Human Health Risk Assessment

Mercury in Fish

Pine Coulee and Twin Valley Water Management Projects
Southern Alberta

October 2009

Government of Alberta

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ISBN: 978-0-7785-8241-0 (Report)
ISBN: 978-0-7785-8242-7 (Online)

Executive Summary

Mercury enters the environment through various natural processes and human activities. Methylmercury is transformed from inorganic forms of mercury via methylation by microorganisms in natural waters, and can accumulate in some fish. Humans are exposed to very low levels of mercury directly from the air, water and food. Fish consumers may be exposed to relatively higher levels of methylmercury by eating mercury-containing fish from local rivers and lakes. Methylmercury can accumulate in the human body over time. Because methylmercury is a known neurotoxin, it is necessary to limit human exposure.

Water Management Operations (WMO) plays a key role in the management of water in Alberta. The two WMO water projects within Southern Alberta presented in this report are the Pine Coulee Reservoir project and the Twin Valley Reservoir project. The monitoring of mercury levels in fish were conducted between 1997 and 2007.

This report deals with (1) concentrations of total mercury levels in various fish species, (2) estimation of exposures, (3) fish consumption limits, (4) fish consumption advisories, and (5) health benefits of fish consumption. The results indicate that:

1. Concentrations of total mercury in fish from these two reservoirs in Southern Alberta were within reported ranges for the same fish species from the rivers and lakes elsewhere in Canada and the United States.
2. The estimated human exposures to mercury were highest for the high fish intake group (over 100 g/d), especially if they consume fish-eating fish like walleye, burbot and northern pike.
3. Restriction of consumption of walleye, burbot and northern pike from the reservoirs was indicated by the risk assessment, especially for women of reproductive age, pregnant women and young children.
4. Fish consumption advisories are voluntary measures to reduce potential health risk to local fish consumers. The balance between risk and benefits of consumption of mercury-containing fish needs to be understood and considered by consumers.

The Science Advisory Committee reviewed this document and made recommendations. The Public Health Management Committee made final decisions on fish consumption advisories and measures to inform the public accordingly.

Acknowledgments

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1. Introduction

Mercury (Hg) occurs naturally in the environment. There are three forms of mercury: elemental (metallic) mercury, inorganic mercury salts and organic mercury compounds. Mercury enters the environment through natural processes and human activities. The form of mercury most commonly found in the air is elemental mercury. Methylmercury (MeHg) is often formed from other forms of mercury during natural biological processes such as methylation by microorganisms in the water and sediment. MeHg can accumulate in some fish. People are exposed to very low levels of mercury in the air, water and food. Some people may be exposed to relatively higher levels of MeHg through eating mercury-containing fish. MeHg accumulates in the human body over time. Because MeHg is a known neurotoxin, it is necessary to limit human exposure.

To protect public health, Health Canada has proposed a few mercury guidelines, and advisories for different fish consumer groups (Health Canada,1979; Feeley and Lo, 1998; Health Canada 2007, Feeley 2008) based on total mercury (THg) or MeHg. These values are expressed either in units of μg THg per g of fish flesh or as a Provisional Tolerable Daily Intake (pTDI) in units of μg MeHg per kg of consumer body mass per day (see Section 2.1):

1. 0.5 μg THg/g for all commercial fish/seafood (Guideline);
2. 0.2 μg MeHg/kg bw/d TDI for women of reproductive age and children (Guideline);
3. 0.47 μg MeHg/kg bw/d TDI for the general population (Guideline);
4. 1.0 μg THg/g for certain commercial fish species such as fresh and frozen tuna, shark, swordfish, escolar, marlin and orange roughy which are known to be consumed less frequently (Advisory); and
5. 0.2 μg THg/g for subsistence consumers (Advisory).

The guidelines for commercial fish/seafood are used as a general screening criterion, with the knowledge that most species of commercial fish usually contain lower levels (< 0.1 μg/g) of mercury. This guideline is enforceable by the Canadian Food Inspection Agency (CFIA). For example, the CFIA has been monitoring total mercury (THg) levels in commercial fish caught from Lake Athabasca in Alberta since the early 1990s. The recommendation for subsistence consumers proposed by the First Nations and Inuit Health Branch (FNIHB) of Health Canada is used for the First Nations and Inuit people relying on subsistence fresh water fishing when FNIHB became aware of long-term fish consumption patterns of over 100 g/d (Health Canada 1979). The First Nations and Inuit consumers should limit their fish consumption if the mercury levels are over 0.2 μg THg/g and under 0.5 μg THg/g.

Fish consumption advisories are developed based on these pTDIs. These advisories provide the public with a warning of potential health risk resulting from consuming local mercury-containing fish. Fish consumption advisories are designed to minimize the potential health risks to fish consumers who can voluntarily restrict their fish consumption.

Water Management Operations (WMO) plays a key role in the management of water in Alberta. WMO water projects in Southern Alberta occur within the Bow River Sub-Basin, Oldman River Sub-Basin, lower Red Deer River Sub-Basin and the South Saskatchewan Sub-Basin (Figure 1). The Pine Coulee Water Management Project included the construction of a diversion of weir and head pond on Willow Creek, a canal, and a dam and saddle dyke in Pine Coulee to form a multi-use, off-stream storage reservoir in Pine Coulee. The Little Bow Water Management Project included construction of a dam on the Little Bow River, a diversion weir on Mosquito Creek, and a canal from Mosquito Creek to Clear Lake. The dam on the Little Bow River forms the Twin Valley reservoir.

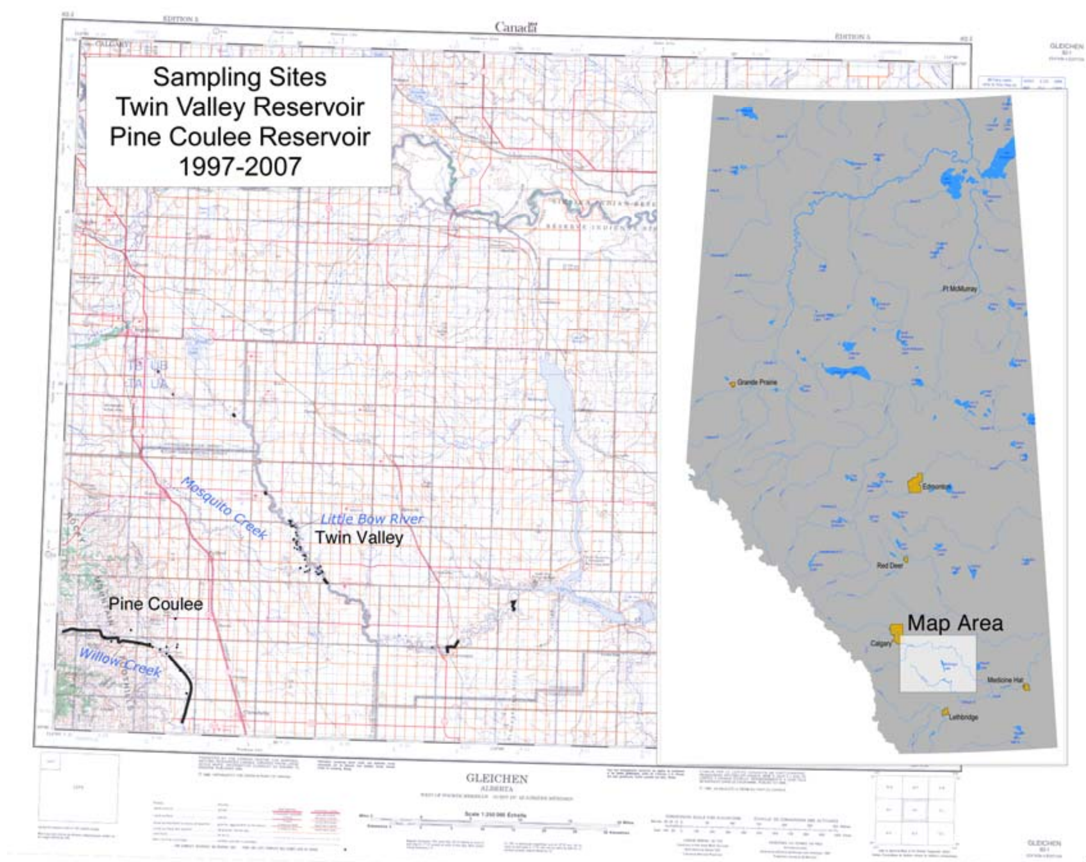

Figure 1 Sampling Locations

Both reservoirs have public access and boat launch facilities and angling is permitted. No angler counts or surveys have been conducted, but both reservoirs receive moderate angling pressure (Bryski 2008). Pine Coulee Reservoir is open for fishing from May 16 to March 31 with a limit of three northern pike per license. Walleye cannot be harvested. The reservoir is popular within the local angling community because of high catch rates for small walleye. Anglers come from Stavely, Claresholm, Calgary, Lethbridge, the Crowsnest Pass and other local communities.

