Total Maximum Daily Load
for Mercury

in McPhee & Narraguinnep Reservoirs, Colorado

Phase I

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**COLORADO DEPARTMENT OF PUBLIC HEALTH
AND ENVIRONMENT**

WATER QUALITY CONTROL DIVISION

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Executive Summary

The Colorado Department of Public Health and the Environment (CDPHE) has identified McPhee and Narraguinnep reservoirs as not supporting their classified uses due to the presence of elevated fish tissue concentrations of mercury that have resulted in the posting of fish consumption advisories. When states and local communities identify problems in meeting water quality standards, a Total Maximum Daily Load (TMDL) can be part of a plan to fix the water quality problems. The purpose of this TMDL is to provide an estimate of pollutant loading reductions needed to restore the classified uses of McPhee and Narraguinnep reservoirs. The U.S. Environmental Protection Agency (EPA), Region 8, is supporting CDPHE in the development of this TMDL.

The TMDL for mercury in McPhee and Narraguinnep reservoirs will follow a phased approach. In a phased TMDL, EPA or the state uses the best information available to establish the TMDL at levels necessary to implement applicable water quality standards and to allocate the pollution sources where applicable. However, the phased TMDL approach recognizes that it may be necessary to collect additional data and information to validate the assumptions of the TMDL and to provide greater certainty that the TMDL will achieve the applicable state water quality standards.

This document comprises Phase I of the TMDL. It consists of the following: identification of data and information collected, the data collection process, the modeling of the results, and preliminary loading estimates and allocations. In addition, Phase I includes a summary of the additional data collection and analyses needed to reduce the uncertainty associated with the preliminary loading estimates and allocations so that revised estimates can be made. In Phase II, CDPHE intends to gather the necessary data and perform the analyses identified in Phase I to produce a revised TMDL for mercury in McPhee and Narraguinnep reservoirs.

State ambient water quality criteria for mercury in water have not been exceeded in either reservoir. However, the physical and chemical characteristics of the reservoirs lead to a situation in which mercury bioaccumulates in fish tissue. Mercury concentrations at the levels observed in some species of gamefish in the reservoirs present a potentially significant health risk to persons who consume these fish.

The threshold used by the CDPHE for the posting of a fish consumption advisory is 0.5 µg/g (micrograms per gram or parts per million). Thus, the targets for this TMDL are a fish tissue concentration of 0.5 µg/g or less in 15-inch smallmouth bass (*Micropterus dolomieui*) for McPhee reservoir and 0.5 µg/g or less in an 18-inch walleye (*Sitzostedion vitreum*) for Narraguinnep reservoir. Using the best available data, a model was used to predict the needed reductions in mercury loading to the reservoirs to achieve the TMDL targets. The model predicted that the targets would be achieved in approximately 20 years with a total mercury load reduction of 15%.

Phase I of the TMDL consists of an estimation of the allocation of the available loading capacity of the reservoirs (the maximum rate of loading that would be consistent with achieving classified uses) to point sources, nonpoint sources, and a margin of safety. The preliminary mercury loading capacity estimates are 2,592 g/year for McPhee reservoir and 39 g/year for Narraguinnep reservoir. Within the upland watersheds that contribute flow to the reservoirs there are no permitted point sources of mercury discharge. Suspected sources of mercury to McPhee reservoir include past mining activities, atmospheric deposition from nearby and distant sources, and naturally occurring background in local geologic formations and soils. Based on the initial loading estimates in Phase I, preliminary load allocations were assigned to suspected mercury sources to meet the TMDL targets in the reservoirs.

In this preliminary allocation assessment, a 75% reduction in atmospheric deposition loads to both reservoirs was used. To meet target goals for McPhee reservoir, an additional 50.8% reduction in loading from the mining areas and a 10% reduction in background loading were used. For Narraguinnep reservoir, the preliminary reductions estimated for McPhee are assumed to lead to a 40.5% reduction in inter-basin transfer from McPhee to Narraguinep. An additional 66% reduction in the background loading to Narraguinnep in addition to the reductions in inter-basin transfer and atmospheric loads was used to meet the TMDL target. Alternatively, a smaller reduction in atmospheric loading could be coupled with a larger reduction in watershed loading to meet the fish tissue concentration goals. However, the loading estimates indicate that some degree of reduction in atmospheric loads likely will be needed to meet the state water quality standards in Narraguinnep reservoir.

It is important to note that the phased approach was used for this TMDL because numerous data gaps and uncertainties were identified in Phase I and only rough estimates of actual contributions of mercury to McPhee and Narraguinnep reservoirs from both point and nonpoint sources could be identified. To reduce this uncertainty, Phase I includes an assessment of the data gaps identified in the initial allocation estimates and a plan for additional data collection and analyses. This information will be incorporated into a refined assessment of the allocation estimates in Phase II of this TMDL.

This TMDL does not independently establish effluent limits or other enforceable measures. In addition, it does not expand the scope of the Division's regulatory authority, as such currently exists. TMDL implementation will have to be accomplished within the constraints of such authority, with specific reference to the Division's limited jurisdiction in matters of land use and water allocation. Phase I merely establishes estimates to be used to identify necessary additional monitoring and evaluation. Final allocations will not be developed until the completion of Phase II.

Glossary

Acute toxicity. A stimulus severe enough to rapidly induce a toxic effect. In aquatic toxicity tests, an effect observed within 96 hours or less is considered acute.

Aerobic. Environmental condition characterized by the presence of dissolved oxygen. Used to describe chemical or biological processes that occur in the presence of oxygen.

Algae. Any organisms of a group of chiefly aquatic microscopic nonvascular plants. Most algae have chlorophyll as the primary pigment for carbon fixation.

Anaerobic. Environmental condition characterized by the absence of dissolved oxygen. Used to describe chemical or biological processes that occur in the absence of oxygen.

Anoxic. Aquatic environmental conditions containing zero or minimal dissolved oxygen.

Benthic. Refers to material, especially sediment, at the bottom of an aquatic ecosystem.

Benthic organisms. Organisms living in or on bottom substrates in an aquatic ecosystem.

Bioaccumulation. The process by which a contaminant accumulates in the tissues of an organism.

Chronic toxicity. Toxic impacts that occur over relatively long periods of time, often one-tenth of the life span or more. Chronic effects may include mortality, reduced growth, or reduced reproduction.

Cinnabar. A compound of sulfide and mercury (HgS), also known as red mercuric sulfide, that is the primary naturally occurring ore of mercury.

Designated uses. Those beneficial uses of a waterbody identified in state water quality standards that must be achieved and maintained as required under the Clean Water Act.

Epilimnion. The surface water layer overlying the thermocline of a lake. This water layer is in direct contact with the atmosphere.

Evapotranspiration. Water loss from the land surface by the combined effects of direct evaporation and transpiration by plants.

Hg. Chemical symbol for mercury.

Hydrophobic. A compound that lacks affinity for water and thus tends to have low solubility in water.

Hypolimnion. The bottom water layer underlying the thermocline of a lake. This layer is isolated from direct contact with the atmosphere.

Lipophilic. A compound that has a high affinity for lipids (fats and oils) and is thus prone to be stored in body tissues.

Load Allocation. The portion of a receiving water's loading capacity that is attributed either to one of its existing or future nonpoint sources of pollution or to natural background.

Loading capacity. The amount of contaminant load (expressed as mass per unit time) that can be loaded to a waterbody without exceeding water quality standards or criteria.

Macrophytes. Macroscopic, multicellular forms of aquatic vegetation, including macroalgae and aquatic vascular plants.

Margin of Safety. A required component of the TMDL that accounts for uncertainty in the relationship between the pollutant loads and the quality of the receiving waterbody.

Metalimnion. The water stratum between the epilimnion and hypolimnion that contains the thermocline.

Methylation. The process of adding a methyl group (CH_3) to a compound, often occurring as a result of bacterial activity under anaerobic conditions.

Methylmercury (MeHg). A compound formed from a mercury ion and a methyl molecule, CH_3Hg, usually by bacterial activity. Methylmercury exhibits chemical behavior of an organic compound and is the form of mercury most likely to be taken up and retained by organisms.

Morphometry. The shape, size, area, and volumetric characteristics of a waterbody.

Nonpoint source pollution. Pollution that is not released through pipes but rather originates from multiple sources over a relatively large area.

Oligotrophic. Waterbodies characterized by low rates of internal production, usually due to the presence of low levels of nutrients to support algal growth.

pH. A measure of acidity and alkalinity of a solution that is a number on a scale on which the value of 7 represents neutrality, lower numbers indicate increasing acidity and higher numbers indicate increasing alkalinity. pH is equivalent to the negative logarithm of hydrogen ion activity.

Photodegradation/photolysis. Degradation of compounds by light energy.

Phytoplankton. Free-floating algae.

Piscivorous. Fish-eating.

Potential evapotranspiration. An estimate of the evapotranspiration that would occur in response to available solar energy if water supply was not limiting.

Redox potential. A measure of the energy available for oxidation and reduction reactions, represented as the negative logarithm of electron activity in a solution.

Stratification (of waterbody). Formation of water layers with distinct physical and chemical properties that inhibit vertical mixing. Most commonly, thermal stratification occurs when warmer surface water overlies colder bottom water.

Tailings. Residue of raw material or waste separated out during the processing of mineral ores.

Thermocline. A lake water layer separating warmer surface waters from colder bottom waters, correctly defined as the plane of maximum rate of decrease of temperature with respect to depth.

Total Maximum Daily Load (TMDL). The sum of the individual wasteload allocations for point sources, load allocations for nonpoint sources and natural background, and a margin of safety as specified in the Clean Water Act. The TMDL must be less than or equal to the loading capacity and can be expressed in terms of mass per time, toxicity, or other appropriate measures that relate to a state’s water quality standards.

Trophic level. One of the hierarchical strata of a food web characterized by organisms that are the same number of steps removed from the primary producers (such as photosynthetic algae). Animals that consume other animals are at higher trophic levels. Certain pollutants such as methylmercury tend to accumulate at higher concentrations in animals at higher trophic levels.

Wasteload Allocation. The portion of a receiving water’s loading capacity that is allocated to one of its existing or future permitted point sources of pollution.

Watershed. The entire upstream land area that drains to a given waterbody.

1. Introduction and Problem Statement

1.1 Description of TMDL Process

Section 303(d) of the Clean Water Act (CWA) requires states to identify waters not meeting ambient water quality standards, define pollutants and the sources responsible for the degradation of each listed water, establish TMDLs necessary to secure those standards and allocate responsibility to sources for reducing their pollutant releases. This process includes identifying the waters for which the effluent limitations required under the National Pollutant Discharge Elimination System (NPDES) or any other enforceable limits are not stringent enough to meet any water quality standard adopted for such waters. The states must also rank these impaired waterbodies by priority, taking into account the severity of the pollution and the uses to be made of the waters. Lists of prioritized impaired waterbodies are known as the “303(d) lists” and must be periodically submitted to the U.S. Environmental Protection Agency (EPA).

The Total Maximum Daily Load (TMDL) program, initiated in the 1972 Clean Water Act, recently emerged as a foundation for the nation’s efforts to meet state water quality standards. A TMDL refers to the “total maximum daily load” of a pollutant that achieves compliance with a water quality standard; the “TMDL process’ refers to the plan to develop and implement the TMDL. Success of the TMDL program is achieved when the condition of a waterbody supports its classified use. Under TMDL regulations promulgated in 1992, U.S. Environmental Protection Agency (EPA) requires state to list waters that are not meeting water quality criteria set for specific classified uses. For each waterbody listed as impaired, the state must identify the amount by which point and non-point sources of pollution must be reduced, in order for the waterbody to meet its stated water quality standards.

A TMDL represents the total loading rate of a pollutant that can be discharged to a waterbody without exceeding the applicable water quality standards. The TMDL can be expressed as the total mass or quantity of a pollutant that can enter the waterbody within a unit of time. In most cases, the TMDL determines the total allowable loading capacity for a constituent and divides it among the various known contributors in the watershed as wasteload (i.e., point source discharge) and load (i.e., nonpoint source) allocations. The TMDL also accounts for natural background sources and provides a margin of safety. For some nonpoint sources it might not be feasible or useful to derive an allocation in mass per unit time. In such cases, a percent reduction in pollutant discharge may be proposed.

TMDLs must include specific information to be approved by USEPA, Region 8. This information can be summarized in the following seven elements:

1. **A plan to meet state water quality standards:** The TMDL includes a study and a plan for the specific water and pollutants that must be addressed to ensure that applicable water quality standards are attained.

2. **The description of the quantified water quality goals, targets, or endpoints:** The TMDL must establish numeric endpoints for the water quality standards, including classified uses to be protected, as a result of implementing the TMDL. This often requires an interpretation that clearly describes the linkage(s) between factors impacting water quality standards and the reason for the 303(d) listing.

3. **An analysis and accounting of all sources of pollutants:** All significant pollutant sources are described, including the magnitude and location of sources.

4. **The identification of the pollution reduction goals:** The TMDL plan includes pollutant reduction targets for all identified causes of pollution, point and nonpoint sources.

5. **The description of the linkage between water quality endpoints and pollutants of concern:** The TMDL must explain the relationship between the numeric targets and the pollutants of concern. That is, will the recommended pollutant load allocations exceed the loading capacity of the receiving water?

6. **Develop a margin of safety that considers uncertainties, seasonal variations, and critical conditions:** The TMDL must describe how any uncertainties regarding the ability of the plan to meet water quality standards have been addressed. The plan must consider these issues in its recommended pollution reduction targets.

7. **Include an appropriate level of public involvement in the TMDL process:** This is usually achieved by publishing public notice of the TMDL, circulating the TMDL for public comment, and holding public meetings in local communities. Public involvement must be documented in the state's TMDL submittal.

1.2 Problem Statement

Generally speaking, mercury, when found in areas of low water flow, low oxygen, high levels of organic matter in decomposition and in the presence of bacteria, will be captured from the water and sediment and incorporated into the food chain. This will happen even when the amount of mercury found in the water occurs in trace, almost non-detectable amounts. Once in the food chain, mercury will bio-magnify and bio-accumulate up the food chain. Once in the tissue of the bigger fish, mercury toxicity is such that, if the fish are consumed by humans, mercury has the potential to negatively impact human health, especially the still-forming fetus and small children.

Based on several fish studies conducted since the 1980's, elevated levels of mercury in fish tissue were detected in some fish sampled from McPhee and Narraguinnep reservoirs (for a complete set of the data, consult *Tetra Tech, 2000 - Review of Past and 1999 Mercury Data and Related Information for Six Colorado Reservoirs.* The finding of fish containing elevated levels of mercury in McPhee and in Narraguinnep reservoirs (above 0.5 ug/g), triggered the posting of fish consumption advisories on both reservoirs, which happened in May 1991.

EPA recommends that waterbodies for which fish consumption advisories have been issued be included on the 303(d) list of impaired waters, based on the Clean Water Act (CWA), Section 101(a)(2) goal of protection of fish. EPA interprets the presence of a fish consumption advisory as evidence of the non-attainment of the "fishable" standard set forth in that statute. The State of Colorado further understands that the protection of the classified use – aquatic life-based fish consumption – cannot be assured simply by examining potential exceedances of numeric water quality standards for mercury. Thus, the application of the narrative standard "...state surface waters shall be free from substances attributable to human-caused point source or nonpoint source discharges in amounts, concentrations, or combinations which… are harmful to the beneficial uses or toxic to humans, animals, plants, or aquatic life..." is also appropriate to better address the complexity of the issues associated with paths of contamination for mercury in the aquatic environment.

The purpose of this TMDL is to provide an estimate of pollutant loading reductions needed to restore the classified uses of McPhee and Narraguinnep reservoirs.

1.3 Waterbody Name and Location

The waterbodies of concern in this TMDL are the McPhee and Narraguinnep reservoirs, located in Montezuma County in southwestern Colorado. The general characteristics of the two reservoirs and their watersheds are described in Tetra Tech (2000) and are summarized only briefly here. McPhee reservoir is an impoundment of the Dolores River (USGS Hydrologic Cataloging Unit [HUC] 14030002) constructed by the Bureau of Reclamation in Montezuma County, Colorado and operated by the Dolores Water Conservancy District. The reservoir was completed in 1986. It has a surface area of 4,470 acres and a storage capacity of 381,051 acre-feet at 6,924 ft Mean Sea Level (MSL).

Narraguinnep reservoir is a privately owned impoundment constructed in 1907. It has a surface area of 625 acres at full pool and a storage capacity of 18,960 acre-feet at 6,680 ft MSL. The watershed for Narraguinnep reservoir lies in a different HUC (14080202) than McPhee reservoir. However, the majority of water in Narraguinnep is supplied by McPhee reservoir via interbasin transfer.

The locations of the two watersheds are shown in Figure 1 in Appendix A. A detailed view of the McPhee and Narraguinnep watersheds is provided in Figure 2 in Appendix A.

1.4 Geographic Coverage of the TMDL

Previous studies and existing documentation show that, although water quality standards for mercury are not exceeded, the aquatic life-based fish consumption classified use cannot be protected within the reservoirs. However, mercury loads are believed to originate within the entire upstream watershed area, including sources from mining activities, soil and geologic background, and atmospheric deposition. Therefore, the geographic coverage of the TMDL is the entire upstream drainage area of the reservoirs, including portions of Montezuma and Dolores Counties, Colorado. In addition, the atmospheric transport of mercury from outside the watershed is also being considered in this TMDL.

The TMDL for Narraguinnep reservoir is combined with that for McPhee reservoir because most of the water supplying Narraguinnep, as well as a substantial portion of the mercury load, is derived from McPhee. Thus, mitigation strategies for the two reservoirs should be linked. The small direct drainage to Narraguinnep reservoir within HUC 14080202 is also included in the analysis.

1.5 TMDL Priority and Targeting

McPhee reservoir is located in the "Dolores River Basin" and the Colorado Water Quality Control Commission (CWQCC) stream segment described as: "Mainstem of the Dolores River from a point immediately above the confluence with Bear Creek to the bridge at Bradfield Ranch including McPhee reservoir". Narraguinnep reservoir is located in the "La Plata River, McElmo Creek, and San Juan River in Montezuma County and Dolores County" basins and the CWQCC stream segment described as: "Narraguinnep, Pruett, and Totten reservoir".

