	lower	middle	lower	middle	upper	middle
8/10/96	10.8	10	9.7	9.5	9.7	8.4
8/11/96	11.7	11.5	10.9	10.4	10.8	9.3
8/12/96	13.2	11.7	12.4	11.7	11.7	10.3
8/13/96	14.1	12.3	12.9	12.8	12.8	11.7
8/14/96	13.7	12.3	12.8	12.4	12.6	11.1
8/15/96	13.1	12.3	12.3	12.0	12.3	10.9
8/16/96	12.6	12	11.2	11.5	11.4	9.8
8/17/96	12	11.2	10.9	11.1	10.9	9.5
8/18/96	12.4	12.6	12	10.9	12.3	11.2
8/19/96	12.8	12.6	12	11.2	12.6	10.6
8/20/96	12	12	11.4	10.4	11.7	10.4
8/21/96	10.9	10.1	9.5	9.7	9.5	8.1
8/22/96	8.9	10	9.2	8.2	9.5	8.6
8/23/96	10.6	11.1	10.6	9.0	11.5	10.1
8/24/96	11.1	11.5	11.1	9.8	11.5	9.8
8/25/96	10.8	10	9.8	10.1	9.5	8.2
8/26/96	10	9	8.6	9.2	8.4	7.8
8/27/96	9.8		8.4	8.9	8.4	6.3

Table 10. Average (± SD) sestonic chlorophyll-a concentrations (mg m^{-3}) at monitoring stations for Badger, Piledriver, and 23-Mile Sloughs, 1996.

	Badger			Piledriver			23-Mile
Date	Upper	Middle	Lower	Upper	Middle	Lower	Middle
1-May	1.18 ± 0.06	2.76 ± 0.22	--	0.23 ± 0.06	--	0.98 ± 0.06	--
14-May	2.96 ± 0.06	4.95 ± 0.42	5.12 ± 0.26	0.48 ± 0.01	0.61± 0.03	1.61 ± 0.15	1.80 ± 0.04
29-May	1.72 ± 0.34	5.02 ± 0.02	8.20 ± 0.16	0.31 ± 0.03	1.08 ± 0.17	0.60 ± 0.09	2.95 ± 0.80
18-Jun	2.39 ± 0.48	5.19 ± 0.05	8.08 ± 0.16	0.69 ± 0.03	0.46 ± 0.02	1.74 ± 0.07	5.14 ± 0.31
8-Jul	1.63 ± 0.07	2.46 ± 0.30	6.69 ± 0.91	0.37 ± 0.02	0.52 ± 0.01	1.18 ± 0.12	1.72 ± 0.14
5-Aug	1.30 ± 0.02	1.28 ± 0.20	1.64 ± 0.08	0.24 ± 0.00	0.35 ± 0.01	1.23 ± 0.12	1.66 ± 0.12
1-Sep	0.97 ± 0.06	1.44 ± 0.36	1.34 ± 0.15	0.25 ± 0.00	0.30 ± 0.00	1.17 ± 0.07	1.10 ± 0.10
Mean	2.25 ± 0.80	3.71 ± 1.65	5.95 ± 2.59	0.42 ± 0.17	0.60 ± 0.28	1.27 ± 0.45	2.65 ± 1.49

Table 11. Gross primary production data for Badger Slough, 1996.

Elevation = 130 m

Date	Station	Gross production ($g\text{-}O_2\ m^{-2}\ d^{-1}$)	Respiration ($g\text{-}O_2\ m^{-2}\ d^{-1}$)	P/R ratio	Mean temp. (°C)	Mean depth (m)
4-Jul	Middle	6.44	1.76	3.65	14.4	0.45
5-Jul		6.61	2.10	3.15	14.7	
6-Jul		6.90	1.73	3.98	14.6	
7-Jul		6.38	1.77	3.61	15.1	0.41
8-Jul		6.72	2.46	2.73	16.3	
9-Jul		5.36	2.40	2.24	14.3	
10-Jul		6.08	2.02	3.01	13.5	0.42
20-Jul	Upper	5.12	2.05	2.49	16.6	0.22
21-Jul		4.47	2.11	2.12	15.4	
22-Jul		4.36	1.88	2.32	14.4	
23-Jul		4.55	1.96	2.33	14.7	0.22
27-Sep		1.57	2.42	0.65	2.1	0.45
28-Sep		1.40	2.75	0.51	1.7	
29-Sep		0.97	2.41	0.40	1.3	
30-Sep		1.13	2.86	0.39	0.9	
1-Oct		1.48	2.67	0.56	1.5	
2-Oct		0.71	2.82	0.25	1.1	
3-Oct		0.63	3.27	0.19	0.3	0.45

Table 12. Gross primary production data for Piledriver Slough, 1996.