Twin Valley Reservoir is open for angling year around. Anglers may harvest up to three northern pike, over 63 cm total length. Anglers from Vulcan, Claresholm and other nearby communities utilize the Twin Valley reservoir.

WMO manages an environmental monitoring program for both projects. Monitoring is conducted to evaluate the performance of fishery mitigation and compensation projects, document the environmental effects of reservoirs and water management, and compared observed effects to expected effects. The relationship was found between reservoir creation and the increased mercury levels in fish in Canada (Verdon et al. 1991; Bodaly et al. 2007). The monitoring of mercury levels in fish is part of the WMO projects.

Baseline mercury levels were established in the Pine Coulee Reservoir project area in 1997, prior to construction of the Pine Coulee Dam. Baseline pre-project mercury levels were sampled in the Twin Valley Reservoir project area in 2002. Post-project mercury levels in fish were monitored in 2003, 2004, 2005, and 2007 at Pine Coulee and in 2004, 2005, and 2006 at Twin Valley.

In June of 2008, Alberta Environment submitted the data of mercury levels in fish to Alberta Health and Wellness for human health risk assessment.

The results from these monitoring programs are discussed as follows:

1. mercury concentrations in fish,
2. comparison of mercury concentrations in the same fish species in the rivers and lakes in Canada and the U.S.,
3. local fish consumption rates,
4. estimated exposures for women at reproductive age, children and adults,
5. fish consumption advisories, and
6. health benefits of fish consumption.

2. Materials and Methods

2.1 Units Used for Expressing Mercury Data

A summary of the different units that may be used for expressing relevant mercury data is provided in Table 1. For the purposes of this report, to facilitate comparison of values reported from different sources, all data on mercury concentration in fish will be expressed as μg of mercury per g of fish, i.e. μg/g, which is equivalent to one unit of mercury per million units of fish (ppm). Likewise, human exposure will be expressed as μg of mercury per kg of human body mass, per day, i.e. μg/kg/d. Consumption advisories will be determined from human exposure limits and expressed as g of fish consumed per week, i.e. g/wk.

Table 1 Units Used for Expressing Mercury Data related to Fish

Measure	Preferred Unit	Alternate Unit	Equivalent Units
Hg Concentration	μg of Hg per g of fish, wet weight **μg/g**	mg of Hg per kg of fish, wet weight **mg/kg**	1 part Hg per million parts of fish **ppm**
pTDI for mercury by humans	μg of MeHg per kg of human body weight (mass) per day **μg MeHg/ kg BW/ d**		
Recommended fish consumption limits	g / mercury-containing fish fillet consumed per week **g / wk**	oz / mercury-containing fish fillet consumed per week **oz / wk**	1 oz = 28.35 g

2.2 Field Collection

The field collection was conducted by Alberta Environment and Sustainable Resource Development between 2003 and 2007. Fish were collected by gill-netting, angling and electrofishing. Each sample was kept on ice, and then frozen flat within 5 hours at - 20 °C. Samples were individually bagged and tagged with a label with a unique number. The samples were shipped to the Alberta Research Council in Vegreville, Alberta for laboratory analysis.

Fish species included

- walleye (*Sander vitreus*),

- northern pike (*Esox lucius*),
- burbot (*Lota lota*),
- white sucker (*Catostomus commersoni*),
- longnose sucker (*Catostomus catostomus*),
- longnose dace (*Rhinichthys cataractae*),
- lake chub (*Couesius plumbeus*),
- trout-perch (*Percopsis omiscomaycus*), and
- yellow perch (*Perca flavescens*).

A total of 463 fish from the Pine Coulee sites and a total of 390 fish from the Twin Valley sites were collected for total mercury analysis. The sample size, and mean of weight and fork length are summarized in Table 2 for the Pine Coulee sites and Table 3 for Twin Valley sites.

2.3 Laboratory Analysis

The analytical method was based on the determination of total mercury in fish tissue in the Methods Manual for Chemical Analysis of Water and Wastes developed by Alberta Environmental Center (AEC 1996). For THg analysis, 1 g of tissue (non-homogenized) was digested using 5mL nitric acid in a microwave digestion, then diluted to 100 mL with distilled water and preserved with bromium chloride. Mercury was then analyzed using Cold-Vapor Atomic Absorption Spectroscopy on a flow injection mercury system. The sample volume used was 500 μL. The method detection limit was 0.003 μg/g, wet weight.

2.4 Estimation of Exposure Ratio

Estimated daily intake (EDI) was calculated as follows:

$$EDI = C * IR * BF/BW$$

C is a representative measured THg concentrations in fish muscle (μg/g). From a human health perspective, the amount of MeHg is of most interest. In mercury analyses of fish, the sum of THg in the sample is measured rather than MeHg because the analysis of MeHg is more expensive. Some studies reported that the percentage of MeHg in THg ranged from 81% to 95% (CFIA 2003). For the purposes of health risk assessments, 100% of THg is assumed to be MeHg thereby erring on the side of caution.

IR is the human rate of fish consumption (g/d).

BF is bioavailability factor (assumed to be 100%).

BW is average body weight in humans (kg). The average of body weight for male and female adults in Alberta is 73 kg. The average human body weights used by Health Canada are 65 kg for women of reproductive age, 26.4 kg for 5-11 years group and 14.4 kg for 1-4 years group (Health Canada 2007).

Exposure ratio (ER, unitless) was calculated by using the following equation:

ER= EDI/pTDI

The tolerable daily intake (pTDI, μg MeHg/kg bw/d) is determined by toxicological risk assessment on mercury (Health Canada 2007). The pTDI for mercury is the maximum amount of mercury that can be ingested on a daily basis over a lifetime without increased risk of adverse health effects. Health Canada proposed a pTDI of mercury as 0.2 μg MeHg/kg bw/d for women of reproductive (childbearing) age and for children. Children refer to two age groups: 5-11 years old group and 1-4 years old group. Health Canada proposed a pTDI of mercury as 0.47 μg MeHg/kg bw/d for adults (adult men and adult women who are not of reproductive age).

2.5 Consumption Limits

For quantitative fish advisories, the lifetime average consumption limits (weekly basis) are calculated. The calculation of the consumption limits (CR, g fish per week) is based on the following equation:

CR = pTDI * BW (7 d/wk) / C

Where pTDI is provisional tolerable daily intake (μg MeHg/kg bw/d),
BW is body weight (mass) in humans (kg), and
C (μg Hg / g fish) is the measured THg concentration in fish muscle.

The consumption limits that correspond to the Health Canada TDI and the commercial fish Hg recommendation (maximum concentration of 0.5 μg Hg /g fish) are provided below as a reference point.