McPhee and Narraguinnep reservoirs appear on the 1998 303(d) list as high priority for development of a mercury TMDL (COSJDO04L and COSJLP08L, respectively). As a result of a settlement in the United States District Court for the District of Colorado, Civil Action No. 97-S-1841, these watersheds were targeted for TMDL development prior to June 30, 2002. The development of this TMDL is consistent with the priority and target schedule assigned to these watersheds.

1.6 Health Effects of Mercury

Colorado's fish consumption advisory program is designed to protect people who eat fish caught at local waterbodies from the health impacts of mercury consumption. The most toxic type of mercury to humans is its organic form, methylmercury. Unfortunately, methylmercury is the predominant form found in fish tissue and consumption of fish is thought to be the primary pathway by which humans are exposed to mercury. The two organ systems most likely affected by methylmercury are the central nervous system and the urinary system, particularly the kidney. However, the most significant concerns regarding chronic exposure to low concentrations of methylmercury in fish are for neurological effects in the developing fetus and children.

Recently, EPA issued a national advisory concerning risks to children and to pregnant or nursing women associated with mercury in freshwater fish caught by their friends and family (USEPA 2001). The groups most vulnerable to the effects of mercury toxicity include: women who are pregnant or may become pregnant, nursing mothers, and young children. To protect against the risks of mercury in fish caught in freshwater, EPA has recommended that these groups limit fish consumption to one meal per week for adults (6 ounces of cooked fish, 8 ounces of uncooked fish) and one meal per week for young children (2 ounces of cooked fish or 3 ounces of uncooked fish). The National Academy of Sciences (NAS) confirms that methylmercury is a potent toxin and concludes that the babies of women who consume large amounts of fish when pregnant are at greater risk for changes in their nervous system that can affect their ability to learn. The advice from EPA was issued to raise awareness of the potential harm that high levels of methylmercury in fish can cause to a child's developing brain and nervous system. This advice provides guidance on the amount of fish that individuals in these groups can safely consume to keep methylmercury from reaching harmful levels.

1.7 Phased Approach to the TMDL

The TMDL for mercury in McPhee and Narraguinnep reservoirs will follow a phased approach. In a phased TMDL, the best information available is used to establish the TMDL at levels necessary to evaluate the pollution sources and calculate initial pollution load reductions that protect the classified uses and achieve water quality standards. However, the phased TMDL approach recognizes that it may be necessary to collect additional data and information to validate the assumptions of the TMDL and to provide greater certainty that the TMDL will achieve the applicable state standard(s).

In the case of the TMDL for mercury in McPhee and Narraguinnep reservoirs, this document comprises Phase 1 of the TMDL. It consists of the following: identification of data and information collected, the data collection process, the modeling of the results, and preliminary loading estimates and allocations. Because this TMDL is done in a phased approach and because the first phase is preliminary and estimative in nature, this current TMDL document cannot be used as a regulatory enforcement instrument.

The above information has been summarized here and is covered in detail in two documents:

1. Tetra Tech, 2000. Review of Past and 1999 Mercury Data and Related Information for Six Colorado Reservoirs.

2. Tetra Tech 2001. Technical Support for Developing a Total Maximum Daily Load for Mercury in McPhee and Narraguinnep Reservoirs, Colorado. The Technical Support Document (Tetra Tech 2001) can be found electronically at U.S. Environmental Protection Agency's Region 8 web site.

The above mentioned documents form the historical background and technical basis for this report (Phase 1 of the TMDL). In addition, Phase 1 includes a summary of the additional data collection and analyses needed to reduce the uncertainty associated with the preliminary loading estimates and allocations identified in Tetra Tech (2001), so that revised estimates can be made (Section 7). The objectives for Phase 2 are to gather the necessary data and perform the analyses identified in Phase 1 to produce a revised TMDL for mercury in McPhee and Narraguinnep reservoirs. The phased approach is used for this TMDL because numerous data gaps were identified in the Technical Support Document that formed the basis of Phase 1 (Tetra Tech, 2001) and only rough estimates of actual contributions of mercury to McPhee and Narraguinnep reservoirs from both point and nonpoint sources could be identified. Additional data collection, analysis, and modeling in Phase 2 will allow the state to better characterize load allocations in the future.

2. Applicable Water Quality Standards

The TMDL is a numerical quantity determining the maximum load of pollutants, from point and nonpoint sources as well as from background sources, to receiving waterbodies that will not violate the state water quality standards, with an adequate margin of safety. The TMDL process is used for implementing state water quality standards that will lead to the goal of meeting the water quality standard.

Water quality standards include numeric and narrative water quality standards that support the designated uses of the waterbody, and other associated indicators of support of beneficial uses. A numeric target identifies the specific goals or endpoints for the TMDL that equate to attainment of the water quality standard. The numeric target may be equivalent to a numeric water quality standard (where one exists), or it may represent a quantitative interpretation of a narrative standard. This section reviews the applicable water quality standards and identifies an appropriate numeric indicator and associated numeric target level for the calculation of the mercury TMDL for McPhee and Narraguinnep reservoirs.

2.1 Numeric Water Quality

The designated use classifications for McPhee reservoir are: Aquatic Life Cold 1, Recreation 1, Water Supply, and Agriculture. The designated use classifications of Narraguinnep reservoir are Aquatic Life Warm 2, Recreation 2, and Agriculture. Colorado has adopted water quality standards for mercury that apply to these classified uses, specifying a Final Residue Value (FRV) criterion in water of 0.01 µg/L total mercury (CDPHE Water Quality Control Commission, Regulation No. 34).

The numeric criterion for mercury in water is intended to ensure protection of the general population from potential adverse health impacts from the ingestion of sport-caught fish. It is based on a water quality value for total mercury that, through the process of bioaccumulation, will result in a FRV in fish tissue at the U.S. Food and Drug Administration (FDA) action level of 1 part per million (ppm = µg/g). Footnote 6 to Table III in CDPHE Regulation 31 (effective October 30, 2001, pp. 55-56) provides the following discussion relative to this criterion:

> "FRV means Final Residue Value and should be expressed as "Total" because many forms of mercury are readily converted to toxic forms under natural conditions. The FRV value of 0.01 µg/liter is the maximum allowed concentration of total mercury in the water that will present bioconcentration or bioaccumulation of methylmercury in edible fish tissue at the U.S. Food and Drug Administration's (FDA) action level of 1 ppm. The FDA action level is intended to protect the average consumer of commercial fish; it is not stratified for sensitive populations who may regularly eat fish.
>
> A 1990 health risk assessment conducted by the Colorado Department of Public Health and Environment indicates that when sensitive subpopulations are considered, methylmercury levels in sport-caught fish as much as one-fifth lower (0.2 ppm) than the FDA level may pose a health risk."

To date, mercury concentrations in the water column in McPhee and Narraguinnep reservoirs have not exceeded the applicable water quality standards. The reservoirs are listed as not supporting classified uses based on the presence of a fish consumption advisory rather than deviations of ambient water quality standards for mercury.

2.2 Narrative Standards

Colorado's narrative standards language for toxics is expressed in part as follows (CDPHE Water Quality Control Commission, Regulation No. 31, effective October 30, 2001, Section 31.11):

> "Except where authorized...state surface waters shall be free from substances attributable to human-caused point source or nonpoint source discharges in amounts, concentrations, or combinations which:
>
> (a) for all surface waters except wetlands:
>
> (iv) are harmful to the beneficial uses or toxic to humans, animals, plants, or aquatic life..."

This clause is applied by the CDPHE to prohibit loading of mercury to the reservoirs in amounts that result in fish tissue contamination levels sufficient to impair recreational uses or present a risk to human health.

2.3 Fish Consumption Guidelines

As noted above, McPhee and Narraguinnep reservoirs are listed as not supporting the classified uses based on the presence of a fish consumption advisory rather than excursions from ambient water quality standards for mercury. Both reservoirs have been included on previous iterations of the 303(d) list, including those promulgated in 1993, 1994, 1996, and 1998. EPA guidance available in 1992 recommended that water bodies for which fish consumption advisories had been issued be included on the 303(d) list. EPA's recommendation is based on the Clean Water Act mandate that waters of the U.S. be: "fishable and swimable". EPA interpreted the presence of a fish consumption advisory to be evidence of non-attainment of the "fishable" standard set forth in the statute.

Colorado does not have a formal regulation establishing guidelines for the issuance of fish consumption advisories due to the presence of mercury in fish tissue. However, CDPHE has issued fish consumption advisories for waterbodies where concentrations of mercury in fish fillets are equal to or exceed the action level of 0.5 µg/g (wet weight) total mercury. CDPHE listings are based on the risk analysis presented in the May 6, 1991 Disease Control and Epidemiology Division *Position Paper for Draft Colorado Health Advisory for Consumption of Fish Contaminated with Methylmercury*.

The risk assessment approach outlined in the paper is based on a toxicity value reference dose (R*f*D) for two groups: 1) 0.3 µg/kg/day (USEPA 1990) for non-pregnant adults; and 2) 0.075 µg/kg/day for women who are pregnant, nursing, or planning to become pregnant, and children nine years old and younger. The following equation is used to determine recommended fish consumption rates for the two groups:

$$\text{Meals per Month} = \frac{R\mathit{f}D \times BW \times CF}{C \times IR}$$

where: R*f*D = EPA Reference Dose, 0.3 µg/kg/day, adults; 0.075 µg/kg/day, women who are pregnant, nursing, or planning to become pregnant, and children nine years old and younger;

BW = Body weight, 70 kg;

CF = Conversion Factors of 7 days per week, and 4.35 weeks per month;

C = Concentration of mercury in edible fish tissue (wet weight analysis);

IR = Ingestion Rate: 227 g/meal for a 70-kg adult.

Table 2.1 below compares recommended consumption levels for these two groups.

Table 2.1. Recommended levels of consumption of mercury-contaminated fish (from CDPHE Disease Control and Epidemiology Division *Position Paper for Draft Colorado Health Advisory for Consumption of fish Contaminated with Methylmercury*, May 6, 1991).

Consumption of Mercury Contaminated FishMeals per month		
Concentration of Mercury in Edible Fish Tissue (µg/g wet weight)[a]	**Non-pregnant adults**	**Women who are pregnant, nursing, or planning to become pregnant; and Children 9 years old & younger**
0.2	7	3.5
>0.2 – 0.35 ppm	4	2
>0.35 – 0.7 ppm	2	1
>0.7 – 1.4	1	0
>1.4 – 2.8	0	0
2.8 or more	0	0

[a] A threshold effect level for methylmercury has not been observed. Therefore, young children and women who are pregnant, nursing or planning to become pregnant may wish to limit their consumption of fish with mercury concentrations below this level.

Based on the equation and the information in Table 2.1, a fish tissue concentration of 0.5 µg/g was established by the CDPHE as the approximate center of the range at which the safe consumption level is four meals per month for non-pregnant adults and one meal per month for women who are pregnant, nursing, or planning to become pregnant; and children 9 years of age or younger. This level was consistent with fish consumption advisory thresholds adopted by other states in the early 1990s.

2.4 Selected Numeric Target for Completing the TMDL

The applicable numeric targets for the McPhee and Narraguinnep TMDLs are the Colorado water quality standard of 0.01 µg/L total mercury in the water column and the fish consumption advisory action level of 0.5 µg/g total mercury concentration in fish tissue. Water column mercury concentrations have not been found in excess of the ambient water quality standard. However, fish tissue concentrations have exceeded the action level of 0.5 µg/g in both reservoirs in studies conducted from 1989 to 1999 (3 smallmouth bass of the 31 fish sampled in McPhee reservoir and 6 walleye of the 32 fish sampled in Narraguinnep reservoir. Tetra Tech, 2001). The fish tissue concentration action level of 0.5 µg/g total mercury was selected as the primary numeric target for calculating this TMDL.

Mercury bio-accumulates in the food chain. Within a lake fish community, top predators usually have higher mercury concentrations than forage fish, and tissue concentrations generally increase with age class. This is particularly true with predatory species that are primarily piscivorous (fish eating) as opposed to those that are primarily insectivorous (insect eating). Unfortunately, top predators (such as bass) are also common target species for sport fishermen. Risks to human health from the consumption of mercury-contaminated fish are based on long-term, cumulative effects, rather than concentrations in individual fish. Therefore, the criterion should not be applied to the extreme case of the most-contaminated age class of fish within a target species;

instead, the criterion is most applicable to concentrations in a top predator species representing an average within the size class allowed to be caught and kept.

Within McPhee reservoir, the top predator sport fish is the largemouth bass (*Micropterus salmoides*), which exhibits the highest mercury concentrations (Tetra Tech, 2001). However, creel surveys conducted in 1993 indicate that largemouth bass constitute less than 1 percent of the total annual catch in McPhee reservoir. In contrast, smallmouth bass (*Micropterus dolomieui*), which are also considered top predators, are regularly caught in McPhee Reservoir (they comprised 19% of the total catch in 1993). Thus, smallmouth bass were used as the target species in McPhee reservoir for this TMDL since they pose the greatest potential risk to human health.

The average mercury concentration in the fish tissue of target species is assumed to be approximated by the average concentration in 15-inch smallmouth bass. While this is the minimum "keepable" size for bass, and mercury body burdens are likely to continue to increase with increased length/age, it appears that few smallmouth bass in excess of 15 inches are present or caught in McPhee reservoir. Use of the 15-inch smallmouth bass thus provides a reasonable maximum estimate for long-term exposure of the fish-consuming public. **Therefore, based on the limited current data, the selected target for the TMDL analysis in McPhee reservoir is an average tissue concentration in 15-inch smallmouth bass of 0.5 µg/g or less.**

The fish community in Narraguinnep reservoir is different from that in McPhee reservoir (reviewed in Tetra Tech, 2001). Here the top predator sport fish, and also the fish with the highest reported tissue methylmercury body burden, is walleye (*Sitzostedion vitreum*). Walleye continue to bioaccumulate mercury with increasing size and age. The largest walleye analyzed in Narraguinnep were 18 inches in length. However, the sample size was small, and it is likely that walleye in excess of 18 inches occur in the reservoir. Until detailed creel surveys of Narraguinnep are conducted, it is not possible to determine the exact age-size structure of the walleye population. **Therefore, the selected target for the TMDL analysis in Narraguinnep Reservoir is an average tissue concentration in 18-inch walleye of 0.5 µg/g or less.** Because the water that supplies Narraguinnep is largely comprised of diversions from McPhee, the target established for Narraguinnep may also affect the TMDL calculations in McPhee.

3. Pollutant Source Assessment

There are a number of potential sources of mercury loading to McPhee and Narraguinnep reservoirs, as described in Tetra Tech (2000). The sources external to the reservoirs themselves may first be separated into direct atmospheric deposition onto the reservoirs (from both near- and far-field sources) and transport into the reservoirs from the watershed. For Narraguinnep, mercury in diversions from McPhee must also be considered. The watershed loading occurs in both dissolved and sediment-sorbed forms. Ultimate sources in the watershed could include mercury in the parent rock, mercury residues from mine tailings and other mine-related discharges, point source discharges, although no significant point source has yet been identified in connection with mercury levels in the fish in the two reservoirs and atmospheric deposition on to the watershed, including deposition and storage in snowpack. Monitoring of streams and stream sediments typically reflects the combined impact of a number of these ultimate sources.

3.1 Point Sources

The EPA Permit Compliance System (PCS) identifies only two permitted discharges to water regulated under the NPDES system within the watersheds of McPhee reservoir and none in the watershed of Narraguinnep reservoir. The point sources in the McPhee watershed are the domestic water treatment plant for the town of Dolores (permit CO0040509) and a small private plant (Dolores River R.V. Park) located 2.5 miles east of Dolores (permit CO0042561).

As discussed in Tetra Tech (2001), neither facility has permit limits for mercury. Given the small amount of flow, most of which does not discharge via direct surface pathways, point sources likely provide an insignificant amount of mercury loading to the reservoirs.

3.2 Mercury Sources from Mining Activities

Past mining activities are likely an important source of mercury load in the McPhee/Narraguinnep watershed. There are three large mining districts in the Dolores River watershed: the La Plata, the Rico, and the area around Dunton on the West Dolores River (see Figure 3 in Appendix A). The known mines in the vicinity of the Dolores River watershed are listed in Appendix A of Tetra Tech (2000).

A discussion of the history of the mining districts and the potential for mercury contamination is presented in Tetra Tech (2000 and 2001). In general, the quantity of mercury loading from mining operations has not been measured directly. Instead, the loads must be estimated through a combination of observed data in the water column and sediment (Section 3.5), coupled with the watershed linkage analysis (Section 4.4). This methodology may not adequately address the specific sources of mercury within the mining districts where the background geologic formations can be potentially the major contributor of mercury. The background mercury in the mining districts is expected to be much greater than in non-mining areas. Metal sulfide mining occurred in geothermically altered areas where native mercury and Cinnabar (mercury sulfide) are concentrated.

3.3 Atmospheric Deposition

Atmospheric deposition is an important source of inorganic mercury loading to surface waters. Much of this mercury originates from a variety of anthropogenic sources. Atmospheric deposition can be divided into short-range or near-field deposition, which includes deposition from sources located near the watershed, and long-range or far-field deposition, which includes mercury deposition from both regional and global sources. No direct measurements of atmospheric deposition of mercury within or near the McPhee-Narraguinnep watersheds are available at this time, although some measurements have been made of mercury in snowpack in the McPhee watershed (see Tetra Tech, 2001).

Near-Field Atmospheric Deposition

Significant atmospheric point sources of mercury often cause locally elevated areas of near-field atmospheric deposition downwind. Mercury emitted from man-made sources usually contains both gaseous elemental mercury (Hg(0)) and divalent mercury (Hg(II)). Hg(II) species, because of their solubility and their tendency to attach to particles, are re-deposited relatively close to their source (probably within a few hundred miles), whereas Hg(0) remains in the atmosphere much longer, contributing to long-range transport.

An evaluation of significant potential point sources of airborne mercury at McPhee and Narraguinnep was conducted to determine whether coal-fired power plants, waste incinerators, cement and lime kilns, smelters, pulp and paper mills, and chlor-alkali factories might be contributing mercury to the reservoirs. These results are summarized below:

As described in Tetra Tech (2000), there are two large coal-fired power plants in the Four Corners area within about 50 miles of the McPhee and Narraguinnep reservoirs: 1) Arizona Public Service - Four Corners Station, which has a 2,040 MW capacity; and 2) The Public Service Company of New Mexico - San Juan plant, which has a 1,500 MW capacity.