Elevation = 144 m

Date	Station	Gross production ($g\text{-}O_2\ m^{-2}\ d^{-1}$)	Respiration ($g\text{-}O_2\ m^{-2}\ d^{-1}$)	P/R ratio	Mean temp. (°C)	Mean depth (m)
20-Jun	Lower	3.37	1.16	2.89	14.2	0.33
21-Jun		3.05	1.11	2.75	14.5	
22-Jun		3.30	1.17	2.82	15	
23-Jun		3.53	1.12	3.16	14.8	
24-Jun		3.14	1.21	2.59	14.1	
25-Jun		3.04	1.17	2.60	13.7	
20-Jul	Middle	1.34	1.28	1.05	14.3	0.25
21-Jul		1.16	1.08	1.08	13.5	
23-Jul		1.10	1.36	0.81	12.8	
8-Aug	Lower	3.11	1.65	1.88	9.6	0.35
11-Aug		3.90	1.91	2.04	10.7	
12-Aug		3.96	2.05	1.93	11.1	
13-Aug		3.80	2.16	1.76	10.8	
17-Sep		1.67	2.25	0.74	4.7	0.28
18-Sep		1.48	2.21	0.67	3.3	

Table 13. Gross primary production data for 23-Mile Slough, 1996.

Elevation = 146 m

	Gross production ($g\text{-}O_2\,m^{-2}\,d^{-1}$)	Respiration ($g\text{-}O_2\,m^{-2}\,d^{-1}$)	P/R ratio	Mean temp. (°C)	Mean depth (m)
19-Jun	0.93	3.36	0.28	11.4	0.29
20-Jun	0.76	3.72	0.20	11.4	
22-Jun	0.43	3.37	0.13	12.7	0.33
24-Jun	0.20	3.17	0.06	12.8	
25-Jun	0.17	3.16	0.05	13.1	0.4
26-Jun	0.15	3.15	0.05	13.1	0.41
18-Aug	0.12	3.84	0.03	10.5	0.46
19-Aug	0.21	3.65	0.06	10.8	
20-Aug	0.11	3.71	0.03	10.6	
23-Aug	0.16	3.84	0.04	9.2	
24-Aug	0.09	4.07	0.02	9	
25-Aug	0.18	3.78	0.05	9.2	
26-Aug	0.19	3.79	0.05	9.4	0.42

Table 14. Length data of age-0 Arctic grayling for Badger and Piledriver Sloughs, 1996. Given are mean lengths, standard deviations (SD), ranges, sample size (N), and 95% confidence intervals (C.I.).

			Fork length (mm)			
Location	Date	N	mean	SD	Range	C.I.
Badger						
	12-Jul	544	51.2	5.6	38-67	(50.7-51.6)
	9-Aug	282	70.0	6.0	52-89	(69.3-70.7)
	30-Aug	312	77.5	8.1	62-103	(76.4-78.4)
	30-Sep	288	82.3	9.0	65-111	(81.1-83.5)
Piledriver						
	11-Jul	758	43.6	4.0	31-61	(43.3-43.9)
	8-Aug	573	66.2	7.2	41-84	(65.6-66.8)
	29-Aug	347	74.4	6.9	56-97	(73.7-75.2)
	30-Sep	288	78.5	8.2	59-98	(77.3-79.7)

Table 15. Average substrate particle size distributions, by mass, for Badger, Piledriver, and 23-Mile Sloughs, 1996. Given are cumulative proportion finer and standard deviation (SD) and sample size (N).