Consumption Limits for adult men and adult women not of reproductive age
CR = (0.47μg MeHg/kg bw/d)(73 kg)(7 d/wk) / (0.5 μg Hg / g fish) = 480 g fish /week

Consumption Limits for women of reproductive age
CR = (0.2μg MeHg/kg bw/d)(65 kg)(7 d/wk) / (0.5 μg Hg / g fish) = 180 g fish /week

Consumption Limits for children age 5 – 11 (body weight 26.4 kg)
CR = (0.2μg MeHg/kg bw/d)(26.4 kg)(7 d/wk) / (0.5 μg Hg / g fish) = 74 g fish

/week

Consumption Limits for children age 1 – 4 (body weight 14.4 kg)

CR = (0.2μg MeHg/kg bw/d)(14.4 kg)(7 d/wk) / (0.5 μg Hg / g fish) = 40 g fish /week

Table 2 Sample Size and Mean of Weight and Length in the Pine Coulee

	Year	Sample Size	Total	Fork Length (cm)	Wet Weight (g)
Reservoir					
Walleye			77		
	2003	15		26	229
	2004	12		30	304
	2005	20		31	308
	2007	30		32	356
Northern pike	2007		3	41	508
White sucker	2007		6	36	800
Willow Creek Downstream					
Burbot			28		
	2003	11		32	313
	2004	4		36	333
	2007	13		35	294
Northern pike			45		
	2003	12		50	806
	2004	20		48	986
	2007	13		50	621
White sucker			73		
	2003	12		19	151
	2004	20		22	225
	2005	20		34	588
	2007	21		28	371
Longnose sucker			63		
	2003	14		24	299
	2004	21		23	266
	2005	7		23	588
	2007	21		26	228
Lake chub	2003		9	8	-
Longnose dace	2003		5	7	-
Trout perch	2003		4	5.6	-
Willow Creek Upstream					
Burbot			27		
	2003	18		23	86
	2004	4		30	191
	2007	5		36	341
White sucker			69		
	2003	18		21	180
	2004	20		12	51
	2005	11		28	408
	2007	20		22	137
Longnose sucker			54		
	2003	16		25	186
	2004	11		21	146
	2005	6		23	172
	2007	21		26	228
Total			**463**		

Table 3 Sample Size and Mean of Weight and Length in the Twin Valley Sites

	Year	Sample Size		Fork Length (cm)	Wet Weight (g)
Reservoir					
Northern pike			93		
	2004	30		52	1067
	2005	30		47	936
	2006	33		53	1588
White sucker			48		
	2004	7		31	481
	2005	24		26	362
	2006	17		31	614
Little Bow River Downstream					
Northern pike			29		
	2004	6		33	562
	2005	3		58	1237
	2006	10		55	1450
White sucker			50		
	2004	20		34	718
	2005	20		41	1172
	2006	10		41	1148
Yellow perch	2004		14	11	20
Little Bow River Upstream					
Northern pike			23		
	2005	14		58	1240
	2006	9		58	1546
White sucker			56		
	2004	20		32	530
	2005	16		35	686
	2006	20		41	1153
Total			**313**		

3. Results and Discussions

3.1 Concentrations in Fish

The total mercury concentrations in wet weight in fish are summarized in Table 4 for the Pine Coulee sites and Table 5 for the Twin Valley sites. In the Pine Coulee sites (Figure 2), the THg levels in walleye were the highest as compared to those in other fish species. Walleye were collected from the reservoir, with a range of the average THg levels from 0.52 to 0.79 μg/g. Only three northern pike samples were collected in 2007. The mean of THg level was relatively lower (0.13 μg/g) as compared to northern pike collected from the Willow Creek downstream, with a range of 0.27 to 0.49 μg/g. Burbot were collected from the Willow Creek downstream and upstream, with a range of 0.20 to 0.40 μg/g. White suckers were collected from the Willow Creek downstream and upstream, with a range of 0.11 to 0.31 μg/g. The THg levels in longnose suckers collected from the Willow Creek downstream and upstream were the lowest of all fish species sampled, with a range of 0.08 to 0.14 μg/g.

In the Twin Valley sites, northern pike were collected from the reservoir, and the Little Bow River downstream and upstream of Twin Valley Reservoir. Average THg levels ranged from 0.44 to 0.68 μg/g, 0.27 to 0.59 μg/g, and 0.04 to 0.16 μg/g, respectively. The THg levels were relatively higher in northern pike from the reservoir and the downstream river section as compared to levels from the river section upstream (Figure 3). White suckers were collected from the reservoir, and the downstream and upstream river section. Average THg levels ranged from 0.22 to 0.25 μg/g, 0.23 to 0.43 μg/g, and 0.10 to 0.15 μg/g, respectively.

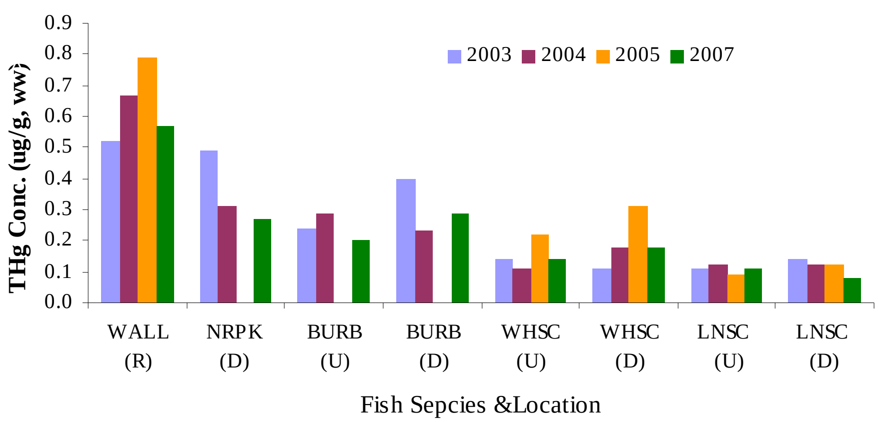

Figure 2 Total Mercury Levels in Fish from the Pine Coulee Sites

(WALL=walleye, NRPK=northern pike, BURB=burbot, WHSC=white sucker, LNSC=longnose sucker, R=reservoir, U=upstream, D=downstream)

Table 4 Total Mercury Levels (μg/g, wet weight) in Fish from the Pine Coulee Sites

Species	Year	Mean	Min	Max
Reservoir				
Walleye	2003	**0.52**	0.36	0.70
	2004	**0.67**	0.53	0.99
	2005	**0.79**	0.49	1.07
	2007	**0.57**	0.04	0.82
Northern pike	2007	0.13	0.11	0.15
White sucker	2007	0.19	0.10	0.27
Willow Creek Downstream				
Burbot	2003	0.40	0.18	0.81
	2004	0.23	0.19	0.29
	2007	0.29	0.10	0.43
Northern pike	2003	0.49	0.15	1.03
	2004	0.31	0.12	0.77
	2007	0.27	0.11	0.54
White sucker	2003	0.11	0.06	0.21
	2004	0.18	0.08	0.47
	2005	0.31	0.06	0.69
	2007	0.18	0.07	0.47
Longnose sucker	2003	0.14	0.04	0.40
	2004	0.12	0.04	0.37
	2005	0.12	0.04	0.31
	2007	0.08	0.04	0.13
Lake chub	2003	0.14	0.07	0.24
Longnose dace	2003	0.09	0.06	0.15
Trout perch	2003	0.08	0.06	0.11
Willow Creek Upstream				
Burbot	2003	0.24	0.04	0.48
	2004	0.29	0.22	0.36
	2007	0.20	0.16	0.28
White sucker	2003	0.14	0.04	0.41
	2004	0.11	0.04	0.19
	2005	0.22	0.05	0.54
	2007	0.14	0.07	0.35
Longnose sucker	2003	0.11	0.06	0.17
	2004	0.12	0.04	0.24
	2005	0.09	0.04	0.26
	2007	0.11	0.08	0.15

THg concentrations exceeding the 0.5 μg/g commercial fish limit are showed in **bold**.

Table 5 Total Mercury Levels (μg/g, wet weight) in Fish from the Twin Valley Sites

Year/Location	Species	Mean	Min	Max
Reservoir				
Northern pike	2004	0.44	0.24	0.78
	2005	**0.68**	0.12	1.26
	2006	**0.56**	0.14	1.69
White sucker	2004	0.22	0.10	0.30
	2005	0.22	0.08	0.58
	2006	0.25	0.07	0.54
Little Bow River Downstream				
Northern pike	2004	0.27	0.10	0.49
	2005	**0.59**	0.41	0.70
	2006	0.49	0.17	0.99
White sucker	2004	0.26	0.08	0.60
	2005	0.43	0.15	0.84
	2006	0.28	0.11	0.44
Yellow perch	2004	0.23	0.11	0.34
Little Bow River Upstream				
Northern pike	2005	0.29	0.08	1.01
	2006	0.23	0.10	0.41
White sucker	2004	0.10	0.02	0.32
	2005	0.11	0.02	0.23
	2006	0.15	0.05	0.36

THg concentrations exceeding the 0.5 μg/g commercial fish limit are showed in **bold**.