Twelve other coal-fired power plants are located within a 200 mile radius of the center of Narraguinnep reservoir (Figure 3-1). Together, these plants generated nearly 81,405,000 MwH of electricity during 1998 (Pechan, 2001).

The USEPA AIRS database was searched to identify nearby incinerators for refuse, medical waste, or cement kilns (Tetra Tech, 2000). There were no incinerators within 50 miles of McPhee and Narraguinnep reservoirs. The nearest cement kiln is in Ridgway on the north slope of the San Juan Mountains. Three other facilities are located further north.

Mercury mobilization and re-deposition from soils during forest fires could also play a significant role in this fire-prone region, but is not well understood at this time.

After July 1999, EPA required large power plants to estimate their mercury emissions and provide the data to the USEPA Toxic Release Inventory. Detailed mercury data for a large number of plants were collected during 1999 as part of EPA's Information Collection Rule. Detailed estimates of emissions for 1999 by plant and boiler are contained in the draft National Emissions Inventory (RTI, 2001). These estimates include influent and stack effluent mercury loading after accounting for reduction expected for a given control technology.

Mercury emissions for the 14 coal-fired power plants within 200 miles of McPhee and Narraguinnep reservoirs are presented in Table 3-1 based on the EPA estimates (RTI, 2001) (see Figure 4 in Appendix A) These estimates differ somewhat from those presented in EPRI (2000), but are generally similar. Plant locations are shown in Figure 5 in Appendix A. Total emissions from the 14 plants amount to 1,636 kg-Hg/yr, of which more than half (about 950 kg) are associated with the San Juan and Four Corners generating plants, the two large facilities that lie within 50 miles of McPhee and Narraguinnep reservoirs.

Table 3-1. Estimated Mercury Emissions from Coal-Fired Power Plants near McPhee and Narraguinnep Reservoirs (source: Tetra Tech, 2001).

Plant	Location	ORISPL	Distance to Narraguinnep (miles)	Bearing from Narraguinnep	Power Generation (MwH)[1]	Emission Control Type[2]	Total Hg Emissions (kg/yr)[3]	Reactive Hg Emissions (kg/yr)[3]
San Juan	Waterflow, NM	2451	39	S	11,618,217	20	472.5	35.4
Nucla	Nucla, CO	527	42	N	586,448	40	9.1	0.3
Four Corners	Fruitland, NM	2442	44	S	14,617,015	16/19	477.0	21.0
Cameo	Palisade, CO	468	92	NNE	517,354	7	0.9	0.6
Escalante	Prewitt, NM	87	118	S	1.362138	19	39.4	1.3
Hunter	Castle Dale, UT	6165	138	NW	9,053,611	10/12	37.5	3.7
Navajo	Page, AZ	4941	139	WSW	16,484,808	11	137.7	8.7
Sunnyside	Sunnyside, UT	50951	142	NW	379,592	27	0.05	0.02
Bonanza	Vernal, UT	7790	144	N	3,458,586	12	1.4	0.6
Huntington	Huntington, UT	8069	158	NW	6,452,895	10/1	67.4	39.5
Carbon	Helper, UT	3644	163	NW	1,288,602	1	18.0	13.4
Cholla	Joseph City, AZ	113	165	SSW	6,370,902	16/14/20	116.1	9.0
Coronado	St. Johns, AZ	6177	165	S	4,797,610	20	113.4	4.8
Springerville	Springerville, AZ	8223	178	S	5,779,231	18	145.9	7.8
TOTAL					**81,404,873**		**1,636.4**	**146.0**

Notes to Table 3-1:

1. 1998 generation from E-GRID2000PC database (Pechan, 2001).
2. Emission Controls from National Emissions Database (RTI, 2001):
3. 1999 emission estimates from National Emissions Database (RTI, 2001). Reactive mercury estimates determined from application of speciation data in BinTable.xls (http://www.epa.gov/ttn/atw/combust/utiltox/control2.zip, accessed 7/17/01). Data from individual plants used where reported; otherwise calculated from national average speciation by control type.

The coal-fired power plants in the Four Corners area are, under some meteorological conditions, upwind of McPhee and Narraguinnep reservoirs. Plumes from other coal-fired plants also impact the reservoirs, under some meteorological conditions. A recent study by researchers at the University of Colorado (Williams and Manthorne, 2001) indicates that power plants in the Four Corners area are a likely source of contaminants to the San Juan Mountains, via atmospheric deposition. Important meteorological variables, such as wind directions, are complex in this area due to the terrain. Given the complex topography of the area, the use of mesoscale meteorological models and non-steady state air quality models would be necessary to fully understand regional patterns of atmospheric transport and deposition. There is a CASTNET site at Mesa Verde National Park, which collects first-order meteorological information. Data from this station have not yet been evaluated, but they should help to confirm wind directions at McPhee and Narraguinnep reservoirs.

Estimates of mercury deposition rates at the reservoirs are presented below (Table 3-2), based on the limited available data. Applying simple screening procedures for air transport (USEPA, 1992), it does not appear that the reactive mercury emissions from nearby power plants are sufficient to account for all of the estimated mercury deposition at the reservoirs, by orders of magnitude. In general, significant large-scale impacts of local reactive mercury emissions are expected to occur within 10 km or so of the source. However, the range of deposition of reactive mercury is considered to be about 50 miles from the source. There are several power plants within this distance from the reservoirs.

In addition to reactive mercury, deposition at the reservoirs is likely affected by oxidation and deposition of elemental mercury. Elemental mercury can be transported over long distances in the atmosphere. Thus, the pool of elemental mercury available for conversion to reactive form and deposition in southwestern Colorado may originate from distant as well as nearby sources. The nearby power plants likely contribute to atmospheric deposition loads at McPhee and Narraguinnep reservoirs by increasing the available pool of elemental mercury. The extent of this contribution, however, has not been established at this time and must await further investigation, including the establishment of a mercury deposition monitoring site in the area (see Section 7).

In sum, power plants within a 200-mile radius of the reservoirs emit a relatively large total mercury load, which is likely to be transported toward McPhee and Narraguinnep, but the reactive mercury component of this load is relatively small. It is likely that the mercury emitted from these plants contributes to the mercury loading of McPhee and Narraguinnep reservoirs. However, the significance of this loading cannot be assessed at this time. Accordingly, the analysis presented in this document proceeds with a generalized estimate of atmospheric deposition rates, without attribution to specific sources.

Long-Range Atmospheric Deposition

Long-range atmospheric deposition (regional atmospheric background) is a major source of mercury in many parts of the country. The long-range component is driven in large part by the transport of elemental mercury. Additional discussion of long-range mercury deposition is included in Tetra Tech (2001).

Deposition and Storage in Snowpack

A potential concern for the high-altitude watershed feeding McPhee reservoir is the atmospheric deposition of mercury, from both near-field and long-range sources, on the winter snowpack. Conceptually, mercury loading could be enhanced during snowmelt as this could release the mercury load accumulated and stored over the winter. However, because elemental mercury is volatile and ionic mercury may leach through the snowpack, only a fraction of the deposited mercury may remain in the snowpack at spring melt.

To investigate these issues, USGS (Ingersoll, 2000) undertook snowpack sampling at the Lizard Head Pass SNOTEL site, at high elevation in a remote headwaters portion of the McPhee watershed, on February 26, 2000, prior to the start of snowmelt. In all three samples, mercury was non-detectable at a 0.0003 µg/L (0.3 ng/L) concentration level. In contrast, total mercury concentrations in McPhee tributary streams in June 1999 ranged from 1 to 21 ng/L (Tetra Tech, 2000). These results suggest that snowpack storage of atmospheric mercury is not a significant factor in the overall mercury loading to the Reservoirs, at least for 1999. However, these data are somewhat misleading because the USGS analysis (Ingersoll, 2000) measured dissolved rather than total mercury in the snowpack. Therefore additional sampling and analysis of snowpack mercury concentrations in the McPhee watershed need to be conducted (see Section 7).

Mercury Deposition Monitoring

Only limited monitoring of the atmospheric deposition of mercury is available in the Southwestern U.S. The Mercury Deposition Network (MDN) measures wet deposition of mercury at a number of locations around the U.S. However, only one MDN station is located in Colorado (Buffalo Pass (CO97). The only other MDN station in the southwest is in southern New Mexico at Caballo (NM10). MDN monitoring records from these stations for 1998-2000 were obtained from the MDN web site (provided in Tetra Tech, 2001; Appendix B).

Atmospheric Loading Estimates

The mercury concentrations and deposition rates observed at Buffalo Pass and Caballo are unlikely to be the same as deposition rates to the McPhee and Narraguinnep watersheds. These stations are hundreds of miles distant from the McPhee/Narraguinnep area, and experience different meteorological patterns. Estimates from Buffalo Pass and Caballo do not account for any influence of near-field sources of deposition at McPhee and Narraguinnep. On the other hand, the Buffalo Pass and Caballo data provide the only direct evidence on mercury deposition that is currently available for this region. A reasonable assumption is that the wet deposition volume-weighted mean concentration of mercury at McPhee and Narraguinnep reservoirs is within the range represented by the moderate concentrations observed at Buffalo Pass (10 ng/L) and the high concentrations observed at Caballo (21.5 ng/L).

To seek to further quantify the potential mercury deposition at McPhee and Narraguinnep reservoirs, a surrogate approach was undertaken, in which the Buffalo Pass mercury deposition estimates are scaled by measures of the atmospheric deposition of sulfate and nitrate from data collected as part of the National Atmospheric Deposition Program (NADP). A discussion of this exercise is included in Tetra Tech (2001).

Both sulfate and nitrate are key components of coal-fired power plant emissions, but may also arise from other sources. Estimation of mercury deposition as proportional to sulfate and nitrate deposition is based on the assumption that wet and dry deposition of mercury is largely a function of the scavenging of reactive gaseous mercury and therefore follows a process similar to the deposition of sulfate and nitrate.

The approach taken to estimate atmospheric deposition of mercury is a first-order, scoping approach, which is believed to approximate mercury deposition rates at the reservoirs. This approach is not a substitute for actual measurements and detailed modeling of mercury deposition. In January 2002, EPA established an MDN station at Mesa Verde National Park, which will provide actual mercury deposition estimates in the neighborhood of McPhee and Narraguinnep reservoirs.

Records for 1990-1999 from several stations in the NADP network were used as surrogates to estimate general deposition rates of pollutants associated with coal-fired boilers in southwestern Colorado. The SO_4 and NO_3 data from 1990 to 1999 were used to develop the empirical models as a function of elevation and time (Tetra Tech, 2001).

Table 3-2 summarizes the resulting mercury wet deposition volume-weighted mean concentrations at the reservoir surfaces. These estimates fall in the center of the range between the Caballo and Buffalo Pass volume-weighted mean concentrations. Estimated average annual precipitation, based on 1980-1999 data from the Dolores COOP station, converts the concentrations to an areal loading rate (the rate of loading per square meter of surface area). Surface areas at full pool were used in this table to provide an upper bound and because direct deposition on the shoreline is likely to be easily washed into the reservoir. Estimates were further partitioned by month based on the seasonal pattern of mercury deposition observed at Buffalo Pass. Both the volume-weighted mean concentration and the estimated wet deposition rate are well within the range of observations from other MDN stations (see Tetra Tech, 2001).

Table 3-2. Mercury Wet Deposition Estimates for Colorado Reservoirs (source: Tetra Tech, 2001).

	McPhee	Narraguinnep
Volume-weighted mean wet Hg concentration (ng/L)	16.0 (10-21)	16.8 (10-21)
Precipitation basis (in/yr, at Dolores, CO, 1980-1998)	20.7	20.7
Wet Hg deposition (µg/m^2-yr)	8.4 (5.2-11.0)	8.8 (5.2-11.0)
Surface area at full pool (acres)	4,470	625
Total wet Hg deposition (g/yr)	152 (95-200)	22 (13-28)

Note: Parentheses show range based on the observed volume-weighted mean concentration at Buffalo Pass (low) and Caballo (high) MDN stations.

The estimates in Table 3-2 include wet deposition only, as the MDN network does not measure dry deposition. Although there are few direct measurements to support well-characterized estimates and reliable sampling protocols have not been standardized, dry deposition of mercury often is assumed to be of the same order of magnitude as wet deposition (e.g., Lindberg et al., 1991). Lacking direct evidence from Colorado, it was assumed that dry mercury deposition in these watersheds was, most likely, on the order of 65 percent of wet deposition (Tetra Tech, 2001). This process yields the estimates of total direct mercury deposition shown in Table 3-3.

A range is also shown, based on the range of wet deposition estimates shown in Table 3-2 and dry-to-wet ratios from 50 to 100 percent. While Narraguinnep receives much less total atmospheric deposition of mercury than does McPhee, areal deposition rates are slightly higher for Narraguinnep, due to its smaller size.

Table 3-3. Total Atmospheric Mercury Deposition Estimates to Surface of Reservoirs (source: Tetra Tech, 2001).

	McPhee	Narraguinnep
Total mercury deposition (g/yr)	251 (142-400)	37 (20-56)
Areal deposition rate (µg/m^2/yr)	13.9	14.6

Note: Numbers in parentheses show range based on the range presented in Table 3-2 and dry-to-wet deposition rates varying from 50 to 100 percent.

Both the magnitude and source of the atmospheric mercury deposition on McPhee and Narraguinnep are subject to considerable uncertainty at this time. Uncertainty in atmospheric deposition estimates does not have a significant impact on the calibration of a lake mercury response model for McPhee reservoir, because mercury loading to this reservoir is dominated by watershed sources (see below). Uncertainty in atmospheric deposition may, however, have a significant impact on the estimation of load allocations to achieve water quality standards in Narraguinnep reservoir, as is discussed further in Chapters 5 and 6.

Atmospheric deposition also contributes mercury to the watershed land surface. Elevated concentrations of mercury in the watershed and in the reservoirs may in part be due to elevated historical atmospheric discharges. Further, changes in atmospheric deposition should ultimately result in changes in the mercury concentration in soil available for washoff. Because there is a poor quantitative understanding of these processes at this time, it is not possible to determine the net contribution of atmospheric sources to the land surface relative to geologic sources in mercury loading from the watershed.

3.4 Nonpoint Background Load

The Dolores River basin is located in the southeastern part of the Paradox basin. Geologic formations in the main Dolores River watershed include alluvium, underlain by intrusive igneous rocks forming dikes, sills, lacoliths, and stocks, above the Mancos shale and Dakota sandstone, and other shale, sandstone, and limestone formations (Whitfield et al., 1983). A discussion of the geological characteristics of the McPhee and Narraguinnep watershed relative to the potential contribution of mercury is included in Tetra Tech (2000 and 2001).

The soils in the watershed include red loam soils derived from the Dakota sandstone and gray alluvial soils derived from the Mancos shale and Mesaverde Formation of Cretaceous age. The average mercury of soils in southwestern Colorado is 0.5 to 1.3 µg/g (Shacklette and Boerngen, 1984). Shale can contain high concentrations of metals, as it is derived from clays, which adsorb metals. Thus, shale formations can be a source of mercury to runoff or streams.

Soils within the watershed also exchange mercury with the atmosphere, as noted above. Because the net balance of mercury deposition and volatilization at the land surface is not known, atmospheric deposition on the land surface is treated as part of the generalized watershed load (see Section 4.4).

3.5 Mercury Concentrations in Watershed Water and Sediment

Although loads from individual nonpoint sources within the watershed are difficult to measure directly, the cumulative impact of these sources can be examined through the mercury concentrations in water and sediment in the watershed. Initial investigations of mercury in the watershed were undertaken by USEPA in 1985 and by USGS and USBR in 1989 and 1992, as discussed in Tetra Tech (2000). Due to high detection limits and lack of ultra-clean sampling and analytical techniques, these data are of limited value for quantitative analysis.

As discussed in Tetra Tech (2000), additional extensive sampling in the watershed using ultra-clean techniques was undertaken in 1999. The mercury samples were taken during two separate monitoring events: the first over the period from June 4, 1999 to June 17, 1999 and the second from August 2, 1999 to August 7, 1999. The locations of the monitoring sites in the McPhee/Narraguinnep watersheds are presented in Figure 6 in Appendix A and Table 3-4. Table 3-4 also provides total mercury results for water and sediment. A more detailed discussion of the 1999 sampling results, along with results for dissolved total mercury and total and dissolved methyl mercury, is provided in Tetra Tech (2000).

Table 3-4. Total Mercury Results from 1999 Sampling, McPhee and Narraguinnep Reservoir Watersheds (source: Tetra Tech, 2001).

Sample ID	Location	Unfiltered Total Mercury in Water (ng/L)		Total Mercury in Sediment (ng/g dry weight)	
		June 1999	August 1999	June 1999	August 1999
MCP-1	Pond near Dolores Treatment Plant	3.65	1.10	9.56	47.54
MCP-2	Lost Canyon Creek	2.34	1.73	4.29	2.37
MCP-3	West Dolores River near Mouth	3.18	1.64	3.74	41.61
MCP-4	West Dolores River - Upper	5.62	1.57	13.78	29.75
MCP-5	Dolores River above W. Dolores River	3.98	1.58	13.70	41.19
MCP-6	Garrison Canyon	1.50		3.85	7.55
MCP-7	Bear Creek	2.92	1.64	3.44	5.81
MCP-7 rep.	Bear Creek	3.36		2.74	
MCP-8	Rio Lado Creek	3.50	2.02	0.91	4.32
MCP-9	Deadwood Creek	4.67	0.68	12.18	17.30
MCP-9 rep.	Deadwood Creek	5.06			
MCP-10	Mine Seep below Poor Boy Mine	0.98	0.41	47.90	26.89
MCP-10 rep.	Mine Seep below Poor Boy Mine	2.27			
MCP-11	Silver Creek near Mouth	4.25	0.75	206.49	103.04
MCP-11 rep.	Silver Creek near Mouth	5.45			
MCP-11B	Mine Seep on Silver Creek	5.44	4.38	8.01	202.80
MCP-12	Silver Creek below Mine Tailings	3.54	0.94	117.81	48.34
MCP-12 rep.	Silver Creek below Mine Tailings	3.68			
MCP-13	Mine Seep at former Sulfuric Acid Plant	2.18	0.73	44.64	95.10
MCP-13 rep.	Mine Seep at former Sulfuric Acid Plant	21.07			
MCP-14	Horse Creek	4.61	1.60	72.36	38.48
MCP-14 rep.	Horse Creek	4.92	1.50		55.87
MCP-15	Upper Mine Seep on Dolores River	1.46	0.45	14.37	284.21
MCP-15 rep.	Upper Mine Seep on Dolores River	1.52			
MCP-17	Dolores River at Big Bend Boat Launch	2.20	1.58		21.64
MCP-19	West Dolores R below Geyser Crk		1.71		16.62
MCP-21	Silver Creek - Upper		0.96		24.93
NAR-1	Unnamed trib., Narraguinnep	1.94	1.04	16.26	15.12
NAR-2	Ditch entering Narraguinnep NW corner	1.91	1.51	1.16	14.54
NAR-3	Pond/backwater in NW corner	1.90	0.73	18.42	<17

3.6 Mercury Concentrations and Water Quality in the Reservoirs

Mercury in Water and Sediment

Historical sampling of McPhee and Narraguinnep reservoirs and their watersheds is summarized in Tetra Tech (2000). Data on mercury prior to 1999 are limited in number, did not use ultra-clean sampling and analysis, and are generally characterized by high detection limits. They are, therefore, of limited use in developing the TMDL.

