Mercury Data from Small Lakes in Voyageurs National Park, Northern Minnesota, 2000–02

By Robert M. Goldstein, Mark E. Brigham, Luke Steuwe, and Michael A. Menheer

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CONVERSION FACTORS AND ABBREVIATIONS

Multiply metric unit	by	to obtain inch-pound unit
centimeter (cm)	0.3937	inch
meter (m)	3.281	foot
kilometer (km)	0.6214	mile
square kilometer (km^2)	0.3861	square mile
Degrees Celsius (ºC)	1.8 temp ºC + 32	degrees Fahrenheit

Abbreviated water quality units: chemical concentrations are given in milligrams per liter (mg/L), micrograms per liter (µg/L), or nanograms per liter (ng/L), units expressing the concentrations of chemical constituents in solution as mass (milligrams, micrograms, or nanograms) per unit volume (liter) of water.

Chemical concentrations in tissues are given in micrograms per gram (µg/g) or nanograms per gram (ng/g), units expressing the concentrations of chemical constituents as mass within one gram of tissue.

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ABSTRACT

Mercury contamination of aquatic ecosystems is a resource concern in Voyageurs National Park. High concentrations of mercury in fish pose a potential risk to organisms that consume large amounts of those fish. During 2000–02, the U.S. Geological Survey measured mercury in water collected from 20 lakes in Voyageurs National Park. Those lakes span a gradient in fish-mercury concentrations, and also span gradients in other environmental variables that are thought to influence mercury cycling. During 2001, near surface methylmercury concentrations ranged from below the method detection limit of 0.04 nanograms per liter (ng/L) to 0.41 ng/L. Near surface total mercury concentrations ranged from 0.34 ng/L to 3.74 ng/L. Hypolimnetic methylmercury ranged from below detection to 2.69 ng/L, and hypolimnetic total mercury concentrations ranged from 0.34 ng/L to 7.16 ng/L. During 2002, near surface methylmercury concentrations ranged from below the method detection limit to 0.46 ng/L, and near surface total mercury ranged from 0.34 ng/L to 4.81 ng/L. {The abstract, table 4, and table 6 were corrected on 14 July 2006.}

INTRODUCTION

Mercury is a ubiquitous environmental contaminant and comes from many natural and anthropogenic sources. Atmospheric deposition and naturally occurring minerals are possible sources of mercury, but various land-use and land-cover types also may contribute disproportionate amounts of methylmercury to aquatic ecosystems. Typically, mercury occurs in very low concentrations in surface waters, in both inorganic and organic forms. Inorganic mercury is not particularly toxic, but under certain conditions can be converted to organic mercury (methylmercury), a potent neurotoxin, by bacterially mediated methylation and assimilated by aquatic organisms and magnified in the food chain (Krabbenhoft and Rickert, 1995). Small amounts of inorganic mercury can cause problems in aquatic ecosystems when conditions are suitable for methylation, which primarily occurs as a by-product of bacterially mediated sulfate reduction.

Methlymercury is a potent form of organic mercury and is among the most toxic and widespread contaminants affecting the Nation's aquatic ecosystems (Brumbaugh and others, 2001). Methylation and bioaccumulation of mercury pose toxicological risks to both fish (Wiener and Spry, 1996) and humans (U.S. Environmental Protection Agency, 1997). Because of concerns about methylmercury toxicity, the U.S. Environmental Protection Agency recently reduced the recommended standard for methylmercury in fish tissue from 0.5 milligram per kilogram to 0.3 milligram per kilogram (U.S. Environmental Protection Agency, 2001). Methylmercury contamination also has caused many states, including Minnesota, to issue human-health advisories for fish consumption.

Mercury contamination of aquatic ecosystems is a resource concern in Voyageurs National Park. High levels of mercury in fish pose a potential risk to organisms that consume large amounts of those fish. This includes both humans and piscivorous (fish-eating) wildlife such as loons, osprey, and eagles.

Concentrations of mercury in northern pike (*Esox lucius*), a common gamefish species in the Park, vary widely among the lakes in Voyageurs National Park. The estimated concentration of mercury in edible fillets of northern pike (standardized to a length of 55-cm to facilitate comparison among lakes) ranges more than ten-fold, from 0.16 µg/g (wet weight) in Mukooda Lake to 2.3 µg/g in Ryan Lake (Jeff Jeremiason, Minnesota Pollution Control Agency, written commun., 2002; including unpublished data from

Gary Glass, University of Minnesota-Duluth).

Tooth and Ryan Lakes in Voyageurs National Park have the greatest concentrations of mercury in fish among Minnesota lakes (using a 55-cm standardized northern pike for comparison). The State of Minnesota recommends no consumption of greater-than-76 cm (30-inch) northern pike from Tooth Lake (Minnesota Department of Health, 1998), which is the single most restrictive advisory the State has issued. Less restrictive fish-consumption advisories exist for many of the Park lakes.

Mercury may be diminishing reproductive success of common loons (*Gavia immer*) and other piscivorous wildlife in the Park. Recent toxicological investigations suggest that methylmercury contamination of aquatic food webs adversely affects piscivorous fish and wildlife. Methylmercury is the most bioaccumulative and toxic form of mercury that occurs in nature, and is of primary concern when studying mercury cycling. Methylmercury damages the central nervous system, and embryos are the most sensitive life stage of vertebrate organisms (Clarkson, 1992; Scheuhammer, 1991). For example, the effects of methylmercury on birds are much more severe in embryos and chicks than in adults, and low-level dietary exposures that cause no measurable effect in adult birds can significantly impair egg fertility, hatchling survival, and overall reproductive success (Scheuhammer, 1991). Common loon chicks feeding on fish from low pH lakes in northern Wisconsin lakes have elevated concentrations of mercury in their blood (Meyer and others, 1995), and diminished reproduction has been observed in some of these lakes (Meyer and others, 1998). In Ontario, Scheuhammer and Blancher (1994) estimate that 30 percent of the lakes had prey-size fish with mercury levels high enough to impair reproduction of common loons.