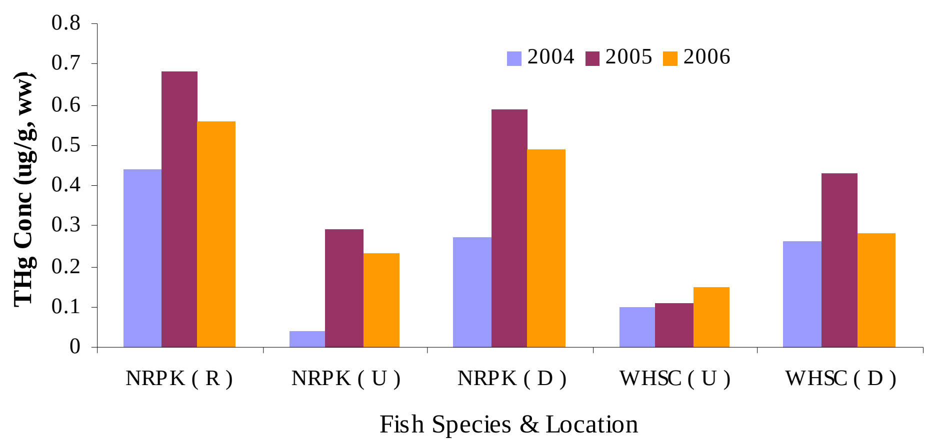

Figure 3 Total Mercury Levels in Fish from the Twin Valley Sites

(NRPK=northern pike, WHSC=white sucker, R=reservoir, U=upstream, D=downstream)

Table 6 Mean THg Concentrations in Fish Muscles Reported in the Literature

Species	Mean (μg/g, ww)	Location	Reference
Walleye	0.05 – 0.99	18 Lakes, Northern Glaciated Plains, US	Selch et al. 2007
	0.19 – 0.30	Reservoirs, Manitoba, Canada	Bodaly et al. 2007
	0.42 – 2.98	Wabigoon River system*, Ontario, Canada	Kinghorn et al. 2007
	0.98 – 1.00	19 undisturbed lakes, Haute Mauricie, Quebec, Canada	Garcia and Carignan, 2005
	1.29 – 3.73	18 disturbed lakes, Haute Mauricie, Quebec, Canada	Garcia and Carignan, 2005
	0.759	lakes, rivers and reservoirs in northeastern of US and Canada (N=19,178)	Kamman et al. 2005
	0.58	Great Lakes, US	Gerstenberger and Dellinger, 2002
	0.47	Lakes in Northern Canada	Lockhart et al. 2005
	0.05 – 1.34	Canadian Arctic, Canada	Braune et al. 1999
	0.32 – 1.26	29 Lakes in the La Grande complex watershed, Quebec, Canada	Verdon et al. 1991
	0.19 – 1.43	Mackenzie River Basin Lakes	Evans et al. 2005 a
Northern Pike	0.26 – 0.32	Reservoirs, Manitoba, Canada	Bodaly et al. 2007
	0.44 – 2.14	Wabigoon River system*, Ontario, Canada	Kinghorn et al. 2007
	1.00 – 2.55	19 undisturbed lakes, Haute Mauricie, Quebec, Canada	Garcia and Carignan, 2005
	1.90 – 6.44	18 disturbed lakes, Haute Mauricie, Quebec, Canada	Garcia and Carignan, 2005
	0.645	lakes, rivers and reservoirs in northeastern of US and Canada (N=19,178)	Kamman et al. 2005
	0.16 – 1.1	Mackenzie River Basin, Canada	Evans, et al. 2005a
	0.12 – 0.74	Mackenzie River Basin, Canada	Evans, et al. 2005b
	0.378	Lakes in Northern Canada	Lockhart et al. 2005
	0.623 – 1.51	Yukon River, Kuskokwim River, US	Jewett et al. 2003
	0.11 – 0.63	Canadian Arctic, Canada	Braune et al. 1999
	0.25 – 0. 90	29 Lakes in the La Grande complex watershed, Quebec, Canada	Verdon et al. 1991
Burbot	2.56	9 disturbed lakes, Haute Mauricie, Quebec, Canada	Garcia and Carignan, 2005
	0.13	The Great Slave Lake, Canada	Evans et al. 2005 a
	0.21	Lakes in Northern Canada	Lockhart et al. 2005
	0.003 - 0.05	Canadian Arctic, Canada	Braune et al. 1999
White Sucker	0.55 – 1.23	19 lakes, Haute Mauricie, Quebec, Canada	Garcia and Carignan, 2005
	0.186	lakes, rivers and reservoirs in	Kamman et al. 2005

		northeastern of US and Canada (N=19,178)	
	0.099	Lakes in Northern Canada	Lockhart et al. 2005
Longnose Sucker	0.187	lakes, rivers and reservoirs in northeastern of US and Canada (N=19,178)	Kamman et al. 2005
	0.108	Lakes in Northern Canada	Lockhart et al. 2005
	0.06 – 0.32	29 Lakes in the La Grande complex watershed, Quebec, Canada	Verdon et al. 1991

* The highest reported levels reflect current recovery levels in the highly contaminated Clay Lake system that received over 10 tonnes of mercury discharge from a chlor-alkalai plant from 1962 to 1970.

Mean THg concentrations in fish in the Pine Coulee and Twin Valley sites ranged from 0.08 to 0.79 μg/g (Table 4 and 5).The average THg concentrations in Canadian market fish reported by Health Canada ranged from 0.02 to 1.82 μg/g (Health Canada 2007). Compared to Canadian market fish for different fish species, mean THg concentrations in local fish in two reservoirs in Southern Alberta were within the ranges of Canadian market fish.

Mean THg levels for walleye, northern pike, burbot, white sucker and longnose sucker from other water bodies in Canada and the U.S. reported in the literature are summarized in Table 6. Mean THg concentrations for the same fish species in the water bodies in the Pine Coulee and Twin Valley areas were well within the ranges for the same fish species reported in the literature for other North American freshwater fish.

Mean THg concentration in fish fillets varied in other lakes, rivers and reservoirs in Canada and the U.S. The highest mean mercury levels in walleye and northern pike in the water bodies in eastern and northern Canada ranged from 1.00 to 2.98 μg/g. High levels tended to be found in larger, older fish. Fish absorb MeHg directly through their gills or through the consumption of prey which contain mercury. MeHg is tightly bound to proteins in all fish tissue resulting in larger, older fish containing higher mercury (Munn and Short 1997, Neumann and Ward 1999). In this survey, the fish caught were generally in the larger size group (Table 2 and 3) except for northern pike caught from the upstream of Twin Valley Reservoir in 2004. The THg level in the small size class of northern pike was lower (0.04 μg/g, Table 5) compared to those in the larger size class of northern pike (0.13 – 0.68 μg/g).

Trophic level is a major factor in mercury accumulation in predatory (fish-eating) fish through biomagnifications (Cabana et al. 1994). Bottom-feeding species may accumulate high mercury concentrations from direct contact with contaminated sediment or by eating benthic invertebrates and epibenthic organisms. Predatory fish species may accumulate and biomagnify mercury concentrations via several trophic levels of the food chains (Suedel et al. 1994). Predators are commonly used as good indicators of mercury contamination. In the Pine Coulee and Twin

Valley project areas, the higher mercury levels were observed in walleye and northern pike than in other fish species. Northern pike and walleye are highly piscivorous predatory fish.

3.2 Local Fish Consumption Rates

Three surveys of fish consumption patterns were conducted in communities of Central Alberta between 1997 and 2000. The first survey was conducted by Alberta Health and Wellness in Swan Hills communities in 1997 (AHW 1997). The second survey was conducted by the First Nations and Inuit Health Branch (FNIHB) of Health Canada for the First Nations people living in the Lesser Slave Lake area in 1999 (Health Canada 1999). The third survey was conducted by the Environmental Health Sciences Program at the University of Alberta for the residents living in the communities near the Athabasaca River and tributaries at Hinton (EHSUA 2000).

Fish consumption rates in different intake groups from these surveys are summarized in Table 7. A small proportion of local fishers and the First Nation people consumed local fish over 100 grams per day. Five per cent of the First Nations pepole in the Lesser Slave Lake communities were high consumers who ate local fish at an average of 273 g/d, much higher than the 2% of those in Swan Hills communities who were high consumers at an average of 167 g/d and those in the communities nearby Hinton who were high consumers at an average rate of 121 g/d. The local fish consumption rates in the survey of the Lesser Slave Lake were similar with the results of the Swan Hills survey in medium, low and very low intake groups. The majority of local fish consumers (85%-92%) consumed fish at a low rate of 1.0 - 15 g/d. The majority of the First Nations group (81%) consumed fish at a low rate of 1.6 – 13 g/d.