	Badger Slough (N = 24)		Piledriver Slough (N=24)		23-Mile Slough (N=20)	
Particle size (mm)	Proportion finer	SD	Proportion finer	SD	Proportion finer	SD
<0.0633	0.03	0.25	0.23	0.88	0.05	0.04
0.0633	1.18	0.78	0.74	0.96	0.54	0.26
0.125	2.04	1.1	1.3	1.1	1.19	0.57
0.25	4.64	2.34	2.76	1.68	3.18	1.09
0.5	9.48	3.91	4.79	2.82	8.42	2.5
1	10.83	4.21	5.61	3.39	10.02	2.86
2	12.36	4.22	6.87	4.12	11.72	3.23
4	17.53	4.59	10.37	5.73	17.08	4.31
8	30.88	6.21	19.54	9.12	29.16	6.64
16	53.41	8.26	34.69	16	45.62	9.2
32	79.32	9.98	59.68	14.81	64.85	12
64	98.38	4.5	87.81	11.35	87.52	15.68
75	99.48	2.52	96.63	6.9	90.39	13.82
100	100	0	100	0	96.35	11.55

Table 16. Water quality data for Badger Slough at lower sampling station, 1996. Means (±SD); n = 3.

Date	Alkalinity ($CaCO_3$ mg/L)	pH	Cond. (µS/cm)	Turbidity (NTU)	TP (µg / L)	TDP (µg / L)	PO_4^{-3} (mg / L)	TN (mg / L)	DN (mg / L)	NO_3-N (mg / L)
16 April	--	--	--	--	--	--	--	--	--	--
01 May	--	--	--	--	--	--	--	--	--	--
14 May	128 ± 6	--	302	7.05±0.98	102 ± 4	27 ± 1	0.26±0.03	0.30± 0.01	.030±0.30	ND
29 May	140 ± 1	7.95	332	9.95±1.57	82 ± 12	38 ± 1	0.21±0.06	0.28±0.03	0.20±0.04	0.4
18 June	140 ± 2	8.21	330	7.20±0.81	89 ± 11	43 ± 2	0.16±0.02	0.20±0.05	0.16±0.05	ND
08 July	138 ± 3	8.31	327	4.04±0.15	61 ± 4	40 ± 2	0.15±0.01	3.36±0.97	2.54±1.24	ND
05 August	134 ± 3	8.25	330	2.23±0.10	30 ± 2	32 ± 7	0.07±0.01	2.04± 1.44	1.74±1.40	ND
01 September	142 ± 1	7.17	332	2.46±0.08	32 ± 2	28 ± 4	0.01±0.02	3.35±0.18	1.67±1.23	ND

Table 17. Water quality data for Badger Slough at middle sampling station, 1996. Means (±SD); n = 3.

Date	Alkalinity ($CaCO^3$ mg/L)	pH	Cond. (µS/cm)	Turbidity (NTU)	TP (µg / L)	TDP (µg / L)	PO_4^{-3} (mg / L)	TN (mg / L)	DN (mg / L)	NO_3-N (mg / L)
02 April	--	--	--	3.30±0.37	--	--	0.11±0.02	--	--	ND
16 April	152 ± 1	--	--	3.78±0.03	27 ± 1	12 ± 1	ND	0.17±0.02	0.21±0.03	1.8
01 May	131 ± 1	7.63	279	3.70±0.44	39 ± 3	18 ± 0	0.02±0.05	0.13±0.01	0.17±0.14	0.1
14 May	127 ± 1	--	301	4.06±0.41	54 ± 6	--	0.08±0.02	--	--	ND
29 May	138 ± 1	7.95	333	3.04±0.07	37 ± 1	21 ± 1	0.05±0.01	0.16±0.0	0.32±0.07	ND
18 June	139 ± 1	8.11	330	3.23±0.17	32 ± 2	30 ± 6	0.05±0.01	0.19±0.04	0.15±0.0	ND
08 July	140 ± 2	8.2	328	1.77±0.03	38 ± 6	33 ± 6	0.08±0.01	3.31±0.88	3.53±0.97	ND
05 August	136 ± 3	7.92	340	1.80±0.08	30 ± 4	23 ± 6	0.08±0.00	1.78±1.16	2.21±1.10	0.0
01 September	142 ± 3	7.15	335	1.88±0.03	28 ± 3	20 ± 3	0.05±0.01	0.94±0.04	1.63±1.18	0.0

Table 18. Water quality data for Badger Slough at upper sampling station, 1996. Means (±SD); n = 3.

