Prepared as part of the
National Water-Quality Assessment Program

Water-Quality Conditions of Chester Creek, Anchorage, Alaska, 1998–2001

Scientific Investigations Report 2006-5229

U.S. Department of the Interior
U.S. Geological Survey

Cover Photograph. Chester Creek at Arctic Boulevard looking upstream (east), May 21, 2003. Photograph taken by Janet P. Curran, U.S. Geological Survey.

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By Roy L. Glass and Robert T. Ourso

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Information regarding the National Water-Quality Assessment (NAWQA) Program is available on the Internet via the World Wide Web: http://water.usgs.gov/nawqa/

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Forword

The U.S. Geological Survey (USGS) is committed to serve the Nation with accurate and timely scientific information that helps enhance and protect the overall quality of life, and facilitates effective management of water, biological, energy, and mineral resources. Information on the quality of the Nation's water resources is of critical interest to the USGS because it is so integrally linked to the long-term availability of water that is clean and safe for drinking and recreation and that is suitable for industry, irrigation, and habitat for fish and wildlife. Escalating population growth and increasing demands for the multiple water uses make water availability, now measured in terms of quantity and quality, even more critical to the long-term sustainability of our communities and ecosystems.

The USGS implemented the National Water-Quality Assessment (NAWQA) Program to support national, regional, and local information needs and decisions related to water-quality management and policy. Shaped by and coordinated with ongoing efforts of other Federal, State, and local agencies, the NAWQA Program is designed to answer: What is the condition of our Nation's streams and ground water? How are the conditions changing over time? How do natural features and human activities affect the quality of streams and ground water, and where are those effects most pronounced? By combining information on water chemistry, physical characteristics, stream habitat, and aquatic life, the NAWQA Program aims to provide science-based insights for current and emerging water issues. NAWQA results can contribute to informed decisions that result in practical and effective water-resource management and strategies that protect and restore water quality.

Since 1991, the NAWQA Program has implemented interdisciplinary assessments in more than 50 of the Nation's most important river basins and aquifers, referred to as Study Units. Collectively, these Study Units account for more than 60 percent of the overall water use and population served by public water supply and are representative of the Nation's major hydrologic landscapes, priority ecological resources, and agricultural, urban, and natural sources of contamination.

Each assessment is guided by a nationally consistent study design and methods of sampling and analysis. The assessments thereby build local knowledge about water-quality issues and trends in a particular stream or aquifer while providing an understanding of how and why water quality varies regionally and nationally. The consistent, multi-scale approach helps to determine if certain types of water-quality issues are isolated or pervasive and allows direct comparisons of how human activities and natural processes affect water quality and ecological health in the Nation's diverse geographic and environmental settings. Comprehensive assessments on pesticides, nutrients, volatile organic compounds, trace metals, and aquatic ecology are developed at the national scale through comparative analysis of the Study-Unit findings.

The USGS places high value on the communication and dissemination of credible, timely, and relevant science so that the most recent and available knowledge about water resources can be applied in management and policy decisions. We hope this NAWQA publication will provide you the needed insights and information to meet your needs and thereby, foster increased awareness and involvement in the protection and restoration of our Nation's waters.

The NAWQA Program recognizes that a national assessment by a single program cannot address all water-resource issues of interest. External coordination at all levels is critical for a fully integrated understanding of watersheds and for cost-effective management, regulation, and conservation of our Nation's water resources. The Program, therefore, depends extensively on the advice, cooperation, and information from other Federal, State, interstate, Tribal, and local agencies, non-government organizations, industry, academia, and other stakeholder groups. The assistance and suggestions of all are greatly appreciated.

Robert M. Hirsch
Associate Director for Water

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CONVERSION FACTORS, VERTICAL DATUM, AND ABBREVIATIONS

Multiply	By	To obtain
	Length	
inch (in.)	25.4	millimeter (mm)
foot (ft)	0.3048	meter (m)
mile (mi)	1.609	kilometer (km)
	Area	
acre	4,047	square meter (m^2)
square mile (mi^2)	2.590	square kilometer (km^2)
	Flow rate	
cubic foot per second (ft^3/s)	0.02832	cubic meter per second (m^3/s)

Water temperature in degrees Celsius (°C) may be converted to degrees Fahrenheit (°F) as follows:

$$°F=(1.8×°C)+32$$

ABBREVIATED WATER-QUALITY UNITS

Chemical concentration and water temperature are given only in metric units. Specific conductance is given in microsiemens per centimeter (µS/cm) at 25°C. Chemical concentration in water is given in milligrams per liter (mg/L) or micrograms per liter (mg/L). Concentrations of coliform bacteria are expressed as the number of colonies per 100 milliliter (col/100 mL) of sample. Concentrations of trace elements in sediment are given in micrograms per gram, dry weight (µg/g), whereas concentrations of organic compounds in sediment are given in micrograms per kilogram, dry weight (µg/kg). Similarly, chemical concentration in fish tissue is given in micrograms per gram wet weight (µg/g) or micrograms per kilogram wet weight (µg/kg).

WATER YEAR

Water year is the 12-month period, October 1 through September 30. The water year is designated by the calendar year in which it ends and includes 9 of the 12 months. Thus, the water year ending September 30, 1999, is called the "1999 water year."

MAP NUMBERING SYSTEM

The map numbers in this report follow the map numbering system for stream-gaging stations and water-quality-monitoring sites in previous Cook Inlet Basin National Water-Quality Assessment reports.

Acronyms used in this report:

cm	centimeters
DDT	dichloro-diphenyl-trichloroethane
DO	dissolved oxygen
EPT	Ephemeroptera, Plecoptera, and Trichoptera
HAL	Lifetime Health Advisory
MCL	Maximum Contaminant Level
mi^2	miles squared
MTBE	Methyl *tert*-butyl ether
NAWQA	National Water-Quality Assessment Program
NWQL	National Water-Quality Laboratory
PAH	polycyclic aromatic hydrocarbon
PCB	polychlorinated biphenyls
PEL	Probable Effect Level
SPMD	semipermeable membrane sampling devices
SVOC	semivolatile organic compounds
USEPA	United States Environmental Protection Agency
USGS	United States Geological Survey
VOC	volatile organic compounds

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Water-Quality Conditions of Chester Creek Anchorage, Alaska, 1998–2001

Abstract

Between October 1998 and September 2001, the U.S. Geological Survey's National Water-Quality Assessment Program evaluated the water-quality conditions of Chester Creek, a stream draining forest and urban settings in Anchorage, Alaska. Data collection included water, streambed sediments, lakebed sediments, and aquatic organisms samples from urban sites along the stream. Urban land use ranged from less than 1 percent of the basin above the furthest upstream site to 46 percent above the most downstream site. Findings suggest that water quality of Chester Creek declines in the downstream direction and as urbanization in the watershed increases.

Water samples were collected monthly and during storms at a site near the stream's mouth (Chester Creek at Arctic Boulevard) and analyzed for major ions and nutrients. Water samples collected during water year 1999 were analyzed for selected pesticides and volatile organic compounds. Concentrations of fecal-indicator bacteria were determined monthly during calendar year 2000. During winter, spring, and summer, four water samples were collected at a site upstream of urban development (South Branch of South Fork Chester Creek at Tank Trail) and five from an intermediate site (South Branch of South Fork Chester Creek at Boniface Parkway).

Concentrations of calcium, magnesium, sodium, chloride, and sulfate in water increased in the downstream direction. Nitrate concentrations were similar at the three sites and all were less than the drinking-water standard. About one-quarter of the samples from the Arctic Boulevard site had concentrations of phosphorus that exceeded the U.S. Environmental Protection Agency (USEPA) guideline for preventing nuisance plant growth. Water samples collected at the Arctic Boulevard site contained concentrations of the insecticide carbaryl that exceeded the guideline for protecting aquatic life. Every water sample revealed a low concentration of volatile organic compounds, including benzene, toluene, tetrachloroethylene, methyl *tert*-butyl ether, and chloroform. No water samples contained volatile organic compounds concentrations that exceeded any USEPA drinking-water standard or guideline. Fecal-indicator bacteria concentrations in water from the Arctic Boulevard site commonly exceeded Federal and State guidelines for water-contact recreation.

Concentrations of cadmium, copper, lead, and zinc in streambed sediments increased in the downstream direction. Some concentrations of arsenic, chromium, lead, and zinc in sediments were at levels that can adversely affect aquatic organisms. Analysis of sediment chemistry in successive lakebed-sediment layers from Westchester Lagoon near the stream's mouth provided a record of water-quality trends since about 1970. Concentrations of lead have decreased from peak levels in the mid-1970s, most likely because of removing lead from gasoline and lower lead content in other products. However, concentrations in recently-deposited lakebed sediments are still about 10 times greater than measured in streambed sediments at the upstream Tank Trail site. Zinc concentrations in lakebed sediments also increased in the early 1970s to levels that exceeded guidelines to protect aquatic life and have remained at elevated but variable levels. Pyrene, benz[*a*]anthracene, and phenanthrene in lakebed sediments also have varied in concentrations and have exceeded protection guidelines for aquatic life since the 1970s. Concentrations of dichloro-diphenyl-trichloroethane, polychlorinated biphenyls (PCBs), or their by-products generally were highest in lakebed sediments deposited in the 1970s. More recent sediments have concentrations that vary widely and do not show distinct temporal trends.

Tissue samples of whole slimy sculpin (*Cottus cognatus*), a non-migratory species of fish, showed concentrations of trace elements and organic contaminants. Of the constituents analyzed, only selenium concentrations showed levels of potential concern for protection of fish-eating wildlife and are most likely because of natural geologic sources. Although detected in sculpin, the total PCB concentration was less than the protection guideline for fish-eating wildlife.

The relative abundance of algae that are tolerant of increased salinity increased from the headwaters to the mouth, as did dissolved minerals in water. Pollution-sensitive benthic macroinvertebrate taxa decreased and dominance of pollution-tolerant worms increased in the downstream direction, indicating water-quality degradation.

Introduction

The National Water-Quality Assessment (NAWQA) Program was implemented in 1991 by the U.S. Geological Survey (USGS) to assess the status and trends in water quality for a large part of the Nation's surface- and ground-water resources and to provide a better understanding of the factors that affect water quality (Gilliom and others, 1995). The assessment of the Cook Inlet Basin, 1 of 51 study units across the Nation, began in 1997.

Understanding the effects of urbanization on water quality is a focus of the NAWQA Program. To help assess the effects of urban development on water quality in the Cook Inlet Basin, chemical, physical, and biological data were collected from sites along Chester Creek in Anchorage, Alaska, that represent a range of urban development intensity. Measurements were made to determine water chemistry in the stream; the presence of contaminants in streambed and lakebed sediments and in tissues of resident fish; the physical habitat within the stream; and the abundance and diversity of attached algae, benthic invertebrates, and fish living in the stream. This report summarizes the chemical analyses of water, bed-sediment, fish-tissue samples, and the biological communities in the Chester Creek watershed during 1998-2001.

Most of the data summarized in this report were discussed or tabulated in various reports describing specific aspects of the assessment of water-quality conditions in the Cook Inlet Basin for the NAWQA program or in annual water-data reports for Alaska (Bertrand and others, 2000; Meyer and others, 2001; Meyer and others, 2002). The environmental setting of the Cook Inlet Basin was described by Brabets and others (1999). The Chester Creek at Arctic Boulevard monitoring site was one of six routinely sampled sites in the Cook Inlet Basin. The water quality, biological, and physical-habitat conditions at these sites are described by Brabets and Whitman (2004). Water-quality data collected by USGS prior to 1998 and water-temperature data collected prior to 1999 in Chester Creek at Arctic Boulevard and other streams in the Cook Inlet Basin are summarized by Glass (1999) and Kyle and Brabets (2001). The occurrence and distribution of organic compounds and trace elements in streambed sediments and fish tissues in the Cook Inlet Basin were described by Frenzel (2000, 2002). The occurrence of fecal-indicator bacteria in Anchorage streams was described by Frenzel and Couvillion (2002). The effects of urbanization on macroinvertebrate communities in streams in Anchorage were discussed by Ourso (2001) and Ourso and Frenzel (2003).

Description of the Study Area

Chester Creek drains 28 square miles (mi^2) in the central part of the Municipality of Anchorage in south-central Alaska (fig. 1). The stream originates along the Chugach Mountains front and flows to the west into the Knik Arm of Cook Inlet. The geology of the watershed consists primarily of metamorphic, volcanic, and igneous rock in the Chugach Mountains and unconsolidated alluvial and glacial deposits in the lower elevations (Brabets and others, 1999). The land cover in the headwaters of the watershed consists of shrubs, tundra, forests, and wetlands (fig. 2) and is part of the U.S. Army's Fort Richardson. The lower portion of the watershed is used primarily for urban purposes, including residential, commercial, institutional (schools and hospitals), and transportation (roads and a municipal airport) uses. Land cover within the watershed during 2000 consisted of approximately 46 percent urban, 32 percent forest, 17 percent shrub or tundra, and 4 percent wetland or water (Brabets and Whitman, 2004). About 78,000 people lived within the watershed during 2000, making it one of the most densely populated watersheds in Alaska.

The stream, its water impoundments (Westchester Lagoon and University Lake, fig. 3), and parks and trails adjacent to the stream are extensively used for recreation by area residents and visitors. The stream historically supported large runs of coho salmon in which several thousand adults returned to spawn (Whitman, 2002). Several government agencies and nongovernment organizations are proposing projects to improve fish passage and the conditions of instream and riparian areas to help restore salmon populations. Water from the stream is not used directly for drinking-water supply, but the stream recharges aquifers from which nearby public-supply and domestic wells obtain their water. Chester Creek has three major tributaries. The north and middle forks are in the north-central part of the watershed and drain mostly residential and commercial areas (fig. 2). Much of these streams have been rerouted through underground pipes and straightened drainage channels. The south fork is the longest tributary and originates on the western slope of the Chugach Mountains in a relatively undeveloped portion of the Fort Richardson military reservation. Near the center of the watershed, the south fork flows through a former gravel pit on a college campus and forms a 37-acre lake, University Lake. Beaver dams are present downstream from the lake. Hillstand Pond is formed by a channel constriction below Lake Otis Parkway and is downstream of the confluence of the middle and south forks. Westchester Lagoon is formed by a weir near the stream's mouth. Although greenbelts and parks parallel much of the main stem and some of the north, middle, and south forks, there are several areas where residential properties extend to the water's edge. The greenbelts and parklands provide buffers of riparian

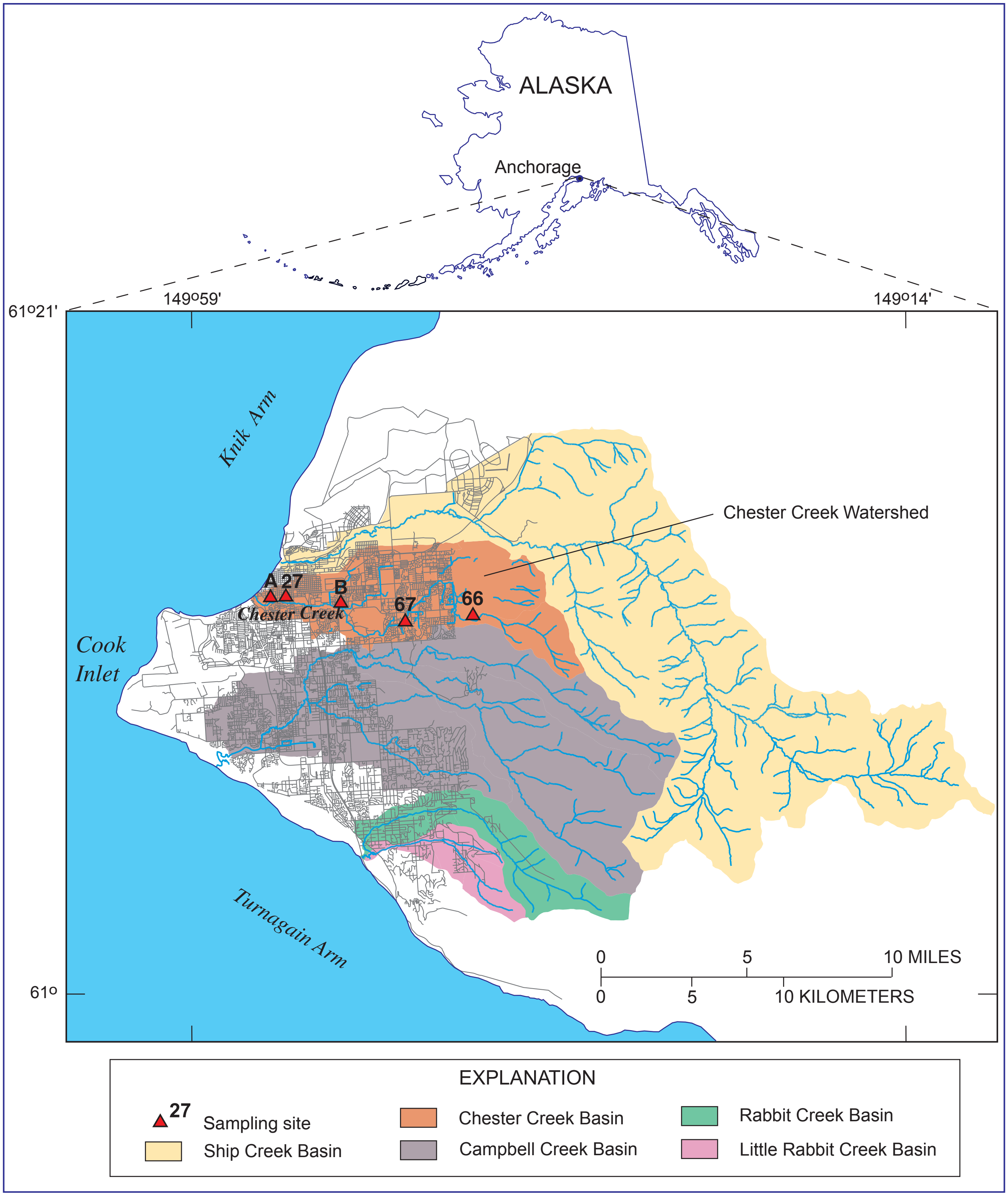

Figure 1. Major streams in the metropolitan area of Anchorage, Alaska.

or wetland vegetation along much of the stream and help intercept runoff of sediment and chemicals from urban areas, provide bank stability, and provide shading and habitat for aquatic and terrestrial animals. However, numerous storm drains empty directly into the creek, bypassing these vegetated buffer zones.