Table 7 Local Fish Consumption Rates in Communities of Central Alberta

Intake Group	**Subsistence Consumer** Lesser Slave Lake*****		**Local Fish Consumer** Swan Hills		**Local Fish Consumer** Athabasaca River	
	mean (g/d)	%** (n=125)	mean (g/d)	% (n=127)	mean (g/d)	% (n=45)
High (>100g/d)	273	5	167	2	121	2
Medium (30-99 g/d)	46	14	47	13	51	6
Low (5-29 g/d)	13	38	13	28	15	26
Very Low (< 4g/d)	1.6	43	2	57	1.0	66

* mean from Phase I and Phase II studies (Health Canada 1999). ** % of surveyed population

The most common fish species consumed by the surveyed populations were rainbow trout, northern pike, walleye, lake whitefish, and lake trout by the First nations people in the Lesser Slave Lake communities, walleye, northern pike, perch, brook trout, lake whitefish and arctic grayling by the residents in Swan Hills communities, and rainbow trout, arctic grayling, mountain whitefish, northern pike and walleye by the residents in the communities nearby Hinton.

These three surveys were conducted with communities in Central Alberta. No equivalent fish consumption surveys are available for Southern Alberta. For the purpose of risk assessment, fish consumption rates used for calculating exposure ratios for sport fishers were 170 g/d for high intake group, 50 g/d for medium intake, 10 g/d for low intake group, and 2 g/d for very low intake group. For the First Nations people, the rate of 270 g/d for the high intake group was used. Because the fish consumption behaviors may differ from one First Nations community to another, this rate may not be generalizable to other First Nations communities, but these are the only Alberta data available at present.

The results from the above surveys were derived from adults only. Fish consumption rates could vary in different subpopulations (USEPA 2000). Children may consume larger quantities compared to their body weight than adults. Prenatal exposure may occur through pregnant women. For the purpose of risk management, these subpopulations are considered as potential high risk groups for exposure to mercury from fish consumption.

3.3 Estimated Exposures

Exposure ratios were estimated for consuming walleye, northern pike and burbot. Estimated exposure ratios based on the pTDIs from Health Canada are summarized in Table 8 for women of reproductive age and in Table 9 for other adults. Specific fish consumption rates were not available for women at reproductive age and young children. As a result, the estimation of exposures for young children was not performed. The fish consumption rate for all adults was used for estimating exposures for women at reproductive age. The fish consumption rate of subsistence consumers from the Lesser Slave Lake communities was used for subsistence consumers in the Southern Alberta communities. Longnose sucker and white sucker and other species with one time measurement showed in Table 2 and 3 are not included for estimating exposures because fish consumers rarely ate these fish.

In general, the estimated exposure ratios were greater than one for the high intake group, especially for a subpopulation of women of reproductive age if consuming predatory fish like the larger walleye, northern pike and burbot.

The values of pTDIs were derived from risk assessment approaches with many assumptions and uncertainties. The risk assessment is specifically designed to avoid underestimating risk. The results do not mean that specific individuals or populations face inevitable or even likely health consequences from mercury exposure. An estimated exposure ratio greater than one should be used as a reference point for making risk management decisions. In particular, those exposure scenarios with an exposure ratio greater than one warrant closer attention including the provision of information about maximum recommended fish consumption to allow individual consumers the opportunity to make risk-informed choices.

Many factors influence the estimated exposure levels such as body weight and consumption rates. The body weight of 73 kg used in this assessment was derived from the 1994 National Population Health survey in Alberta adults. In this report, the age-specific body weights for women at reproductive age and young children in Alberta were not available. The average body weights used by Health Canada were 65 kg for women at reproductive age, 26.4 kg for 5-11 years old group, and 14.4 kg for 1-4 years old group. The consumption rates used in this report were based on three surveys in adults living in Northern Alberta. The consumption rates in local fish consumers in Southern Alberta may vary from the results from those in Northern Alberta although there is no reason to expect consumption to be higher. The estimated exposure was solely based on fish from local specific sources. People may also be exposed to mercury from market fish and other market food items.

Table 8 Estimated Exposure Ratios for Women at Reproductive Age

		Local Consumer High Intake (170 g/d)	Local Consumer Medium Intake (50 g/d)	Subsistence Consumer High Intake (270 g/d)
Pine Coulee				
Reservoir				
Walleye				
	2003	6.7	1.9	11
	2004	8.6	2.4	14
	2005	10	2.9	16
	2007	7.3	2.1	12
Northern pike				
	2007	1.5	<1	2.4
Willow Creek Downstream				
Northern pike				
	2003	6.3	1.8	10
	2004	4.0	1.1	6.4
	2007	3.5	<1	5.6
Burbot				
	2003	5.1	1.5	8.3
	2004	3.0	<1	4.8
	2007	3.7	<1	6.0
Willow Creek Upstream				
Burbot				
	2003	3.1	<1	5.0
	2004	3.7	<1	6.0
	2007	2.6	<1	4.2
Twin Valley				
Reservoir				
Northern pike				
	2004	5.7	1.6	9.1
	2005	8.7	2.5	14
	2006	7.2	2.0	12
Little Bow River Downstream				
Northern pike				
	2004	3.5	<1	5.6
	2005	7.6	2.1	12
	2006	6.3	1.8	10
Little Bow River Upstream				
Northern pike				
	2005	3.7	<1	6.0
	2006	3.0	<1	4.8

Note: mean of total mercury listed in Table 4 &5; body weight = 65 kg; pTDI = 0.2 μg/kg bw/d

Table 9 Estimated Ratios for Adults

		Local Consumer High Intake (170 g/d)	**Local Consumer** Medium Intake (50 g/d)	**Subsistence Consumer** High Intake (270 g/d)
Pine Coulee				
Reservoir				
Walleye				
	2003	2.5	<1	4.1
	2004	3.3	<1	5.3
	2005	3.9	<1	6.2
	2007	2.8	<1	4.5
Northern pike				
	2007	<1	<1	1.0
Willow Creek Downstream				
Northern pike				
	2003	2.4	<1	3.9
	2004	1.5	<1	2.4
	2007	1.3	<1	2.1
Burbot				
	2003	2.0	<1	3.2
	2004	1.1	<1	1.8
	2007	1.4	<1	2.3
Willow Creek Upstream				
Burbot				
	2003	1.2	<1	1.9
	2004	1.4	<1	2.3
	2007	<1	<1	1.6
Twin Valley				
Reservoir				
Northern pike				
	2004	2.1	<1	3.5
	2005	3.3	<1	5.4
	2006	2.7	<1	4.4
Little Bow River Downstream				
Northern pike				
	2004	1.3	<1	2.1
	2005	2.9	<1	4.6
	2006	2.4	<1	3.9
Little Bow River Upstream				
Northern pike				
	2005	1.1	<1	2.3
	2006	1.1	<1	1.8

Note: mean of total mercury listed in Table 4 &5; body weight = 73 kg; pTDI = 0.47 μg/kg bw/d

3.4 Consumption Limits

For the purpose of quantitative fish advisories, the lifetime consumption limits were calculated for subgroups of women, young children and adults (Table 10). These consumption limits were specific to fish species and site. The values provide the information on the maximum amount of local fish that can be safely consumed on a weekly basis for a lifetime by subpopulations. Fish preparation and cooking methods do not reduce the concentrations of total mercury in fish (Morgan et al. 1997).

Table 10 Lifetime Fish Consumption Limits

Species	**THg***	**Women**		**Children (5-11 yr)**		**Children (1-4 yr)**		**Adults**	
	μg/g	g/w	oz/w	g/w	oz/w	g/w	oz/w	g/w	oz/w
Pine Coulee *Reservoir*									
Walleye	0.64	140	5	60	2	30	1	400	14
Northern pike	0.13	700	25	300	10	150	5	Not limit	
Willow Creek Downstream									
Burbot	0.31	300	10	120	4	60	2	800	28
Northern pike	0.36	250	9	100	4	50	2	700	24
Willow Creek Upstream									
Burbot	0.24	400	14	160	6	80	3	900	32
Twin Valley *Reservoir*									
Northern pike	0.56	160	6	65	2	35	1	400	14
Little Bow River Downstream									
Northern pike	0.43	200	7	90	3	45	2	560	20
Little Bow River Upstream									
Northern pike	0.26	350	12	140	5	70	2.5	900	32

Note: mean of total mercury is an average level from all years, body weight = 73 kg for adults, 65 kg for women, 26.4 for children 5 – 11 yr, and 14.4 kg for children 1 – 4 yr; pTDI = 0.2 μg/kg bw/d for women at reproductive age and young children, and 0.47 μg/kg bw/d for adults.