Additional intensive sampling of the water in the reservoirs was conducted in June and August of 1999 using ultra-clean methods, as described in Tetra Tech (2000). These results are summarized in Table 3-5. Sampling locations within the reservoirs are shown in Figure 6 in Appendix A.

Table 3-5. Mercury in Water Column Samples, McPhee and Narraguinnep Reservoirs, 1999 (source: Tetra Tech, 2001).

Sample ID	Date	Unfiltered Total Mercury (ng/L)	Dissolved Total Mercury (ng/L)	Unfiltered Methylmercury (ng/L)	Dissolved Methylmercury (ng/L)
McPhee Reservoir					
MCP-A (3')	6/12/99	1.08	1.63	0.026	0.032
MCP-A (3') (rep)	6/13/99	1.76	NA	NA	NA
MCP-A (40')	6/12/99	1.99	1.36	0.045	0.022
MCP-B (3')	6/13/99	1.86	2.18	0.045	0.018
MCP-B (43')	6/13/99	2.46	1.64	0.030	0.035
MCP-C (3')	6/13/99	NA	1.12	0.045	0.021
MCP-C (43')	6/13/99	2.37	1.49	0.036	0.014
MCP-D (3')	6/13/99	1.73	1.36	0.023	0.017
MCP-D (43')	6/13/99	1.87	1.18	0.026	0.011
MCP-A (20')	8/9/99	0.88	0.56	0.031	<0.012
MCP-A (20') (rep)	8/10/99	1.22	0.78	0.012	0.017
MCP-A (35')	8/9/99	2.35	0.81	0.013	0.015
MCP-B (25')	8/10/99	0.87	0.67	0.014	0.012
MCP-B (40')	8/10/99	1.44	0.98	0.019	<0.012
MCP-C (25')	8/10/99	1.44	0.91	0.016	0.012
MCP-C (35')	8/10/99	1.56	1.01	0.034	0.017
MCP-D (25')	8/10/99	1.04	0.73	0.021	<0.012
MCP-D (40')	8/10/99	1.54	0.97	0.023	<0.012
Narraguinnep Reservoir					
NAR-A (1.5')	6/14/99	0.74	0.55	0.029	0.016
NAR-A (1.5') (rep)	6/15/99	0.80	0.46	0.018	0.026
NAR-A (13')	6/14/99	2.07	1.56	0.040	0.028
NAR-B (1.5')	6/15/99	0.75	0.62	0.031	<0.004
NAR-B (15')	6/15/99	0.94	0.63	<0.006	0.016
NAR-C (1.5')	6/15/99	1.53	1.36	0.009	0.032
NAR-C (6')	6/15/99	0.56	3.21	0.032	0.027
NAR-D (1.5')	6/15/99	1.12	0.51	<0.003	0.026
NAR-D (26')	6/15/99	1.49	0.70	0.050	0.026
NAR-A (3')	8/11/99	0.97	0.54	0.037	0.017
NAR-A (11.5')	8/11/99	0.85	0.45	0.032	<0.012
NAR-B (3')	8/11/99	0.90	0.40	0.025	0.021
NAR-B (8')	8/11/99	0.84	0.54	0.029	0.017
NAR-C (1.5')	8/11/99	1.85	1.06	0.022	0.025
NAR-D (20')	8/11/99	0.73	0.67	0.015	0.017
NAR-D (20') (rep)	8/11/99	0.60	0.63	0.020	<0.012
NAR-D (40')	8/11/99	0.73	0.56	0.028	0.015

Mercury sampling results for sediment are summarized in Table 3-6. In McPhee reservoir, the observed total mercury in sediment ranged from 13 to 131 ng/g. Methylmercury in the sediment was low in all samples (less than 0.6 ng/g) and did not appear to be strongly correlated with total mercury concentration. In Narraguinnep reservoir, the total mercury in sediment ranged from 15 to 60 ng/g. Methylmercury concentrations in Narraguinnep sediment were higher than those observed in McPhee, with a maximum of 1.2 ng/g. The highest methylmercury concentration in the sediment in June and August was in the eastern part of the Narraguinnep reservoir, near the inlet from McPhee.

Table 3-6. Mercury in Sediment Samples, McPhee and Narraguinnep Reservoirs, 1999 (source: Tetra Tech, 2001).

Sample ID	Date	% Moisture	pH (S.U.)	Total Hg (ng/g) dry wt.	Methyl Hg (ng/g) dry wt.	TOC (%)	Sulfate (mg/kg – dry)	Sulfide-S (mg/kg – dry)
McPhee Reservoir								
MCP-A-B	6/12/99	71.6	-	63.50	0.232	3.05	-	191(55)
MCP-B-B	6/13/99	68.3	-	55.07	0.085	2.25	-	139
MCP-C-B	6/13/99	51.2	-	131.48	0.557	2.62	-	34
MCP-D-B	6/13/99	38.0	7.1	22.56	0.132	0.98	-	13
MCP-A-B	8/9/99	78.6	7.4	13.05	0.015	0.14	11	<5.1
MCP-A-B-rep	8/10/99	53.5	7.4	40.23	0.234	0.11	11	<5.4
MCP-B-B	8/10/99	46.0	6.4	62.69	0.198	0.62	18	20
MCP-C-B	8/10/99	64.4	6.5	28.89	0.145	0.61	360	<9.7
MCP-C-B-rep	8/10/99	64.4	-	34.49	-	-	-	-
MCP-D-B	8/10/99	52.2	6.7	39.07	0.377	0.99	17	28
Narraguinnep Reservoir								
NAR-A-B	6/14/99	32.9	-	26.64	1.187	0.90	-	179
NAR-A-B-rep	6/14/99	28.4	-	24.89	0.960	0.62	-	187
NAR-B-B	6/15/99	44.8	7.9	23.50	0.156	0.65	-	423
NAR-C-B	6/15/99	22.2	-	18.34	0.059	0.29	-	5
NAR-D-B	6/15/99	54.8	-	36.20	0.046	1.03	-	84(79)
NAR-A-B	8/11/99	67.9	6.7	28.70	0.337	0.73	9.8	<6
NAR-B-B	8/11/99	68.5	7.0	15.52	0.142	0.62	18	20
NAR-C-B	8/11/99	76.7	6.7	16.49	0.129(.128)	0.61	360	<6.2
NAR-D-B	8/11/99	49.2	6.7	55.25	0.168	0.38	53	1600
NAR-D-B-rep	8/11/99	52.3	6.8	59.70	0.185	0.35	51	44

Note: Results of replicates shown in parentheses.

Mercury in Biota

A wide variety of both warm and cold water fish species exist in McPhee reservoir because of its large size and depth. The warm water gamefish species include the largemouth bass, smallmouth bass, northern pike (*Esox lucius*), walleye, channel catfish (*Ictalurus punctatus*), bluegill (*Lepomis macrochirus*), crappie (*Pomoxis annularis*), yellow perch (*Perca flavescens*), and others. The cold water gamefish species include the McConaughy rainbow trout (*Oncorhynchus mykiss*) and kokanee (*Oncorhynchus nerka*). A 1993 creel survey showed that rainbow trout and Kokanee salmon each accounted for 37 percent of the catch each, while smallmouth bass constituted 19 percent of the catch and yellow perch 6 percent. Largemouth bass and other species constituted less than one percent of catch.

Narraguinnep reservoir contains mostly warm water fish species. However, CDOW occasionally stocks some rainbow trout into the reservoir. The warm water gamefish species found in this reservoir include northern pike, walleye, bass, bluegill, crappie, and channel catfish. The CDOW also periodically stocks fingerling walleye into the reservoir.

Fish tissue samples were collected in McPhee and Narraguinnep reservoirs on several occasions between 1988 and 1991 (see Tetra Tech, 2000). In 1988, three whole-body samples were collected from each of the reservoirs. These samples showed that fish in Narraguinnep, but not McPhee, had whole-body mercury concentrations in fish above 0.5 µg/g wet weight (Butler et al., 1995). More extensive fish data were collected in 1989, 1990, and 1991 by CDOW and U.S. Fish and Wildlife Service (USFWS). These data are summarized in detail in Tetra Tech (2000). Most of the fish samples from McPhee had concentrations of mercury less than 0.5 µg/g. The range of mercury concentrations in the fish tissue was 0.08 µg/g in a composite Kokanee salmon sample from 1991 to 0.73 in a largemouth bass composite fillet sample from 1989, with four samples out of 25 above 0.5 µg/g wet weight. In May 1991, CDPHE established a fishing advisory for mercury in McPhee based on the elevated mercury concentrations observed in some largemouth bass samples.

The 1989-1991 fish tissue mercury concentrations reported for Narraguinnep ranged from 0.11 to 1.2 µg/g wet weight, all analyzed as fillets. As expected, the larger piscivorous fish, such as walleye and northern pike, had higher mercury concentrations than the non-piscivorous fish. Five of the nine samples had mercury concentrations above 0.5 µg/g, including walleye bigger than 12 inches long and northern pike bigger than 18 inches long. In May 1991, CDPHE established a fishing advisory for mercury in Narraguinnep based on the elevated mercury concentrations observed in some walleye and northern pike samples.

Additional fish samples were collected in 1999. These data are summarized in Table 3-7. The fish species analyzed at McPhee included smallmouth bass, black crappie (*Pomoxis nigromaculatus*), yellow perch, and rainbow trout. In McPhee reservoir, the highest mercury concentrations were measured in a 14-inch smallmouth bass (0.99 µg/g with replicate value of 0.52) and a 15-inch smallmouth bass (0.64 µg/g). Of the thirty samples analyzed, mercury concentrations in only these two smallmouth bass samples exceeded a concentration of 0.5 µg/g. Mercury concentrations in the different species increased with size and were consistent with diet in that the piscivorous fish such as smallmouth bass had higher mercury than fish that eat primarily insects and benthic invertebrates such as yellow perch.

The fish species analyzed for mercury from Narraguinnep included channel catfish, northern pike, walleye, and yellow perch. The highest mercury concentrations were measured in a 17-inch walleye (1.50 µg/g) and a 16-inch walleye (0.74 µg/g). There was one fish above 1.0 µg/g and five above 0.5 µg/g. All were walleye. The 1999 field sampling program confirmed that fish are present in both McPhee and Narraguinnep reservoirs with mercury concentrations above 0.5 µg/g in fillet samples. Most of the fish with elevated tissue concentrations are large piscivorous fish.

A variety of benthic invertebrates were also sampled in the reservoirs in 1999, as discussed in Tetra Tech (2000).

Table 3-7. Fish Tissue Samples from McPhee and Narraguinnep Reservoirs, 1999 (source: Tetra Tech, 2001).

Fish Type	Sample No.	Length (in.)	Weight (g)	Total Mercury (µg/g wet wt.)	Methylmercury (µg/g - wet wt.)	Tissue Wt. (g)	Percent Moisture	Date	Origin
McPhee Reservoir									
Smallmouth bass	MP01	15.35	760	0.6432	0.7451	85	79.3%	7/13/99	CDOW
Smallmouth bass	MP02	13.98	560	0.4118	0.3280	84	78.9%	7/13/99	CDOW
Smallmouth bass	MP03	7.09	79	0.1212	0.1019	19	79.2%	7/13/99	CDOW
Smallmouth bass	MP04	9.06	145	0.2834	0.2153	22	79.0%	7/13/99	CDOW
Smallmouth bass	MP05	4.37	15	0.1295	0.1130	2.5	80.3%	7/13/99	CDOW
Smallmouth bass	MP06	13.78	650	0.5147	0.4090	110	77.1%	7/13/99	CDOW
Smallmouth bass	MP06 (rep.)	13.78	650	0.9930	0.4889	110	77.1%	7/13/99	CDOW
Smallmouth bass	MP07	7.09	70	0.1711	0.1302	25	78.9%	7/13/99	CDOW
Smallmouth bass	MP08	11.02	310	0.1808	0.1693	50	79.5%	7/13/99	CDOW
Smallmouth bass	MP09	9.84	170	0.1978	0.1939	25	80.5%	7/13/99	CDOW
Smallmouth bass	MP10	12.60	440	0.2623	0.2514	65	77.4%	7/13/99	CDOW
Smallmouth bass	MP10 (rep.)	12.60	440	0.2597	NA	65	77.4%	7/13/99	CDOW
Black crappie	MP11	5.91	55	0.0832	0.0890	15	78.8%	7/13/99	CDOW
Black crappie	MP12	4.33	18	0.0733	0.0713	6	77.4%	7/13/99	CDOW
Black crappie	MP13	6.10	62	0.1146	0.1237	10	78.7%	7/13/99	CDOW
Yellow perch	MP14	6.30	55	0.1480	0.1557	9	77.1%	7/13/99	CDOW
Yellow perch	MP15	7.87	110	0.1416	0.1576	20	78.8%	7/13/99	CDOW
Yellow perch	MP16	6.50	68	0.2294	0.2334	10	78.4%	7/13/99	CDOW
Yellow perch	MP17	5.71	36	0.1629	0.1458	6	76.4%	7/13/99	CDOW
Yellow perch	MP18	5.91	50	0.1223	0.1031	7	77.2%	7/13/99	CDOW
Yellow perch	MP19	5.12	28	0.1112	0.0942	4	76.2%	7/13/99	CDOW
Yellow perch	MP20	4.72	18	0.0743	0.0794	3	79.8%	7/13/99	CDOW
Yellow perch	MP21	6.69	70	0.1665	NA	12	77.9%	7/13/99	CDOW
Yellow perch	MP22	7.09	90	0.1176	NA	14	78.6%	7/13/99	CDOW
Yellow perch	MP23	4.37	15	0.1140	NA	2	79.1%	7/13/99	CDOW
Rainbow trout	MP24	8.07	84	0.0308	NA	15	80.4%	7/13/99	CDOW
Rainbow trout	MP25	9.06	126	0.0264	NA	22	79.6%	7/13/99	CDOW
Rainbow trout	MP26	10.63	215	0.3078	NA	40	80.7%	7/13/99	CDOW
Rainbow trout	MP27	8.86	125	0.0268	NA	24	79.9%	7/13/99	CDOW
Rainbow trout	MP28	8.66	105	0.0280	NA	16	79.4%	7/13/99	CDOW
Rainbow trout	MP29	8.27	84	0.0392	NA	12	80.1%	7/13/99	CDOW
Rainbow trout	MP30	8.27	105	0.0246	NA	17	79.6%	7/13/99	CDOW

Fish Type	Sample No.	Length (in.)	Weight (g)	Total Mercury (µg/g wet wt.)	Methylmercury (µg/g - wet wt.)	Tissue Wt. (g)	Percent Moisture	Date	Origin
Table 3-7. (Continued)									
Narraguinnep Reservoir									
Walleye	NR01	18.11	1000	0.5914	NA	185	78.5%	7/13/99	CDOW
Walleye	NR02	16.93	750	0.5811	NA	104	74.6%	7/13/99	CDOW
Walleye	NR03	14.17	380	0.3435	NA	78	79.1%	7/13/99	CDOW
Walleye	NR04	13.39	340	0.3084	NA	62	78.6%	7/13/99	CDOW
Walleye	NR05	16.93	650	1.4977	NA	118	78.8%	7/13/99	CDOW
Walleye	NR06	16.14	625	0.7400	NA	125	78.1%	7/13/99	CDOW
Walleye	NR06 (rep.)	16.14	625	0.7416	NA	125	78.1%	7/13/99	CDOW
Walleye	NR07	15.35	550	0.5430	NA	105	78.6%	7/13/99	CDOW
Walleye	NR08	11.02	170	0.1709	NA	25	79.1%	7/13/99	CDOW
Northern pike	NR09	18.90	600	0.2215	NA	110	79.2%	7/13/99	CDOW
Northern pike	NR10	20.08	700	0.4197	NA	148	79.3%	7/13/99	CDOW
Yellow perch	NR11	11.42	400	0.1736	NA	55	76.6%	7/13/99	CDOW
Yellow perch	NR11 (rep.)	11.42	400	0.1736	NA	55	76.6%	7/13/99	CDOW
Yellow perch	NR12	11.81	455	0.1744	NA	85	76.1%	7/13/99	CDOW
Yellow perch	NR13	11.02	320	0.1250	NA	60	76.2%	7/13/99	CDOW
Yellow perch	NR14	13.58	580	0.2793	NA	100	72.9%	7/13/99	CDOW
Yellow perch	NR15	9.45	250	0.1152	NA	39	76.9%	7/13/99	CDOW
Yellow perch	NR16	7.09	85	0.1387	NA	20	77.0%	7/13/99	CDOW
Yellow perch	NR17	8.66	170	0.1397	NA	27	80.0%	7/13/99	CDOW
Yellow perch	NR18	7.48	95	0.0904	NA	16	77.5%	7/13/99	CDOW
Yellow perch	NR19	11.22	240	0.1512	NA	64	75.1%	7/13/99	CDOW
Yellow perch	NR20	9.06	175	0.1342	NA	23	76.4%	7/13/99	CDOW
Channel catfish	NR21	24.02	2730	0.3595	NA	360	76.4%	7/13/99	CDOW
Channel catfish	NR22	23.62	2755	0.3371	NA	355	74.9%	7/13/99	CDOW
Channel catfish	NR23	19.49	1420	0.3663	NA	170	62.9%	7/13/99	CDOW
Channel catfish	NR24	16.54	885	0.3027	NA	85	73.9%	7/13/99	CDOW
Channel catfish	NR25	23.43	2445	0.4374	NA	265	75.8%	7/13/99	CDOW
Channel catfish	NR26	20.47	1640	0.3101	NA	140	68.7%	7/13/99	CDOW
Yellow perch	NR27	11.22	415	0.1619	NA	82	74.8%	7/13/99	CDOW
Yellow perch	NR28	10.43	305	0.1378	NA	60	76.1%	7/13/99	CDOW
Yellow perch	NR29	7.87	130	0.1284	NA	23	77.4%	7/13/99	CDOW
Yellow perch	NR30	7.87	125	0.1046	NA	22	77.4%	7/13/99	CDOW

4. Linkage Analysis

A linkage analysis defines the connection between numeric targets and identified pollutant sources. The linkage is defined as the cause-and-effect relationship between the selected indicators, the associated numeric targets, and the identified sources. This provides the basis for estimating total assimilative capacity of the water body and any needed load reductions. For this TMDL, several models were used for the linkage analysis (see Tetra Tech, 2001). Specifically, models of the watershed loading of mercury were combined with a model of mercury cycling and the bioaccumulation in the reservoir fish to establish the relationship between the numeric target (expressed as a fish tissue concentration of mercury) and mercury loading rates. The loading capacity is then determined via the linkage analysis as the mercury loading rate that is consistent with meeting the target fish tissue concentration.