The climate of the Chester Creek watershed is transitional between continental and maritime (Brabets and others, 1999). Average annual air temperature, measured

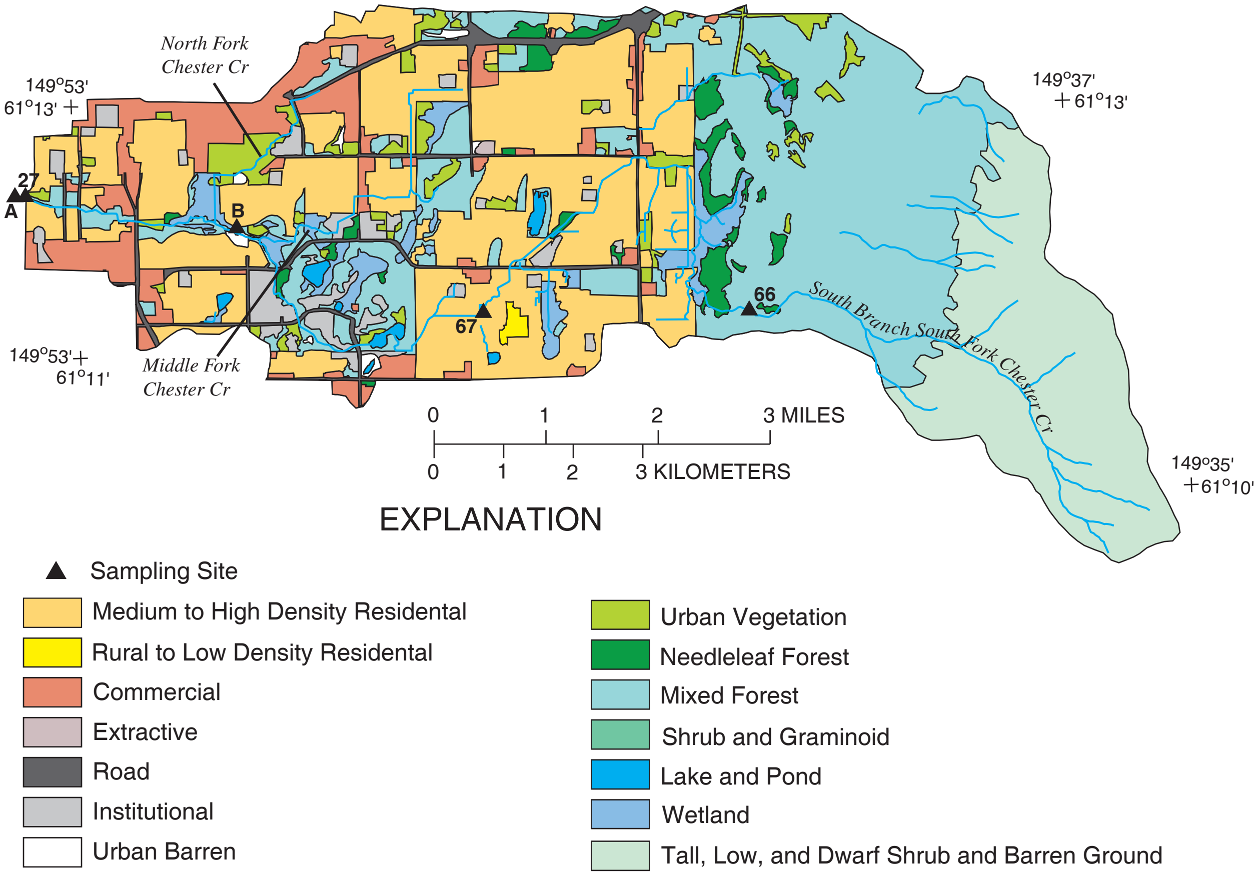

Figure 2. Land cover in the Chester Creek watershed during 2000.

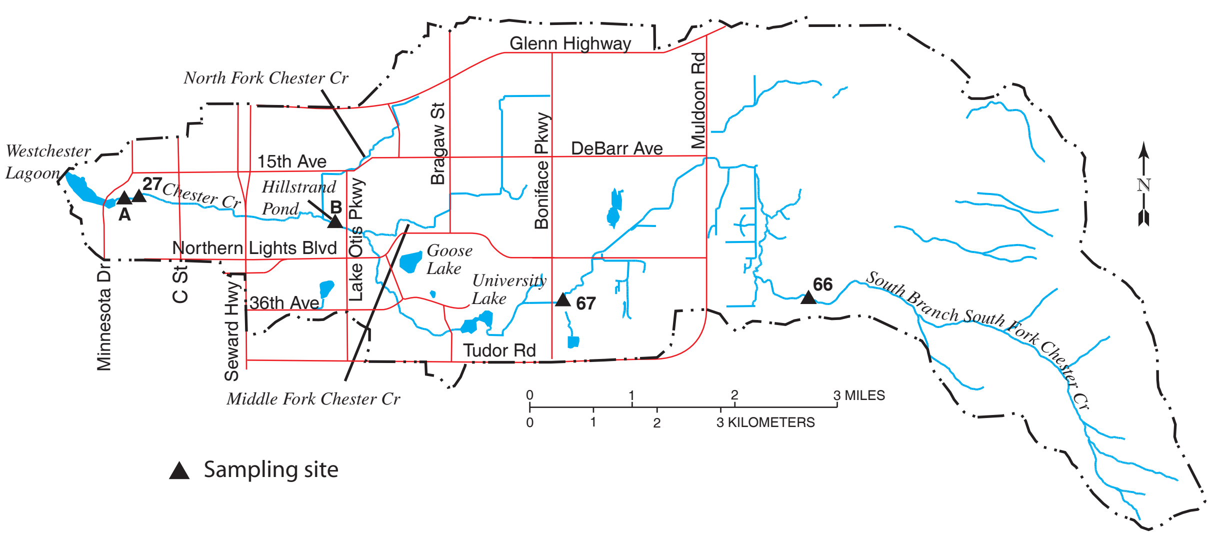

Figure 3. Sampling sites in the Chester Creek watershed, 1998-2001. See Table 1.

Table 1. Sampling sites in the Chester Creek watershed, 1998-2001.

[Sample type: BS, streambed sediment; BSC, cores of lakebed sediments; E, ecological assessment; T, fish tissue; W, water chemistry; --, no data]

Site No. (from fig. 1)	Site Name	USGS Station Number	Latitude	Longitude	Sample Type	Basin Size (square miles)	Urban Land Cover within basin (percent)
66	South Branch of South Fork Chester Creek at Tank Trail	15274796	61°11’25”	149°42’13”	BS, E, W	4.3	<1
67	South Branch of South Fork Chester Creek at Boniface Parkway	15274830	61°11’23”	149°46’33”	BS, E, W	14.8	20
B	Hillstrand Pond below Lake Otis Parkway	611202149502000	61°12’02”	149°50’20”	BSC	20	--
27	Chester Creek at Arctic Boulevard	15275100	61°12’19”	149°53’43”	BS, E, T, W	27.4	46
A	Westchester Lagoon above Minnesota Drive	611226149544601	61°12’16”	149°54’28”	BSC	28	--

at the Ted Stevens Anchorage International Airport about 3 mi. southwest of the watershed, is about 37°F, based on the 30-year period from 1971 through 2000. Mean monthly temperatures at the airport range from a low of 17°F in January to a high of 59°F in July. Precipitation averages 16.0 inches per year (in/yr) at the airport, but may be 25 in/yr or more at higher elevations in the stream’s headwater area. Precipitation measured at the airport for water years 1999-2001 was near normal during 1999 and 2000 and below normal in 2001—16.1, 16.3, and 13.7 inches, respectively. Generally, about half of the precipitation falls during July through October as rain. Precipitation from November through March is usually as snow. Snow remains on the land surface and ice covers much of the stream from November through March.

Human activities have affected the timing of water runoff and surface-water quality in the watershed (Barnwell and others, 1972; Brabets, 1987). The conversion of forests and wetlands to urban uses and the channelizing, straightening, and lowering of streams have caused more rapid rises and declines in streamflows. Runoff from roads, parking lots, and yards, and emissions from vehicles have increased the concentrations of many contaminants in stream water—including road deicing salts, trace elements, insecticides, petroleum products, and bacteria. Chester Creek, University Lake, and Westchester Lagoon have been classified as water-quality impaired by the Alaska Department of Environmental Conservation (1998) due to high concentrations of fecal-coliform bacteria.

Data Collection and Analysis

An integrated monitoring program was conducted that included collection of water, sediment, fish tissue, and aquatic organisms to help obtain an understanding of urban influences on stream health. Samples were collected for this study in accordance with methods required by the NAWQA Program (U.S. Geological Survey, 1997 to present; U.S. Geological Survey, 2002; Shelton, 1994; and Shelton and Capel, 1994).

Three water, streambed-sediment, and ecological-assessment monitoring sites and two lakebed sediment sites (fig. 3 and table 1) were established in the Chester Creek watershed to represent a range of urban intensity. Chester Creek at Arctic Boulevard (termed “Arctic Boulevard” and numbered 27) and Westchester Lagoon (site A) are near the stream’s mouth. About half of the area upstream of these two sites is used for residential, commercial, institutional, and transportation uses. South Branch of South Fork Chester Creek at Tank Trail (termed “Tank Trail” and numbered 66 in this and previous reports for the Cook Inlet Basin NAWQA program) is on the Fort Richardson Army Reservation and is upstream of urban development. South Branch of South Fork Chester Creek at Boniface Parkway (termed “Boniface Parkway” and numbered 67) is downstream from the Tank Trail site. Forests, shrubs, and wetlands cover the upper 12 mi^2 of Boniface Parkway’s basin, whereas landcover in the 3 mi^2 immediately upstream of this site consists mostly of residential urban development. Hillstrand Pond (site B) incorporates a drainage area of 20 mi^2.

Water

The Arctic Boulevard site was one of six intensively sampled sites (termed fixed sites) in the Cook Inlet Basin NAWQA study (Brabets and Whitman, 2004). At each fixed site, water samples were collected in January and March and monthly from April or May to November and analyzed for dissolved ions, nutrients, dissolved and suspended organic carbon, and suspended sediment. Field measurements of specific conductance, pH, water temperature, dissolved oxygen (DO), alkalinity, and bicarbonate were completed according to NAWQA protocols (Shelton, 1994; Wilde and Radtke, 1998). Instantaneous discharge was obtained from a continuous-recording streamflow gage at the site in accordance with standard USGS procedures (Rantz and others, 1982). In addition to the fixed-site sampling constituents, selected pesticides and volatile organic compounds (VOCs) were analyzed monthly during water year 1999, and concentrations of fecal-indicator bacteria were determined monthly during calendar year 2000. Measurements of specific conductance were recorded continuously from June 2000 through September 2001. Measurements of water temperature were recorded continuously from October 1998 through September 2001 at each of the three water-monitoring sites.

Water samples from the Tank Trail and Boniface Parkway sites were collected less frequently (five or fewer times) than from the Arctic Boulevard site. Samples for dissolved ions, nutrients, dissolved and suspended organic carbon, suspended sediment, and fecal-indicator bacteria were collected in winter, spring, and summer. Field measurements of specific conductance, pH, water temperature, DO, alkalinity, and bicarbonate were made each time water samples were collected. No water samples from these two upstream sites were analyzed to determine concentrations of pesticides or VOCs.

Most water samples were obtained by collecting depth-integrated subsamples at equal-width increments across the stream channel by wading (Shelton, 1994). A weighted-bottle sampler was used separately to collect dissolved and suspended organic-carbon samples in a baked amber glass bottle at the midpoint in the stream. Water samples for VOC analysis were collected with a specially designed Wildco sampler at the midpoint in the stream (Shelton, 1997). Lipid-containing semipermeable membrane devices (SPMDs) were also used to determine the presence of pesticides, VOCs, and semivolatile organic compounds (SVOCs) in water at the Arctic Boulevard site. The SPMDs are passive *in situ* water samplers that mimic the uptake of contaminants by biota (Huckins and others, 1993). Three SPMDs were placed in stream water at the Arctic Boulevard site from May 18 to July 13, 2000. Uptake by SPMDs indicates the compounds were dissolved in the water, and therefore, there was potential exposure for aquatic organisms at the site. Concentrations of organic compounds in the water column were estimated from extracts from the SPMDs.

Water samples were processed in the field according to NAWQA protocols (Shelton, 1994). A cone splitter was used to composite most of the samples into Teflon bottles. Samples analyzed for dissolved ions, nutrients, and field alkalinity were filtered through a 0.45-µm pore-size capsule filter. Samples analyzed for dissolved and suspended organic carbon were filtered through a 0.45-µm pore-size silver filter, and samples analyzed for pesticides were filtered through a 0.7-µm pore-size glass-fiber filter. Suspended-sediment samples were collected and processed according to methods described by Edwards and Glysson (1988) and shipped to the USGS Sediment Laboratory in Louisville, Ky., for particle-size and concentration analysis. All other water-quality samples were shipped to the USGS National Water-Quality Laboratory (NWQL) in Denver, Colo., for analysis using methods described by Fishman (1993), Sandstrom and others (1992), Zaugg and others (1995), and Furlong and others (1996).

Summary statistics for field parameters and concentrations of inorganic constituents include the number of analyses and the minimum, median, and maximum values measured. When more than one field value or concentration of inorganic constituent was reported in a day at a site, the median value for that day was used to determine the summary statistics. For organic constituents, only compounds that were detected are listed, along with the number of analyses, the number of times the compound was detected, and the maximum concentration. Concentrations that were estimated or less than the method-detection limit are marked with an “E”. Comparisons are made with drinking-water standards and guidelines established by the U.S. Environmental Protection Agency (USEPA) and guidelines for the protection of aquatic life set by the Canadian Council of Ministers of the Environment (2002b). A maximum contaminant level (MCL) is the maximum allowable concentration of a contaminant in water delivered to any user of public-water systems (USEPA, 2002). The MCLs are enforceable standards based on an average concentration taken from four quarterly samples of finished (treated) drinking water. A Lifetime Health Advisory (HAL) is a nonenforceable, risk-based guideline below which no short- or long-term human-health effects are expected, based on drinking a specific amount of water for a specific period of time. Probable effect levels (PELs) are used to indicate contaminant concentrations in water or freshwater sediment associated with adverse effects on aquatic life. The PEL is an estimate of the concentration levels above which adverse biological effects occur frequently. Standards and guidelines to evaluate the potential adverse effects of organic compounds in water have limitations because not all organic compounds or their breakdown products have standards or guidelines, and the standards and guidelines are based on toxicity tests on a single compound and do not evaluate the additive or synergistic effects of multiple compounds.

Sediment

Samples of recently-deposited streambed sediments were collected at least once from depositional areas near each water-monitoring site and analyzed for selected trace elements and organic contaminants using techniques described by Shelton and Capel (1994). The top 2 cm of sediment were collected from several areas and composited to form a large sample volume. Streambed sediments were wet sieved so that only particles finer than 0.063 mm (the silt and clay fractions) were analyzed for trace elements and only particles finer than 2 mm (the sand, silt, and clay fractions) were analyzed for organic contaminants. Sediments were digested in strong acid prior to analysis by the NWQL. One unsieved streambed-sediment sample was collected from the Arctic Boulevard site on May 13, 1998, and was analyzed by the USGS Columbia Environmental Research Laboratory in Columbia, Mo., to determine concentrations of total mercury and methylmercury (Brumbaugh and others, 2001). Concentration data are reported on a dry-weight basis in micrograms per gram (µg/g) for trace elements and micrograms per kilogram (µg/kg) for organic compounds.

Cores of lakebed sediments from two impoundments on Chester Creek, Hillstrand Pond (site B in fig. 3) and Westchester Lagoon (site A), were collected and segments from each core sample were analyzed for selected trace elements and organic contaminants (P.C. VanMetre, U.S. Geological Survey, written commun., 2001). Analyses of individual layers of lakebed sediments were performed on bulk (whole) samples.

Concentrations of contaminants in sediments are compared to guidelines for the protection of aquatic life set by the Canadian Council of Ministers of the Environment (2002a, 2002b). The PELs are established for eight of the trace elements and 18 of the organochlorine and semivolatile organic compounds analyzed. These sediment guidelines are based on bulk (whole) sediment samples. For this study, analyses of lakebed sediments were performed on bulk samples, whereas streambed sediments were sieved so that only particles finer than 0.063 mm were analyzed for trace elements and only particles finer than 2 mm were analyzed for organic contaminants. Some trace elements and organic compounds attach strongly to fine-grained sediment, thus their concentrations are expected to be higher in sieved streambed samples than in bulk samples and their toxicity may be overestimated.

Fish Tissue

Slimy sculpin, *Cottus cognatus*, were collected in 1998 and 1999 near the Arctic Boulevard site and composite samples of whole fish were analyzed for selected trace elements and organic contaminants. Concentration data are reported on a wet-weight basis in µg/g for trace elements and µg/kg for organic compounds. For contaminants in whole fish, comparisons with the New York fish-flesh criteria for protection of fish-eating wildlife (Newell and others, 1987) are used. These animal-tissue guidelines are intended to protect wildlife from adverse effects other than cancer, such as mortality, reproductive impairment, and organ damage. Wildlife guidelines from the State of New York were used because no comparable national guidelines are available for a large number of contaminants.