Walleye from Pine Coulee Reservoir should be limited for consumption at the lower amounts of 140 grams per week for women of reproductive age, 60 grams per week for children at age of 5 – 11 years old, and 30 grams per week for children at age of 1 – 4 years old. Burbot from Willow Creek should be limited for consumption at the amounts of 300 grams per week for women of reproductive age, 120 grams per week for children at age of 5 – 11 years old, and 65 grams per week for children at age of 1 – 4 years old. Northern pike from Willow Creek should be limited for consumption at the amounts of 250 grams per week for women of reproductive age, 100 grams per week for children at age of 5 – 11 years old, and 60 grams per week for children at age of 1 – 4 years old. Northern pike from Pine Coulee reservoir should be limited for consumption at the amounts of 700 grams per week for women of reproductive age, 280 grams per week for children at age of 5 – 11 years old, and 150 grams per week for children at age of 1 – 4 years old.

Northern pike from Twin Valley Reservoir should be limited for consumption at the amounts of 160 grams per week for women of reproductive age, 65 grams per week for children at age of 5 – 11 years old, and 35 grams per week for children at age of 1 – 4 years old. Northern pike from the downstream section of the Little Bow River should be limited for consumption at the amounts of 215 grams per week for women of reproductive age, 90 grams per week for children at age of 5 – 11 years old, and 50 grams per week for children at age of 1 – 4 years old. Northern pike from the upstream section of the Little Bow River should be limited for consumption at the amounts of 500 grams per week for women of reproductive age, 200 grams per week for children at age of 5 – 11 years old, and 110 grams per week for children at age of 1 – 4 years old.

3.5 Fish Consumption Advisories

Fish consumers may be exposed to MeHg by consuming locally-caught fish. MeHg is rapidly absorbed after ingestion and distributed throughout the body (WHO 1990). MeHg in the body is relatively stable and can cross the placental and blood/brain barriers (Kerper et al. 1992). The half-life of MeHg in the human body varies from 44 to 80 days (USEPA 2000). MeHg leaves the human body via urine, feces and breast milk. Small amounts of ingested MeHg are eliminated from the body with no overall adverse effects. At the high exposure levels, MeHg produces a variety of health effects. Larger amounts of MeHg may damage the nervous system. Neurotoxicity may occur in the developing embryo or fetus during pregnancy, young children and adults. As a result, it is prudent to reduce MeHg exposure for women of reproductive age and younger children. The TDIs proposed by Health Canada are intended to protect susceptible populations.

Because mercury occurs naturally, mercury is found in all commercial or non-commercial fish and other foods at low levels. People are exposed to very low levels of mercury via sources such as breathing the air, mercury amalgam dental fillings and eating other foods. Alberta Health and Wellness conducted a survey of mercury levels in blood, urine and hair in adults and children living in the Wabamun Lake and surrounding area communities in 2006 (AHW 2006). The survey found that the average levels of total mercury in blood, urine and hair in Alberta participants were lower than people living in other areas and countries.

MeHg levels are high enough in some fish species in some rivers and lakes that limitation of fish consumption is warranted. Although fish consumers may be exposed to relatively higher levels of MeHg if they eat large amounts of local mercury-containing fish, the results from three surveys from Northern Alberta indicated that local fish consumption is not the primary source of dietary mercury intake for most surveyed populations.

In order to protect all human consumers, issuing a fish consumption advisory is one risk management option. Fish consumption advisories are designed to reduce potential health risks of consumption for local fish consumers. Advisories should provide the necessary information to the public, so that local fish consumers can voluntarily restrict their fish consumption to a level judged to be safe. Fish consumption advisories elicit voluntary actions unlike mandatory measures such as catch and release regulations or outright fishing bans which restrict consumer actions.

Since the early 1990s, some fish consumption advisories related to mercury have been issued and published in the *Alberta Guide to Sportfishing Regulation* annually. In Alberta, the provincial government is responsible for issuing and reviewing fish consumption advisories for non-commercial fish. The Ministries of Alberta Environment (then including the current Department of Sustainable Resource and Developments) and Alberta Health and Wellness established the process to issue food consumption advisories in 1997. The advisories can take the form of non-consumption or restricted-consumption advisories for adults and sensitive subpopulations.

3.6 Benefits of Fish Consumption

The benefits and risk of fish consumption is a recent focus of public health interest. Fish is an important source of nutrition for people, because it contains beneficial nutrients like the long-chain omega-3 fatty acids like eicosapentaenoic acid (EPA) and docosahexaenoic acid (DHA), vitamin D, selenium and iodine. Fish is considered an excellent source of high quality protein. The benefits of fish consumption include the prevention of cardiovascular diseases, myocardial infarction (heart attack) and arrhythmia, especially reduction of risk for ischemic heart disease and stroke (Zhang et al. 1999; Chan and Egeland 2004; Bouzanc et al. 2005; Cohen et al. 2005; Koning et al. 2005; Kris-Etherton et al. 2005; Stern 2005). Health Canada reviewed the evidence showing an association between reduced risk of sudden cardiac death and fish consumption frequency at least once per week (Health Canada 2007). In one case-control study, researchers found that the reduced risk of myocardial infarction with fish consumption of at least one meal per week was not diminished by mercury (Hallgren et al. 2001). In contrast, one population-based cohort study found that the higher mercury levels in human hair samples attenuated the benefits of the omega-3 fatty acids (Virtanen et al. 2005).

Fish consumption is important for neurodevelopment in infant and young children. DHA is an integral structural component of the brain and essential nutrient for pregnant women. DHA can be easily and rapidly absorbed into the developing fetal brain during gestation and in the early years of life of young children (Dovydaitis 2008). DHA was found to improve the visual-motor development in healthy term infants (Uauy et al. 2003; Oken et al. 2008). Some studies showed that fish consumption can increase a child's intelligence quotient (Helland et al. 2003; Cohen et al. 2005a; Dunstan et al. 2008). Meanwhile, the Cohen et al. (2005b) analysis indicated that sufficient prenatal exposure to MeHg could decrease a child's intelligence quotient. A cohort studies found that maternal fish consumption was associated with subtle neurodevelopment deficits in children (Debes et al. 2006). In another study, researchers found that the benefits of the modest fish consumption (1-2 servings per week) for women of reproductive age outweighed the potential risks from exposure to MeHg in fish (Mozaffarian and Rimm, 2006). Although scientific evidence in the literatures does not adequately demonstrate causation, evidence suggests that there are benefits from fish consumption, but consuming large quantities of fish containing high Hg should be avoided. (Cohen et al. 2005c; Mozaffarian and Rimm 2006; Domingo 2007; Mahaffey et al. 2008; Oken and Bellinger 2008).

From a nutritional perspective, regular fish consumption is beneficial to the general population. From a toxicological perspective, fish is associated with environmental contaminants like methylmercury, which pose a potential threat to humans. Fish consumers are often confused by the conflicting message. People appeared to be influenced more strongly by the danger message (toxicological risk of mercury) as compared to beneficial (nutritional) message (Verbeke et al. 2008). Following the issue of some national fish consumption advisories in the U.S. in 2001, some pregnant women reduced their fish consumption (Oken et al. 2003). Communication to the public about the competition between benefits and risks is important to include in a fish consumption advisory. Fish consumption advisories should enable people to make informed decisions about what is a safe amount of fish consumption in order to address risks posed by environmental hazards, and to optimize the nutritional benefits of fish consumption with regard to preventable disease while improving neurodevelopment in infants and young children.

The establishment of guidelines for fish consumption is an important part of public health practices. The American Heart Association recommended fish consumption of at least two servings per week (125 g uncooked fish per serving) (Levenson and Axelrad 2006). For commercial fish, Health Canada's current advice is provided in Canada's Food Guide. For large predatory fish, adults can eat up to 150 g per **week**. Women who are or may become pregnant and breastfeeding mothers can eat up to 150 g per **month**. Young children between 5 and 11 years of age can eat up to 125 g per **month**. Very young children between 1 and 4 years of age should eat no more than 75 g per month of large predatory fish species.