A key issue for the linkage analysis for a lake mercury TMDL is that fish tissue concentrations may not be directly predictable from external mercury loads alone. Instead, in-lake processes controlling water chemistry and consequent effects on mercury speciation and cycling may play a key role in determining the rate of mercury bioaccumulation and the resulting fish tissue concentration associated with a given loading rate. In particular, methylmercury concentrations in surface water and in shallow sediment areas where fish feed, rather than total mercury load to the reservoirs will drive mercury bioaccumulation. The linkage analysis therefore requires use of coupled models that: 1) estimate mercury loading to the Reservoirs; and 2) predict mercury cycling and speciation within the Reservoirs.

The biological mechanism that mediates the bioaccumulation process in McPhee and Narraguinnep reservoirs is not well-understood. The models used herein do not attempt to completely understand the bioaccumulation process, but rather to develop a relationship between water mercury levels and fish tissue mercury. That relationship is then used to estimate the necessary reduction in mercury levels in water to meet target mercury levels in fish tissue.

4.1 The Mercury Cycle

Development of a linkage analysis requires an understanding of how mercury cycles in the environment. Mercury chemistry in the environment is quite complex. Mercury has the properties of a metal (including great persistence due to its inability to be broken down), but also some of the properties of a hydrophobic organic chemical due to its ability to be methylated through a bacterial process. Methylmercury is easily taken up by organisms and tends to bioaccumulate; it is very effectively transferred through the food web, magnifying at each trophic level. This can result in high levels of mercury in organisms high on the food chain, despite nearly unmeasurable quantities of mercury in the water column. Usually, mercury levels found in fish are not high enough to cause toxic effects on the fish themselves, but wildlife that habitually eat contaminated fish may be at risk of accumulating mercury at toxic levels, and the mercury in sport fish can present a potential health risk to humans. The mercury cycle is discussed in detail in Tetra Tech (2001).

4.2 Structure of the Watershed Loading Component for the TMDL

While a mercury load can originate from a wide variety of sources, information characterizing many of these sources is limited. Lake and stream water and sediment monitoring for mercury in the McPhee and Narraguinnep watersheds by modern ultra-clean analytical methods consists primarily of the two sampling events conducted by Tetra Tech in June and August 1999 (Tetra Tech, 2000). There are consistent differences in concentrations between the two sampling events. Although these sampling events achieved good spatial coverage, two points in time are not enough to establish a reliable average, and cannot resolve seasonal trends.

Given the available data, it is useful to consider three components of the watershed transport of mercury: 1) dissolved and suspended particulate mercury during non-snowmelt conditions; 2) dissolved and suspended particulate mercury derived from the melting of the winter snowpack; and 3) bedload transport of particulate mercury.

Accordingly, the watershed ("external") loading of mercury is estimated using the three components described below. Each of these components is assessed on a geographic basis, and tied to individual source areas where data allow.

> ***1. Non-snowmelt loading of dissolved and suspended particulate mercury.*** The non-snowmelt portion of the water column transport of mercury is estimated from the average of total mercury concentrations in the June and August Tetra Tech samplings coupled with an analysis of flow.
>
> ***2. Snowmelt loading of dissolved and suspended particulate mercury.*** Mercury transport is potentially enhanced during the melting of the winter snowpack, as this may release any atmospheric deposition load accumulated and stored over the winter. Mercury loading in the water during snowmelt includes the "normal" load in the water, plus any additional mercury from the snowpack.
>
> ***3. Watershed sediment-associated mercury load.*** Much of the mercury load from the watershed likely moves in association with sediment during a few high flow scour events. The available sampling represents this mercury in terms of concentrations in bed sediments. Sufficient data are not available to calibrate a model of sediment transport in the watersheds. Therefore, an approximate approach was used, based on an assumption of long-term dynamic equilibrium in stream channels.

Each of these assumptions is a rough approximation only; however, they may be combined to provide an order-of-magnitude estimate of sediment-associated mercury delivery. It is important to note that the watershed load estimates implicitly account for the net effects of atmospheric deposition onto the watershed and its snowpack.

4.3 Watershed Hydrologic and Sediment Loading Model

An analysis of watershed loading can be conducted at many different levels of complexity, ranging from simple export coefficients to a dynamic model of watershed loads. For this TMDL, data were not available to specify parameters or calibrate a detailed representation of flow and sediment delivery within the watersheds. Therefore, a relatively simple, scoping-level analysis of watershed mercury load, based on an annual mass balance of water and sediment loading from the watershed was used (see Tetra Tech, 2001 for details). Uncertainty, introduced in the analysis by the use of a simplified watershed loading model, is addressed in the Margin of Safety.

4.3.1 Model Selection

Watershed-scale loading of water and sediment was simulated using the Generalized Watershed Loading Function (GWLF) model (Haith et al., 1992). The complexity of this loading function model falls between that of detailed simulation models, which attempt a mechanistic, time-dependent representation of pollutant load generation and transport, and simple export coefficient models, which do not represent temporal variability. GWLF provides a mechanistic, simplified simulation of precipitation-driven runoff and sediment delivery, yet is intended to be applicable as a scoping tool without formal calibration. Solids load, runoff, and ground water seepage can then be used to estimate particulate and dissolved-phase pollutant delivery to a stream, based on pollutant concentrations in soil, runoff, and ground water (Tetra Tech, 2001).

4.3.2 GWLF Model Input

The GWLF application requires information on land use distribution, meteorology, and parameters that govern runoff, erosion, and nutrient load generation. Four primary data sources were used to develop the model parameters used for the watershed simulations; 1) Digital Elevation Models (DEMs), 2) Land Use/ Land Cover geographic coverages, 3) soil characteristics databases, and 4) meteorological data (see Tetra Tech 2001 for details on data sources and input variables).

4.3.3 Watershed Model Results

The GWLF flow and sediment model was run for the period from May 1981 through April 1999 for the McPhee and Narraguinnep watersheds. The GWLF water and sediment simulation results were judged to provide sufficient accuracy for the intended purpose of initial mercury load estimation, although the over-prediction of average flows is likely to result in a high bias in the estimation of the water column mercury loads. The need for refinement of the watershed model will be evaluated based on the relative significance of this load component.

Sufficient data were not available to calibrate a model of sediment transport in the watersheds.

4.4 Watershed Mercury Loading Model

Estimates of watershed mercury loading are based on the flow and sediment loading estimates generated by GWLF through application of observed mercury concentrations in the two samplings. The observed concentrations were collected in 1999 and are described in Section 3.5. It is assumed that much of the mercury load from the watersheds moves in association with sediment during high flow scour events. Instream loadings were calculated by multiplying the observed mercury concentrations by estimated streamflow for the watershed area above the monitoring point. Similarly, the sediment-associated load was calculated by applying a sediment potency factor expressed as the mass of mercury per mass of sediment to the total estimated sediment load. Runoff and erosion estimates for individual watersheds were aggregated at tributary confluences to determine the total upstream load (see Tetra Tech, 2001).

For the Narraguinnep watershed, direct watershed loading to the reservoir is simply the sum of loading from individual watersheds. This is not the case in the more complex McPhee watershed, where sub-watersheds drain one into another before reaching the reservoir. In these watersheds, a sediment or water column sample at one point represents the net effects of all upstream areas, and several sample points may be present in sequence along a given path to the reservoir. Therefore, the analyses of the McPhee data incorporated the assessment of cumulative loads at specific monitored nodes within the watershed, as shown in Table 4-1.

Loads for individual sub-basins within the McPhee and Narraguinnep watersheds were calculated based on data collected at monitored nodes (see Tetra Tech, 2001 for description of nodes; see Figure 7 in Appendix A for sub-basin locations). The loads from individual sub-basins are summarized in Table 4-2 for the McPhee watershed and in Table 4-3 for the Narraguinnep watershed. Details of sub-basin load calculations are presented in Tetra Tech (2001).

The highest areal loading rate by far in the McPhee watershed is estimated for sub-basin 2, the Silver Creek drainage. The station at the outlet of this creek (MCP-11) had 4.25 ng/L total mercury in water in June 1999 but only 0.75 ng/L in August (see Tetra Tech, 2000 for sample results). On the other hand, sediment concentrations were 48 ng/g total mercury in June and 103 ng/g mercury in sediment in August 1999.

Sub-basins 1 and 2 intersect the Rico mining district. A large number of abandoned mines and several mine weeps are present in this area (see Tetra Tech, 2000). The Rico-Argentine mine on Silver Creek was one of the largest mines in this drainage and it has previously been suggested as a source of mercury contamination (Tetra Tech, 2000).

On the West Dolores River (sub-basins 4 and 10), samples were collected at the mouth (MCP-3) and at an up-river location (MCP-4). All sediment concentrations reported are relatively unremarkable (less than 50 ng/g total mercury), but water column mercury concentrations were elevated, reaching as high as 5.62 ng/L total mercury in June sampling at MCP-4. Significant mining activity occurred in the West Dolores watershed, primarily on Cold Creek near Dunton, about 36 miles upstream of the Reservoir. The elevated water column concentrations at MCP-4 suggest there are likely unidentified mine seep sources in this watershed, or high background mercury leaching from natural sources.

Within sub-basin 11 (Bear Creek), only an outlet station was sampled. Sediment concentrations were quite low, about 5 ng/g, but water column concentrations were elevated. Again, this may indicate loading to the water column from upstream mine seeps (see Tetra Tech, 2000).

For the Narraguinnep watershed, estimated loads by sub-basin are low (Table 4-3), relative to those for the McPhee watershed.

Estimates of mercury loading in the interbasin transfer from McPhee to Narraguinnep are based on the median total mercury concentration in the water column observed in McPhee during 1999 sampling (1.65 ng/L). This median value was multiplied times the average amount of the diversion from McPhee to the Montezuma Valley Irrigation Company (MVIC) reported as going into storage on Annual Water Diversion Reports filed with the State Engineer over the period 1989-1998 (7,952 ac-ft per yr). The resulting estimate for mercury loading via interbasin transfer is 15.9 g Hg/yr (Table 4-3).

Table 4-1. Cumulative Upstream Mercury Loads at Nodes in the McPhee Watershed (source: Tetra Tech, 2001).

Node	Sample Station	Sub-basins	Water Column Mercury Load (g/yr)	Sediment Mercury Load (g/yr)	Total Mercury Load (g/yr)	Total Mercury Areal Loading (mg/km^2/yr)	Areal Water Column Loading (mg/km^2/yr)	Areal Sediment Hg Loading (mg/km^2/yr)
2	MCP-11	2	49.5	37.4	86.9	4830.1	2750.0	2080.1
4	MCP-3	4,10	647.1	61.0	708.1	1626.7	1486.6	140.1
5	MCP-5	1,2,3,5,11	1283.2	72.0	1355.2	1860.2	1751.40	98.8
6	Median*	6,8	296.8	88.2	385.0	873.6	673.5	200.2
9	MCP-2	9	85.5	0.4	85.9	474.1	471.6	2.4
10	MCP-4	10	137.3	8.9	146.2	1352.5	1270.1	82.3
11	MCP-7	11	140.3	0.5	140.8	1576.9	1571.1	5.8
12	MCP-17	1,2,3,4,5,7,9, 10,11,12	2278.7	133.4	2412.1	1455.5	1374.9	80.5

* No monitoring data are available for this watershed. Data from adjacent location were used to estimate mercury loadings.

Table 4-2. Individual Sub-basin Mercury Loads in the McPhee Watershed (source: Tetra Tech, 2001).

Watershed	Sample Station	Water Column Mercury Load (g/yr)	Sediment Mercury Load (g/yr)	Total Mercury Load (g/yr)	Total Mercury Areal Loading (mg/km^2/yr)	Areal Water Column Loading (mg/km^2/yr)	Areal Sediment Hg Loading (mg/km^2/yr)
1	Difference[b]	349.2	10.4	359.6	1901.2	1846.3	55.0
2	MCP-11	49.5	37.4	86.9	4835.8	2754.6	2081.2
3	Difference[b]	566.9	17	583.9	967.5	939.4	28.1
4	Difference[b]	509.8	52.1	561.9	1290.9	1171.2	119.7
5	Median[a]	177.3	6.7	184.0	252.6	243.4	9.2
6	Median[a]	156.2	52.2	208.4	472.9	354.4	118.5
7	Difference[b]	172.4	0	172.4	131.8	131.8	0.0
8	Median[a]	140.6	36	176.6	957.9	762.6	195.2
9	MCP-2	85.5	0.4	85.9	474.1	471.6	2.4
10	MCP-4	137.3	8.9	146.2	1352.3	1270.0	82.3
11	MCP-7	140.3	0.5	140.8	1576.7	1570.9	5.8
12	Difference[b]	90.5	0	90.5	54.6	54.6	0.0
Total to Reservoir		**2575.5**	**221.6**	**2797.1**	**1333.2**	**1227.6**	**105.6**

[a] No monitoring data are available for this watershed. The median of sample values was used to estimate mercury loadings.

[b] Watershed estimate obtained by differencing cumulative estimates in Table 4-1.

Table 4-3. Individual Sub-basin Mercury Loads in the Narraguinnep Watershed (source: Tetra Tech, 2001).

Watershed	Sample Station	Water Column Mercury Load (g/yr)	Sediment Mercury Load (g/yr)	Total Mercury Load (g/yr)	Total Mercury Areal Loading (mg/km^2/yr)	Areal Water Column Loading (mg/km^2/yr)	Areal Sediment Hg Loading (mg/km^2/yr)
1	Nar-2	0.3	20.2	20.5	8877.5	121.6	8755.9
2	Median[a]	0.2	0.9	1.1	604.5	120.7	483.8
3	Median[a]	1.4	1.5	2.9	239.2	112.1	127.1
4	Nar-1	0.2	0	0.3	111.7	99.5	12.2
5	Median[a]	0.4	0	0.4	170.5	169.8	0.7
6	Median[a]	0.3	0	0.3	136.5	120.7	15.8
Inflow from McPhee	MCP-A	15.9	0	15.9	0	0	0
Total to Reservoir[b]		**18.7**	**22.6**	**41.4**	**1109.9**	**118.8**	**991.1**

[a] No monitoring data are available for this watershed. The median of sample values was used to estimate mercury loadings.

[b] Areal estimates include load from direct watershed only and exclude inflow from McPhee.

To estimate total external mercury loads, the watershed loading estimates of mercury (summarized in Tables 4-2 and 4-3) were combined with the estimates of direct atmospheric deposition of mercury to the Reservoir surface (summarized in Table 3-3). The total load estimates are summarized in Table 4-4. In addition to loading rates, this Table also summarizes load per volume and surface area of the reservoirs, both of which are useful indices of potential biotic impact.

Table 4-4. Summary of Mercury Load Estimates for McPhee and Narraguinnep Reservoirs (source: Tetra Tech, 2001).

Reservoir	Watershed Runoff (g/yr)	Watershed Sediment (g/yr)	Interbasin Transfer (g/yr)	Atmos. Deposition (g/yr)	Total (g/yr)	Load per Volume (mg/ac-ft)	Load per Surface Area (mg/m^2)
McPhee	2,576	222	0	251	3,049	4.66	0.098
Narraguinnep	2.7	22.7	15.9	36.8	78.1	4.59	0.035

The loads are expressed on a percentage basis in Table 4-5. Based on these values, loading to McPhee appears to be dominated by water column loads derived from watershed runoff. This likely reflects the significance of mercury loading in dissolved and suspended form from mine seeps. Atmospheric deposition to the reservoir surface accounts for less than 10 percent of the total load to McPhee reservoir. In contrast, atmospheric deposition accounts for close to 50 percent of the total load for Narraguinnep reservoir. The reason that the two reservoirs, within a few miles of each other, can have substantially different mercury contributions from atmospheric deposition is because Narraguinnep reservoir represents a larger percentage of the drainage basin than does McPhee reservoir’s surface area. Loads to Narraguinnep also include a significant contribution (estimated at 20%) via interbasin transfer from McPhee.

Table 4-5. Summary of Mercury Load Estimates for McPhee and Narraguinnep Reservoirs on a Percentage Basis (source: Tetra Tech, 2001).

Reservoir	Watershed Runoff	Watershed Sediment	Interbasin Transfer	Atmospheric Deposition
McPhee	84.5 %	7.3 %	0.0 %	8.2 %
Narraguinnep	3.4 %	29.1 %	20.4 %	47.1 %

4.5 Lake Hydrologic Model

The hydrologic behavior of the reservoirs, particularly the residence time of stored water, is an important factor in determining mercury response. Because the estimates of watershed loading are best interpreted as long-term averages, the hydrologic behavior of the reservoirs was also represented on a long-term average basis by generating average monthly water balances. Details of the hydrologic characteristics of the reservoirs are presented in Tetra Tech (2001).