Based on relations between predator and prey fish species, it is likely that some Park lakes with high levels of mercury in gamefish have mercury levels of 0.3-0.4 μg/g in prey species, such as young yellow perch (James Wiener, U.S. Geological Survey, La Crosse, Wisc., oral commun., 2000). These levels in prey fish species have been shown to adversely effect loon reproduction (Barr, 1986), and may adversely affect other piscivores such as gamefish. Friedmann and others (1996) found that testicular development and immune function were inhibited by mercury levels of 100 ng/g (0.1 μg/g) in food, a dietary methylmercury concentration available to piscivorous fish in many North American waters.

The processes and factors causing large variability in fish-mercury levels among Voyageurs National Park lakes have not yet been identified. It is likely that within this small geographic area, atmospheric mercury deposition is uniform. Greater than 90 percent of the mercury that enters remote lakes is derived from the atmospheric deposition (Swain and others, 1992). Large inter-lake variability in fish-mercury levels indicates that factors other than mercury deposition control mercury accumulation in fish.

Many factors affect mercury cycling and bioaccumulation, although the cycling is complex and not completely understood. Variability in lake trophic status, food web structure, size, and morphometry all influence, or at least correlate with, mercury levels in fish (Wiener and Spry, 1996). Low-alkalinity, low-pH lakes, such as those found in the Park, often have fish with high fish-mercury levels (Swain and Helwig, 1989; Wiener and Spry, 1996). Lakes that have large watershed-area to lake-surface-area ratios tend to have greater mercury accumulation rates, because some fraction of mercury deposited in upland areas is delivered to the lake (Swain, and others, 1992). Wetlands can be net sinks of total mercury, but net sources of methylmercury (St. Louis and others, 1994).

Analysis of mercury in lake-sediment cores from mid North American lakes has shown that mercury accumulation rates have almost tripled since pre-industrial times (Swain and others, 1992), and this increase has been attributed to atmospheric transport and deposition from industrial sources. Recent measurements of methylmercury in lake-sediment cores indicates that the percentage of total mercury that is in the methylmercury form has increased substantially since the mid 1900’s in some lakes—including four lakes in Voyageurs National Park (Engstrom and others, 1999).

The U.S. Geological Survey, in cooperation with the National Park Service, and the Minnesota Pollution Control Agency conducted a study to measure seasonality and spatial variability of total mercury and methylmercury concentrations in 20 lakes in Voyageurs National Park. This report presents the data collected from this study during 2000-02.

METHODS

Mercury occurs in low concentration in water, and may be present in low concentrations in the atmosphere and on surfaces near or in the sampling and processing environment. Precautions are necessary during sample collection such that exposure of the water sample to different collection containers, humans, and the atmosphere must be minimized. For this study, two-person ultra-clean sampling procedures (U.S. Environmental Protection Agency (USEPA) Method 1669 (U.S. Environmental Protection Agency, 1996)) were used to collect the water samples analyzed for mercury constituents. The collectors wore disposable shoulder-length polyethylene gloves and wrist-length latex gloves. Sample bottles were contained with double polyethylene bags, and any materials and containers that contacted the sample water were cleaned following procedures outlined by Olson and DeWild (1999).

Twenty lakes (fig. 1) were sampled in May, July, and September during 2001 and during May and July 2002 for determination of total mercury and methylmercury from epilimnetic (near surface) waters. The same lakes were sampled for major ions, nutrients, and organic carbon once. Water also was collected from the hypolimnion (near bottom) waters once during midsummer (July 2001). This sampling was conducted using trace-metal-clean protocols that have been demonstrated to not contaminate samples. Total mercury, methylmercury, elemental mercury, and total organic carbon were analyzed at the USGS-WRD mercury laboratory in Middleton, Wisconsin (the "Laboratory" hereinafter). This laboratory is a class-100 clean-room facility, and quality-assurance procedures are available at URL http://infotrek.er.usgs.gov/doc/mercury/. Total mercury concentrations were determined using USEPA method 1631 (U.S. Environmental Protection Agency, 1999) as modified by Olson and DeWild (1999). Methylmercury concentrations were determined using methods described in De Wild and others (2002). Total organic carbon concentrations were determined using a carbon analyzer (model 1010, OI Analytical, College Station Texas) using Standard Method 5301D (American Public Health Association and others, 1998). Major ions were analyzed at the USGS National Water Quality Laboratory in Lakewood, Colorado. A vertical profile of field parameters (specific conductance, temperature, dissolved oxygen, pH, and Secchi transparency) was obtained at each sampling. Twenty percent of all field-submitted samples were quality-control samples (field blanks and replicates) and in-lake spatial variability samples.

The 20 study lakes (fig. 1; table 1) were selected to maximize within-Park gradients in water chemistry, fish-mercury levels, and landscape features. Use of data was maximized from past and ongoing studies in the Park. Each of the study lakes has been sampled for routine water-quality parameters. Nearly all have been sampled for gamefish that were analyzed for mercury (typically northern pike; some walleye and muskellunge; cited above) and age-1 yellow perch, and this work is planned to continue under State programs and MPCA-USGS cooperative studies.

Four lakes were sampled for total mercury, and methylmercury as a pilot study during May-September 2000 (Little Trout, Locator, Shoepack, and Tooth Lakes) (table 2). These lake bottoms were cored, and sediment-mercury accumulation rates were determined, and three of these four lakes had methylmercury analyzed in sediment profiles (Engstrom and others, 1999).

Surface-water sampling during 2001 was conducted during May, July, and September. Concentrations of methylmercury, total mercury, and other water-chemistry parameters in surface water for May, July, and September 2001 are presented in tables 3, 4, and 5, respectively. The results of the July hypolimnetic samples are presented in table 6.