Fish consumers can ingest both omega-3 fatty acids and MeHg. MeHg may attenuate the beneficial effects from the omega-3 fatty acids so the balance between the risks and benefits of consuming mercury-containing fish needs to be considered before issuing local fish consumption advisories (Mergler et al. 2007). For local fish, the fish-species-specific, site-specific consumption limits were calculated in this report. Unless local residents in Southern Alberta consume commercial fish every day, recommended consumption amounts for different groups are presented in Table 11. If local residents do consume commercial fish frequently, they should reduce any additional exposure to local fish accordingly.

Table 11 Recommended Fish Consumption Limits

Water Body	Species	Fish Size (lb) Over	Consumption Limit (serving/week)			
			Women	Child 1 – 4 yr	Child 5 – 11 yr	Adult +
Pine Coulee Reservoir	Walleye	1	avoid	avoid	avoid	5
	Northern Pike	1	8	2	4	no limit
Twin Valley Reservoir	Northern Pike	2	avoid	avoid	avoid	5
Willow Creek	Northern Pike	2	4	1	2	no limit
	Burbot	1	4	1	2	no limit
Little Bow River *(downstream)*	Northern Pike	2	2	0.5	1	8
Little Bow River *(upstream)*	Northern Pike	2	4	1	2	no limit

*1 lb = 454 grams. **1 serving = 75 grams, ½ cup, 2.5 ounces, or a piece of cooked fish that fits into the palm of your hand. *** “Women” refers to women of child-bearing age (15-49 yr) and pregnant women.
Adult$^+$ includes adults and child over 12 yr.

4. Conclusions

Concentrations of total mercury in fish varied among fish species and water bodies in two reservoirs in Southern Alberta, but were within the ranges reported in the literature for the same fish species from other rivers and lakes elsewhere in Canada and the U.S. The higher mercury levels were observed in large piscivorous (predatory) fish such as walleye, burbot and northern pike. This was expected based on North American monitoring results elsewhere and our current understanding of how mercury contamination occurs in fish.

The estimated mercury exposures warranted limitation of consumption for the higher fish intake group (over 100 grams per day), especially if they consumed some species like walleye, burbot and northern pike. Restriction of consumption of some fish species was indicated for specific groups such as women of reproductive age, pregnant women and young children (Table 11). If the mercury levels in fish are over 0.5 μg/g, people in specific groups should avoid eating these fish and adults should limit fish consumption. If the mercury levels in fish are between 0.1 - 0.5 μg/g, people in specific groups should limit fish consumption.

Fish consumption advisories promote voluntary reductions in consumption to minimize potential health risk to local fish consumers. The balance between risk and benefits of consumption of mercury-containing fish needs to be considered.

The Science Advisory Committee reviewed the human health risk assessment document. The recommendations are made as below:

1. Consumption limits should be set for Alberta fish consumers to make informed decisions as outlined in this report;
2. The healthy benefits of fish consumption should be balanced with any mercury-related health risk; and
3. Mercury levels in fish in water bodies of the reservoir area should continue to be monitored.

Provincial Chief Medical Officer issued the fish consumption advisories (Appendix). The information of new advisories is published in the *Alberta Guide to Sportfishing Regulation* and posted in Alberta government websites.

5. References

1. AEC (Alberta Environmental Centre). Methods Mannual for Chemical Analysis of Water and Wastes. AECV96-M1. Vegreville, Alberta, Canada:Alberta Environmental Centre, (1996).

2. AHW (Alberta Health and Wellness). Mercury in fish from six rivers in Southern Alberta. AEC84-R2. Vegreville, Alberta: Alberta Environmental Centre, (1984).

3. AHW (Alberta Health and Wellness). Swan Hills Special Waste Treatment Centre - Human Health Impact Assessment. Edmonton, Alberta, Canada (1997).

4. AHW (Alberta Health and Wellness). Wabamun and Area Community Exposure and Health Effects Assessment Program. Edmonton, Alberta, Canada: Alberta Health and Wellness, (2006).

5. Bodaly RA, St Louis VL, Paterson MJ, Fudge RJ, Hall BD, Rosenberg DM, Rudd JW. Bioaccumulation of mercury in the aquatic food chain in newly flooded areas. Met Ions Biol Syst 34:259-287 (1997).

6. Bodaly RA, Jansen WA, Majewski AR, Fudge RJ, Strange NE, Derksen AJ, Green DJ. Postimpoundment time course of increased mercury concentrations in fish in hydroelectric reservoirs of northern Manitoba, Canada. Arch Environ Contam Toxicol 53:379-389 (2007).

7. Bouzan C, Cohen JT, Connor WE, Kris-Etherton PM, Gray GM, Konig A, Lawrence RS, Savitz DA, Teutsch SM. A quantitative analysis of fish consumption and stroke risk. Am J Prev Med 29:347-352 (2005).

8. Braune B, Muir D, DeMarch B, Gamberg M, Poole K, Currie R, Dodd M, Duschenko W, Eamer J, Elkin B, Evans M, Grundy S, Hebert C, Johnstone R, Kidd K, Koenig B, Lockhart L, Marshall H, Reimer K, Sanderson J, Shutt L. Spatial and temporal trends of contaminants in Canadian Arctic freshwater and terrestrial ecosystems: a review. Sci Total Environ 230:145-207 (1999).

9. Bryski M. Water Management Project in Southern Alberta. Personal communication (2008).

10. Cabana G, Tremblay A, Rasmussen JB. Pelagic food chain structure in Ontario Lakes: a determinant of mercury levels in Lake Trout. Canadian Journal of Fisheries and Aquatic Sciences 51:381-389 (1994).

11. Canadian Food Inspection Agency (CFIA). Draft Sablefish Mercury Report - Investigation of mercury in B.C. Sablefish sampled between October 2002 and November 2003. Unpublished document. (2003).

12. Chan HM, Egeland GM. Fish consumption, mercury exposure, and heart diseases. Nutr Rev 62:68-72 (2004).

13. Cohen JT, Bellinger DC, Connor WE, Shaywitz BA. A quantitative analysis of prenatal intake of n-3 polyunsaturated fatty acids and cognitive development. Am J Prev Med 29:366-374 (2005a).

14. Cohen JT, Bellinger DC, Connor WE, Kris-Etherton PM, Lawrence RS, Savitz DA, Shaywitz BA, Teutsch SM, Gray GM. A quantitative risk-benefit analysis of changes in population fish consumption. Am J Prev Med 29:325-334 (2005b).

15. Cohen JT, Bellinger DC, Shaywitz BA. A quantitative analysis of prenatal methyl mercury exposure and cognitive development. Am J Prev Med 29:353-365 (2005c).

16. Debes F, Budtz-Jorgensen E, Weihe P, White RF, Grandjean P. Impact of prenatal methylmercury exposure on neurobehavioral function at age 14 years. Neurotoxicol Teratol 28:536-547 (2006).

17. Domingo JL. Omega-3 fatty acids and the benefits of fish consumption: is all that glitters gold? Environ Int 33:993-998 (2007).

18. Dovydaitis T. Fish consumption during pregnancy: an overview of the risks and benefits. J Midwifery Women Health 53:325-330 (2008).

19. Dunstan JA, Simmer K, Dixon G, Prescott SL. Cognitive assessment of children at age 2(1/2) years after maternal fish oil supplementation in pregnancy: a randomised controlled trial. Arch Dis Child Fetal Neonatal Ed 93:F45-F50 (2008).

20. EHSUA (Environmental Health Sciences Program UoA. Development of A Fish Consumption Advisory Risk Communication/Public Participation Protocol for Alberta: A Case Study in Athabasaca River and Tributaries.unpublished, internal report, (2000).

21. Evans MS, Muir D, Lockhart WL, Stern G, Ryan M, Roach P. Persistent organic pollutants and metals in the freshwater biota of the Canadian Subarctic and Arctic: an overview. Sci Total Environ 351-352:94-147 (2005).

22. Evans MS, Lockhart WL, Doetzel L, Low G, Muir D, Kidd K, Stephens G, Delaronde J. Elevated mercury concentrations in fish in lakes in the Mackenzie River Basin: the role of physical, chemical, and biological factors. Sci Total Environ 351-352:479-500 (2005).