Aquatic Communities

An inventory of instream and riparian characteristics was conducted along a 300- to 500-ft-long reach near each water-quality site using methods described by Fitzpatrick and others (1998). Measures of instream habitat were made along 11 transects perpendicular to the streamflow and at approximately equal intervals within each of the three reaches. Attached algae, benthic macroinvertebrates, and fish were collected within each reach to determine the spatial distributions and community structures of these aquatic species using methods described in Porter and others (1993), Cuffney and others (1993), Meador and others (1993), and Moulton and others (2002).

Water-Quality Characteristics

Summary statistics for selected water-quality field measurements and inorganic constituents analyzed for each site are presented in table 2 and discussed in the following sections. Streamflow conditions at the Arctic Boulevard site are described briefly and compared to historical mean streamflows.

Streamflow

Streamflow often affects the water-quality conditions of a stream. During high flows, concentrations of some water-quality constituents may decrease as a result of dilution or increase as a result of inputs from stormwater runoff. A hydrograph showing daily mean streamflow for the sampling period and the sampling dates for the Arctic Boulevard site is presented in figure 4. Streamflows in Chester Creek are high from April through October due to runoff from snowmelt and rain and are low during winter. The mean annual discharge for the watershed site is 20.2 cubic feet per second (ft^3/s), based on records collected intermittently from 1966 through 2001 at the Arctic Boulevard site. Annual discharges during water years 1999-2001 were 20.0, 25.7, and 20.5 ft^3/s, respectively.

Field Measurements

Water temperatures in Chester Creek are reflective of climatic and local physical conditions, such as shading. Figure 5 shows daily mean water temperatures at the Arctic Boulevard site. Temperatures were cooler at the two upstream sites. For water year 2001, mean water temperatures at the Tank Trail, Boniface Parkway, and Arctic Boulevard sites were 3.1, 4.4, and 5.9°C, respectively. State water-quality standards (Alaska Department of Environmental Conservation, 2003) require that water temperatures in streams used by fish are not to exceed 15°C in migration routes or in rearing areas and temperatures are not to exceed 13°C in spawning areas and during egg and fry incubation periods. Daily maximum water temperatures were as great as 17°C at the Arctic Boulevard site and 15°C at the Boniface Parkway site, indicating that there may be occasional stress to fish from elevated stream temperatures.

Specific conductance is a measure of the capacity of a sample of water to conduct electricity and is proportional to the concentration of the charged ion species in the water and to the concentration of dissolved solids of the water. The concentrations of dissolved solids and values of specific conductance increased from the stream's headwaters to its mouth. For example, during a low-flow period in mid-March 2000, concentrations of dissolved solids (sum of constituents) at the Tank Trail, Boniface Parkway, and Arctic Boulevard sites were 80, 112, and 156 milligrams per liter (mg/L), respectively, and specific conductance values were 122, 211, and 272 microsiemens per centimeter at 25°C (µS/cm), respectively. Specific conductance and concentrations of dissolved solids at the Tank Trail site did not vary appreciably, ranging from 109 to 129 µS/cm and 68 to 80 mg/L, respectively, whereas values of specific conductance and concentrations of dissolved solids at the lower two sites had greater variations that changed with changes in stream discharge. During snowmelt, specific conductance at the Arctic Boulevard site generally increased with increasing streamflow (fig. 6) due to the flushing of surface contaminants, such as road deicing salts, into the stream. The daily mean specific conductance at the Arctic Boulevard site was as great as 668 µS/cm on January 15, 2001. During summer rains, specific conductance commonly decreased with increasing streamflow due to dilution.

Stream water in Chester Creek is alkaline as median pH values ranged from 7.5 to 7.9 units at the three sites (table 2). Stream water was well oxygenated at all sites. Concentrations of DO at the Arctic Boulevard site ranged from 9.2 to 14.6 mg/L, with saturation ranging from 79 to 113 percent.

Inorganic Constituents

Calcium and bicarbonate were typically the dominant cation and anion, respectively, in Chester Creek stream water. The use of sodium chloride and magnesium chloride as road deicing salts increased the amount of these ions in stream water, as can be seen in the ionic compositions of snowmelt runoff at the Arctic Boulevard site (fig. 7). In each of the three panels of the trilinear diagram, results from the water samples collected March 26 and 27, 1999, are located to the right of samples collected at other times, indicating higher proportions

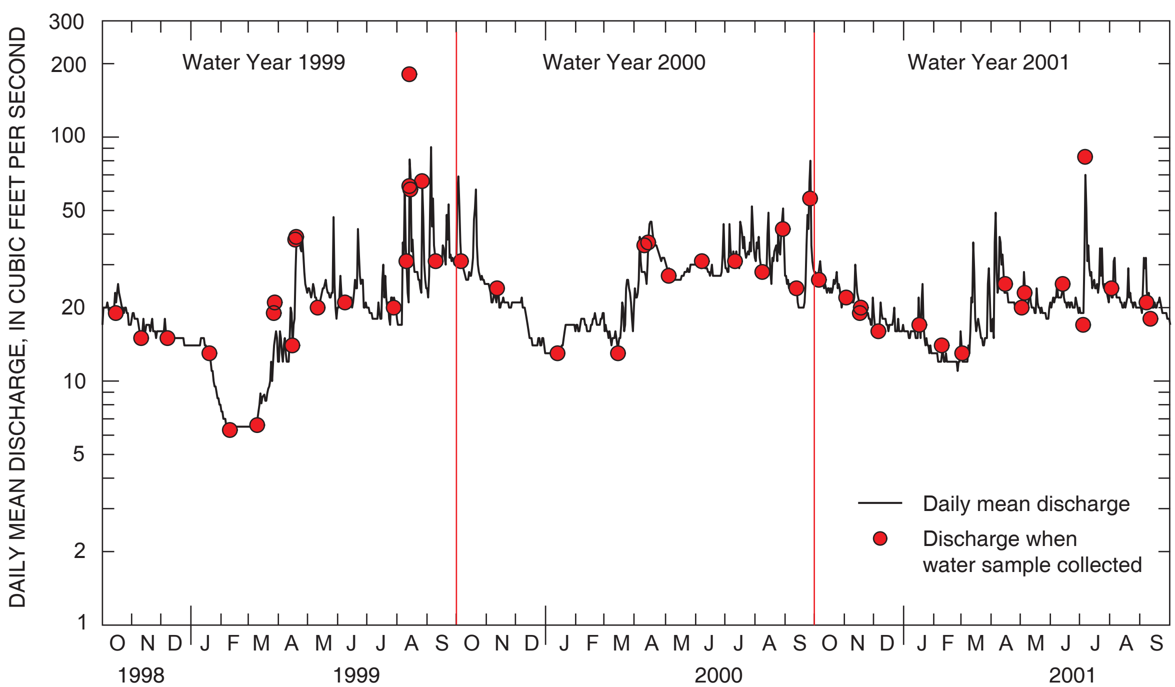

Figure 4. Discharge hydrograph for Chester Creek from gage at Arctic Blvd. showing time distribution and flow distribution of water samples.

Table 2. Statistical summary of selected water-quality data from Chester Creek, 1998-2001.

[When more than one value was reported in a day at a site, the median value for that day was used to determine these summary statistics. Number in parenthesis is the number used by both USEPA and USGS to identify that parameter in computerized data bases. Abbreviated site names: Tank Trail, South Branch of South Fork Chester Creek at Tank Trail; Boniface Parkway, South Branch of South Fork Chester Creek at Boniface Parkway; Arctic Bouelvard, and Chester Creek at Arctic Boulevard. mg/L, milligram per liter; µg/L, microgram per liter; cols/100 ml, bacteria colonies per 100 milliliter; <, less than; E, estimated]

Constituent	Abbreviated Site Name	Value or Concentration			
		Number of Analyses	Minimum	Median	Maximum
Stream Discharge					
Instantaneous discharge, in cubic feet per second (00061)	Tank Trail	6	2.2	3.8	6.4
	Boniface Parkway	5	8.9	13.0	23.0
	Arctic Boulevard	49	6.3	23.0	122.0
Field Measurements					
Water temperature, in degrees Celsius (00010)	Tank Trail	7	1.0	6.6	7.5
	Boniface Parkway	5	1.5	8.0	10
	Arctic Boulevard	49	0.0	3.5	15.4
Specific conductance, in microsiemens per centimeter (00095)	Tank Trail	6	109	115	129
	Boniface Parkway	5	132	188	217
	Arctic Boulevard	49	120	261	480
Dissolved oxygen, in mg/L (00300)	Tank Trail	7	11.0	11.4	13.9
	Boniface Parkway	4	10.2	11.1	12.4
	Arctic Boulevard	49	9.2	12	15
Dissolved oxygen saturation, in percent (00301)	Tank Trail	5	89	93	102
	Boniface Parkway	4	79	91	97
	Arctic Boulevard	48	79	96	110
pH, in pH units (00400)	Tank Trail	7	7.5	7.9	8.2
	Boniface Parkway	5	7.3	7.5	8.2
	Arctic Boulevard	49	7.1	7.8	8.6
Hardness, in mg/L as $CaCO_3$ (00900)	Tank Trail	4	52	56	62
	Boniface Parkway	5	54	77	85
	Arctic Boulevard	44	48	110	130
Inorganic Constituents					
Calcium, dissolved, in mg/L (00915)	Tank Trail	4	15.9	17.4	18.9
	Boniface Parkway	5	16.6	23.4	25.4
	Arctic Boulevard	49	14	32	37
Magnesium, dissolved, in mg/L (00925)	Tank Trail	4	2.9	3.3	3.6
	Boniface Parkway	5	3.2	4.6	5.3
	Arctic Boulevard	49	3.1	7.5	14.7
Sodium, dissolved, in mg/L (00930)	Tank Trail	4	1.7	1.8	1.9
	Boniface Parkway	5	2.5	5.9	8.2
	Arctic Boulevard	49	3.9	8.0	35
Acid neutralizing capacity, in mg/L (00410)	Tank Trail	3	39	50	51
	Boniface Parkway	5	50	62	63
	Arctic Boulevard	46	31	78	100

Table 2. Statistical summary of selected water-quality data from Chester Creek, 1998-2001.—Continued

[When more than one value was reported in a day at a site, the median value for that day was used to determine these summary statistics. Number in parenthesis is the number used by both USEPA and USGS to identify that parameter in computerized data bases. Abbreviated site names: Tank Trail, South Branch of South Fork Chester Creek at Tank Trail; Boniface Parkway, South Branch of South Fork Chester Creek at Boniface Parkway; Arctic Bouelvard, and Chester Creek at Arctic Boulevard. mg/L, milligram per liter; µg/L, microgram per liter; cols/100 ml, bacteria colonies per 100 milileter; <, less than; E, estimated]

Constituent	Abbreviated Site Name	Value or Concentration			
		Number of Analyses	Minimum	Median	Maximum
Inorganic Constituents—Continued					
Potasium, dissolved, in mg/L (00935)	Tank Trail	4	0.2	0.3	0.5
	Boniface Parkway	5	0.5	0.6	3
	Arctic Boulevard	49	0.8	1	5
Bicarbonate, in mg/L as HCO_3 (00453)	Tank Trail	3	46	54	56
	Boniface Parkway	5	60	73	80
	Arctic Boulevard	49	43	94	120
Alkalinity, field incremental titration, in mg/L as $CaCO_3$ (39086)	Tank Trail	3	38	48	50
	Boniface Parkway	5	49	61	65
	Arctic Boulevard	49	21	77	100
Sulfate, dissolved, in mg/L (00945)	Tank Trail	4	9.3	11.6	12.9
	Boniface Parkway	5	9.2	13.8	16.6
	Arctic Boulevard	49	8.7	21	27
Chloride, dissolved, in mg/L (00940)	Tank Trail	4	0.3	0.6	0.7
	Boniface Parkway	5	2.6	9.6	15.6
	Arctic Boulevard	49	6.6	16	94
Fluoride, dissolved, in mg/L (00950)	Tank Trail	4	<0.1	<0.1	<0.1
	Boniface Parkway	5	<0.1	<0.1	<0.1
	Arctic Boulevard	49	<0.1	<0.1	<0.1
Silica, dissolved, in mg/L as SiO_2 (00955)	Tank Trail	4	9.8	10.4	11.7
	Boniface Parkway	5	7.0	10.1	11.7
	Arctic Boulevard	49	5.4	10.3	13.5
Nitrite, dissolved in mg/L as N (00613)	Tank Trail	4	<0.001	0.001	0.001
	Boniface Parkway	5	<0.001	0.004	0.011
	Arctic Boulevard	49	0.001	0.006	0.069
Nitrite plus nitrate, dissolved, in mg/L as N (00631)	Tank Trail	4	0.37	0.5	1.02
	Boniface Parkway	5	0.341	0.5	0.578
	Arctic Boulevard	49	0.005	0.62	0.91
Ammonia, dissolved, in mg/L as N (00608)	Tank Trail	4	<0.002	<0.002	0.004
	Boniface Parkway	5	<0.002	0.005	0.392
	Arctic Boulevard	49	0.002	0.024	0.48
Nitrogen, total ammonia plus organic, in mg/L as N (00625)	Tank Trail	4	E0.06	0.07	0.23
	Boniface Parkway	5	0.12	0.3	1.1
	Arctic Boulevard	49	0.08	0.24	2.40
Nitrogen, dissolved ammonia plus organic, in mg/L as N (00623)	Tank Trail	4	<0.1	0.1	0.21
	Boniface Parkway	5	E0.08	0.2	0.73
	Arctic Boulevard	49	0.068	0.17	1.26
Total phosphorus, in mg/L as P (00665)	Tank Trail	4	0.008	0.01	0.022
	Boniface Parkway	5	0.008	0.026	0.171
	Arctic Boulevard	49	0.004	0.020	0.590

Table 2. Statistical summary of selected water-quality data from Chester Creek, 1998-2001.—Continued

[When more than one value was reported in a day at a site, the median value for that day was used to determine these summary statistics. Number in parenthesis is the number used by both USEPA and USGS to identify that parameter in computerized data bases. Abbreviated site names: Tank Trail, South Branch of South Fork Chester Creek at Tank Trail; Boniface Parkway, South Branch of South Fork Chester Creek at Boniface Parkway; Arctic Bouelvard, and Chester Creek at Arctic Boulevard. mg/L, milligram per liter; µg/L, microgram per liter; cols/100 ml, bacteria colonies per 100 millileter; <, less than; E, estimated]

Constituent	Abbreviated Site Name	Value or Concentration			
		Number of Analyses	Minimum	Median	Maximum
Inorganic Constituents—Continued					
Phosphorus, dissolved, in mg/L asP (00666)	Tank Trail	4	<0.004	E0.004	E0.005
	Boniface Parkway	5	E0.004	0.004	0.082
	Arctic Boulevard	49	0.002	0.006	0.21
Orthophosphorus, dissolved, in mg/L as P (00671)	Tank Trail	4	<0.001	0.003	0.006
	Boniface Parkway	5	<0.001	0.002	0.057
	Arctic Boulevard	49	0.001	0.004	0.094
Dissolved solids, residue at 180 degrees Celsius, in mg/L (70300)	Tank Trail	4	76	85	89
	Boniface Parkway	5	83	123	129
	Arctic Boulevard	49	72	160	279
Dissolved solids, sum of constituents, in mg/L (70301)	Tank Trail	4	68	75	80
	Boniface Parkway	5	78	103	116
	Arctic Boulevard	49	66	145	248
Iron, dissolved, in µg/L (01046)	Tank Trail	3	<10	<10	<10
	Boniface Parkway	5	60	160	240
	Arctic Boulevard	49	30	100	520
Manganese, dissolved, in µg/L (01056)	Tank Trail	4	<2.0	<2.2	<3.0
	Boniface Parkway	5	29.7	69.9	139
	Arctic Boulevard	49	32	75	215
Total organic particulate carbon, in mg/L as C (00689)	Tank Trail	3	<0.2	0.2	0.3
	Boniface Parkway	4	0.2	2.0	3.9
	Arctic Boulevard	49	0.2	0.6	5
Organic carbon, dissolved, in mg/L (00681)	Tank Trail	4	1.0	1.7	2.7
	Boniface Parkway	5	1.6	3.9	6.8
	Arctic Boulevard	49	1.5	2.5	7.9
Total inorganic plus organic carbon, in mg/L as C (00694)	Boniface Parkway	1	5.2	5.2	5.2
	Arctic Boulevard	15	0.5	1.1	5.1
Suspended Sediment					
Suspended sediment, in mg/L (80154)	Tank Trail	3	3	4	6
	Boniface Parkway	4	4	24	50
	Arctic Boulevard	49	1	9	322
Suspended sediment finer than 0.062 mm, in percent (70331)	Tank Trail	1	26	26	26
	Boniface Parkway	3	86	89	96
	Arctic Boulevard	23	55	92	97
Fecal-Indicator Bacteria					
E. coli bacteria, in cols/100 ml (31633)	Tank Trail	3	<1	<1	E5
	Boniface Parkway	3	67	350	700
	Arctic Boulevard	16	E20	148	E1500

Table 2. Statistical summary of selected water-quality data from Chester Creek, 1998-2001.—Continued

[When more than one value was reported in a day at a site, the median value for that day was used to determine these summary statistics. Number in parenthesis is the number used by both USEPA and USGS to identify that parameter in computerized data bases. Abbreviated site names: Tank Trail, South Branch of South Fork Chester Creek at Tank Trail; Boniface Parkway, South Branch of South Fork Chester Creek at Boniface Parkway; Arctic Bouelvard, and Chester Creek at Arctic Boulevard. mg/L, milligram per liter; µg/L, microgram per liter; cols/100 ml, bacteria colonies per 100 millileter; <, less than; E, estimated]

Constituent	Abbreviated Site Name	Value or Concentration			
		Number of Analyses	Minimum	Median	Maximum
Fecal-Indicator Bacteria—Continued					
Enterococci bacteria, in cols/100 ml (31649)	Tank Trail	3	<1	4	30
	Boniface Parkway	2	87	1228	2370
	Arctic Boulevard	17	29	180	3400
Fecal-coliform bacteria, in cols/100 ml (31625)	Tank Trail	4	<1	4	E7
	Boniface Parkway	2	90	395	E700
	Arctic Boulevard	18	E17	280	1994