For the 2002 sampling season, two sets of samples were collected. Methylmercury and total mercury concentrations from surface-water samples collected in May and July of 2002 are presented in tables 7 and 8. In addition, during the May sampling, samples were collected for nutrients (table 9) and for major ions (table 10).

Two types of quality assurance samples were collected: replicate samples and blank samples. Replicate samples were additional samples collected at the same location and with the same methods as the regular environmental sample. Blank samples were collected by processing low-mercury de-ionized water (obtained from the USGS Wisconsin District Mercury Laboratory) as if it were an environmental sample. This process involved pouring blank water into sample containers at the field site (field blank, table 12) or at the office (office blank, table 12). During July 2001, when hypolimnetic waters were sampled with a peristaltic pump, pump blanks (table 12) were obtained after rinsing the pump tubing with 1 percent hydrochloric acid (standard procedure after sampling each site). Quality assurance sample results are presented in tables 11 and 12.

To assess spatial variability of methylmercury and total mercury concentrations, sets of spatial-variability samples were collected from Locator Lake during July 2001 and Net Lake during August 2002. Surface samples were collected from 5-6 points across each lake (table 13). The data also can be found on the USGS web site (U.S. Geological Survey, 2003).

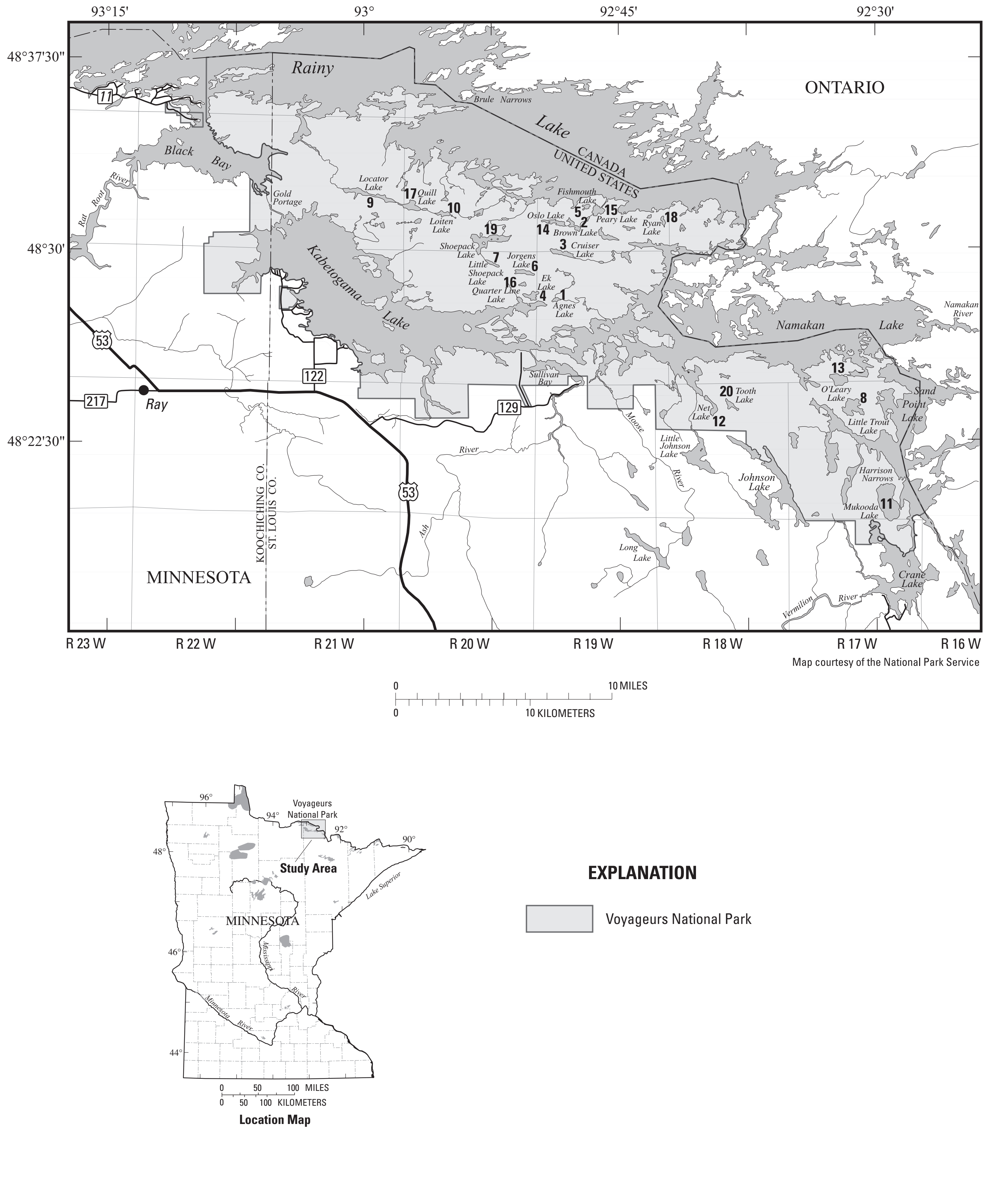

Figure 1. Location of study lakes in Voyageurs National Park (Number corresponds to lake number in table 1).