Date	Alkalinity ($CaCO^3$ mg/L)	pH	Cond. (µS/cm)	Turbidity (NTU)	TP (µg / L)	TDP (µg / L)	PO_4^{-3} (mg / L)	TN (mg / L)	DN (mg / L)	NO_3-N (mg/L)
02 April	--	--	--	--	--	--	--	--	--	--
16 April	144 ± 3	--	--	3.85±0.05	25 ± 1	--	ND	0.13±0.05	0.57±0.58	1.2
01 May	135 ± 2	7.28	300	3.79±0.13	33 ± 1	15 ± 1	0.1±0.01	0.11±0.02	0.10±0.01	ND
14 May	128 ± 1	--	307	4.10±0.21	42 ± 3	19 ± 1	0.11±0.01	0.13±0.05	0.13±0.06	ND
29 May	136 ± 3	7.99	326	2.47±0.14	32 ± 8	21 ± 1	0.10±0.02	0.07±0.05	0.14±0.04	ND
18 June	133 ± 1	7.76	328	1.91±0.06	29 ± 8	20 ± 1	0.04±0.01	0.12±0.02	0.08±0.04	ND
08 July	133 ± 1	8.01	328	2.03±0.22	31 ± 4	24 ± 4	0.05±0.01	0.83±0.23	1.67±1.30	ND
05 August	131 ± 1	7.79	338	1.97±0.02	38 ± 9	22 ± 6	0.05±0.01	2.69±1.41	1.95±1.32	ND
01 September	138 ± 2	7.06	336	2.07±0.05	24 ± 2	20 ± 4	0.05±0.01	1.84±1.45	2.11±1.51	ND

Table 19. Water quality data for Piledriver Slough at lower sampling station, 1996. Means (±SD); n = 3.

Date	Alkalinity ($CaCO^3$ mg/L)	pH	Cond. (µS/cm)	Turbidity (NTU)	TP (µg / L)	TDP (µg / L)	PO_4^{-3} (mg/L)	TN (mg / L)	DN (mg / L)	NO_3-N (mg/L)
02 April	--	--	--	0.52±0.02	--	--	--	--	--	0.4
16 April	128 ± 0	--	--	0.46±0.01	13 ± 1	6 ± 2	0.01±0.00	0.34±0.51	0.29±0.16	1.7
01 May	116 ± 0	6.85	285	1.24±0.10	24 ±6	18 ± 2	0.06±0.01	0.10±0.02	0.15±0.06	0.4
14 May	115 ± 1	6.90	277	1.26±0.09	18 ± 2	12 ± 3	0.05±0.01	0.06±0.01	0.12±0.13	ND
29 May	120 ± 2	7.61	291	0.67±0.04	18 ± 1	13 ± 0	0.01±0.00	0.12±0.02	0.10±0.01	ND
18 June	124 ± 2	8.00	308	0.64±0.07	16 ± 1	13 ± 1	0.04±0.01	0.08±0.03	0.17±0.01	ND
08 July	122 ± 1	7.38	310	0.54±0.10	22 ± 3	20 ± 6	0.01±0.01	2.30±1.73	1.76±1.54	ND
05 August	119 ± 1	7.40	316	0.77±0.26	20 ± 0	16 ± 2	0.04±0.01	2.4±1.45	2.02±1.16	ND
01 September	123 ± 1	7.16	335	0.59±0.08	18 ± 5	18 ± 1	ND	3.19±1.14	2.46±1.42	ND

Table 20. Water quality data for Piledriver Slough at middle sampling station, 1996. Means (±SD); n = 3.