For McPhee reservoir, data from October 1, 1986 (when the reservoir reached full capacity) through September 30, 1999 were used to estimate average monthly conditions. Over this period, McPhee had an average depth of 81.5 feet, an average surface area of 3,890 acres, an average volume of 318,000 acre-feet, and an average annual inflow of about 380,000 acre-feet. This yields an average residence time of 0.82 years. The water balance information available for

Narraguinnep reservoir is much less detailed. However, depths and volumes appear to have been relatively stable, with an average depth of about 67.5 feet, an average volume of about 17,000 acre feet, an average surface area of 550 acres, and an average annual inflow of 7,952 acre-feet. This corresponds to a residence time of 2.5 years.

4.6 Lake Mercury Cycling and Bioaccumulation Model

Cycling and bioaccumulation of mercury within McPhee reservoir were simulated using the Dynamic Mercury Cycling Model (D-MCM; Tetra Tech, 1999c). D-MCM is a Windows 95/NT-based simulation model that predicts the cycling and fate of the major forms of mercury in lakes, including methylmercury, Hg(II), and elemental mercury. D-MCM is a time-dependent mechanistic model, designed to consider the most important physical, chemical, and biological factors affecting mercury concentrations in lake fish. It can be used to develop and test hypotheses, scope field studies, improve understanding of cause/effect relationships, predict responses to changes in loading, and help design and evaluate mitigation options.

Three compartments are included in the model: 1) water column; 2) sediments; and 3) a food web. The food web compartment consists of six trophic levels (phytoplankton, zooplankton, benthos, non-piscivorus fish, omnivorous fish, and piscivorus fish). Mercury concentrations in fish tend to increase with fish age and, thus, increase with subsequent year classes.

The D-MCM model (or precursors to it) has been applied to 21 lakes in Wisconsin; Lake Barco, Florida; and Lake 240 at the Experimental Lakes Area, Ontario (Tetra Tech, 2001). In general, the performance of the model has been very good. However, the predictive capability of D-MCM is evolving and is currently limited by some scientific knowledge gaps, which include:

- The true rates and governing factors for methylation and Hg(II) reduction;
- Factors governing methylmercury uptake at the base of the food web; and
- The effects of anoxia and sulfur cycling

4.7 D-MCM Model Application to McPhee Reservoir

4.7.1 Approach to Model Calibration

The model was initially calibrated on the basis of estimated long-term average conditions for McPhee reservoir. Most of the site mercury data used for the calibration were collected by Tetra Tech, Inc. during field campaigns in June and August 1999 (Tetra Tech, 2000). Watershed loads for total mercury were estimated from a watershed model as described in Tetra Tech (2001). Estimates of atmospheric wet Hg(II) deposition are described in detail in Section 3.3. They are based primarily on 1999 mercury deposition data from Buffalo Pass, Colorado and a relationship to SO_4/NO_3 deposition in southwest Colorado, monitored by NADP.

The D-MCM model was calibrated to reproduce observed mercury concentrations in sediments, water and fish. An existing calibration for Little Rock Reference Lake in Wisconsin was used as a starting point that included previously calibrated values for all parameters relevant to mercury cycling (partitioning and reaction rate constants, etc.). Inputs associated with site conditions (bathymetry, flow rates, temperature, water chemistry, particulates, etc.) and external mercury loading were then modified to reflect conditions at McPhee reservoir, where data were available or could be estimated. Adjustments were also made to modeling factors, such as partitioning methylmercury into benthic organisms and the activity coefficient for fish, in order to calibrate the model to predict why low levels of mercury in water were related to high levels in fish tissue. The model was then run and results compared to field data (see Tetra Tech, 2001 for details).

Following calibration, the model was run for simulations of 100 years with annual deposition patterns and site conditions repeating year after year, often with monthly frequencies for inputs. The resulting estimates of mercury concentrations and fluxes after the system had effectively stabilized (i.e., concentrations were not changing year to year) were reported on a weekly basis for the 101st year of the simulation to examine the seasonality of the predictions (see Tetra Tech, 2001 for details).

4.7.2 Approach to Developing an Hg(II) Dose-Fish Response Curve

One of the central questions for the McPhee reservoir mercury TMDL modeling exercise was to predict the relationship between external Hg(II) loading and long-term fish mercury concentrations. This TMDL adopts a 15-inch (38.1 cm) smallmouth bass as the benchmark standard for the analyses, as described in Section 2. To make these predictions, simulations were conducted with different Hg(II) loads maintained for a period of 100 years until fish mercury concentrations were at a quasi-steady state from year to year. Simulations focused on the potential effects of Hg(II) load reductions on fish mercury concentrations, with predictions made for load reductions of 15, 25, 50, and 60 percent. These results were then combined in plots to show the shape of the Hg(II) dose/long-term fish Hg response curve, as detailed in Tetra Tech (2001).

4.8 Lake Model Scenario Development

4.8.1 Inputs for Model Simulations

Input data and sources for simulations of McPhee reservoir are summarized in Table 4-6. Additional details of the development of specific inputs are provided in Tetra Tech (2001).

Table 4-6. Summary of Lake Model Inputs for McPhee Reservoir by Major Data Type Category (source: Tetra Tech, 2001).

Data Type	Parameter Estimate and Source
Hydrologic Data	
Precipitation	Monthly aggregation of daily data observed at Dolores (1980-99) (see Section 4.3)
Surface water elevations	Obtained from U.S. Bureau of Reclamation operational data for Reservoir
Surface flow	Smoothed average of U.S. Bureau of Reclamation data for Oct. 1986 (reservoir first approaches full pool) to Sept. 1999
Physical Data	
Water and air temperature	Data estimated from daily air temperature values for Yellow Jacket COOP SOD station (see section 4.3)
Mercury Loadings	
Wet Hg(II) deposition	Estimated as described in Section 3.3
Dry Hg(II) deposition	Estimated using assumption that dry = 0.65 of wet deposition (see Section 3.3)
Upstream surface water concentrations – Hg(II)	Concentrations based on June and August 1999 data reported in Tetra Tech (2000) as processed in the watershed model (Section 4.3) to calculate long-term average flow-weighted concentrations using watershed simulation for 1980-1999 meteorology
Upstream surface water concentrations – MeHg (unfiltered)	Based on average of Dolores River data (June and August, 1999, sites NCP3, MCP5, MCP17), Tetra Tech (2000)
Surface Water Chemistry	
Dissolved Organic Carbon (DOC)	Mean value of field data from 6/99 and 8/99 (Tetra Tech, 2000)
pH and dissolved oxygen	Mean value of field data from 6/99 and 8/99
SO_4^{2-}	Mean value of field data from 6/99 and 8/99
Hg Concentrations in Reservoir	
Surface water Hg_{total} and MeHg (filtered and unfiltered)	Mean value of field data from 6/99 and 8/99
Sediment Hg	Mean value of field data from 6/99 and 8/99
Sediment pore-water chemistry	No data available
Food Web	
Yellow perch Hg concentrations for model calibration	1999 sampling (see Section 3.6)
Smallmouth bass mercury concentrations for model calibration	1999 sampling (see Section 3.6). The data are contained in MCP899.xls (1/12001) and Tetra Tech, Inc. (2000)
Fish growth	No site data available. Used average growth rate of fish in the Central Front Range of Colorado (CO Fishing Federation, 1996)
Phytoplankton mercury	No data available
Zooplankton mercury	1999 sampling
Benthos mercury (Oligochaetes [red worms] and fly larvae)	August 1999 field data (Tetra Tech, 2000)

4.9 McPhee Reservoir Simulation Results

4.9.1 D-MCM Calibration to Current Loadings, McPhee Reservoir

Good agreement between model predictions and observed mercury levels in sediments and surface waters were achieved using the original parameters from the model calibration. Model predictions for McPhee reservoir are presented together with observed concentrations for Hg(II) and methylmercury in surface waters and sediments in Table 4-7. Model predictions fall within the range of observed values for both unfiltered and dissolved total mercury in surface waters and for particulate total mercury in the sediments. After initial calibration, adjustments were made to model components as part of the calibration process (Tetra Tech, 2001).

Table 4-7. Comparison of Observed and Predicted Hg Concentrations in Surface Waters and Sediments in McPhee Reservoir (source: Tetra Tech, 2001).

Parameter	Units	Predicted		Observed	
		Mean	Range	Mean	Range
Unfiltered total Hg, surface water	ng/L	1.56	1.24 to 2.58	1.61 (n=9)	0.87 to 2.46
Unfiltered MeHg, surface water	ng/L	0.029	0.020 to 0.051	0.026 (n=9)	0.012 to 0.045
Total Hg, sediment solids	ug/g dry	0.053	0.052 to 0.055	0.049 (n=10)	0.023 to 0.131
MeHg, sediment solids	ug/g dry	0.00052	0.0003 to 0.0006	0.00022 (n=9)	0.00002 to 0.0006

The discrepancy between low methylmercury concentrations measured in water and sediments versus the higher levels in smallmouth bass requires further field studies to refine the modeling to determine the mechanisms involving biomagnification and bioaccumulation. In particular, the modeling effort suggests that there may be prey items in the fish diet that had higher methylmercury concentrations than those sampled in the field. These could represent either species not sampled or elevated concentrations at localized areas not occupied during the sampling (see Section 7), or other uptake mechanism not well known at this time.

4.9.2 Dynamic Response of MeHg Levels in Smallmouth Bass

A fundamental purpose for the modeling effort was to examine the temporal response of mercury levels in McPhee reservoir smallmouth bass to reductions in external mercury loading (see Tetra Tech, 2001). The estimated dynamic response of the methylmercury concentration in smallmouth bass to load reductions of 15, 25, 52 and 60 percent is presented in Figure 8 in Appendix A. In all cases, methylmercury concentrations were estimated to achieve a quasi-steady state predicted level within 25-30 years. The model predicts that the target concentration of 0.5 µg/g will be achieved in under 20 years with a 15 percent reduction in loads. The existing mercury load to McPhee reservoir is estimated to be 3,049 g/yr (Table 4-4). Thus, a 15% reduction results in a loading capacity to the reservoir of 2,592 g/yr to achieve the target concentration of $\leq$ 0.5 µg/g in smallmouth bass. For purposes of this Phase 1 TMDL, this estimated value forms the basis of the load allocation portion of the TMDL (Section 5).

4.10 Discussion of McPhee Reservoir Results

D-MCM reasonably predicted concentrations of total and methylmercury in surface waters and sediments (Table 4-7). Total mercury and methylmercury concentrations in the surface waters and sediments of McPhee reservoir are within the typical range for freshwater systems. This suggests that if there was an increase in methylmercury levels following the creation of the reservoir in the mid 1980s, this reservoir effect is no longer producing elevated MeHg concentrations in surface waters or sediments, at least in the areas sampled.

Mercury concentrations in yellow perch and smallmouth bass were initially under-predicted by the model, reflecting the low methylmercury concentrations predicted in surface waters, sediments, and the lower food web (plankton and benthos). However, once calibration adjustments were made, the model reasonably predicted MeHg levels in smallmouth bass (see Tetra Tech, 2001).

Overall, the basic discrepancy between low methylmercury concentrations observed (and modeled) in water and sediments, as opposed to the higher levels seen in fish, particularly smallmouth bass, will require further field studies to assess likely explanations. The modeling effort suggests there are probably dietary items eaten by perch and bass that have higher methylmercury concentrations than those sampled during field programs. It is also possible that while the model assumes homogeneous conditions within each sediment zone, there could be localized areas, not sampled, with increased sediment methylmercury production and higher benthic methylmercury concentrations than the model predicted.

Figure 8 in Appendix A shows that mercury concentrations in 15-inch smallmouth bass in McPhee reservoir are predicted to respond significantly within the first decade following Hg loading reductions. Regardless of the magnitude of the load reduction, fish mercury concentrations are predicted to change by 50 percent of the ultimate response within 6 years. Within 25 years, 90 percent of the ultimate predicted response is predicted to occur. The actual magnitude of the change in fish Hg is of course dependent on the magnitude of the load reduction, as shown in Figure 8. These results are significantly influenced by the assumption that concentrations of Hg(II) and methylmercury in inflows would drop immediately in proportion to reduced atmospheric deposition. If a lag time is involved between reduced atmospheric Hg deposition and Hg concentrations in inflows, the response time for fish in McPhee reservoir would be slower. This situation is quite plausible.

The predicted response of fish mercury concentrations to load reductions in this study reflects the current level of understanding. This level of understanding is currently inadequate, however, to place a robust confidence in the predictions. Finally, there is uncertainty associated with this modeling assessment because a sampling program on two dates in a single year (June and August 1999) cannot incorporate the natural variability of mercury concentrations and fluxes both seasonally and from year to year. The same limitation exists due to the lack of a long-term monitoring dataset for atmospheric mercury deposition at or near the site. Further data collection and analysis are needed to reduce the level of uncertainty (see Section 7).

4.11 Mercury Responses in Narraguinnep Reservoir

There were neither sufficient hydrologic data nor available resources to complete a detailed lake model application for Narraguinnep Reservoir. However, Narraguinnep is supplied predominantly by water diverted from the McPhee reservoir and is physically near McPhee, experiencing the same climate and areal atmospheric mercury loading. Thus, general mercury dynamics in Narraguinnep are expected to be similar to those in McPhee. However, the specifics of mercury dynamics in Narraguinnep are expected to differ from those in McPhee due to a number of factors, including different residence time, the size and shape of the reservoir, different fish populations, and the probable significance of methylation of mercury in wetlands surrounding the reservoirs (which are in part fed by irrigation water diverted from McPhee).

The key assumption made for the analysis of mercury responses in Narraguinnep is that, over the long term, fish body burdens will respond approximately linearly to reductions in external mercury load, as is predicted for McPhee. Given similar water column mercury concentrations in McPhee and Narraguinnep, and assumed nearly identical atmospheric conditions, the slope of the fish mercury response curve to external loading is expected to be similar in Narraguinnep and McPhee reservoirs. This assumption needs to be verified through additional data collection and modeling for Narraguinnep reservoir (see below and Section 7).

The analysis for Narraguinnep was therefore developed through an empirical analogy to the detailed modeling work for McPhee, while accounting for the different biological characteristics of the two reservoirs. As discussed in Section 2, the target species for Narraguinnep reservoir is an 18-inch walleye. The analysis was then developed using the following steps (as detailed in Tetra Tech, 2001):

1. The walleye data for Narraguinnep (Tetra Tech, 2000) were analyzed based on a log-log regression of fish mercury versus length. This yielded an estimated best estimate of current mercury tissue concentrations in 18-inch walleye of 0.93 µg/g wet weight.

2. The D-MCM modeled relationships from McPhee were used to predict the fractional reduction in long-term fish tissue concentrations of mercury as a function of reductions in external mercury loading.

The regression relationship from the D-MCM application to McPhee is $y = 0.9298 \cdot x + 0.0702$, where y is the fraction of current mercury in top-predator fish and x is the fraction of current external mercury loading. This relationship was developed for 15-inch smallmouth bass in McPhee, but the model simulation results for McPhee show that the predicted effects of load reductions on long-term fish mercury levels are similar across fish species and/or sizes. Thus, in the long-term, this relationship should also be appropriate for walleye in Narraguinnep. Using this regression relationship, the D-MCM model predicted that the target concentration of 0.5 µg mercury/g in walleye from Narraguinnep reservoir will be achieved in under 20 years with a 49.9% reduction in total mercury loads. The existing load to Narraguinnep is estimated to be 78.1 g mercury/yr (Table 4-4). Thus, a 49.9% reduction will result in a total mercury loading capacity for Narraguinnep reservoir of 39.1 g/yr.

The lack of a detailed, site-specific model introduces additional uncertainty into the analysis of fish response in Narraguinnep reservoir. This uncertainty could be reduced through the development and calibration of a detailed lake response model for Narraguinnep. Without such a model the data indicate that significant reductions in mercury loading are needed to achieve the TMDL fish tissue target in Narraguinnep reservoir, but the estimated level of needed reductions is less certain than it would be with creation of a model. For both McPhee and Narraguinnep, collection of additional data over additional seasons and for additional physical and biotic compartments would improve both the understanding of mercury dynamics and the accuracy of modeling. Thus, ongoing data collection will be pursued, together with creation of a model for Narraguinnep reservoir, concurrent with efforts to reduce loads (see Section 7).

5. TMDL, Load Allocations, and Wasteload Allocations

The linkage analysis provides the quantitative basis for determining the loading capacity of McPhee and Narraguinnep reservoirs. This in turn allows estimation of the Total Maximum Daily Load (TMDL) and allocation of that load to point sources (wasteload allocations) and nonpoint sources (load allocations). The TMDL must also contain a Margin of Safety, which is described in detail in Section 6.

5.1 Determination of Loading Capacity

A waterbody’s loading capacity represents the maximum rate of loading of a pollutant that can be assimilated without violating state water quality standards. Application of the D-MCM lake mercury model provides best estimates of the loading capacity for mercury of McPhee reservoir of 2,592 grams total mercury per year (Section 4.9.2). This is the maximum rate of loading consistent with meeting the numeric target of 0.5 µg/g mercury in fish tissue. This value is derived from the D-MCM model calculations reviewed in Section 4, which predicted that a mercury concentration of 0.5 µg/g in smallmouth bass would be achieved in under 20 years with a 15% reduction in loads to McPhee reservoir (Figure 8 in Appendix A). The existing load to the reservoir is 3,049 g Hg/yr (Table 4-4). Thus, a 15% reduction results in a total loading capacity of 2,592 g Hg/yr.

For Narraguinnep reservoir, the existing load is estimated to be 78.1 g total mercury per year (Table 4-4) and the loading capacity is estimated to be 39.1 grams total mercury per year (Section 4.11). The loading capacity is based on a 49.9% reduction in total loads, which was derived from the regression relationship for Narraguinnep described in Section 4-11.

The loading capacity estimates for McPhee and Narraguinnep reservoirs are subject to considerable uncertainty, as described in the preceding sections. The CWA requires that a TMDL incorporate “a Margin of Safety which takes into account any lack of knowledge concerning the relationship between effluent limitations and water quality”. Thus, uncertainty in the estimation of the loading capacity, and the TMDL, is addressed through the assignment of a Margin of Safety (Section 6).

It should also be noted that the loading capacity is not necessarily a fixed number. The numeric target for the TMDL is expressed as a mercury concentration in fish tissue. This numeric target is linked to the external mercury load through a complex series of processes, including methylation/ demethylation of mercury and burial of mercury in reservoir sediments, which are not well understood. Any alterations in rates of methylation or in rates of mercury loss to deep sediments will change the relationship between external mercury load and fish tissue concentration and would thus result in a change in the loading capacity for external mercury loads.