Table 1. Mercury study lakes in Voyageurs National Park, Minnesota

[USGS, U.S. Geological Survey; Modified from Kallemeyn and others, 2003]

Lake number (figure 1)	USGS Station number	Lake	Surface area (hectares)	Mean depth (meters)
1	482805092484101	Agnes	12.9	2.5
2	483059092474501	Brown	30.8	4.2
3	482958092484501	Cruiser	46.5	13.2
4	482812092500801	Ek	36.0	2.4
5	483142092465201	Fishmouth	12.9	3.8
6	482903092504701	Jorgens	24.7	3.0
7	482924092525101	Little Shoepack	22.7	2.5
8	482353092311901	Little Trout	96.7	13.0
9	483226092001401	Locator	56.7	8.1
10	483139092553801	Loiten	36.6	7.8
11	482018092292001	Mukooda	305	12.2
12	482358092392701	Net	43.7	2.0
13	482459092320101	O'Leary	78.5	7.1
14	483103092482501	Oslo	42.5	4.7
15	483129092462001	Peary	45.3	2.6
16	482838092504001	Quarter Line	8.3	3.1
17	483157092565701	Quill	34.4	6.9
18	483109092422601	Ryan	14.2	2.1
19	482951092531601	Shoepack	123.8	2.9
20	482355092383601	Tooth	23.5	5.9

Table 2. Surface-water data from selected lakes, Voyageurs National Park, May through September 2000

[mm/dd/yyyy, month, date, year; µS, microsiemens; cm, centimeter; °C, degrees Celsius; mg/L, milligrams per liter; ng/L, nanograms per liter; --, not sampled; <, less than the method detection limit; E, estimated]

Lake	Date (mm/dd/yyyy)	Specific conductance, µS/cm at 25 °C	pH, standard units	Temperature, °C	Dissolved oxygen, mg/L	Methylmercury, unfiltered, µg/L	Total mercury, unfiltered, µg/L	Total organic carbon, mg/l as C
Little Trout	05/02/2000	--	--	--	--	E.035	0.38	3.7
Little Trout	05/04/2000	--	--	--	--	E.032	0.38	4.1
Little Trout	07/11/2000	--	7.1	22.6	8.3	<.03	0.56	3.2
Little Trout	09/20/2000	--	6.7	16.8	9.5	<.03	0.56	4.1
Locator	05/04/2000	19	6.5	13.3	10.7	0.51	1.63	10
Locator	07/13/2000	23	7.3	23.6	7.3	0.10	1.79	7.2
Locator	09/21/2000	24	7.5	15.2	8.7	0.07	1.57	11
Shoepack	05/03/2000	13	5.8	12.8	10.1	0.34	2.33	12
Shoepack	09/20/2000	17	6.6	15.7	7.9	0.20	2.1	14
Tooth	05/02/2000	23	6.2	11.5	10.9	0.53	1.99	11
Tooth	07/11/2000	29	7.2	22.3	8.1	0.13	2.02	8.8
Tooth	09/19/2000	25	7.2	17.0	8.3	0.12	1.7	10

Table 3. Surface-water data from selected lakes, Voyageurs National Park, May 2001

[µS, microsiemens; cm, centimeters; °C, degrees Celsius; mg/L, milligrams per liter; ng/L, nanograms per liter; --, not sampled; <, less than the method detection limit]

Lake	Specific conductance, µS/cm at 25 °C	pH, standard units	Temperature, °C	Dissolved oxygen, mg/L	Methylmercury, unfiltered, ng/L	Total mercury, unfiltered, ng/L	Total organic carbon, mg/L as C
Agnes	7	6.2	13.9	6.5	0.26	2.99	16
Brown	16	7.0	16.5	9.5	0.09	2.05	8.8
Cruiser	13	--	14.5	11.0	<0.04	0.44	3.1
Ek	18	6.8	14.5	8.5	0.08	1.97	12
Fishmouth	15	--	17.1	9.2	0.12	1.49	7.3
Jorgens	14	6.8	14.3	8.2	0.12	2.07	9.4
Little Shoepack	14	6.8	14.4	8.9	0.15	2.54	11
Little Trout	29	7.5	13.9	10.0	0.05	0.86	4.0
Locator	14	6.7	14.6	10.8	0.15	2.72	11
Loiten	14	6.9	14.7	10.9	0.13	2.22	9.0
Mukooda	48	7.1	12.2	11.0	<0.04	0.55	5.2
Net	23	6.5	13.7	8.7	0.40	3.52	17
O'Leary	61	7.5	14.0	10.0	<0.04	0.78	6.9
Oslo	15	7.2	16.6	8.7	0.16	2.16	10
Peary	17	7.3	16.7	9.0	0.13	1.77	9.4
Quarter Line	13	6.4	13.8	7.6	0.12	3.33	18
Quill	14	6.8	15.3	10.8	0.08	2.38	9.2
Ryan	18	--	16.5	8.3	0.24	3.52	12
Shoepack	13	6.6	14.1	8.0	0.24	2.85	14
Tooth	20	6.6	14.3	11.1	0.17	3.74	11

Table 4. Surface-water data from selected lakes, Voyageurs National Park, July 2001

[µS, microsiemens; cm, centimeter; °C, degrees Celsius; mg/L, milligrams per liter; ng/L, nanograms per liter; --, not sampled; <, less than the method detection limit]

Lake	Specific conductance, µS/cm at 25 °C	pH, standard units	Temperature, °C	Secchi disk transparency, meters	Dissolved oxygen, mg/L	Methylmercury, unfiltered, ng/L	Total mercury, unfiltered, ng/L	Total organic carbon, mg/L as C
Agnes	18	6.3	24.5	0.9	5.2	0.41	2.74	17
Brown	13	7.1	25.0	2.0	9.0	0.12	1.83	9.3
Cruiser	12	6.6	23.3	5.5	8.1	<0.04	0.39	3.6
Ek	29	6.9	25.2	1.6	8.3	0.28	1.92	13
Fishmouth	21	7.6	24.5	3.9	8.2	0.04	1.08	7.9
Jorgens	24	6.5	24.6	1.9	8.4	0.08	1.74	9.6
Little Shoepack	15	6.7	25.4	2.1	7.7	0.15	1.99	11
Little Trout	27	7.7	24.6	4.5	7.9	<0.04	0.43	4.2
Locator	16	6.4	26.7	2.5	10.5	0.08	2.12	11
Loiten	24	6.9	26.4	3.9	8.2	0.10	2.02	8.6
Mukooda	44	7.3	23.9	4.2	8.2	<0.04	0.52	5.4
Net[1]	--	--	--	--	--	--	--	--
O'Leary	55	8.0	26.6	4.9	8.3	0.05	0.68	7.0
Oslo	13	7.5	24.8	2.0	9.1	0.11	2.74	12
Peary	25	6.9	24.7	2.3	7.9	0.2	1.60	10
Quarter Line	23	6.8	26.2	1.4	8.2	0.17	2.79	18
Quill	23	7.2	27.0	3.0	7.7	0.09	1.81	9.0
Ryan	25	7.0	24.9	2.8	8.1	0.15	2.82	13
Shoepack	12	6.2	24.5	1.6	8.0	0.27	2.56	14
Tooth	29	7.1	26.3	2.5	7.9	0.16	2.48	11

[1]Net Lake had drained due to the failure of a beaver dam.