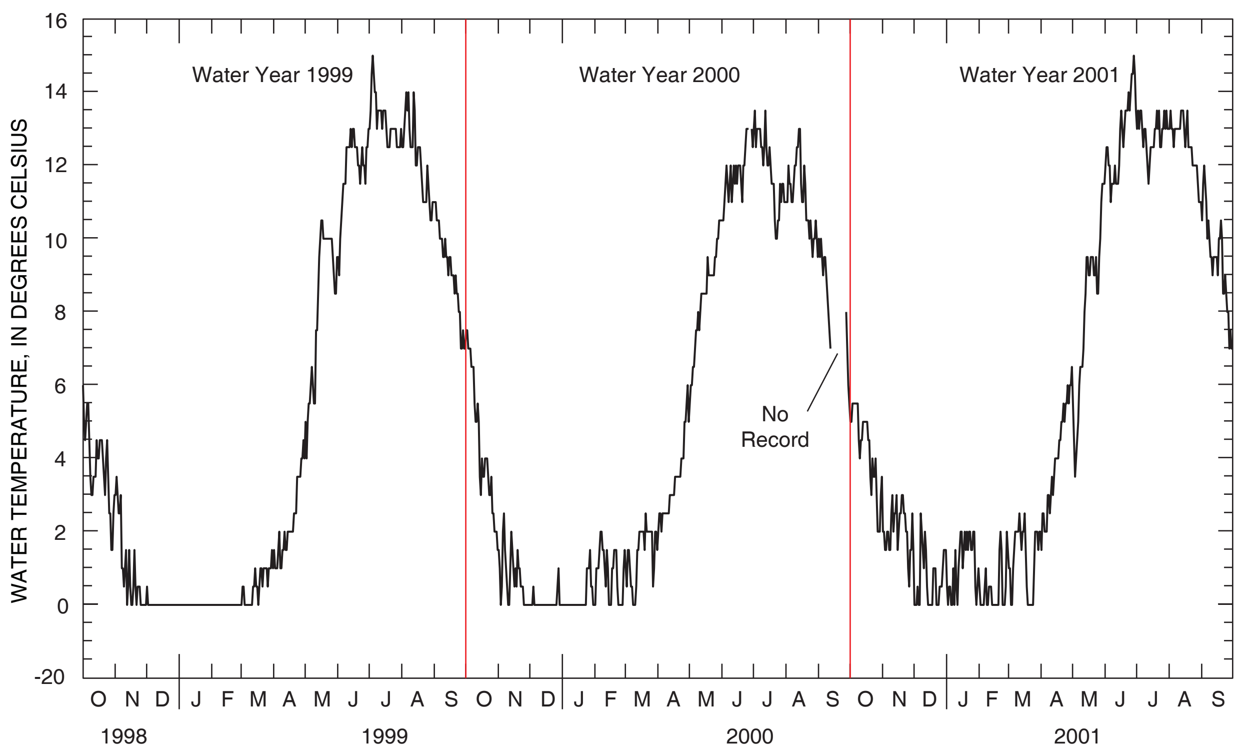

Figure 5. Daily mean water temperature for Chester Creek at Arctic Boulevard, water years 1999 to 2001.

of sodium and chloride in the water. The water sample collected on March 26, 1999, had a specific conductance value of 480 µS/cm and a dissolved-solids concentration of 248 mg/L, with 34 mg/L of sodium (approximately 35 percent of the cations were sodium, when concentrations are expressed in milliequivalents per liter) and 94 mg/L of chloride (about 60 percent of the anions were chloride). Median concentrations of chloride and sodium increased in the downstream direction indicating the influence of urbanization.

Nitrogen and phosphorus are essential nutrients for a healthy aquatic ecosystem because they help regulate the productivity of organisms in freshwater systems. However, excessive amounts of nitrogen and phosphorus can adversely affect surface-water quality through eutrophication (excessive aquatic-plant growth) and toxicity to aquatic life. Concurrent measurements of nitrite-plus-nitrate concentrations at the three sites were similar. Almost all concentrations were less than one-tenth of the USEPA's drinking-water standard of 10 mg/L for nitrate.

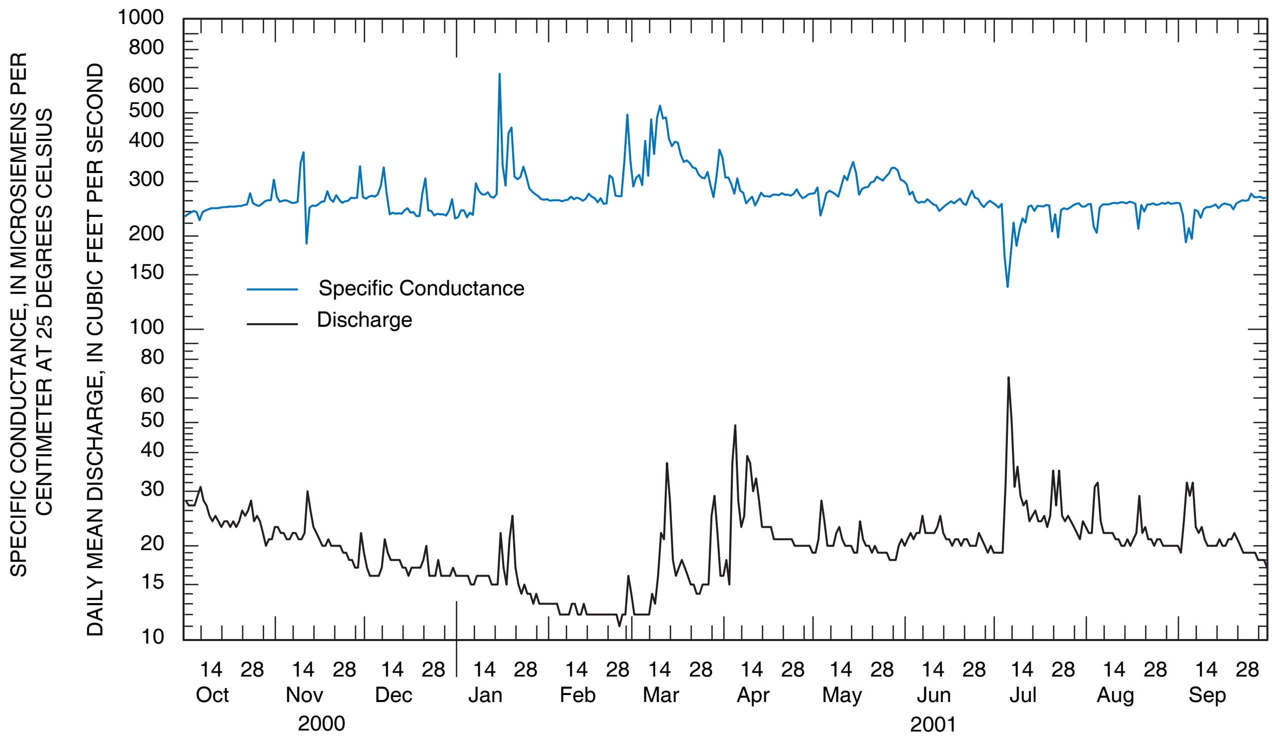

Figure 6. Specific conductance and daily discharge for Chester Creek at Arctic Boulevard, water year 2001.

Nitrate concentrations at the Arctic Boulevard site generally decreased with increasing discharge and generally were higher during winter than summer. These results suggest that ground-water discharge may be a significant contributor of nitrate and/or that nitrate is not taken up by plant life and converted to other forms of nitrogen during winter. Possible sources of nitrate to the ground-water and stream systems include animal wastes, fertilizers applied to lawns, effluent from septic systems or leaky sewer lines, and nitrogen-fixing plants such as alder and clover. In contrast to nitrate's inverse relation with discharge, concentrations of total nitrogen (ammonia plus organic nitrogen) typically increased during snowmelt and rainfall runoff (fig. 8). The highest total ammonia plus organic nitrogen value observed in Chester Creek during this study was 2.40 mg/L on April 17, 1999, during snowmelt runoff.

Twenty-six percent of the total phosphorus concentrations measured at the Arctic Boulevard site exceeded 0.1 mg/L, the USEPA desired (maximum) goal for preventing nuisance plant growth in streams (USEPA, 1986a). Elevated phosphorus concentrations were associated with the transport of suspended sediment. The maximum value observed, 0.59 mg/L, was during runoff from snowmelt on April 17, 1999, when discharge was 38 ft^3/s and the suspended-sediment concentration was 322 mg/L, the highest suspended-sediment concentration observed during this study. Concentrations of dissolved orthophosphate were low, the median of 45 samples collected was 0.004 mg/L and the maximum value was 0.094 mg/L, indicating that inorganic suspended phosphorus is the primary form of total phosphorus in the water.

Fecal-Indicator Bacteria

Sixteen to 18 water samples were collected from the Arctic Boulevard site and analyzed to determine concentrations of fecal coliform, *Escherichia coli* (*E. coli*), and enterococci bacteria (Frenzel and Couvillion, 2002). Fecal coliform and *E. coli* are indicator organisms and two species of bacteria in the total coliform group. Although fecal coliforms may originate in the intestines of warm-blooded animals and humans, they have also been found in non-fecal sources. *E. coli* originates in the intestines warm-blooded animals and humans and provides specific evidence of fecal contamination from warm-blooded animals. Enterococci are a subgroup of the fecal-streptococci bacteria, but are a more specific indicator of fecal contamination in water than fecal-streptococci bacteria (Francy and others, 2000). The presence of *E. coli* and enterococci bacteria is evidence that fecal contamination has occurred and increases the concern that disease-causing organisms are present in the water. The USEPA recommends sampling of *E. coli* and enterococci bacteria in recreational-use water because studies show statistically significant relations between concentrations of those indicator bacteria and gastrointestinal illness in swimmers (USEPA, 1986a). Recommended guidelines

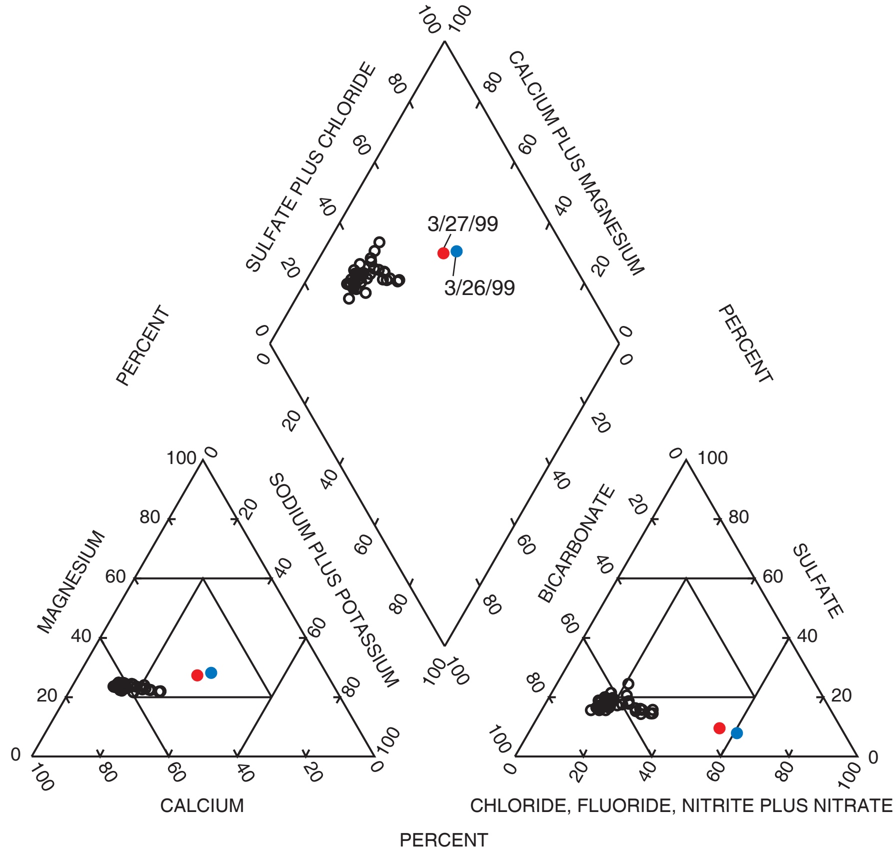

Figure 7. Trilinear diagram showing the major-ion compositions of 49 water samples collected from Chester Creek at Arctic Boulevard, water years 1999-2001.

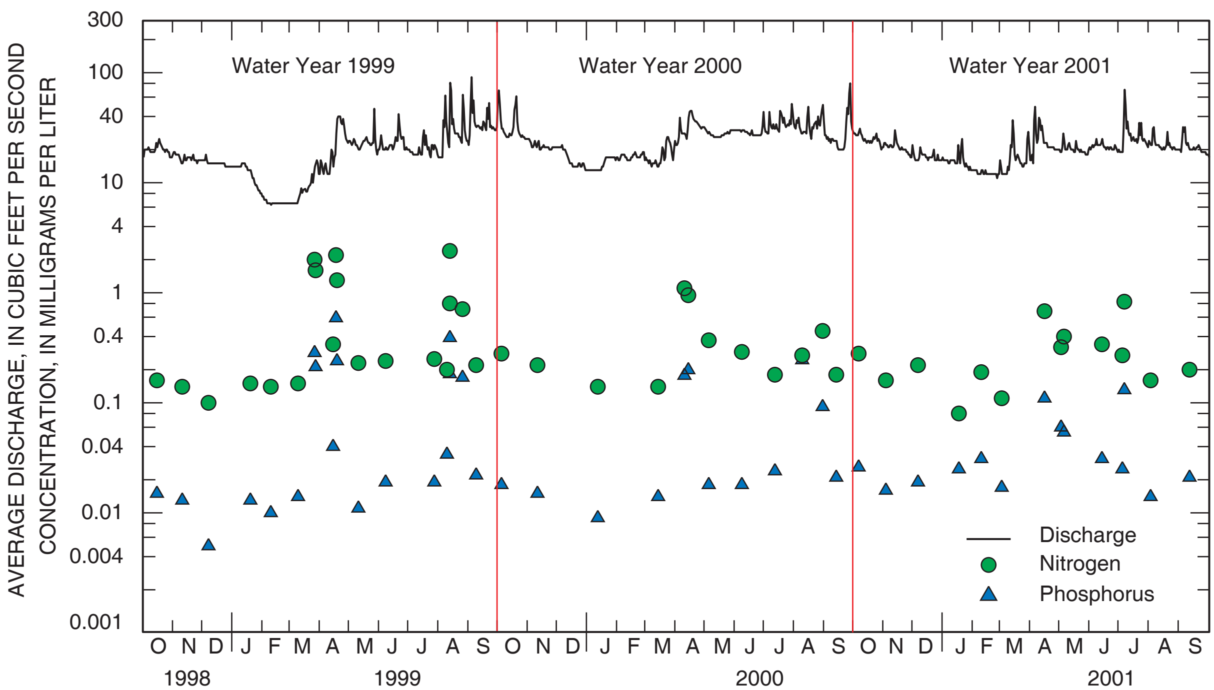

Figure 8. Total nitrogen (ammonia plus organic nitrogen) and total phosphorus in water from Chester Creek at Arctic Boulevard, water years 1999-2001.

for moderate-contact recreational waters for *E. coli* and enterococci bacteria are 298 and 78 organisms per 100 milliliters (col/100 mL), respectively, based on the geometric mean of generally not less than 5 samples equally spaced during a 30-day period (USEPA, 1986a). The Alaska State standard for fecal coliform bacteria in water used for recreation is 100 col/100 mL (Alaska Department of Environmental Conservation, 2003) and is intended to apply to the geometric mean of concentrations in samples collected during a period of no more than 30 days. Concentrations of bacteria in Chester Creek at the Arctic Boulevard site (table 2) generally exceeded guidelines for recreational use. Potential sources of fecal bacteria may include wastes from onsite septic systems, leaking sewer lines, domestic animals, waterfowl, and other wildlife.

Only a few fecal-indicator bacteria samples were analyzed from the Tank Trail and Boniface Parkway sites. All concentrations at the Tank Trail site were lower than recreational-use guidelines. Concentrations at the Boniface Parkway site were higher than at the Tank Trail site, but varied widely.

Organic Constituents

All samples analyzed contained low concentrations of at least one organic compound (table 3). Most of the detected compounds were at concentrations less than the method-detection limit for the analytical procedure used. All organic compounds detected in water samples were at concentrations less than USEPA drinking-water standards or guidelines.

Pesticides

Nine different pesticide compounds were detected in water from Chester Creek at Arctic Boulevard. Carbaryl, prometon, diazinon, and 2,4-D were the most frequently detected pesticides. Carbaryl, a broad-spectrum insecticide that is widely used throughout the Anchorage area to control spruce bark beetles, was detected in 75 percent of the samples. Prometon, a nonselective herbicide commonly used to control broadleaf weeds and grasses around homes and along rights-of-ways, was detected in 70 percent of the samples. Diazinon and 2,4-D were detected in 25 and 40 percent of the samples, respectively. Most concentrations were estimated to be less than 0.05 μg/L, a value often used as the common minimum reporting level for pesticides. Carbaryl exceeded the 0.2 μg/L Canadian guideline for the protection of aquatic life (Canadian Council of Ministers of the Environment, 2002b) in 15 percent of the samples, the greatest concentration was 0.33 μg/L. All carbaryl concentrations were substantially less than the USEPA guideline for drinking water of 700 μg/L. No other pesticide exceeded applicable aquatic-life guidelines. The occurrence of pesticides in Chester Creek is consistent with what has been found in other urban streams throughout the nation by the NAWQA program, where the insecticides diazinon, carbaryl, chlorpyrifos, and malathion, and the herbicides atrazine, simazine, and prometon, were frequently detected in urban streams (U.S. Geological Survey, 1999).