23. Feeley MM, Lo M-T. Risk Assessment for Mercury in Health Canada - Development of the Provisional Tolerable Daily Intake (pTDI) Value. In: Proceedings of the Conference on Mercury in Eastern Canada and the Northeast States, 21-23 September, 1998 (Pilgrim W, Burgess N, Giguère M-F, eds).www.eman-rese.ca/eman/reports/publications/98_mercury2/oralpresentations_day2.html#head2_1, (1998).

24. Feeley MM. Health Canada Mercury Guidelines. Personal communication (2008).

25. Garcia E, Carignan R. Mercury concentrations in fish from forest harvesting and fire-impacted Canadian Boreal lakes compared using stable isotopes of nitrogen. Environ Toxicol Chem 24:685-693 (2005).

26. Gerstenberger SL, Dellinger JA. PCBs, mercury, and organochlorine concentrations in lake trout, walleye, and whitefish from selected tribal fisheries in the Upper Great Lakes region. Environ Toxicol 17:513-519 (2002).

27. Hallgren CG, Hallmans G, Jansson JH, Marklund SL, Huhtasaari F, Schutz A, Stromberg U, Vessby B, Skerfving S. Markers of high fish intake are associated with decreased risk of a first myocardial infarction. Br J Nutr 86:397-404 (2001).

28. Health Canada. Human Health Risk Assessment of Mercury in Fish and Health Benefits of Fish Consumption. Ottawa, Canada:Health Canada, (2007).

29. Health Canada. Lesser Slave Lake Health Study. Unpublished, Medical Service Branch, Health Canada, (1999).

30. Helland IB, Smith L, Saarem K, Saugstad OD, Drevon CA. Maternal supplementation with very-long-chain n-3 fatty acids during pregnancy and lactation augments children's IQ at 4 years of age. Pediatrics 111:e39-e44 (2003).

31. Jewett SC, Zhang X, Naidu AS, Kelley JJ, Dasher D, Duffy LK. Comparison of mercury and methylmercury in northern pike and Arctic grayling from western Alaska rivers. Chemosphere 50:383-392 (2003).

32. Kamman NC, Burgess NM, Driscoll CT, Simonin HA, Goodale W, Linehan J, Estabrook R, Hutcheson M, Major A, Scheuhammer AM, Scruton DA. Mercury in freshwater fish of northeast North America--a geographic perspective based on fish tissue monitoring databases. Ecotoxicology 14:163-180 (2005).

33. Kerper LE, Ballatori N, Clarkson TW. Methylmercury transport across the blood-brain barrier by an amino acid carrier. Am J Physiol 262:R761-R765 (1992).

34. Kinghorn A, Solomon P, Chan HM. Temporal and spatial trends of mercury in fish collected in the English-Wabigoon river system in Ontario, Canada. Sci Total Environ 372:615-623 (2007).

35. Konig A, Bouzan C, Cohen JT, Connor WE, Kris-Etherton PM, Gray GM, Lawrence RS, Savitz DA, Teutsch SM. A quantitative analysis of fish consumption and coronary heart disease mortality. Am J Prev Med 29:335-346 (2005).

36. Kris-Etherton PM, Harris WS, Appel LJ. Fish consumption, fish oil, omega-3 fatty acids, and cardiovascular disease. Arterioscler Thromb Vasc Biol 23:e20-e30 (2003).

37. Levenson CW, Axelrad DM. Too much of a good thing? Update on fish consumption and mercury exposure. Nutr Rev 64:139-145 (2006).

38. Lockhart WL, Stern GA, Low G, Hendzel M, Boila G, Roach P, Evans MS, Billeck BN, Delaronde J, Friesen S, Kidd K, Atkins S, Muir DC, Stoddart M, Stephens G, Stephenson S, Harbicht S, Snowshoe N, Grey B, Thompson S, DeGraff N. A history of total mercury in edible muscle of fish from lakes in northern Canada. Sci Total Environ 351-352:427-463 (2005).

39. Mahaffey KR, Clickner RP, Jeffries RA. Methylmercury and omega-3 fatty acids: co-occurrence of dietary sources with emphasis on fish and shellfish. Environ Res 107:20-29 (2008).

40. Mergler D, Anderson HA, Chan LH, Mahaffey KR, Murray M, Sakamoto M, Stern AH. Methylmercury exposure and health effects in humans: a worldwide concern. Ambio 36:3-11 (2007).

41. Morgan JN, Berry MR, Graves RL. Effects of commonly used cooking practices on total mercury concentration in fish and their impact on exposure assessments. J Expo Anal Environ Epidemiol 7:119-133 (1997).

42. Mozaffarian D, Rimm EB. Fish intake, contaminants, and human health: evaluating the risks and the benefits. JAMA 296:1885-1899 (2006).

43. Munn MB, Short TM. Spatial heterogeneity of mercury bioaccumulation by walleye in Franklin D. Roosevelt Lake and the Upper Columbia River, Washington. Trans Am Fish Soc 126:477-487 (1997).

44. Neumann RM, Ward SM. Bioaccumulation and biomagnification of mercury in two warmwater fish communities. J Freshwater Ecol 14:487-494 (1999).

45. Oken E, Kleinman KP, Berland WE, Simon SR, Rich-Edwards JW, Gillman MW. Decline in fish consumption among pregnant women after a national mercury advisory. Obstet Gynecol 102:346-351 (2003).

46. Oken E, Radesky JS, Wright RO, Bellinger DC, Amarasiriwardena CJ, Kleinman KP, Hu H, Gillman MW. Maternal fish intake during pregnancy, blood mercury levels, and child cognition at age 3 years in a US cohort. Am J Epidemiol 167:1171-1181 (2008).

47. Oken E, Bellinger DC. Fish consumption, methylmercury and child neurodevelopment. Curr Opin Pediatr 20:178-183 (2008).

48. Selch TM, Hoagstrom CW, Weimer EJ, Duehr JP, Chipps SR. Influence of fluctuating water levels on mercury concentrations in adult walleye. Bull Environ Contam Toxicol 79:36-40 (2007).

49. Stern AH. A review of the studies of the cardiovascular health effects of methylmercury with consideration of their suitability for risk assessment. Environ Res 98:133-142 (2005).

50. Suedel BC, Boraczek JA, Peddicord RK, Clifford PA, Dillon TM. Trophic transfer and biomagnification potential of contaminants in aquatic ecosystems. Rev Environ Contam Toxicol 136:21-89 (1994).

51. Uauy R, Hoffman DR, Mena P, Llanos A, Birch EE. Term infant studies of DHA and ARA supplementation on neurodevelopment: results of randomized controlled trials. J Pediatr 143:S17-S25 (2003).

52. USEPA (United States Environmental Protection Agency). Guidance for Assessing Chemical Contaminant Data for Use in Fish Advisories II Risk Assessment and Fish Consumption Limits. EPA 823-B-00-008. Washington, DC:Office of Sceince and Technology, Office of Water, USEPA, (2000).

53. Verbeke W, Vanhonacker F, Frewer LJ, Sioen I, De Henauw S, Van Camp J. Communicating Risks and Benefits from Fish Consumption: Impact on Belgian Consumers' Perception and Intention to Eat Fish. Risk Anal (2008).

54. Verdon R, Brouard D, Demers C, Lalumiere R, Laperle M, Schetagen R. Mercury evolution (1978-1988) in fishes of the La Grande Hydroelectric complex, Quebec, Canada. Water, Air, and Soil Pollution 56:405-417 (1991).

55. Virtanen JK, Voutilainen S, Rissanen TH, Mursu J, Tuomainen TP, Korhonen MJ, Valkonen VP, Seppanen K, Laukkanen JA, Salonen JT. Mercury, fish oils, and risk of acute coronary events and cardiovascular disease, coronary heart disease, and all-cause mortality in men in eastern Finland. Arterioscler Thromb Vasc Biol 25:228-233 (2005).

56. Wheatly B. Methylmercury in Canada. Exposure of Indian and Inuit Residents to Methylmercury in the Canadian Environment. Ottawa:Ministry of National Health and Welfare, Medical Services Branch, (1979).

57. WHO (World Health Organization). Methylmercury. Geneva:World Health Organization, (1990).

58. Zhang J, Sasaki S, Amano K, Kesteloot H. Fish consumption and mortality from all causes, ischemic heart disease, and stroke: an ecological study. Prev Med 28:520-529 (1999).