Note: This table shows corrected values for Shoepack Lake, methylmercury and total mercury concentrations. An Erratum to this report (14 July 2006) explains the error in the original report.

Table 5. Surface-water data from selected lakes, Voyageurs National Park, September 2001

[µS, microsiemens; cm, centimeter; °C, degrees Celsius; mg/L, milligrams per liter; ng/L, nanograms per liter; --, not sampled; <, less than the method detection limit]

Lake	Specific conductance, µS/cm at 25 °C	pH, standard units	Temperature, °C	Secchi disk transparency, meters	Dissolved oxygen, mg/L	Methylmercury, unfiltered, ng/L	Total mercury, unfiltered, ng/L	Total organic carbon, mg/L as C
Agnes	21	5.7	15.3	0.9	0.23	0.30	2.43	19
Brown	20	6.7	17.3	2.2	8.3	<0.04	1.84	10
Cruiser	18	7.5	18.4	6.5	9.0	<0.04	0.46	3.8
Ek	28	7.2	18.3	1.8	8.3	0.09	1.66	13
Fishmouth	22	7.0	17.5	2.7	8.3	0.05	0.97	8.4
Jorgens	24	6.6	17.7	2.5	7.5	0.21	1.74	11
Little Shoepack	20	7.1	18.1	1.4	8.4	0.27	2.01	13
Little Trout	38	7.7	18.4	6.2	8.7	<0.04	0.41	4.5
Locator	24	6.8	18.6	2.4	7.8	0.12	2.24	12
Loiten	24	6.8	18	3.6	8.0	0.08	2.15	11
Mukooda	57	8.0	18.2	3.5	8.7	<0.04	0.34	5.9
Net[1]	--	--	--	--	--	--	--	--
O'Leary	68	7.5	18.1	4.7	8.3	<0.04	0.47	7.3
Oslo	18	6.7	17.3	1.8	8.0	0.22	2.14	12
Peary	25	7.2	17.3	1.7	7.6	0.24	1.43	11
Quarter Line	22	6.7	17.1	1.3	7.4	0.30	2.68	20
Quill	26	7.2	18.6	3.3	8.2	0.08	1.75	10
Ryan	25	6.6	17.8	2.0	8.0	0.32	2.85	13
Shoepack	19	6.5	17.6	0.9	8.1	0.39	2.80	18
Tooth	30	7.0	17.4	2.1	8.4	0.18	2.33	12

[1]Net Lake had drained due to the failure of a beaver dam.

Table 6. Hypolimnion (bottom water) data from selected lakes, Voyageurs National Park, July 2001

[µS, microsiemens; cm, centimeter; °C, degrees Celsius; mg/L, milligrams per liter; ng/L, nanograms per liter; --, not sampled; <, less than the method detection limit]

Lake	Specific conductance, µS/cm at 25°C	pH, standard units	Temperature, °C	Dissolved oxygen, mg/L	Methylmercury, unfiltered, ng/L	Total mercury, unfiltered, ng/L	Total organic carbon, mg/L as C
Agnes	32	5.9	10.7	0.2	1.81	5.98	17
Brown	14	6.3	10.5	0.8	0.17	1.86	8.3
Cruiser	11	5.8	5.1	5.2	<0.04	0.34	3.2
Ek	68	6.3	11.3	0.2	0.75	4.94	13
Fishmouth	25	7.2	13.3	6.7	0.05	0.95	8.0
Jorgens	31	6.0	16.1	0.3	0.14	2.15	9.6
Little Shoepack	21	6.0	16.3	0.6	2.69	7.16	12
Little Trout	24	7.0	5.1	8.3	<0.04	0.44	3.5
Locator	16	5.8	14.2	6.8	0.11	2.08	9.8
Loiten	26	5.9	6.2	2.3	0.28	1.60	7.7
Mukooda	40	6.9	6.3	4.7	<0.04	0.64	4.7
Net[1]	--	--	--	--	--	--	--
O'Leary	55	7.0	7.5	0.9	0.10	0.66	6.8
Oslo	13	6.4	14.9	2.6	0.14	1.86	9.8
Peary	44	6.4	15.0	0.4	0.15	1.52	10
Quarter Line	40	5.8	8.3	0.2	0.18	3.11	18
Quill	27	6.1	5.2	0.5	0.17	1.40	8.0
Ryan	25	6.5	18.0	4.0	0.17	2.73	13
Shoepack	13	5.7	19.6	3.7	1.02	3.82	14
Tooth	30	5.9	5.1	0.3	0.17	2.57	9.5

[1]Net Lake had drained due to the failure of a beaver dam.

Note: This table shows corrected values for Shoepack Lake, methylmercury and total mercury concentrations. An Erratum to this report (14 July 2006) explains the error in the original report.