Low concentrations of hexachlorobenzene, used in making other organic chemicals including wood preservatives, and pentachloroanisole, a degradation product of the wood preservative/fungicide pentachlorophenol banned in 1987, were detected in water using lipid-containing SPMDs.

Volatile Organic Compounds

All water samples collected from the Arctic Boulevard site contained a mixture of VOCs, including components of petroleum products and the probable by-products of chlorinated disinfection of public-water supplies. Yet, most concentrations of detected VOCs were quite low, below 1 μg/L. Only methylbenzene (also known as toluene) and methyl *tert*-butyl ether (MTBE) were detected at concentrations exceeding 0.2 μg/L—these compounds are associated with gasoline. No VOC concentration exceeded applicable drinking-water standards or guidelines or aquatic-life guidelines. However, not all of the detected VOCs in surface water have a federally established drinking-water standard or guideline.

Toluene and trichloromethane (chloroform) were present in every water sample from Chester Creek that was analyzed for VOCs. Concentrations of toluene were as great as 0.22 μg/L in high streamflows after rains, most likely from surface runoff from roads and parking areas. Concentrations of MTBE, a gasoline additive that was used in Anchorage during the 1992-93 winter, were as great as 0.8 μg/L in Chester Creek during winter low-flow conditions during 1999, most likely from ground-water discharge. MTBE concentrations became diluted and decreased as rain and snowmelt runoff increased. A likely source of the frequent occurrence of chloroform in Chester Creek is surface runoff and ground-water discharge derived from chlorinated public-supply water. Chloroform is typically formed in drinking water during and after chlorination when naturally occurring organic substances in water react with chlorine.

Semivolatile Organic Compounds

SVOCs include many compounds associated with industrial activities and processes, such as phthlates used in plastics, phenols used in disinfectants and in manufacturing chemicals. SVOCs also include polycyclic aromatic hydrocarbons (PAHs) (Lopes and Furlong, 2001) which are a large group of compounds comprised of fused benzene rings and are a result of a mix of anthropogenic and

Table 3. Summary of organic compounds detected in water sampled from Chester Creek at Arctic Boulevard, 1998-2001.

[--, no data, standard, or guideline; E, estimated value; USEPA, U.S. Environmental Protection Agency; MCL, maximum contaminant level; HAL, Lifetime health advisory level]

Constituent	Number of samples analyzed	Number of detections	Concentration, in micrograms per liter: Method-detection limit	Maximum concentration	USEPA drinking-water standard or guideline[1]	Canadian guideline for freshwater aquatic life, Probable effect level[2]	Predominant use
Pesticides							
Carbaryl	20	15	0.003	E0.33	700 (HAL)	0.2	Insecticide
Prometon	20	14	0.018	0.073	100 (HAL)	--	Herbicide
2,4-D	20	8	0.08-0.15	0.41	70 (MCL, HAL)	--	Herbicide
Diazinon	20	5	0.002-0.04	0.043	0.6 (HAL)	--	Insecticide
Dichlorprop	20	2	0.03-0.05	0.13	--	--	Herbicide
p,p'-DDE	20	2	0.006	E0.002	--	--	Degredation product of the insecticide DDT
2,4-D methyl ester	12	1	0.086	E0.024	--	--	Herbicide
Bendiocarb	12	1	0.06	E0.020	--	--	Insecticide
Clopyralid	20	1	0.04-0.23	E0.06	--	--	Herbicide
Hexachlorobenzene <3>	1	1	--	Detected	1 (MCL)	--	Wood preservative
Pentachloroanisole <3>	1	1	--	Detected	--	--	Wood preser vative and fungicide
Volatile organic compounds							
Chloroform (trichloromethane)	11	11	0.024	0.18	100 (MCL)	1.8	Solvent and by-product of chlorination
Toluene (methylbenzene)	11	11	--	0.23	1,000 (MCL)	2.0	Gasoline aromatic hydrocarbon
Benzene	11	10	0.1	E0.08	5 (MCL)	370	Gasoline aromatic hydrocarbon
Tetrachloroethylene (PCE)	11	9	0.2	0.05	5 (MCL)	111	Solvent
Methyl *tert*-butyl ether (MTBE)	11	6	0.3	0.8	20-40 (HAL)	--	Gasoline oxygenate
Ethylbenzene	11	5	0.06	E0.03	700 (MCL)	90	Gasoline aromatic hydrocarbon
m- & *p* Xylene (1,3-dimethylbenzene and 1,4-dimethylbenzene)	11	5	0.12	E0.10	10,000 (MCL)	--	Gasoline aromatic hydrocarbon

Table 3. Summary of organic compounds detected in water sampled from Chester Creek at Arctic Boulevard, 1998-2001.—Continued

[--, no data, standard, or guideline; E, estimated value; USEPA, U.S. Environmental Protection Agency; MCL, maximum contaminant level; HAL, Lifetime health advisory level]

Constituent	Number of samples analyzed	Number of detections	Concentration, in micrograms per liter: Method-detection limit	Maximum concentration	USEPA drinking-water standard or guideline[1]	Canadian guideline for freshwater aquatic life, Probable effect level[2]	Predominant use
Volatile organic compounds							
Ortho-Xylene (1,2-dimethylbenzene)	11	4	0.12	E0.05	10,000 (MCL)	--	Gasoline aromatic hydrocarbon
1,2,4-Trimethylbenzene	11	3	0.11	E0.06	--	--	Organic synthesis
cis-1,2-dichloroethene	11	3	0.04	E0.05	70 (MCL)	--	Solvent
Methylene chloride (dichloromethane)	11	3	0.8	E0.1	5 (MCL)	98.1	Solvent
Dichlorodifluoromethane (CFC-12)	11	2	0.3	E0.1	1,000 (HAL)	--	Refrigerant
Isopropylbenzene (1-Methylethyl benzene)	11	1	0.06	E0.01	--	--	Organic synthesis
n-propylbenzene	11	1	0.08	E0.01	--	--	Solvent
Bromodichloromethane	11	1	0.05	E0.02	1,000 (HAL)	--	Organic synthesis
Methylchloride (Chloromethane)	11	1	0.5	E0.1	3 (HAL)	--	Refrigerant
Trichloroethylene (TCE)	11	1	0.08	E0.01	5 (MCL)	21	Solvent
Trichlorofluoromethane (CFC-11)	11	1	0.18	E0.07	2,000 (HAL)	--	Refrigerant
Semivolatile organic compounds - polycyclic aromatic hydrocarbons							
Chrysene[3]	1	1	--	E0.0008	--	--	Found in fossil fuels, tar, and asphalt, and occurs as a by-product of the incomplete combustion of wood or gasoline
Fluoranthene[3]	1	1	--	E0.0012	--	0.04	
Pyrene[3]	1	1	--	E0.0035	--	0.025	

[1]U.S. Environmental Protection Agency (2002).

[2]Canadian Council of Ministers of the Environment (2002b).

[3]Concentrations of these organic compounds were determined using extracts from semipermeable membrane sampling devices that were in the stream from May 18 to July 13, 2000.

natural activities, primarily combustion of fossil fuels and wood. Some PAHs, phthalates, and phenols are probable human carcinogens and endocrine disruptors.

Analyses of extracts from SPMDs placed in Chester Creek at Arctic Boulevard indicate that few SVOCs were detectable in the water column. Total PAH concentration was estimated as 0.018 µg/L (Jim Petty, USGS Columbia Environmental Research Center, written commun., 2001). Three priority-pollutant PAH compounds (fluoranthene, pyrene, and chrysene) were detected. The estimated pyrene concentration of 0.0035 µg/L was within the range known to cause adverse effects on fingerling fishes (Jim Petty, USGS Columbia Environmental Research Center, written commun., 2001). Estimated concentrations of fluoranthene and pyrene in water were less than the Canadian environmental quality guidelines for the protection of aquatic life, 0.04 and 0.025 µg/L, respectively (Canadian Council of Ministers of the Environment, 2002b). No aquatic-life guideline exists for chrysene.

Chemical Analyses of Streambed and Lakebed Sediments

Trace elements and some organic compounds occur naturally in the environment, but also may be redistributed and concentrated by human activities. They are unevenly distributed in the aquatic environment and, by the process of adsorption, some tend to be associated with fine-grained sediment particles (Horowitz and Elrick, 1988). Bed-sediment samples can be used to provide time-integrated records of contaminant concentrations.

Trace Elements

Elevated concentrations of some trace elements—such as arsenic, cadmium, chromium, copper, lead, mercury, nickel, selenium, and zinc—can be toxic to aquatic organisms. The slow elimination rate of some trace elements from many aquatic organisms can lead to bioaccumulation and biomagnification in aquatic food chains. Table 4 summarizes the concentrations of selected trace elements found in streambed sediments in Chester Creek, in Cook Inlet Basin streams, and in streams throughout the nation that were sampled by the NAWQA program. Arsenic, chromium, copper, mercury, nickel, and selenium appear to be at somewhat higher concentrations in sediments from Chester Creek relative to median concentrations from streambed sediments collected throughout the nation. Concentrations of cadmium, copper, lead, and zinc increased in the downstream direction in Chester Creek; these increases in concentrations greater than the level present at the upstream site are most likely from urban rather than geologic sources. Concentrations of selenium in streambed sediments decreased in the downstream direction. Arsenic, chromium, lead, and zinc in some sediment samples from Chester Creek exceeded the PEL based on bulk sediments and may adversely affect aquatic organisms. One chromium concentration of 200 µg/g from a streambed sample collected at the most upstream site may be anomalous and does not compare well to a concentration of 81 µg/g collected at the same site (table 4).

Cores of lakebed sediments from Westchester Lagoon and Hillstrand Pond were collected during June 1998 and individual layers were analyzed to determine how concentrations of trace elements have changed with time. One particular element of interest whose history was reconstructed was lead, which is toxic to humans and animals. Natural and anthropogenic sources contribute lead to the environment, but lead from anthropogenic sources, mainly from atmospheric emissions, is many times the total contribution from natural sources. Lead concentrations in the lakebed sediment cores (fig. 9) followed a trend similar to that shown in other urban lakes sampled in the NAWQA program throughout the nation. Specifically, lead concentrations increased in urban reservoir and lake sediments from the 1960s through the early 1970s, peaked in the mid 1970s, and then decreased with the introduction of unleaded gasoline (Callender and Van Metre, 1997). The use of lead in other products, such as paints, ceramics, caulk, and pipe solder, has also been reduced greatly in recent years. Concentrations of lead in the sediment cores from Hillstrand Pond and Westchester Lagoon have decreased by 73 and 84 percent, respectively, from their peak levels yet remain near or greater than the PEL of 91.3 µg/g (fig. 9). Lead concentrations in recently deposited lakebed sediments are nearly 10 times greater than predevelopment levels and levels in streambed sediments above urban development. Large amounts of lead remain in local urban soils and aquatic sediments, and it may take years or even decades to reduce these concentrations to background levels, even if there are no new sources of lead pollution.

In contrast to the trend in lead concentrations, concentrations of zinc (fig. 10) and cadmium in lakebed sediments increased during the 1970s and remained at elevated levels during the 1980s and 1990s. Zinc concentrations in sediments from Westchester Lagoon ranged from 129 µg/g in the deepest sample to 690 µg/g in the shallowest sample, with a peak concentration of 921 µg/g in sediments deposited around 1993. Cadmium concentrations in sediments from Westchester Lagoon ranged from 0.2 µg/g in sediments deposited around 1971 to 1.7 µg/g in most recently deposited sediments. Canadian guidelines for the protection of aquatic life for zinc and cadmium are 315 and 3.5 µg/g, respectively (Canadian Council of Ministers of the Environment, 2002b). Zinc concentrations have exceeded this PEL in sediments from Hillstrand Pond and Westchester Lagoon since the mid-1970s (fig. 10). Zinc is an additive to rubber in automobile tires and is used as a protective plating on metals. Elevated zinc concentrations relative to levels at the upstream site may be associated with automobile use (tire wear) or from the contact of water with galvanized metal products. Cadmium is used for electroplating and for pigments used in paint, printing ink, and plastics (Hem, 1985). It also is used extensively as a stabilizer for PVC plastic and in electrical batteries and fluorescent and video tubes.

Methylmercury is produced from inorganic mercury by methylation, a microbial process that is controlled by certain bacteria and enhanced by chemical and environmental variables, such as the presence of organic matter and oxygen. Methylmercury is readily bioaccumulated and biomagnified. It is also the primary form of mercury in fish and is a potent neurotoxin to humans and wildlife (fish, birds, and mammals). The concentration of total mercury in a bulk sample from the Arctic Boulevard site (0.109 µg/g) was lower than concentrations in sieved samples from the same site (0.17–0.18 µg/g). The concentration of methylmercury in the bulk sediment sample was 0.00038 µg/g, indicating that small amounts of mercury may be methylating. Mercury concentrations in sieved

Table 4. Concentrations of selected trace elements and organic compounds in streambed and lakebed sediments from the Chester Creek watershed, 1998-2001.

[Concentrations of trace elements in streambed sediments are in micrograms per gram, dry weight, using particles finer than 0.063 millimeter in diameter; concentrations of trace elements in lakebed sediments are in micrograms per gram, dry weight, using bulk samples; concentrations of organic carbon are in percent; Concentrations of organic compounds in streambed sediments are in micrograms per kilogram, dry weight, using particles finer than 2 millimeters in diameter; Concentrations of organic compounds in lakebed sediments are in micrograms per kilogram, dry weight, using bulk samples; <, less than; E, estimated; --, not determined or no guideline]

	Concentration							
	Streambed sediment					Lakebed sediment		
Constituent	**South Branch of South Fork Chester Creek at Tank Trail**	**South Branch of South Fork Chester Creek at Boniface Parkway**	**Chester Creek at Arctic Boulevard**	**Range of concentrations in streambed sediments in the Cook Inlet Basin**	**National median concentration from NAWQA streambed-sediment sites[1]**	**Hillstrand Pond below Lake Otis Parkway**	**Westchester Lagoon above Minnesota Drive**	**Canadian guideline for the protection of aquatic life, Probable effect level[2]**
Trace elements	**2 samples**	**1 sample**	**2 samples**	**49 samples from 47 sites**		**10 samples**	**20 samples**	
Arsenic	15 - 17	15	23 - 26	1.7 - 88	7.7	15 - 18	5 - 7.7	17
Cadmium	0.2	0.7	1.0 - 1.2	<0.1 - 4.6	0.45	0.4 - 1.2	0.2 - 1.7	3.5
Chromium	81 - 200	110	120	3 - 220	63.5	94 - 110	86 - 103	90
Copper	38 - 42	53	60 - 64	3 - 92	28	52 - 63	51 - 72	197
Lead	10 - 12	61	90 - 110	<1 - 230	25.9	76 - 280	29 - 544	91.3
Mercury	0.16	0.17	0.17 - 0.18	0.03 - 0.81	0.073	0.20 - 0.27	0.14 - 0.31	0.49
Nickel	29 - 47	47	50 - 64	<2 - 130	29	50 - 60	40 - 55	--
Selenium	2.5 - 5.8	1.4	0.8 - 1.1	<0.1 - 5.8	0.7	0.9 - 1.9	--	--
Zinc	82 - 110	420	590 - 600	16 - 1,800	110	170 - 980	129 - 921	315
Organic carbon	**2 samples**	**1 sample**	**2 samples**	**49 samples from 47 sites**		**10 samples**	**20 samples**	
Organic carbon	7.1 - 16	6.9	6.0 - 7.0	0.05 - 16	2.5	6.5 - 10	1.9 - 8.5	--
Organic compounds Methylmercury			**1 sample**	**5 sites**				
Methylmercury[3]	--	--	0.000	0.00001-0.0051	--	--	--	--
Polycyclic aromatic hydrocarbons (PAHs)	**1 sample**	**1 sample**	**3 samples**	**49 samples from 47 sites**		**11 samples**	**8 samples**	
Benz[*a*]anthracene	<50	170	120-530	<50-530	--	9-126	340-601	385
Benzo[*a*]pyrene	<50	170	120-540	<50-540	--	11-122	276-555	782
Benzo[*ghi*]perylene	<50	E70	E60-E230	<50-230	--	7-120	294-540	--
Benzo[*k*]fluoranthene	<50	190	120-480	<50-480	--	10-184	316-464	--
Chrysene	<50	290	E150-670	<50-670	--	19-306	785-1060	862
Fluoranthene	<50	470	340-1200	<50-1200	--	19-425	800-1740	2355
Indeno[1,2,3-*cd*]pyrene	<50	E100	80-360	<50-360	--	7-90	270-434	--
Naphthalene	<50	<50	<50-E50	<50-78	--	7-24	44-80	391
Phenanthrene	<50	330	220-730	<50-730	--	33-232	617-974	515
Pyrene	<50	420	320-1100	<50-1100	--	30-490	884-2100	875
2,6-Dimethylnaphthalene	<50	60	50-E80	<50-80	--	--	--	--

Table 4. Concentrations of selected trace elements and organic compounds in streambed and lakebed sediments from the Chester Creek watershed, 1998-2001.