5.2 Total Maximum Daily Load

A TMDL represents the sum of all individual allocations of portions of a waterbody's loading capacity. Allocations are made to all point sources (wasteload allocations) and nonpoint sources or natural background (load allocations). The TMDL (sum of allocations) must be less than or equal to the loading capacity. It is equal to the loading capacity only if the entire loading capacity is allocated. In many cases it is appropriate to hold in reserve a portion of the loading capacity to provide a Margin of Safety, as provided for in the TMDL regulation.

Because of the uncertainties associated with modeling and source assessments identified previously (summarized in Section 6) and the need for additional data identified in Phase 2 (Section 7), Phase 1 of this TMDL provides a preliminary allocation assessment. Future data collection and analysis efforts identified in Section 7 will allow for a more refined allocation assessment in the future. The preliminary allocations presented here are considered a good estimate of the true allocations based on the existing data, but additional data (which will be collected in Phase 2 of the TMDL) are needed to increase the reliability of the estimates.

5.3 Unallocated Reserve

The best estimate of uncertainty in the loading capacity analysis is that the true loading capacity lies within plus or minus 25 percent of the best estimate of annual loading (see Section 6 for a rationale). In the preliminary allocation assessment presented here, thirty percent of the estimated loading capacity is held as an unallocated reserve. The unallocated reserve is thus greater than the estimated Margin of Safety for the TMDL.

Therefore, the TMDL calculated for McPhee reservoir is equivalent to a total annual mercury loading rate of 1,814 g/yr (70 percent of the loading capacity of 2,592 g/yr), while the TMDL for Narraguinnep reservoir is equivalent to a total annual mercury loading rate of 27.3 g/yr (70% of 39.1 g/yr). This equates to an estimated unallocated reserve of 778 g-Hg/yr in McPhee and 11.8 g-Hg/yr in Narraguinnep. The load allocation estimates are summarized in Table 5-1 for McPhee reservoir and in Table 5-2 for Narraguinnep reservoir.

5.4 Load Allocations

Load allocations represent assignment of a portion of the TMDL to nonpoint sources. These allocations must be made even where there is considerable uncertainty about nonpoint loading rates. Federal regulations (40 CFR 130.2(g)) define a load allocation as follows:

> The portion of a receiving water's loading capacity that is attributed either to one of its existing or future nonpoint sources of pollution or to natural background sources. Load allocations are best estimates of the loading, which may range from reasonably accurate estimates to gross allotments, depending on the availability of data and appropriate techniques for predicting loading. Wherever possible, natural and nonpoint source loads should be distinguished.

The current state of knowledge about mercury sources in the McPhee and Narraguinnep watersheds as well as the transport mechanism of mercury to the reservoirs requires use of a “gross allotment” approach to the watershed as a whole, rather than the assignment of individual load allocations to specific tracts or land areas within the watershed. Loading from geologic sources has also not been separated from the net impacts of atmospheric deposition onto the watershed.

For McPhee reservoir, the following sources were identified for load allocations.

- Direct atmospheric deposition onto the reservoir surface.
- Loading from the Rico/Silver Creek mining area.
- Loading from the Dunton mining area.
- Loading from the La Plata mining area.
- Generalized background watershed loading, including mercury derived from parent rock and soil material, residual mercury from mining operations other than those addressed above, and the net contribution of atmospheric deposition onto the watershed land surface.

For Narraguinnep reservior, one important source of mercury load is inter-basin transfer from McPhee. This means that the allocations for McPhee might also need to be limited to meet targets in Narraguinnep.

For Narraguinnep reservoir, the following sources were identified for load allocations:

- Direct atmospheric deposition onto the reservoir surface.
- Inter-basin transfer from McPhee reservoir.
- Generalized background watershed loading, including the net contribution of atmospheric deposition onto the watershed land surface.

Direct Atmospheric Deposition

Direct deposition to the surface of McPhee reservoir (exclusive of the load from the rest of the watershed) is estimated to provide about 251 g-Hg/yr (Table 3-3). This amount is less than 10 percent of the estimated total annual mercury loading (all sources) to the reservoir (3,049 g/yr - Table 4-4). In contrast, the atmospheric load to the surface of Narraguinnep reservoir is estimated at 37 g-Hg/yr (Table 3-3), or about 47 percent of the total load to the Reservoir (78.1 g/yr - Tables 4-4 and 4-5). The estimated areal rate of mercury deposition (the rate of loading per square meter of surface area) is similar for both reservoirs (Table 3-2). However, the relative contribution of mercury from atmospheric sources is estimated to be much higher for Narraguinnep (Table 4-5) than for McPhee because contributions of mercury to Narraguinnep from other sources (e.g., inter-basin transfer and watershed) are small compared to those for McPhee. Thus, fish tissue concentrations in Narraguinnep are much more strongly driven by atmospheric deposition than are fish tissue concentrations in McPhee. Therefore, the need for reductions in direct atmospheric deposition is driven by the goal of meeting fish tissue concentrations in Narraguinnep.

In this preliminary allocation assessment, a 75 percent reduction in atmospheric deposition loads to both reservoirs is used to meet the TMDL goals. The estimates of direct atmospheric deposition of mercury are 251 g/yr to the surface of McPhee reservoir and 36.8 g/yr to the surface of Narraguinnep reservoir (Table 4-4). Thus, a 75% reduction results in direct atmospheric deposition allocations of 63 g Hg/yr for McPhee reservoir and 9.2 g-Hg/yr for Narraguinnep reservoir (Tables 5-1 and 5-2).

Table 5-1. Summary of Preliminary TMDL Allocations and Needed Load Reductions (in g-Hg/yr) for McPhee Reservoir (source: Tetra Tech, 2001).

Source	Existing Load	Needed Reduction	Allocation[1]
Wasteload Allocations (WLA)	0	0	0
Load Allocations (LA)			
Atmospheric Deposition	251	188	63
Rico/Silver Creek Mining Area	1,030	523	507
Dunton Mining Area	708	360	348
La Plata Mining Area	141	72	69
Watershed Background	919	92	827
Load & Wasteload Allocation Total	3,049	1,235	1,814
Unallocated Reserve (UR)			778
Loading Capacity (LC = TMDL)[2]			2,592

[1] to calculate the Allocation, subtract the Needed Reduction from the Existing Load.

[2] The TMDL, or Loading Capacity, for the Reservoir was calculated using the following equation:

TMDL = LC = WLA + LA + UR, where,

TMDL = the Total Maximun Daily Load or Loading Capacity (LC) of the Reservoir (see Section 5.1)
WLA = the Wasteload Allocations (see Section 5.5)
LA = the Load Allocations (see Section 5.4)
UR = the Unallocated Reserve, which includes the Margin of Safety (see Section 5.3)

Table 5-2. Summary of Preliminary TMDL Allocations and Needed Load Reductions (in g-Hg/yr) for Narraguinnep Reservoir (source: Tetra Tech, 2001).

Source	Existing Load	Needed Reduction	Allocation[1]
Wasteload Allocations (WLA)	0	0	0
Load Allocations (LA)			
Atmospheric Deposition	36.8	27.6	9.2
Inter-basin Transfer from McPhee Reservoir	15.9	6.4	9.5
Watershed Background	25.4	16.8	8.6
Load & Wasteload Allocation Total	78.1	50.8	27.3
Unallocated Reserve (UR)			11.8
Loading Capacity (LC = TMDL)[2]			39.1

See footnotes for Table 5-1.

Alternatively, a smaller reduction in atmospheric loading could be coupled with a larger reduction in watershed loading to seek to meet the fish tissue concentration goals. For instance, if it were assumed that fish tissue mercury levels could be met in McPhee reservoir solely through reductions in watershed loads. If the estimates developed to support this TMDL are correct, however, the needed reduction in loads for Narraguinnep (reduction of 51 g-Hg/yr) is greater than the existing load from the watershed and via inter-basin transfer (41 g-Hg/yr). Therefore, it appears that some degree of reduction in atmospheric loads (at least 25 percent, even if all other sources were eliminated according to the estimates presented in this report) will be needed to meet water quality objectives in Narraguinnep.

The current data are insufficient to allocate the atmospheric deposition component to individual sources. This will require further study, including both validation of the estimated atmospheric deposition rates and attribution of a portion of this load to specific stationary sources. It is anticipated that the proposed 75 percent reduction in atmospheric load might be achieved in part through reduced emissions at the major coal-fired power plants located within several hundred miles of the reservoir. However, a portion of the net reduction might be obtained through reduction in the long-range background from increased emissions controls on mercury in the United States and elsewhere. These issues will need to be resolved before full implementation of the TMDL is feasible. If emissions are reduced at the coal-fired power plants, continued monitoring (and adaptive management, as appropriate) should be pursued to monitor the mercury status in the reservoirs - particularly at Narraguinnep, which is expected to respond more strongly than McPhee to changes in atmospheric loading of mercury.

Mining Areas

The analysis of the areal loading rates of mercury in the McPhee watershed (Table 4-2) shows three areas where loading, on a per-acre basis, is elevated. These areas are associated with the three historic mining districts in the watershed (Rico/Silver Creek, Dunton, and La Plata), and constitute model sub-basins 1, 2, and 3 (Rico); 4 and 10 (Dunton); and 11 (La Plata). Loading from these sub-basins is elevated due to a combination of input from mine tailings and mine drainage, plus naturally elevated background levels in mercury-bearing sulfide ores. Estimated annual average mercury loads from these three areas amount to 1,879 g/yr (1,030 g/yr from Rico, 708 g/yr from Dunton, and 141 g/yr from LaPlata; Table 4-2). This constitutes 67 percent of the watershed mercury load in the McPhee basin (2,797 g/yr - Table 4-2).

Sufficient data are not available at this time to determine allocations for individual mining sources. Indeed, it does not appear to be the case that there is a small number of dominant sources. For instance, the Rico-Argentine mine on Silver Creek has been identified as a significant source of mercury load, but the entire Silver Creek basin (sub-basin 2) appears to contribute only about 3 percent of the total watershed mercury load to McPhee reservoir.

Although there does not appear to be single dominant sources, the estimated load from the mining district sub-basins (sub-basins 1-4, 10, and 11) appears to constitute the bulk of the mercury load in the watershed. Reductions in load to attain the TMDL target would likely need to rely on reductions from the numerous sources in these areas. Therefore, in addition to the proposed 75% reduction in direct atmospheric deposition in this preliminary allocation assessment, the estimated needed reduction in loads from the mining areas to achieve the total allocation is 50.8 percent. The estimated existing mercury load from the mining sub-basins (Rico/Silverton, Dunton, and LaPlata) is 1,879 g/yr (Table 5-1). Thus, a 50.8% reduction corresponds to an allocation for these areas of 924 g/yr.

No known mining areas contribute mercury directly to Narraguinnep reservoir. However, reduction in loads from mining sources to McPhee will also reduce the inter-basin transfer load to Narraguinnep.

Inter-basin Transfer

The amount of mercury transferred from McPhee to Narraguinnep is dependent on the water column mercury concentrations within McPhee. The lake modeling suggests that, over the long term, these concentrations will decrease on an approximately one-to-one basis as external loads to McPhee decrease. Therefore, the reduction in inter-basin transfer load from McPhee to Narraguinnep is assumed to be equal to the total decrease in mercury loading to McPhee needed to meet fish consumption guidelines in McPhee. This amounts to a 40.5 percent reduction (3,049 g Hg/yr to 1,814 g Hg/yr - see Table 5-1). Thus, the inter-basin transfer allocation of mercury to Narraginnep reservoir is a 40.5% reduction from the existing inter-basin transfer load to Narraguinnep (15.9 g/yr - Table 5-2), which equals 9.5 g/yr (Table 5-2). In this preliminary assessment, the 40.5% reduction in inter-basin transfer is assumed to be achieved through the proposed reductions in loading to McPhee reservoir (Table 5-1).

It is important to note that the reduction in inter-basin transfer loading allocation refers only to reductions in the concentration of mercury in McPhee reservoir. This TMDL does not incorporate reductions in the volume of water supplied from McPhee to Narraguinnep as a viable management option. A 40% reduction in flow in inter-basin transfer (so as to obtain a 40% reduction in loading) would significantly diminish the size of Narraginnep reservoir and, under drought conditions, could reduce the minimum pool to an insignificant size.

Background Watershed Loading to McPhee

Background loading from the non-mining areas of the watershed draining to McPhee reservoir (areas other than sub-basins 1-4, 10, and 11) is estimated to contribute 919 g Hg/yr (Table 4-2). This mercury arises from apparently diffuse geologic sources, storage in stream beds, and atmospheric deposition onto the watershed (this estimate does not include atmospheric deposition directly to the surface of the reservoir or loading from mining area sub-basins). The diffuse watershed background will be difficult to control, given the large contributing area. Some reduction in background loading is expected if reductions in atmospheric deposition onto the watershed are achieved. It has not been possible to quantify the extent of these reductions at this time. Indeed, the complex exchange processes between soil and atmosphere may result in a very slow response to changes in atmospheric loading. USEPA (1997, pp. 2-11) notes: “Even if anthropogenic emissions were to stop entirely, leaching of mercury from soil would not be expected to diminish for many years.”

As a result of these uncertainties, a nominal 10% reduction in the existing background watershed loads from non-mining areas in the McPhee watershed is used in this preliminary allocation (i.e., a watershed background allocation of 827 g/yr - Table 5-1) to achieve the total allocation of 1,814 g Hg/yr.

Background Watershed Loading to Narraguinnep

Even with a 75% reduction in atmospheric loads and the 40.5% reduction that would be achieved in the inter-basin transfer loading to Narraguinnep through the proposed McPhee reservoir reductions, further reductions in net mercury loading to Narraguinnep appear to be needed to meet the TMDL. This additional reduction is assigned to the direct watershed loading allocation for Narraguinnep.

The existing watershed loading of mercury to Narraguinnep is 25.4 g/yr (sum of sub-basins 1-6 - Table 4-3). It is estimated that a 66% reduction in the background watershed loading to Narraguinnep (from 25.4 to 8.6 g-Hg/yr - Table 5-2) will be needed in combination with the atmospheric load reduction and McPhee watershed reductions to meet the fish tissue target in Narraguinnep. Background loads to Narraguinnep may be easier to address than background loads in the McPhee watershed, due to the small size of the direct drainage area. In addition, a significant part of the watershed mercury load to Narraguinnep may actually be attributable to mercury in irrigation water diverted through the Lone Pine lateral to agricultural land in the basin. Thus, reductions in the mercury concentrations (not water volume) in inter-basin transfer from McPhee to Narraguinnep may also help to reduce the background watershed load to Narraguinnep.

5.5 Wasteload Allocations

Wasteload allocations constitute an assignment of a portion of the TMDL to permitted point sources. There are no permitted point source discharges within the Narraguinnep watershed. Two small point sources within the McPhee watershed do not have mercury limits and are not believed to contribute significant amounts of mercury (see Section 3.1). Therefore, no wasteload allocations are included in the TMDL.

5.6 Allocation Summary

Summaries of the preliminary allocations outlined above are presented in Table 5-1 for McPhee reservoir and Table 5-2 for Narraguinnep reservoir. These allocations are based on best currently available information and are predicted to result in attainment of acceptable fish tissue concentrations within a time horizon of approximately 20 years. A delay in achieving standards is unavoidable because time will be required for mercury to cycle through the lake and food chain after loads are reduced.

It should be emphasized that these are potential, rather than final allocations. Additional data are necessary in order to characterize the loading among various pathways and sources. Refined allocations will be identified in Phase 2 of the TMDL (see Section 7). A key issue is the balance of allocations between watershed sources (including mining sources) and atmospheric sources. A much larger reduction in atmospheric loading as compared to watershed loading appears to be needed to achieve goals in Narraguinnep than in McPhee reservoir, and addressing the mercury problems in McPhee alone could rely more on watershed controls than on atmospheric controls (see further discussion in Section 6). No analysis of the cost-effectiveness of potential allocations has been conducted at this time.

The analysis presented in this TMDL has a significant amount of uncertainty, as discussed further in Section 6. The preliminary allocations are believed to be conservative, because an unallocated portion of the TMDL is held in reserve. In addition, reduction in atmospheric deposition of mercury for the purpose of controlling direct deposition to the surface of the reservoirs may also result in a greater reduction in the watershed background mercury loading than can be attributed at this time.

Although estimates of the assimilative capacity and load allocations are based on best available data and incorporate a Margin of Safety, these estimates will likely need to be revised as additional data are obtained. To provide reasonable assurances that the assigned load allocations will indeed result in compliance with the fish tissue criterion, a commitment to continued monitoring and assessment is warranted. The purposes of such monitoring will be (1) to evaluate the efficacy of control measures instituted to achieve the needed load reductions, (2) to document trends over time in mercury loading, and (3) to determine if the load reductions proposed for the TMDL lead to attainment of the TMDL targets.

6. Margin of Safety, Seasonal Variations, and Critical Conditions

6.1 Sources of Uncertainty

The analysis for this TMDL contains numerous sources of uncertainty, and load allocations must be proposed as best estimate “gross allotments”, in keeping with the TMDL regulation at 40 CFR 130.2(g). Key areas of uncertainty have been highlighted in the Source Assessment and Linkage Analysis sections and are summarized below. The need for additional data collection, analysis, and modeling to reduce these areas of uncertainty will form the bulk of Phase II of this TMDL, which is outlined in Section 7.

The sources of uncertainty can be divided into two groups:

> 1) The first group consists of sources of uncertainty that directly affect the ability of the linkage analysis to relate the numeric target fish tissue concentration to environmental mercury exposure concentrations in the reservoirs. These sources of uncertainty relate directly to uncertainty in the estimation of the loading capacity.
>
> 2) The second group consists of uncertainty in the estimation of external loads. These impact primarily allocations and affect the estimation of loading capacity only indirectly by causing a potential mis-specification in the data used for lake model calibration. The loading capacity estimate is much more sensitive to uncertainty in the first group and relatively robust to uncertainty in the second group.

The first set of uncertainty arises from the following issues:

- Fish data from the reservoirs are sparse. While the presence of problem concentrations of mercury in fish has been confirmed, the limited number of samples and collection times leads to uncertainty regarding the average population response as a function of fish species, weight and age.

- Even fewer data are available on small forage fish and invertebrates, which drive the food chain pathways, leading to bioaccumulation in sport fish.