Table 7. Surface-water data from selected lakes, Voyageurs National Park, May 2002

[µS, microsiemens; cm, centimeter; °C, degrees Celsius; mg/L, milligrams per liter; ng/L, nanograms per liter, --not sampled; <, less than the method detection limit]

Lake	Specific conductance, µS/cm at 25 °C	Field pH, standard units	Laboratory pH, standard units	Temperature, degrees C	Secchi disk transparency, meters	Dissolved oxygen, mg/L	Bicarbonate, field, mg/L as HCO_3	Methyl-mercury, unfiltered, ng/L	Total mercury, unfiltered, ng/L
Agnes	19	--	6.5	7.9	1.0	9.3	5	0.33	3.07
Brown	13	6.4	7.1	6.7	2.6	11	7	0.15	1.83
Cruiser[1]	--	--	--	--	--	--	--	--	--
Ek	26	6.9	7.1	8.6	2.0	10.8	14	0.08	1.74
Fishmouth	17	6.6	6.9	7.9	3.0	11.3	14	0.07	1.00
Jorgens	20	6.7	7.0	9.5	2.2	10.6	9	0.11	1.82
Little Shoepack	20	--	6.6	7.9	1.5	10.6	12	0.12	2.08
Little Trout	33	7.2	7.2	5.8	3.1	11.7	18	<0.04	0.38
Locator	22	6.9	6.8	5.5	2.5	10.5	8	0.20	2.26
Loiten	22	6.7	6.9	5.8	3.5	10.8	8	0.20	2.07
Mukooda	50	7.5	7.5	5.1	3.5	11.9	32	<0.04	0.34
Net	29	6.8	6.9	7.8	1.4	11.2	14	0.18	3.05
O'Leary	62	7.7	7.5	6.0	3.0	11.8	38	0.06	0.55
Oslo	12	6.6	6.6	6.2	2.0	11.4	7	0.30	2.26
Peary	18	6.5	7.0	7.7	3.2	10.0	14	0.08	1.51
Quarter line	22	--	6.7	9.2	1.5	11.1	7	0.22	3.02
Quill	23	6.7	7.2	6.1	3.0	10.5	8	0.25	1.66
Ryan	20	6.6	6.9	8.1	2.6	11.1	10	0.21	2.74
Shoepack	19	6.2	6.6	7.3	1.0	10.5	8	0.20	3.24
Tooth	22	6.7	7.1	6.3	2.3	11.4	16	0.25	2.20

[1]Cruiser Lake was not included in this study because of consistently low mercury and methylmercury concentrations, and because a collaborative fish study did not sample fish from this lake.

Table 8. Surface-water data from selected lakes, Voyageurs National Park, July 2002

[µS, microsiemens, cm, centimeters; °C, degrees Celsius; mg/L, milligrams per liter; ng/L, nanograms per liter; --, not sampled; <, less than the detection limit]

Lake	Specific conductance, µS/cm at 25 °C	pH, standard units	Temperature, °C	Secchi disk transparency, meters	Dissolved oxygen, mg/L	Methylmercury, unfiltered, ng/L	Total mercury, unfiltered, ng/L
Agnes	17	6.2	29.2	0.9	7.1	0.46	3.67
Brown	9	6.6	26.6	1.7	7.4	0.13	3.07
Cruiser[1]	--	--	--	--	--	--	--
Ek	24	6.6	28.3	1.5	7.9	0.20	2.66
Fishmouth	--	--	--	2.6	--	0.07	1.73
Jorgens	21	6.1	27.4	1.9	7.7	0.13	2.86
Little Shoepack	12	6.1	27.2	1.5	7.1	0.18	3.22
Little Trout	32	7.5	26.8	6.0	7.3	<0.04	0.51
Locator	--	--	--	1.7	--	0.16	3.12
Loiten	14	6.6	28.1	2.4	7.7	0.4	3.06
Mukooda	56	7.4	26.4	4.3	8.1	<0.04	0.43
Net	37	6.3	26.9	1.0	7.4	0.41	3.67
O'Leary	70	8.1	27.2	4.5	7.5	0.05	0.72
Oslo	7	6.9	27.7	1.7	7.4	0.17	3.53
Lake	22	6.0	26.6	1.8	8.3	0.21	2.38
Quarter Line	20	6.1	28.0	1.2	7.1	0.20	4.32
Quill	14	7.1	28.2	2.1	7.5	0.13	2.69
Ryan	14	6.5	28.1	1.5	6.8	0.22	4.81
Shoepack	20	6.0	26.1	1.0	7.2	0.34	3.83
Tooth	30	6.7	27.0	2.5	7.2	0.23	3.26

[1]Cruiser Lake was not included in this study because of consistently low mercury and methylmercury concentrations, and because a collaborative fish study did not sample fish from this lake.

Table 9. Nutrient water chemistry in selected lakes, Voyageurs National Park, May 2002
[mg/L, milligrams per liter; --, not sampled; <, less than the method detection limit; E, estimated]