[Concentrations of trace elements in streambed sediments are in micrograms per gram, dry weight, using particles finer than 0.063 millimeter in diameter; concentrations of trace elements in lakebed sediments are in micrograms per gram, dry weight, using bulk samples; concentrations of organic carbon are in percent; Concentrations of organic compounds in streambed sediments are in micrograms per kilogram, dry weight, using particles finer than 2 millimeters in diameter; Concentrations of organic compounds in lakebed sediments are in micrograms per kilogram, dry weight, using bulk samples; <, less than; E, estimated; --, not determined or no guideline]

	Concentration							
	Streambed sediment					Lakebed sediment		
Constituent	**South Branch of South Fork Chester Creek at Tank Trail**	**South Branch of South Fork Chester Creek at Boniface Parkway**	**Chester Creek at Arctic Boulevard**	**Range of concentrations in streambed sediments in the Cook Inlet Basin**	**National median concentration from NAWQA streambed-sediment sites[1]**	**Hillstrand Pond below Lake Otis Parkway**	**Westchester Lagoon above Minnesota Drive**	**Canadian guideline for the protection of aquatic life, Probable effect level[2]**
Phthalates	**1 sample**	**1 sample**	**3 samples**	**29 samples from 27 sites**				
bis(2-Ethylhexyl) phthalate	E20	1500	1000-2400	<50-2400	--	--	--	--
Di-*n*-butyl phthalate	<50	80	50-E140	<50-140	--	--	--	--
Di-*n*-octyl phthalate	<50	<50	110-420	<50-420	--	--	--	--
Phenols	**1 sample**	**1 sample**	**3 samples**	**29 samples from 27 sites**		**11 samples**	**8 samples**	
p-Cresol	100	780	50-620	<50-1200	--	32-531	110-2500	--
Phenol	E30	130	E50-130	<50-130	--	35-552	152-357	--
Organochlorine pesticides				**6 samples from 6 sites**		**11 samples**	**8 samples**	
p,p'-DDD	--	--	--	<1	--	1.2-24	1.8-25	8.51
p,p'-DDE	--	--	--	<1	--	1.3-13	3.3-14	6.75
p,p'-DDT	--	--	--	<2	--	<1	<1-12	4.77
Polychlorinated biphenyls				**6 samples from 6 sites**		**10 samples**	**8 samples**	
Total polychlorinated biphenyls	--	--	--	<50	--	37-245	70-620	277

[1]National median concentrations from Chalmers (2002)

[2]Guidelines from Canadian Council of Ministers of the Environment (2003) using bulk samples

[3]Concentration of methylmercury is from a bulk sample

sediment samples from all three sites on Chester Creek were greater than the national median concentration from NAWQA sites (0.07 μg/g), but less than Canadian guidelines for the protection of aquatic organisms (0.49 μg/g).

Semivolatile Organic Compounds

Concentrations of SVOCs in streambed sediments generally increased in the downstream direction in Chester Creek. Lakebed sediments from Westchester Lagoon also contained higher concentrations of SVOCs than Hillstrand Pond or recently deposited streambed samples. No PAH compounds were detected in streambed sediments at the Tank Trail site, but several PAH compounds were detected at the streambed sediments at the Arctic Boulevard site and in lakebed sediments from Westchester Lagoon (table 4). Some of the streambed sediments from the Arctic Boulevard site and lakebed sediments from Westchester Lagoon had concentrations of three PAHs—benz(*a*)anthracene, phenanthrene, and pyrene—that exceeded Canadian sediment guidelines for protection of aquatic life.

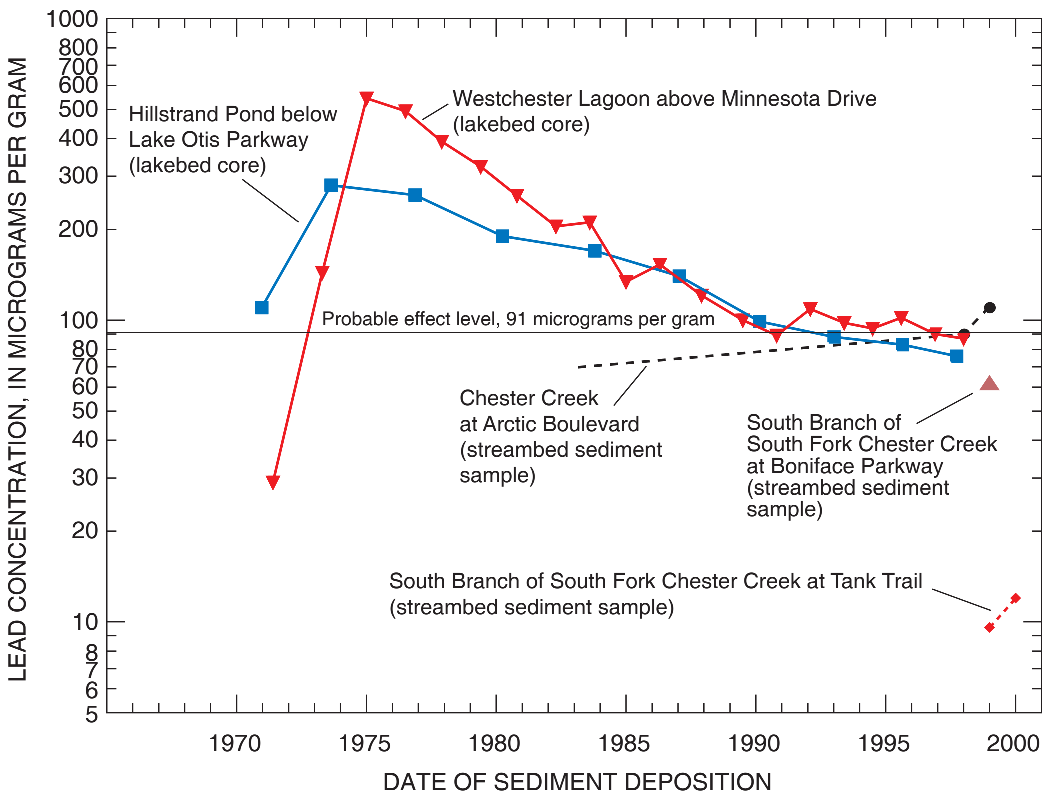

Figure 9. Temporal trends in lead concentrations in streambed sediments and cores of lakebed sediments from the Chester Creek watershed, 1970-2000.

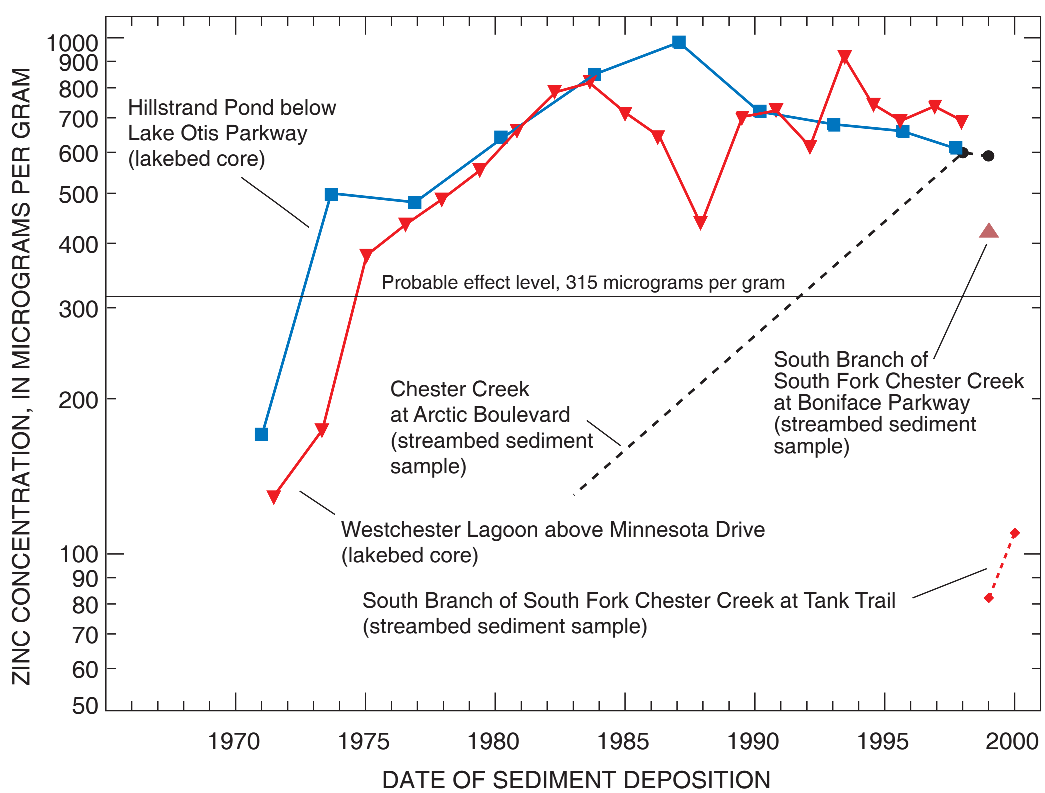

Figure 10. Temporal trends in zinc concentrations in streambed sediments and cores of lakebed sediments from the Chester Creek watershed, 1970-2000.

Organochlorine Pesticides and Polychlorinated Biphenyls

Even though the uses of organochlorine pesticides, such as chlordane, dieldrin, dichloro-diphenyl-trichloroethane (DDT), and polychlorinated biphenyls (PCBs) were banned in the United States in 1970s and 1980s because of human health and ecosystem concerns, they are extremely persistent in the environment and are still found in stream and lake sediments and in tissues of aquatic organisms throughout the nation. DDT and PCB compounds were detected in sediment cores from Hillstrand Pond and Westchester Lagoon. The summed concentration of DDT and its metabolites was as high as 51 µg/kg in lakebed sediments deposited during the mid-1970s in Westchester Lagoon, whereas the concentration in recently-deposited (around 1998) sediments was 8.1 µg/kg (fig. 11). In the 1970s, some individual concentrations of the DDT metabolites *p,p'*-DDD, *p,p'*-DDE, and *p,p'*-DDT in the lakebed sediments exceeded Canadian guidelines for protection of aquatic life (1.8, 6.3, and <2 µg/kg, respectively). Concentrations of DDT metabolites in recently deposited sediments did not exceed these guidelines. Concentrations of total PCBs in lakebed sediments from Westchester Lagoon deposited in the mid-1970s were as great as 620 µg/kg—the most recently deposited sediments had a concentration of 147 µg/kg (fig. 12). The Canadian guideline for protection of aquatic life is 277 µg/kg of total PCB (Canadian Council of Ministers of the Environment, 2002b).

Chemical Analyses of Fish Tissues

Like sediment, concentrations of contaminants in fish tissue can provide a time-integrated assessment of water quality and can help assess the potential ecological effects on aquatic organisms. Table 5 shows concentrations of selected trace elements and organic compounds in samples of whole slimy sculpin (*Cottus cognatus*) collected near the Arctic Boulevard site in 1998 and 1999.

Trace Elements

Concentrations of lead and zinc in sculpin collected from Chester Creek at Arctic Boulevard were among the highest in the Cook Inlet Basin (Frenzel, 2000). Arsenic, chromium, copper, selenium, and zinc in sculpin from Chester Creek and other Cook Inlet Basin streams had higher concentrations than were observed in sculpin samples from urban, forest, and reference sites in the Puget Sound NAWQA Study Unit in Washington (Frenzel, 2000). Concentrations of mercury in whole sculpin from Chester Creek (0.07-0.11 µg/g) were lower than median value in sculpin from Puget Sound's forest reference sites (0.14 µg/g) and less than levels of concern for potential toxicity. For comparison, the "action level" for methylmercury, the primary form of mercury in fish, established by the U.S. Food and Drug Administration (2001) is 1.0 µg/g for the edible portions of all fin fish, crustaceans, and mollusks. Of the trace elements analyzed, only selenium concentrations appear to be at levels of potential concern. Typical selenium concentrations at background sites throughout the United States are less than 2 µg/g (U.S. Department of Interior, 1998), whereas selenium concentrations of 3.0 and 4.9 µg/g were observed in composite samples of whole slimy sculpin from Chester Creek. Lemly (1996) suggested that selenium concentrations greater than 4 µg/g in whole fish produce adverse health effects in some fish species.

Organochlorine Pesticides and Polychlorinated Biphenyls

No organochlorine pesticides were detected in whole slimy sculpin at the 5 µg/kg level, however, the concentration of total PCBs was 79 µg/kg. Slimy sculpin are not commonly consumed by humans, but may be consumed by other fish and birds. Because a national standard for the protection of fish-eating wildlife does not exist, a comparison was made to a guideline from the State of New York (Newell and others, 1987). That guideline recommends that for the protection of fish-eating wildlife, total PCB concentrations in fish tissues do not exceed 110 µg/kg, wet weight.

Ecological Characteristics

The examination of number and types of aquatic organisms present in a stream reach can be used to assess the physical, chemical, and biological qualities of that reach because each of the numerous species has its own environmental requirements and tolerances. In general, the number of distinct species, genera, or families of algae, aquatic macroinvertebrates, and fish reflects the health of the community. Species richness generally increases with increasing water quality, habitat stability, and habitat diversity. In Chester Creek, the composition of the algal and invertebrate communities at the three water-monitoring sites indicates that the overall quality of the stream degrades in the downstream direction and as the amount of urbanization in the watershed increases.

Physical Environment

Aquatic biological communities are affected not only by water quality but also by its aquatic and riparian habitat. Clearing of forests, draining and filling of wetlands, and

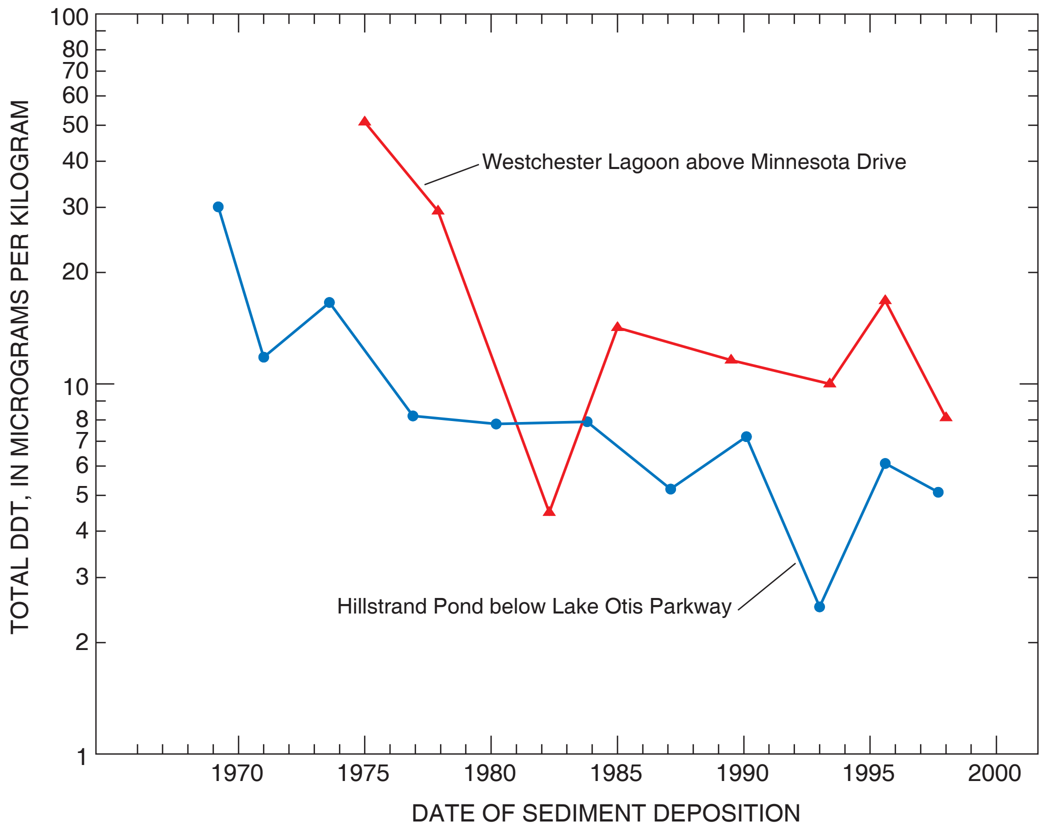

Figure 11. Temporal trends in total DDT concentrations in sediment cores from Westchester Lagoon and Hillstrand Pond, 1970-2000.

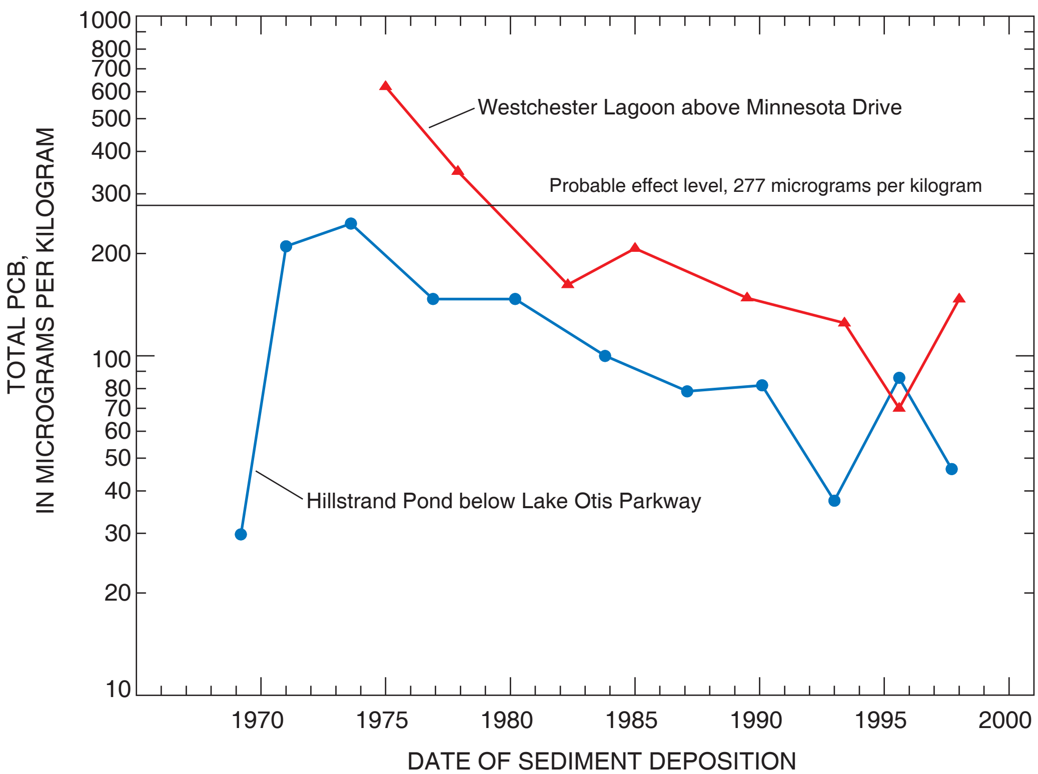

Figure 12. Temporal trends in total PCB concentrations in sediment cores from Westchester Lagoon and Hillstrand Pond, 1970-2000.