Date	Alkalinity ($CaCO^3$ mg/L)	pH	Cond. (µS/cm)	Turbidity (NTU)	TP (µg / L)	TDP (µg / L)	PO_4^{-3} (mg / L)	TN (mg / L)	DN (mg / L)	NO_3-N (mg / L)
16 April	--	--	--	--	--	--	--	--	--	--
01 May	--	--	--	--	--	--	--	--	--	--
14 May	111 ± 1	--	270	0.67±0.04	7 ± 1	--	ND	--	--	ND
29 May	117 ± 1	7.90	267	0.39±0.02	9 ± 1	7 ± 1	ND	0.05±0.0	0.11±0.02	ND
18 June	115 ± 1	7.74	301	0.53±0.03	8 ± 0	7 ± 1	ND	0.08±0.01	0.66±0.74	ND
08 July	117 ± 1	7.89	298	0.64±0.06	12 ± 2	6 ± 1	ND	2.82±1.39	2.56±1.57	ND
05 August	111 ± 0	7.39	316	0.77±0.26	12 ± 2	9 ± 3	0.01±0.00	1.87±1.39	0.96±0.15	ND
01 September	115 ± 1	7.16	308	0.65±0.14	12 ± 3	8 ± 2	ND	--	--	ND

Table 21. Water quality data for Piledriver Slough at upper sampling station, 1996. Means (±SD); n = 3.

Date	Alkalinity ($CaCO^3$ mg/L)	pH	Cond. (µS/cm)	Turbidity (NTU)	TP (µg / L)	TDP (µg / L)	PO_4^{-3} (mg / L)	TN (mg / L)	DN (mg / L)	NO_3-N (mg / L)
02 April	--	--	--	--	--	--	--	--	--	--
16 April	131 ± 4	--	--	0.61±0.07	4 ± 1	--	ND	0.17±0.01	0.18±0.01	1.6
01 May	107 ± 1	6.85	272	1.11±0.22	11 ± 2	--	0.02±0.01	0.13±0.03	0.11±0.02	0.4
14 May	96 ± 0	--	275	0.87±0.02	8 ± 0	6 ± 1	ND	0.09±0.02	0.11±0.05	ND
29 May	112 ± 1	7.90	301	0.55±0.02	7 ± 2	6 ± 2	ND	0.09±0.01	0.13±0.05	ND
18 June	112 ± 1	7.80	313	0.79±0.08	12 ± 3	7 ± 2	ND	0.21±0.17	--	ND
08 July	118 ± 1	7.84	310	0.76±0.06	11 ± 1	11 ± 2	ND	2.82±1.39	2.00±1.19	ND
05 August	112 ± 2	7.22	306	0.74±0.10	11 ± 4	9 ± 3	ND	1.81±1.38	2.63±1.31	ND
01 September	114 ± 1	7.05	313	0.70±0.06	8 ± 3	8 ± 3	ND	2.29±1.71	1.99±1.29	ND

Table 22. Water quality data for 23-Mile Slough, 1996. Means (±SD); n = 3.

Date	Alkalinity ($CaCO_3$ mg/L)	pH	Cond. (µS/cm)	Turbidity (NTU)	TP (µg / L)	TDP (µg / L)	PO_4^{-3} (mg / L)	TN (mg / L)	DN (mg / L)	NO_3-N (mg / L)
02 April	--	--	--	0.06±0.34	--	--	0.02±0.01	--	--	0.5
16 April	114 ± 1	--	--	0.73±0.01	6 ± 0. 6	5 ± 0.5	ND	0.13±0.05	0.22±0.07	1.6
01 May	114 ± 1	--	--	1.22±0.03	--	--	0.01±0.01	--	--	ND
14 May	114 ± 2	6.75	283	8.03±0.35	14 ± 1.5	7 ± 1.5	0.01±0.01	0.23±0.29	0.08±0.05	ND
29 May	112 ± 1	6.70	295	0.60±0.04	8 ± 1.7	5 ± 1.2	ND	0.04±0.01	0.08±0.04	ND
18 June	95 ± 0	6.87	261	55±10	55 ± 7.0	10 ± 1.0	ND	0.37±0.11	0.23±0.24	ND
08 July	81 ± 1	6.82	240	565±38	359 ± 33.8	17 ± 2	0.01±0.02	0.51±0.57	2.06±1.19	ND
05 August	80 ± 1	6.84	222	917±35.16	577 ± 55.2	25 ± 2.1	ND	1.56±1.17	2.51±1.24	ND
01 September	78 ± 1	6.87	240	628 ±29	251 ± 28.9	18 ± 5	0.01±0.01	1.12±.094	1.09±0.10	ND