Lake	Dissolved nitrite nitrogen, mg/L as N	Dissolved nitrite plus nitrate nitrogen, mg/Las N	Dissolved ammonia nitrogen, mg/L as N,	Total ammonia plus organic nitrogen, mg/L as N	Dissolved ammonia plus organic nitrogen, mg/L as N	Total Phosphorus, mg/L as P	Dissolved Phosphorus, mg/L as P	Dissolved orthophosphate phosphorus, mg/l as P
Agnes	<0.008	0.07	0.06	1.5	0.6	0.025	0.009	<0.02
Brown	<0.008	0.08	0.03	0.4	0.4	0.009	0.004	<0.02
Cruiser[1]	--	--	--	--	--	--	--	--
Ek	<0.008	0.13	<0.04	1.3	0.5	0.012	0.006	<0.02
Fishmouth	<0.008	E0.03	0.26	0.7	0.7	0.008	0.004	<0.02
Jorgens	<0.008	0.12	E0.03	0.8	0.4	0.007	0.005	<0.02
Little Shoepack	<0.008	0.17	0.05	1.5	0.5	0.012	0.005	<0.02
Little Trout	<0.008	<0.05	<0.04	0.6	0.2	0.004	<0.004	<0.02
Locator	<0.008	0.07	<0.04	1.1	0.3	0.01	0.004	<0.02
Loiten	<0.008	0.09	<0.04	0.9	0.3	0.006	0.004	<0.02
Mukooda	<0.008	<0.05	<0.04	0.5	0.3	0.012	0.004	<0.02
Net	<0.008	0.05	<0.04	0.7	0.5	0.024	0.008	<0.02
O'Leary	<0.008	<0.05	<0.04	1.0	0.3	0.014	0.005	<0.02
Oslo	<0.008	0.08	E0.02	0.5	0.4	0.012	0.005	E0.01
Peary	<0.008	0.07	<0.04	0.5	0.4	0.016	0.007	<0.02
Quarter Line	<0.008	0.06	<0.04	2.0	0.6	0.018	0.010	<0.02
Quill	<0.008	0.12	<0.04	0.8	0.3	0.007	0.004	<0.02
Ryan	<0.008	0.06	0.13	0.6	0.6	0.009	0.005	<0.02
Shoepack	<0.008	0.16	E0.03	1.6	0.5	0.027	0.007	<0.02
Tooth	<0.008	E0.04	<0.04	0.5	0.4	0.010	0.005	<0.02

[1]Cruiser Lake was not included in this study because of consistently low mercury and methylmercury concentrations, and because a collaborative fish study did not sample fish from this lake.

Table 10. Major ion water chemistry in selected lakes, Voyageurs National Park, May 2002

[mg/L, milligrams per liter; µg/L, micrograms per liter; --not sampled; <, less than the method detection limit; E, estimated]

Lake	Total alkalinity, mg/L as $CaCO_3$	Dissolved sulfate, mg/l as SO_4	Dissolved chloride, mg/L as Cl	Dissolved fluoride, mg/L as F	Dissolved silica, mg/L as SiO_2	Dissolved iron, µg/L as Fe	Dissolved manganese, µg/L as Mn
Agnes	4	0.9	0.2	<0.1	5.1	480	59
Brown	6	1.5	<0.3	<0.1	2.8	160	3
Cruiser[1]	--	--	--	--	--	--	--
Ek	12	1.1	<0.3	<0.1	2.0	250	2
Fishmouth	12	1.4	0.2	<0.1	0.77	26	2
Jorgens	7	1.7	<0.3	<0.1	2.5	280	40
Little Shoepack	9	1.5	<0.3	<0.1	2.2	160	3
Little Trout	15	2.7	0.2	E0.06	0.49	<10	<2
Locator	6	2.3	0.4	<0.1	2.8	190	6
Loiten	7	2.6	0.3	<0.1	2.6	130	4
Mukooda	26	1.7	0.2	<0.1	0.81	11	<2
Net	11	2.2	0.2	<0.1	3.0	170	3
O’Leary	31	1.9	0.2	<0.1	0.87	25	<2
Oslo	6	1.4	0.2	<0.1	3.6	190	4
Peary	12	1.4	0.2	<0.1	2.4	260	14
Quarter Line	6	1.7	0.2	<0.1	3.0	340	17
Quill	7	2.3	0.4	<0.1	2.5	190	6
Ryan	8	3.0	0.3	<0.1	2.9	220	39
Shoepack	7	1.6	0.2	<0.1	3.7	470	82
Tooth	13	2.9	0.2	E0.07	2.4	72	3

[1]Cruiser Lake was not included in this study because of consistently low mercury and methylmercury concentrations, and because a collaborative fish study did not sample fish from this lake.

Table 11. Quality-assurance results of replicate samples from selected lakes in Voyageurs National Park, 2000-02

[mg/L, milligrams; ng/L, nanograms per liter; 9, routine sample; R, replicate; --, not sampled; <, less than the method detection limit; E, estimated]