Table 5. Concentrations of selected trace elements and organic compounds in whole slimy sculpin collected from Chester Creek at Arctic Boulevard and other streams and rivers in the Cook Inlet Basin, 1998-2001.

[Concentrations of trace elements in micrograms per gram, dry weight; Concentrations of organic compounds in micrograms per kilogram, wet weight; <, less than; --, not determined]

	Concentration in whole slimy sculpin		
	Chester Creek at Arctic Boulevard		Range of concentrations in fish tissue from other streams and rivers in the Cook Inlet Basin
	Date sampled		Date sampled
	5/13/1998	8/9/1999	5/5/1998 - 8/8/2000
Trace elements			**14 sites**
Aluminum	350	260	39-267
Antimony	<0.2	<0.2	Not detected
Arsenic	0.8	1.1	0.4-1.6
Barium	8.7	5.4	2.6-31
Beryllium	<0.2	<0.2	Not detected
Boron	1.8	0.7	<0.2-1.9
Cadmium	0.3	<0.2	<0.2-0.4
Chromium	3	1.7	<0.5-3.6
Cobalt	0.5	0.4	<0.2-1.2
Copper	3.5	3.8	0.7-6.1
Iron	800	350	71-1000
Lead	1.3	0.8	<0.2-0.4
Manganese	50	52	5.4-230
Mercury	0.11	0.07	0.05-0.21
Molybdenum	<0.2	<0.2	<0.2-0.3
Nickel	1.1	1.0	0.3-1.6
Selenium	3	4.9	1.4-10
Silver	<0.2	<0.2	Not detected
Strontium	83	62	17-180
Uranium	<0.2	<0.2	Not detected
Vanadium	2.5	1.4	0.5-2.5
Zinc	160	98	16-240
Organochlorine pesticides			**10 sites**
p,p'-DDE	<5	--	<5 - 9.0
p,p'-DDT	<5	--	<5 - 6.1
Polychlorinated biphenyls			**10 sites**
Total PCBs	79	--	Not detected

channelizing and constraining the stream for urban development can change a stream's substrate, in-stream cover, channel morphology, and riparian conditions. The physical conditions at each of the water monitoring sites were documented so that future comparisons could be made.

Chester Creek upstream of the Tank Trail is an unmodified stream channel in a forested setting (fig. 13 and table 6). The reach is the steepest of the Chester Creek sites and is dominated by riffle habitat. The streambed substrate is primarily composed of coarse gravel—fine-grained sediments embed less than 10 percent of the streambed. The reach's meandering channel pattern contributes to a relatively high abundance of undercut banks. The stream is mostly shaded by vegetation.

The Boniface Parkway reach is a low gradient, highly-modified straight channel upstream of Boniface Parkway. Multi-family housing units are present near the right (north) bank, and single-family homes occur near its left bank. The reach has culverts at both its upgradient and downgradient ends and mainly consists of run habitat.

The streambed contains coarse and very-coarse gravels which are highly-embedded with fine-grained sediments. Although this section of the stream is the most shaded of the Chester Creek reaches, the banks are largely void of underbrush and are closely bordered by housing structures.

The Arctic Boulevard reach is upstream of the Arctic Boulevard crossing. A park is present near the reach's right (north) bank, and single-family homes are near its left bank. The reach has a modified straight channel with relatively high and unstable banks. It contains runs and riffles and its streambed consists of highly-embedded fine-to-medium gravels. The reach is heavily shaded and residential lawns border the stream on much of its southern side.

Algae

The algal communities in the three reaches were examined during a summer low-flow period in 2000. Five algal phyla were identified. The diatom phyla had the greatest richness with greater than 30 species, varieties, or forms. The euglenoid, red, blue-green, and green algae phyla each had fewer than 10 species, varieties, or forms. In gravel riffles, blue-green algae was the most abundant algal division (having the greatest number of individuals) at the Tank Trail and Arctic Boulevard sites, whereas diatoms and red algae were the most abundant divisions at the Boniface Parkway site. In pools, the dominant division at the Tank Trail and Boniface sites was the diatom phyla, but blue-green algae was dominant at the Arctic Boulevard site.

The composition of algal communities changed as the stream flowed downstream and as the land contributing water to the stream became more urbanized. Although nutrient concentrations did not change appreciably, concentrations of sodium, magnesium, and chloride increase in the downstream direction. The relative abundance of algae that are tolerant of increased salinity, such as *Diatoma moniliformis* and *Diatoma tenuis*, increased from the headwaters to the mouth, as did specific conductance, an indicator of the amount of dissolved minerals in water (fig. 14).

Benthic Macroinvertebrates

Macroinvertebrates in this report refer to organisms such as insects, mollusks, and worms that spend some portion of their life cycle in streams on or within bottom sediments, debris, logs, macrophytes, or living or dead plant material. Many of these invertebrates live in or on streambed sediments where contaminants tend to concentrate; thus, the chance that the organisms may react to toxic substances is increased. Benthic invertebrates are sensitive indicators of many types of stream disturbances (Barbour and others, 1999). Ephemeroptera, Plecoptera, and Trichoptera are orders of insects considered to be relatively intolerant to environmental alteration, whereas, true flies (Diptera), such as midges, and worms can tolerate poor environmental conditions. Fairly even distribution among the four insect groups, with substantial representation of the three most sensitive groups, is indicative of good biotic conditions. Worms and midges tend to become increasingly dominant with decreasing habitat quality.

Macroinvertebrate samples were collected from five riffle locations and from all available habitats within each reach at each of the three sites along Chester Creek (Ourso, 2001; Ourso and Frenzel, 2003). Invertebrate-community structure appears to be affected by water quality, channelization, and accumulations of fine sediment (Ourso, 2001; Ourso and Frenzel, 2003). The relative compositions of the five major macroinvertebrate groups in riffles at the Tank Trail site were fairly evenly distributed, but the non-insect group was overwhelmingly dominant at the Arctic Boulevard site (fig. 15). Worms made up most of the organisms present at the Arctic Boulevard site in the summer and fall samples. Midges made up about one-half of the organisms at the Boniface Parkway site during June 2000.

Fish

The composition of fish has changed in the Chester Creek watershed during the last 30 years. During the early 1970s, coho salmon were the most common salmonid fish species, however, their population has been adversely affected by barriers to migration and degraded habitat and water quality, including sedimentation, channelization, bank damage, loss of riparian areas, storm-drain discharge, and residential and commercial runoff (Davis and Muhlberg, 2001). The dam and weir creating Westchester Lagoon is a partial barrier to returning anadromous fish and numerous culverts along the main stem and its tributaries limit the movements of juvenile and adult fish due to high water velocities. Although difficult, some adult coho salmon do make it to the upper reaches of the stream. A total of four species of fish were observed in the three reaches of Chester Creek during 1999-2000: rainbow trout (*Oncorhynchus mykiss*), slimy sculpin, Dolly Varden char (*Salvelinus malma*), and coho salmon (*Oncorhynchus kisutch*) (table 7). Threespine sticklebacks (*Gasterosteus aculeatus*) were observed downstream of the Arctic Boulevard reach, but none were observed in the three study reaches. The proximity of the sticklebacks to the stream mouth is typical, as they often reside in estuaries or saltwater and spawn in freshwater. Sculpins were present in all three reaches during each sampling. Dolly Varden were abundant in the two upstream reaches but were absent at the downstream. Rainbow trout and coho salmon were present in all reaches, but not during each sampling. The abundance of rainbow trout is partially due to the stocking of this species by the Alaska Department of Fish and Game since 1971. Rainbow trout are not native to Chester Creek.

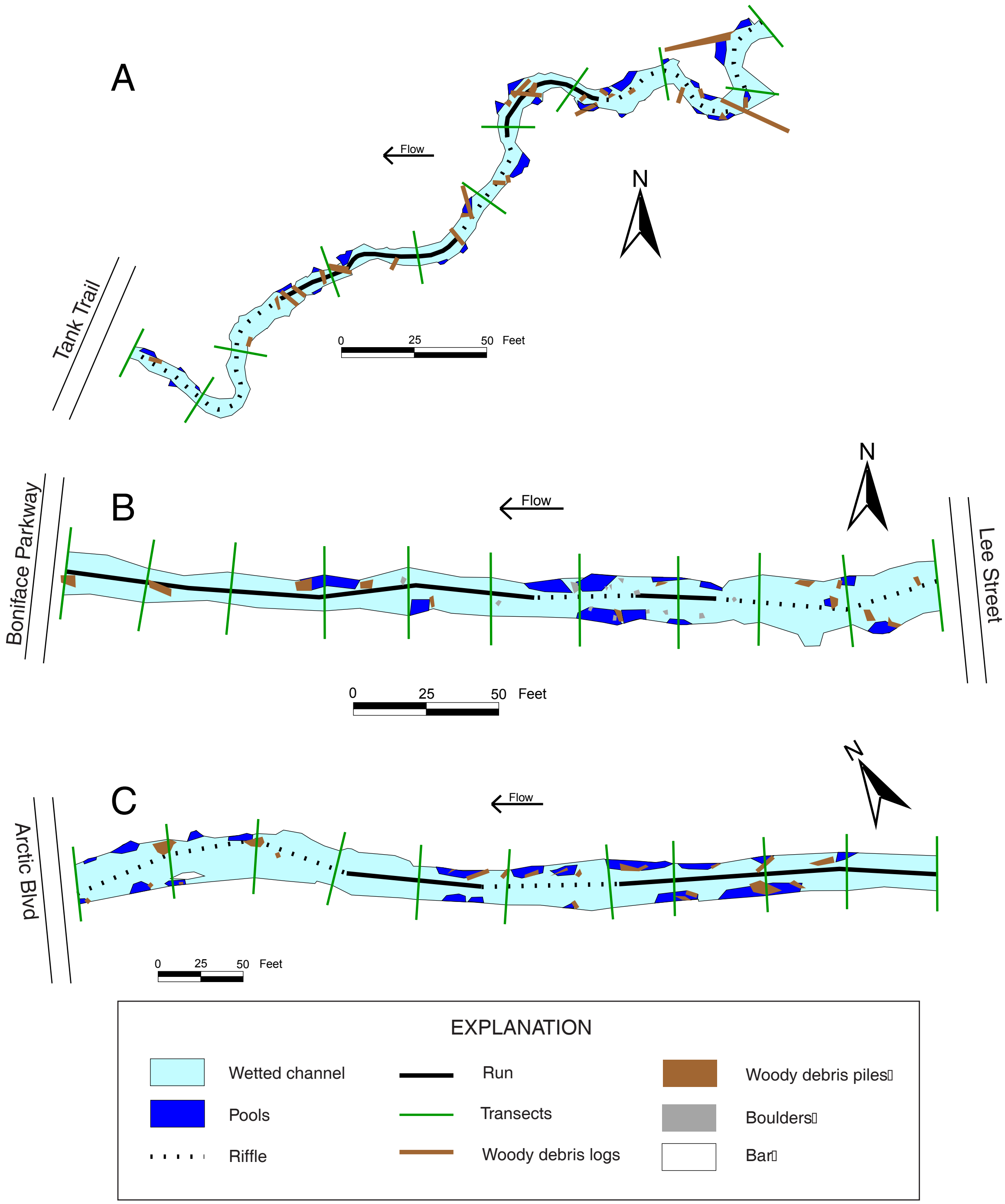

Figure 13. Reaches associated with the water-sampling sites: (a) South Branch of South Fork Chester Creek at Tank Trail, (b) South Branch of South Fork Chester Creek at Boniface Parkway, and (c) Chester Creek at Arctic Boulevard.

Summary and Conclusions

In 1998, the U.S. Geological Survey, as part of the National Water-Quality Assessment Program, began an assessment of water quality in the Cook Inlet Basin. One of the watersheds studied was Chester Creek, which drains shrub and forest covered uplands and urbanized lowlands in Anchorage, Alaska. Analyses of water, streambed and lakebed sediment, and aquatic organisms at multiple locations in the watershed found that the overall quality of the stream degraded in the downstream direction as the amount of urbanization in the watershed increased.

Concentrations of calcium, magnesium, sodium, chloride, and sulfate in stream water increased in the downstream direction. Sodium chloride and magnesium chloride are used as road and sidewalk deicers. Nitrate

Table 6. Physical characteristics for three reaches along Chester Creek.

Characteristic[1]	South Branch of South Fork Chester Creek at Tank Trail	South Branch of South Fork Chester Creek at Boniface Parkway	Chester Creek at Arctic Boulevard, Reach C
Date of measurement	**7/13/2000**	**7/6/2000**	**5/9/2000**
Reach and transect characteristics			
Reach length (feet)	300	300	500
Reach sinuosity	1.47	1.01	1.03
Gradient (percent)	2.86	0.72	0.40
Riffle length (percent of reach)	54	27	34
Run length (percent of reach)	40	73	54
Pool length (percent of reach)	6	0	11
Frequency of pools with cover (number/bankfull width)	1.8	0.8	1.4
Frequency of wood (approximate pieces/bankfull width)	2.1	1.5	1.5
Channel morphology characteristics			
Width (feet)	5.9	14.9	22.4
Ratio of bankfull width to depth	12.7	26.9	11.5
Bank Stability Index	8	9	11
Bank erosion abundance (percent)	77	0	45
Streambed characteristics			
Silt (percent)	0	18	3
Sand (percent)	6	0	6
Fine-to-medium gravel (percent)	12	18	64
Coarse gravel (percent)	73	27	27
Very coarse gravel (percent)	9	27	0
Small cobble (percent)	0	6	0
Large cobble (percent)	0	0	0
Small boulder (percent)	0	3	0
Less than 1 percent embedded (percent of reach)	94	24	24
1-20 percent embedded (percent of reach)	0	21	12
Greater than 20 percent embedded (percent of reach)	6	55	64
Habitat characteristics			
Overall habitat abundance (percent)	33	49	38
Woody debris abundance (percent)	2	20	22
Overhanging vegetation abundance (percent)	9	18	0
Boulder habitat abundance (percent)	0	11	0
Man-made habitat abundance (percent)	0	0	2
Undercut bank abundance (percent)	73	55	36
Riparian and related characteristics			
Riparian closure (percent)	74	96	84
Shade (percent)	89	96	87

[1]The definitions of these habitat characteristics and methods of measurement are described in Fitzpatrick and others, 1998

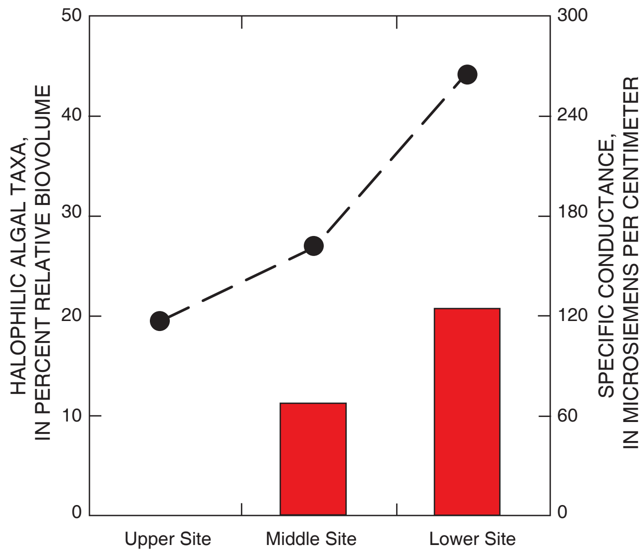

Figure 14. Relation of the proportion of algae that prefer water enriched with dissolved minerals (halophilic algae) to specific conductance.

concentrations were low, generally about one-tenth of the drinking-water standard of 10 mg/L and did not change appreciably along the stream. About 25 percent of the water samples collected near the stream's mouth contained total phosphorus exceeding 0.1 mg/L, the water-quality guideline for preventing nuisance plant growth in streams. High concentrations of phosphorus occurred when streamflows and suspended-sediment concentrations were greatest. Fecal-indicator bacteria concentrations at the intermediate (Boniface Parkway) and downstream urban (Arctic Boulevard) sites commonly exceeded Federal and State guidelines for water-contact recreation. Sources of fecal bacteria may include wastes from humans (domestic sewage), domestic animals, waterfowl, and other wildlife.

One or more pesticides and volatile organic compounds were found in low concentrations in almost every stream sample collected at the Arctic Boulevard site, but their concentrations were generally less than 1 µg/L and did not exceed applicable drinking-water standards or guidelines. The most frequently detected pesticides were carbaryl, prometon, 2,4-D, and diazinon. Concentrations of carbaryl exceeded a Canadian guideline for the protection of aquatic organisms in about 15 percent of the samples. Chloroform (a solvent and a by-product formed when chlorinated water reacts with organic matter) and toluene (a fuel-related product and by-product of petroleum combustion) were present in every water sample collected. Other fuel-related products, such as benzene, ethylbenzene, xylene, and MTBE, and the solvent tetrachloroethylene also were frequently detected. In general, the highest concentrations of inorganic and organic constituents were detected during runoff from snowmelt and rain at the downstream site, indicating that flushing of contaminants from urban land surfaces (such as roads, parking lots, and domestic yards) has a large influence on the water quality of Chester Creek.

Arsenic, chromium, copper, mercury, and nickel appear to be at naturally high concentrations in sediments from Chester Creek relative to streambed sediments collected throughout the nation, possibly due to local sources in the rocks. Runoff from urban activities increased concentrations of cadmium, copper, lead, and zinc in Chester Creek's streambed and lakebed sediments relative to levels present at the site upstream of urban development. Arsenic, chromium, lead, and zinc in some sediment samples were at levels that can adversely affect aquatic organisms. Concentrations of lead in sediments from Hillstrand Pond and Westchester Lagoon have decreased since lead was removed from gasoline in the 1970s, but are still at levels exceeding background concentrations. Concentrations of three PAHs in sediments from the downstream site and from Westchester Lagoon exceeded Canadian guidelines for the protection of aquatic life. The source of these organic compounds may be from the burning of fossil fuels or wood.

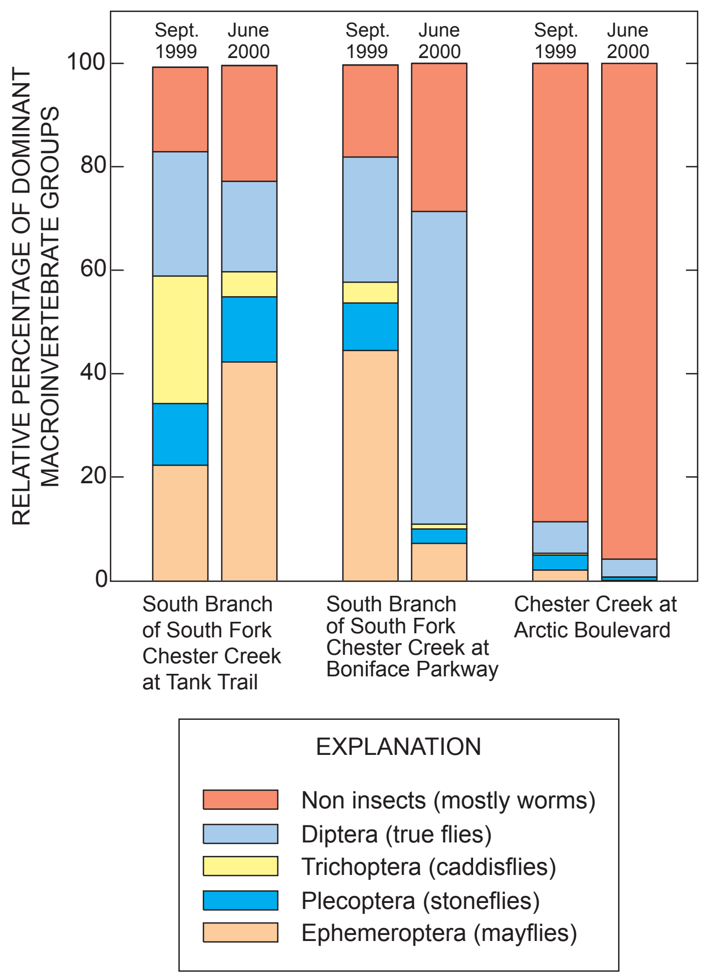

Figure 15. Dominant macroinvertebrate groups.

Table 7. Abundances of fish in three reaches of Chester Creek.

Reach	Date	Common name of fish species	Abundance
South Branch of South Fork Chester Creek at Tank Trail	June 21, 2000	slimy sculpin	4
		coho salmon	2
		rainbow trout	5
		Dolly Varden	89
South Branch of South Fork Chester Creek at Boniface Parkway	June 15, 2000	slimy sculpin	48
		coho salmon	31
		rainbow trout	29
		Dolly Varden	91
Chester Creek at Arctic Boulevard	September 9, 1999	slimy sculpin	23
	October 19, 1999	slimy sculpin	40
		rainbow trout	82
	June 14, 2000	slimy sculpin	104
		coho salmon	37

Selenium concentrations in some samples of whole slimy sculpin were at levels that may cause adverse effects; however, concentrations of selenium in streambed sediments in Chester Creek decreased in the downstream direction and appear to be naturally high relative to sites across the nation. Other trace elements, including lead and mercury, and selected organic compounds, including DDT and PCBs, were not present in tissues of whole slimy sculpin at levels of concern for fish-eating wildlife.

Communities of attached algae and benthic invertebrates showed impairment in the downstream direction as chemical concentrations and the amount of urbanization in the watershed increased. The relative abundance of algae that are tolerant of increased salinity increased from the headwaters to the mouth, as did the amount of dissolved minerals in water. The relative abundance of pollution-sensitive benthic invertebrate taxa decreased in the downstream direction, and the dominance of pollution-tolerant worms increased.

References Cited

Alaska Department of Environmental Conservation, 1998, Section 303(d) List of water quality-limited waterbodies: Alaska Department of Environmental Conservation, Air and Water Quality Division, data available on the World Wide Web, accessed October 2, 2003, at http://www.state.ak.us/local/akpages/ENV.CONSERV/dawq/tmdl/98onepage.htm.

Alaska Department of Environmental Conservation, 2003, Alaska water quality standards, 18 AAC 70: Alaska Administrative Code, Title 18, Chapter 70, accessed March 3, 2004, at http://www.state.ak.us/local/akpages/ENV.CONSERV/title18/70wqs.pdf.

Barnwell, W.W., George, R.S., Dearborn, L.L., Weeks, J.B., and Zenone, Chester, 1972, Water for Anchorage—An atlas of the water resources of the Anchorage area, Alaska: City of Anchorage and Greater Anchorage Area Borough, 77 p.

Bertrand, C.M., Hess, D.L., Kemnitz, R.T., Meyer, D.F., and Swanner, W.C., 2000, Water resources data, Alaska, water year 1999: U.S. Geological Survey Open-File Report AK-99-1, 508 p.

Brabets, T.P., 1987, Quantity and quality of urban runoff from the Chester Creek Basin, Anchorage, Alaska: U.S. Geological Survey Water-Resources Investigations Report 86-4312, 47 p.

Brabets, T.P., Nelson, G.L., Dorava, J.M., and Milner, A.M., 1999, Water-quality assessment of the Cook Inlet Basin Alaska—Environmental setting: U.S. Geological Survey Water-Resources Investigations Report 99-4025, 65 p.

Brabets, T.P., and Whitman, M.S., 2004, Water quality, biological, and physical conditions at fixed sites in the Cook Inlet Basin, Alaska: U.S. Geological Survey Scientific Investigations Report 2004-5021, as accessed February 2005, at http://water.usgs.gov/pubs/sir/2004/5021/.

Barbour, M.T., Gerritsen, J., Snyder, B.D., and Stribling, J.B., 1999, Rapid bioassessment protocols for use in streams and wadeable rivers: periphyton, benthic macroinvertebrates, and fish, second edition: U.S. Environmental Protection Agency, Office of Water, Washington, D.C., EPA 841-B-99-002, accessed February 2002, at http://www.epa.gov/owowwtr1/monitoring/rbp/index.html.

Brumbaugh, W.G., Krabbenhoft, D.P., Helsel, D.R., Wiener, J.G., and Echols, K.R., 2001, A national pilot study of mercury contamination of aquatic ecosystems along multiple gradients—bioaccumulation in fish: U.S. Geological Survey Biological Science Report 2001-0009, 21 p.

Callender, Edward, and Van Metre, P.C., 1997, Reservoir sediment cores show U.S. lead declines: Environmental Science and Technology, v. 31, no. 9, p. 424a-428a.

Canadian Council of Ministers of the Environment, 2002a, Canadian sediment quality guidelines (CseQGs): accessed February 27, 2003, at http://www.ec.gc.ca/ceqg-rcqe/English/Ceqg/Sediment/default.cfm.

Canadian Council of Ministers of the Environment, 2002b, Summary of existing Canadian environmental quality guidelines, Summary table, updated 2002, 12 p., accessed February 27, 2003, at http://www.ccme.ca/assets/pdf/e1_06.pdf.

Canadian Council of Ministers of the Environment, 2003, Summary of existing environmental quality guidelines, Summary table, updated 2003, 12 p., accessed June 3, 2005, at http://www.ccme.ca/assets/pdf/e1_062.pdf.

Chalmers, Ann, 2002, Trace elements and organic compounds in streambed sediment and fish tissue of coastal New England streams, 1998-99: U.S. Geological Survey Water Resources Investigations Report 02-4179, 30 p.

Cuffney, T.F., Gurtz, M.E., and Meador, M.R., 1993, Methods for collecting benthic invertebrate samples as part of the National Water-Quality Assessment Program: U.S. Geological Survey Open-File Report 93-406, 66 p.

Davis, J.C., and Muhlberg, G.A., 2001, Chester Creek stream condition evaluation: Alaska Department of Fish and Game, Habitat and Restoration Division, Technical Report No. 01-7, 41 p., accessed November 18, 2003, at http://www.sf.adfg.state.ak.us/SARR/Publications/PDFs/chestrck.pdf.

Edwards, T.K., Glysson, G.D., 1988, Field methods for measurement of fluvial sediment: U.S. Geological Survey Open File Report 86-531, 118 p.

Fishman, M.J., 1993, Methods of analysis by the U.S. Geological Survey National Water Quality Laboratory—Determination of inorganic and organic constituents in water and fluvial sediments: U.S. Geological Survey Open-File Report 93-125, 217 p.

Fitzpatrick, F.A., Waite, I.R., D'Arconte, P.J., Meador, M.R., Maupin, M.A., and Gurtz, M.E., 1998, Revised methods for characterizing stream habitat in the National Water-Quality Assessment Program: U.S. Geological Survey Water Resources Investigations Report 98-4052, 67 p.

Francy, D.S., Myers, D.N., and Helsel, D.R., 2000, Microbiological monitoring for the U.S. Geological Survey National Water-Quality Assessment Program: U.S. Geological Survey Water-Resources Investigations Report 00-4018, 31 p.

Frenzel, S.A., 2000, Selected organic compounds and trace elements in streambed sediments and fish tissues, Cook Inlet Basin, Alaska: U.S. Geological Survey Water-Resources Investigations Report 00-4004, 39 p.

Frenzel, S.A., 2002, Priority-pollutant trace elements in streambed sediments of the Cook Inlet Basin, Alaska, 1998-2000: U.S. Geological Survey Water-Resources Investigations Report 02-4163, 12 p.

Frenzel, S.A., and Couvillion, C.S., 2002, Fecal-indicator bacteria in streams along a gradient of residential development: Journal of the American Water Resources Association, v. 38, no. 1, p. 265-273.

Furlong, E.T., Vaught, D.G., Merten, L.M., Foreman, W.T., and Gates, P.M., 1996, Methods of analysis by the U.S. Geological Survey National Water-Quality Laboratory—Determination of semivoloatile organic compounds in bottom sediment by solvent extraction, gel permeation chromatographic fractionation, and capillary-column gas chromatography/mass spectrometry: U.S. Geological Survey Open-File Report 95-719, 67 p.

Gilliom, R.J., Alley, W.M., and Gurtz, M.E., 1995, Design of the National Water-Quality Assessment Program: Occurrence and distribution of water-quality conditions: U.S. Geological Survey Circular 1112, 33 p.

Glass, R.L., 1999, Water-quality assessment of the Cook Inlet Basin, Alaska—Summary of data through 1997: U.S. Geological Survey Water-Resources Investigations Report 99-4116, 110 p.

Hem, J.D., 1985, Study and interpretation of the chemical characteristics of natural water, 3rd ed.: U.S. Geological Survey Water-Supply Paper 2254, 263 p.

Horowitz, A.J. and Elrick, K.A., 1988, Interpretation of bed sediment trace metal data: Methods for dealing with the grain size effect. in: Lichtenberg, J.J. winter, T.A., Weber, C.I., and Franklin, L. (eds), Chemical and biological characterization of municipal sludges, sediments, dredge spoils, and drilling muds: ASTM STP 976, American Society for Testing and Materials, Philadelphia, PA, p. 114-128.

Huckins, J.N., Manuweera, J.D., Petty J.D., Mackay, D., and Lebo, J.A., 1993, Lipid-containing semipermeable membrane devices for monitoring contaminants in water: Environmental Science and Technology, v. 27, p. 2,489-2,496.

Kyle, R.E., and Brabets, T.P., 2001, Water temperature of streams in the Cook Inlet basin, Alaska, and implications of climate change: U.S. Geological Survey Water-Resources Investigation 2001-4109, 24 p.

Lemly, A.D., 1996, Selenium in aquatic organisms, in Beyer, W.N., Heinz, G.H., and Redmon-Norwood, A.W., (eds.), Environmental contaminants in wildlife—Interpreting tissue concentrations: Boca Raton, Florida, CRC Pres, Lewis Publishers, p. 427-445.

Lopes, T.J., and Furlong, E.T., 2001, Occurrence and potential adverse effects of semivolatile organic compounds in streambed sediment, United States, 1992-95: Environmental Toxicology and Chemistry, v. 20, no. 4, p. 727-737.

Meador, M.R., Cuffney, T.F., and Gurtz, M.E., 1993, Methods for sampling fish communities as part of the National Water-Quality Assessment Program: U.S. Geological Survey Open-File Report 93-104, 66 p.

Meyer, D.F., Hess, D.L., Schellekens, M.F., Smith, C.W., Snyder, E.F., and Solin, G.L., 2001, Water resources data, Alaska, water year 2000: U.S. Geological Survey Open-File Report AK-00-1, 438 p.

Meyer, D.F., Solin, G.L., Apgar, M.L., Hess, D.L., and Swenson, W.A., 2002, Water resources data for Alaska, water year 2001: U.S. Geological Survey Water-Data Report AK-01-1, 444 p.

Moulton, S. R., Kennen, J.G., Goldstein, R.M., and Hambrook, J.A., 2002, Revised protocols for sampling algal, invertebrate, and fish communities as part of the National Water-Quality Assessment Program: U.S. Geological Survey Water-Resources Investigations Report 02-150, 75 p.

Newell, A.J., Johnson, D.W., and Allen, L.K., 1987, Niagara River biota contamination project: Fish flesh criteria for piscivorous wildlife: New York Department of Environmental Conservation, Division of Fish and Wildlife, Bureau of Environmental Protection, Technical Report 87-3, 182 p.

Ourso, R.T., 2001, Effects of urbanization on benthic macroinvertebrate communities in streams, Anchorage, Alaska: U.S. Geological Survey Water-Resources Investigations Report 01-4278, 38 p., accessed on March 14, 2002, at http://water.usgs.gov/pubs/wri/wri014278/.

Ourso, R.T., and Frenzel, S.A., 2003, Identification of linear and threshold responses in streams along a gradient of urbanization in Anchorage, Alaska: Hydrobiologia, v. 501, no. 1-3, p. 117-131.

Porter, S.D., Cuffney, T.F., Gurtz, M.E., and Meador, M.R., 1993: Methods for collecting algal samples as part of the National Water-Quality Assessment Program: U.S. Geological Survey Open-File Report 93-409, 39 p.

Rantz, S.E. and others, 1982, Measurement and computation of streamflow: Volume 1, Measurement of stage and discharge: U.S. Geological Survey Water Supply Paper, v. 1, 284 p.

Sandstrom, M.W., Wydoski, D.S., Schroeder, M.P., Zamboni, J.L., and Foreman, W.T., 1992, Methods of analysis by the U.S. Geological Survey National Water-Quality Laboratory—Determinations of organonitrogen herbicides in water by solid-phase extraction and capillary-column gas chromatography/mass spectrometry with selected-ion monitoring: U.S. Geological Survey Open-File Report 91-519, 26 p.

Shelton, L.R., 1994, Field guide for collecting and processing stream-water samples for the National Water-Quality Assessment Program: U.S. Geological Survey Open-File Report 94-455, 42 p.

Shelton, L.R., and Capel, P.D., 1994, Guidelines for collecting and processing samples of streambed sediment for analysis of trace elements and organic contaminants for the National Water-Quality Assessment Program: U.S. Geological Survey Open-File Report 94-458, 20 p.

Shelton, L.R., 1997, Field guide for collecting samples for analysis of volatile organic compounds in stream water for the National Water-Quality Assessment Program: U.S. Geological Survey Open-File Report 97-401, 14 p.

U.S. Department of the Interior, 1998, Guidelines for interpretation of the biological effects of selected constituents in biota, water, and sediment: National Irrigation Water Quality Program Information Report No. 3, 198 p. + appendixes.

U.S. Environmental Protection Agency, 1986, Quality criteria for water 1986: Washington D.C., U.S. Environmental Protection Agency Report 440/5-86-001, Office of Water [variously paginated].

U.S. Environmental Protection Agency, 2002, 2002 edition of the drinking water standards and health advisories: U.S. Environmental Protection Agency EPA 822-R-02-038, accessed October 8, 2003, at http://www.epa.gov/waterscience/drinking/standards/dwstandards.pdf, [19] p.

U.S. Food and Drug Administration, 2001, Fish and fishery products hazards and controls guide, 3rd ed.: U.S. Food and Drug Administration, Center for Food Safety and Applied Nutrition, Accessed October 28, 2003, html and pdf versions available at http://www.cfsan.fda.gov/~comm/haccp4.html.

U.S. Geological Survey, 1999, The quality of our nation's water, nutrients and pesticides: U.S. Geological Survey Circular 1225, 82 p.

U.S. Geological Survey, 2002, National Water-Quality Assessment (NAWQA) Method, Sampling, and Analytical Protocols: accessed May 13, 2002, at URL http://water.usgs.gov/nawqa/protocols/doc_list.html.

Whitman, M.S., 2002, A protocol for assessing the impacts of urbanization on coho salmon with application to Chester Creek, Anchorage, Alaska: University of Alaska, Fairbanks, M.S. Thesis, 79 p.

Wilde, F.D., and Radtke, D.B., 1998, National field manual for collection of water-quality data: Field measurements: Techniques of Water-Resource Investigation 09-A6 [variously paged].

Zuagg, S.D., Sandstrom, M.W., Smith, S.G., and Fehlberg, K.M., 1995, Methods of analysis by the U.S. Geological Survey National Water-Quality Laboratory—Determinations pesticides in water by C-18 solid-phase extraction and capillary-column gas chromatography/mass spectrometry with selected-ion monitoring: U.S. Geological Survey Open-File Report 95-181, 60 p.