Lake	Date (mm/dd/yyyy)	Sample start time	Medium Code	Sampling depth, meters	Alkalinity, mg/L as $CaCO_3$	Dissolved nitrite nitrogen, mg/L as N	Dissolved nitrite plus nitrate nitrogen, mg/L as N	Dissolved ammonia nitrogen, mg/Las N	Total nitrogen ammonia plus organic, mg/L as N	Dissolved ammonia nitrogen plus organic mg/L as N	Total phosphorus, mg/L as P	Dissolved phosphorus, mg/L as P	Phosphorus orthophosphate dissolved, mg/L as P	Mercury, unfiltered, ng/L	Methylmercury, unfiltered, ng/L	Total organic carbon, mg/L as C
Agnes	07/19/2001	0730	9	0.05	--	--	--	--	--	--	--	--	--	2.74	0.41	17
Agnes	07/19/2001	0735	R	0.05	--	--	--	--	--	--	--	--	--	3.05	0.36	17
Agnes	07/19/2001	0740	R	0.05	--	--	--	--	--	--	--	--	--	2.88	0.44	17
Agnes	07/19/2001	0810	9	4.5	--	--	--	--	--	--	--	--	--	5.98	1.81	17
Agnes	07/19/2001	0815	R	4.5	--	--	--	--	--	--	--	--	--	4.53	1.14	17
Agnes	07/19/2001	0820	R	4.5	--	--	--	--	--	--	--	--	--	4.55	1.15	17
Ek	05/07/2002	1125	9	0.05	12	<0.008	0.13	<0.04	1.3	0.5	0.01	0.006	<0.02	1.74	0.08	--
Ek	05/07/2002	1130	R	0.05	--	--	--	--	--	--	--	--	--	1.75	0.09	--
Ek	05/07/2002	1135	R	0.05	10	<0.008	0.12	<0.04	1.3	0.5	0.01	0.007	<0.02	1.76	0.07	--
Little Trout	05/03/2000	1244	9	5.0	--	--	--	--	--	--	--	--	--	0.35	0.05	3.8
Little Trout	05/03/2000	1251	R	5.0	--	--	--	--	--	--	--	--	--	0.36	<0.025	3.7
Little Trout	05/04/2000	1200	9	0.05	--	--	--	--	--	--	--	--	--	0.38	E.032	4.1
Little Trout	05/04/2000	1201	R	0.05	--	--	--	--	--	--	--	--	--	0.39	--	--
Little Trout	07/13/2000	0800	9	0.05	--	--	--	--	--	--	--	--	--	0.47	<0.03	2.9
Little Trout	07/13/2000	0801	R	0.05	--	--	--	--	--	--	--	--	--	0.46	E.03	--
Little Trout	07/13/2000	0802	R	0.05	--	--	--	--	--	--	--	--	--	0.61	E.03	--
Little Trout	09/20/2000	1000	9	0.05	--	--	--	--	--	--	--	--	--	0.56	<0.03	4.1
Little Trout	09/20/2000	1005	R	0.05	--	--	--	--	--	--	--	--	--	0.53	<0.01	--
Little Trout	09/20/2000	1010	R	0.05	--	--	--	--	--	--	--	--	--	0.72	0.02	--
Mukooda	05/24/2001	1030	9	0.05	--	--	--	--	--	--	--	--	--	0.55	<0.04	5.2
Mukooda	05/24/2001	1035	R	0.05	--	--	--	--	--	--	--	--	--	0.57	<0.04	5.1
Mukooda	05/24/2001	1040	R	0.05	--	--	--	--	--	--	--	--	--	0.5	<0.04	5.2
Mukooda	07/17/2002	1125	9	0.05	--	--	--	--	--	--	--	--	--	0.43	<0.04	--
Mukooda	07/17/2002	1131	R	0.05	--	--	--	--	--	--	--	--	--	0.44	<0.04	--
Ryan	07/16/2001	1610	9	0.05	--	--	--	--	--	--	--	--	--	2.82	0.15	13
Ryan	07/16/2001	1615	R	0.05	--	--	--	--	--	--	--	--	--	3.37	0.16	13
Ryan	07/16/2001	1620	R	0.05	--	--	--	--	--	--	--	--	--	2.95	0.16	13
Ryan	07/16/2001	1625	9	4.0	--	--	--	--	--	--	--	--	--	2.73	0.17	13
Ryan	07/16/2001	1630	R	3.5	--	--	--	--	--	--	--	--	--	3.42	0.1	13
Ryan	07/16/2001	1635	R	3.5	--	--	--	--	--	--	--	--	--	2.72	0.32	13
Tooth	09/18/2001	1140	9	0.05	--	--	--	--	--	--	--	--	--	2.33	0.18	12
Tooth	09/18/2001	1143	R	0.05	--	--	--	--	--	--	--	--	--	2.27	0.15	13
Tooth	09/18/2001	1146	R	0.05	--	--	--	--	--	--	--	--	--	3.39	0.10	13

Table 12. Quality-assurance results of blanks from selected lakes, Voyageurs National Park, 2000-02

[mm/dd/yyyy, month, date, year; mg/L, milligrams per liter; ng/L, nanograms per liter; E estimated;--, not sampled; <, less than the method detection limit]

Lake	Sample date (mm/dd/yyyy)	Sample start time	Type of sample	Mercury, unfiltered, ng/L	Methylmercury, unfiltered, ng/L	Total organic carbon, mg/L as C
Fishmouth	09/19/2001	1200	field blank	0.79	--	--
Little Shoepack	05/23/2001	1630	field blank	<0.04	<0.04	<0.04
Locator	09/22/2000	1000	office blank	0.11	E.03	0.1
Locator	07/19/2001	1235	pump blank	0.15	<0.04	0.3
Mukooda	09/18/2001	1105	field blank	0.09	<0.04	<0.04
Mukooda	07/17/2002	1132	field blank	0.05	<0.04	--
Shoepack	0920/2001	1240	field blank	0.13	<0.04	0.14
Tooth	07/18/2001	1300	pump blank	0.10	<0.04	--

Table 13. Spatial-variation sampling data from selected lakes, Voyageurs National Park, July 2001 and August 2002

[mm/dd/yyyy; month, date, year; °C, degrees Celsius; µS, microsiemens; cm, centimeters; mg/L. milligrams per liter; ng/L, nanograms per liter; --, not sampled]

Lake	Date (mm/dd/yyyy)	Sample start time	Temperature, °C	Specific conductance, µS/cm at 25°C	Sampling Depth, meters	Dissolved oxygen, mg/L	Dissolved oxygen, percent of saturation	pH, Field, Standard Units	Total organic carbon, mg/L as C	Methylmercury, unfiltered, recoverable, ng/L	Mercury, unfiltered, ng/L
Locator	07/19/2001	1238	26.7	16.0	0.05	10.5	138	6.4	11	0.08	2.12
Locator	07/19/2001	1335	--	--	0.05	--	--	--	11	0.07	2.52
Locator	07/19/2001	1350	--	--	0.05	--	--	--	11	0.08	2.02
Locator	07/19/2001	1400	--	--	0.05	--	--	--	10	0.12	2.22
Locator	07/19/2001	1420	--	--	0.05	--	--	--	11	0.08	2.32
Net	08/14/2002	1200	21.7	35.4	0.05	7.15	85.7	7.0	--	0.30	2.86
Net	08/14/2002	1210	21.8	35.4	0.05	7.06	85	6.9	--	0.34	2.98
Net	08/14/2002	1230	21.9	35.0	0.05	6.89	82.1	6.9	--	0.33	2.90
Net	08/14/2002	1240	21.8	35.5	0.05	6.84	81.5	6.8	--	0.49	2.94
Net	08/14/2002	1250	21.8	35.2	0.05	6.85	82	6.9	--	0.33	2.96
Net	08/14/2002	1320	21.6	35.2	0.05	7.10	84.8	6.9	--	0.35	2.92

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