- Sediment mercury concentrations are characterized by a limited number of samples.

- Information on the vertical distribution of mercury in the water column and associated water chemistry is available for only two points in time (June and August 1999). Without additional sampling it is not possible to determine the extent to which these two times characterize the annual mercury cycle and whether 1999 conditions are representative of conditions in other years.

- Neither available resources nor available data allowed the development and calibration of a detailed lake mercury cycling model for Narraguinnep. Instead, the estimates of loading capacity for Narraguinnep are based on analogy to the McPhee model. Systematic differences may exist between responses in McPhee and Narraguinnep reservoirs.

The second set of uncertainty arises from the following issues:

- Watershed background loading of mercury is estimated using a simple water balance/sediment yield model. While the concentrations in tributary sediments are based on measured data, the estimated actual rates of movement of this sediment to the Reservoir are not constrained by field measurements at this time.

- Estimates of atmospheric wet deposition of mercury are based on a limited period of record at a site several hundred miles removed from the McPhee/Narraguinnep watersheds and using a relationship between mercury deposition and nitrate and sulfate deposition. Actual deposition of mercury at or near the reservoirs has not been measured. Total mercury deposition to the watershed may well differ from the estimates used by a factor of 3 or more, based on best professional judgement of the modelers.

- The extent to which atmospheric deposition of mercury onto the land surface contributes to watershed mercury loads is not known at this time, nor is the relative importance of local versus global mercury sources. Therefore, the benefit that might be obtained through reductions in mercury emissions from nearby power plants cannot be accurately determined.

- The need to gather more data within mining districts. This needs to be conducted in order to better ascertain how much of the mercury load is derived from mining as opposed to the background geologic formations.

- Applicability and calibration of the models used in the Phase 1 TMDL to the high elevation areas of southwest Colorado.

One area in which the level of uncertainty is particularly acute is in the estimation of atmospheric deposition of mercury. As described in Chapter 3, no direct measurements of atmospheric deposition of mercury are available at or near the reservoirs. Estimates of deposition were made using nitrate and sulfate deposition as a surrogate. This procedure produces what appear to be reasonable results, but data are not available to confirm the estimates.

As described in Chapter 4, atmospheric deposition appears to account for a relatively small proportion (less than 10 percent) of the total mercury load to McPhee reservoir. As a result, it is the opinion of the modelers that the uncertainty in the estimates of atmospheric deposition of mercury does not have a significant impact on the calibration of the D-MCM lake response model. This, in turn, means that the uncertainty in estimates of atmospheric deposition does not propagate significantly into estimates of assimilative capacity of the two reservoirs.

Where the uncertainty in atmospheric deposition estimates does have a major impact is in the estimation of potential load allocations involving Narraguinnep reservoir. This occurs because Narraguinnep, unlike McPhee reservoir, appears to derive a significant amount of its total mercury load from atmospheric deposition. Current best estimates of mercury loads to Narraguinnep suggest that a significant reduction in atmospheric loading may be needed to achieve water quality standards.

The preliminary allocations presented in Chapter 5 treat McPhee and Narraguinnep reservoirs as a pair, and identify a large reduction in atmospheric loads to both reservoirs in order to achieve standards in Narraguinnep. It is important to note that water quality standards in McPhee alone could apparently be achieved solely through reductions in watershed mercury loading, without reductions in atmospheric deposition of mercury.

The analysis of loading to Narraguinnep reservoir suggests that existing watershed and inter-basin mercury loads slightly exceed the loading capacity for this waterbody, while atmospheric deposition of mercury is likely of the same order of magnitude as the watershed and inter-basin loads. This suggests that some reduction in atmospheric loading of mercury will likely be needed to meet standards in Narraguinnep. The magnitude of this reduction, however, is uncertain as a result of the uncertainty in the atmospheric deposition estimates. New data on atmospheric deposition of mercury in this part of Colorado (which will be collected at Mesa Verde National Park) should help to resolve this uncertainty (see Section 7).

There are, thus, many sources of uncertainty in the estimation of the mercury TMDL for McPhee and Narraguinnep reservoirs. It is evident, however, that existing loads of mercury are too high to support designated uses, as shown by the tissue concentrations observed in fish.

Quantitative estimates are possible at this time for only some of the sources of uncertainty in the TMDL. It is also not appropriate to assume that all the sources of uncertainty are additive, since some sources will have positive or negative correlations with other sources. A full, quantitative analysis of uncertainty in the TMDL has not yet been feasible, but it might be appropriate as additional data are collected. However, there is a high probability that the true loading capacity of McPhee reservoir lies within plus or minus 25 percent of the best estimates presented above.

Additional uncertainty is present in the estimates of loading capacity for Narraguinnep, as a complete lake model has not been constructed for this Reservoir. Given the near proximity of Narraguinnep to McPhee and the fact that water in Narraguinnep is primarily derived from diversions from McPhee, it is reasonable to assume that responses to loads in Narraguinnep will be similar to those in McPhee. Most important, it is assumed that fish body burdens in Narraguinnep will experience a near-linear response to declines in external mercury loads, as predicted by the McPhee model.

The TMDL regulation requires that estimates of loading capacity be made even where there is uncertainty in load estimates, and only “gross allotments” are possible for nonpoint loads. This report provides a best estimate, from currently available data, of the loading capacity for mercury and the needed load reductions for the two reservoirs. However, the uncertainty in these estimates is high. This uncertainty is addressed in part through use of a Margin of Safety (Section 6.2). The level of uncertainty, however, suggests the need for ongoing, adaptive management to meet water quality standards in the two reservoirs. In particular, a monitoring program must be part of any implementation plan. Such a monitoring program will allow tracking of progress in attaining acceptable fish tissue concentrations in response to management actions. It would also provide the basis for potential revision of the estimated load allocations consistent with attaining standards in the reservoirs.

The uncertainty in the estimation of loading capacity and the TMDL should be reduced directly through collection of additional data to better characterize external loading rates, internal stores of mercury, and year-to-year variability in lake response. General monitoring recommendations appropriate to assess trends and refine estimates of loading and loading capacity include the following:

- Continue fish monitoring in the reservoirs using a standardize sample collection protocol.

- Continue tributary mercury monitoring at key locations, including Dolores River near Dolores, key upstream tributaries draining mining areas, and the Lone Pine Lateral between McPhee and Narraguinnep.

- Establish a mercury deposition monitoring station near the reservoirs as a part of the Mercury Deposition Network. Co-location of this station with the Mesa Verde NADP site is paramount. This site is near the reservoirs but in the direction of the major power plants and provides a good database of nitrate and sulfate deposition data. In January 2002, an MDN site was established at the Mesa Verde location and is currently collecting data. This station follows the MDN protocol of monitoring wet deposition. While dry deposition is also important, methods for estimating dry deposition are not standardized and attempts to measure dry deposition should wait until the measurement methods move beyond the realm of research.

Uncertainty in the D-MCM modeling of mercury cycling within the reservoirs could also be reduced through the following special-study efforts:

- Collect additional data on the mercury concentrations in biota, including lower trophic levels, and on seasonal and annual variability in concentrations.

- Collect higher-frequency data on thermal stratification and water chemistry within the lake, including mercury species, pH, chlorine, DOC, sulfur species, and particulate concentrations.

- Obtain better characterization of the particulate matter in the reservoirs, including settling velocity and mercury sorption characteristics.

- Construct a site-specific lake response model for Narraguinnep reservoir.

6.2 Margin of Safety

All TMDLs are required to include a Margin of Safety to account for uncertainty in the understanding of the relationship between pollutant discharges and water quality impacts. The Margin of Safety may be provided explicitly through an unallocated reserve or implicitly through use of adequately conservative assumptions in the analysis.

The preliminary TMDL presented in Section 5 incorporates an explicit Margin of Safety as an unallocated reserve equal to 30 percent of the estimated loading capacity. As described in Section 6.1, the margin of uncertainty about the estimated loading capacity is believed to be plus or minus 25 percent for McPhee and somewhat larger for Narraguinnep.

Uncertainty in the analysis for Narraguinnep is caused in large part by uncertainty in estimates of atmospheric deposition of mercury, including both the magnitude of wet deposition and the ratio of dry deposition to wet deposition. This uncertainty can only be addressed through the collection of deposition monitoring data and/or regional-scale modeling of mercury transport.

In sum, the preliminary TMDL incorporates a Margin of Safety that is believed to account for uncertainty in the understanding of the relationship between pollutant discharges and water quality impacts. It is not, however, possible at this time to precisely estimate the magnitude of uncertainty in the estimation of reservoir loading capacities, particularly for Narraguinnep reservoir. As a result, there is a small but non-zero potential risk that the proposed allocations will not result in achieving water quality standards.

6.3 Seasonal Variations and Critical Conditions

Federal regulations require consideration of seasonal variations and critical conditions in the estimation of a TMDL. The TMDL for McPhee and Narraguinnep has been developed to address fish tissue concentrations associated with bioaccumulation of mercury within McPhee and Narraguinnep reservoirs. There is no evidence of excursions from water quality standards for mercury. Because methylmercury is a bioaccumulating toxin, concentrations in tissue of game fish integrate exposure over a number of years. As a result, annual mercury loading is more important for the attainment of standards than instantaneous or daily concentrations, and the TMDL is appropriately expressed in terms of annual mercury loads. It is not necessary to address standard wasteload allocation critical conditions, such as concentrations under 7Q10 flow, because it is loading, rather than instantaneous concentration, that is linked to impairment.

The impact of seasonal and other short-term variability in loading is damped out by the biotic response. The numeric target selected is tissue concentration in piscivorus game fish of edible size, which represents an integration over several years of exposure, suggesting that annual rather than seasonal limits are appropriate. Nonetheless, the occurrence of loading that impacts fish does involve seasonal components. First, watershed mercury loading, which is caused by infrequent major washoff events in the watershed, is highly seasonal in nature, with most loading occurring during the early summer snowmelt period. Second, bacterially mediated methylation of mercury is also likely to vary seasonally. The timing of washoff events is not amenable to management intervention. Therefore, it is important to control average net annual loading, rather than establishing seasonal limits, in calculating the TMDL consistent with the existing loading capacity.

7. Additional Analysis and Characterization

Because of the uncertainties that exist with respect to mercury sources and accumulation, the relationships between these sources, and the dynamics of biomagnification within the reservoirs, the WQCD has elected to promulgate the McPhee and Narraguinnep TMDL in a multi-step or phased fashion (as described in Section 6.1). Phase 1 consisted of initial data collection, analysis, and modeling that resulted in a preliminary estimate of mercury loading to the reservoirs. Loading estimates were used in the models to produce an estimated loading capacity for both McPhee and Narraguinnep reservoirs and preliminary loading allocations were assigned to various sources. Throughout this process, numerous data gaps and uncertainties were identified and summarized in Section 6. Section 7 describes Phase 2 of this TMDL, which identifies additional data collection and analysis efforts needed to provide a basis for more accurate identification and quantification of mercury loading and allocations. This will help minimize the data gaps and uncertainties identified in Phase 1. The TMDL will be modified at such time as adequate data are made available to validate additional model runs.

As described in Section 6, the uncertainties identified in Phase 1 can be grouped into one of two categories: 1) estimation of the loading capacity of the reservoirs; and 2) estimation of external loads.

7.1 Estimation of the Loading Capacity to the Reservoirs

Several areas of uncertainty were identified in estimations of loading capacity of the reservoirs. The recommended additional sampling and analysis needed to address these uncertainties is outlined below:

1. Only a limited number of samples and collection times related to fish data were available for analysis in Phase 1. Additional data from both reservoirs are needed to strengthen the population response component of the model, especially data related to fish weight, age, and trophic status.
2. Even less data are available on small forage fish and invertebrates, which drive the food chain pathways leading to bioaccumulation in sport fish.
3. Sediment mercury concentrations are characterized by a limited number of samples. Additional samples are needed to fill data gaps in both temporal and spatial scales.
4. Information on the vertical distribution of mercury in the water column and associated water chemistry is available for only two points in time (June and August 1999). Additional sampling is needed to determine the extent to which these two times characterize the annual mercury cycle or whether 1999 conditions are representative of conditions in other years.
5. Neither available resources nor available data allowed the development and calibration of a detailed lake mercury cycling model for Narraguinnep reservoir. Instead, the estimates of loading capacity for Narraguinnep are based on analogy to the McPhee model. Systematic differences may exist between responses in McPhee and Narraguinnep reservoirs. Thus, modeling Narraguinnep reservoir would help to decrease this area of uncertainty.
6. Review the assumptions in the Phase I TMDL. Develop a better understanding of the bioaccumulation mechanism in both reservoirs.
7. Soils sampling and geological survey evaluation of mercury in soil, especially those tributary to Narraguinnep.
8. Identification of Methylation hot spots.
9. Narraguinnep site-specific models.
10. Calibration and validation of all models, after setting modeling acceptance criteria.

7.2 Estimation of External Loads

The 1999 sampling event for the McPhee watershed has enabled an initial estimate of mercury loading rates by sub-basin. The assessment, however, needs additional data to better identify significant sources of mercury loading within the watersheds.

7.2.1 Watershed Sources of Mercury

Establishing new water and sediment sampling points will help indicate where the loads arise in the mining areas of the McPhee watershed (sub-basins 1-4, 10, and 11 - Figure 7 in Appendix A). Better and more location-specific estimates of mercury loading from these areas will provide the basis for field reconnaissance to identify specific source areas for potential remediation. The previous (1999) sampling round provided a good start in this regard, but could not be comprehensive due to lack of available resources relative to the large size of the watershed. The 1999 sampling did demonstrate that there is not one overwhelming source of mercury load in the McPhee watershed. Rather, the watershed load appears to derive from multiple sources in the Rico, Dunton, and La Plata mining areas. Additional sample locations will further refine this assessment. For the Rico area, in particular, there is a lack of mainstem sampling stations that can help to determine in which areas the major loads arise.

To further refine the assessment, the next round of sampling should include several new sampling locations. In addition, key sampling stations evaluated previously should be re-sampled to confirm and refine previous estimates. Several new sampling locations are recommended. These are divided into several geographic areas:

Dolores River Mainstem/ Rico Mining District

The Dolores mainstem drains the Rico Mining District, which appears to be a major source of mercury load to McPhee, based on preliminary analysis of historical data. The 1999 sampling covered many of the smaller tributaries, but had no samples on the Dolores mainstem upstream of MCP-5, just above the confluence with the West Dolores River (Figure 6 in Appendix A). Additional sampling points are needed in the mainstem to further describe the areas of significant mercury loading. Recommended new sampling points (all of which appear to have potential road access) are:

1. Dolores River upstream of Barlow Creek north of Rico. This can describe a boundary condition for the area that appears to be upstream of the historic mining district.
2. Dolores River near settling ponds at Rico, upstream of Silver Creek.
3. Dolores River below Deadwood Creek, south of Rico and downstream of the historic mining area.
4. Stoner Creek above confluence with Dolores River. Stoner Creek enters the Dolores just upstream of existing station MCP-5 and is a major unmonitored sub-watershed. The uppermost reaches of Stoner Creek extend into the Rico mining district, so loading from this area should also be monitored.

West Dolores River

The 1999 sampling includes three stations along the West Dolores (MCP-4, MCP-19, and MCP-3), the first two of which bracket the heart of the Dunton Mining District (Figure 6 in Appendix A). However, much of the mercury load appears to come from upstream of MCP-4, while additional load appears to arise downstream of MCP-19. Additional sampling is recommended at the following locations:

5. West Dolores River above Meadow Creek northeast of Dunton. This is upstream of MCP-4 and appears to be the limit of ready road access.

6. West Dolores River upstream of Groundhog Creek, downstream of Dunton. Some mining activity occurred in this area, downstream of MCP-19. A station here would help determine whether additional mercury load occurs in this area.
7. Groundhog Creek above confluence with West Dolores. Not known to be a mining area, but represents a significant drainage area that can perhaps be confirmed as not a significant source area.

La Plata Mining District

The headwaters of Bear Creek reach into the La Plata mining district (Figure 7 in Appendix A). Samples at the mouth of Bear Creek (MCP-7 - Figure 6 in Appendix A) suggest a significant mercury load. An additional sampling site upstream of MCP-7, near the mining area, would be helpful in estimating loads from the La Plata mining district.

8. Upper Bear Creek, approximately 10 km upstream of mouth, depending on accessibility.

Other Areas

The other major drainage areas that lack sampling sites are Beaver Creek and Plateau Creek, which drain to the north side of McPhee (Figure 6 in Appendix A). The Beaver Creek drainage is estimated to contribute significant flow and sediment loading, so it would be advisable to determine the mercury content of the load. Plateau Creek drains a fairly large watershed, but has not yet been monitored for potential mercury loading.

9. Beaver Creek. Accessibility will need to be determined.
10. Plateau Creek. Accessibility will need to be determined.

Re-sampling of Existing Stations

Of the stations sampled in 1999, those stations that are of key importance in evaluating sub-watershed loads should be re-sampled to confirm and refine previous estimates. The following seven stations (Figure 6 in Appendix A) are recommended for re-sampling:

1. MCP-3: West Dolores River near Mouth
2. MCP-4: West Dolores River above Dunton
3. MCP-5: Dolores River above West Dolores River
4. MCP-7: Bear Creek near confluence with Dolores River
5. MCP-11: Silver Creek near mouth
6. MCP-17: Dolores River at Big Bend Boat Launch
7. MCP-19: West Dolores River below Geyser Creek

7.2.2 Atmospheric Sources of Mercury

As discussed in Sections 3 and 6, the atmospheric loading model was based on surrogate analysis of sulfate and nitrate deposition at monitoring stations throughout the state. There were no actual measurements of mercury deposition, except for one station on Buffalo Pass in northern Colorado. Although the assumptions that formed the basis of this model are reasonable in terms of general depositional patterns in Colorado, there is a need to collect additional data specific to mercury deposition in the McPhee and Narraguinnep watersheds. Data specific to reducing uncertainty in this area are expected to come from four sources:

1. A mercury deposition monitoring station has been established in association with the Mesa Verde NADP site. This site is located in the Mesa Verde National Park and is

within the immediate atmospheric influence of the coal fired power plants. Wet mercury deposition data have been collected at the site since January 2002.

2. Additional data on high-elevation snowpack analysis will be collected by the USGS in March 2002. This information will help describe the (winter) atmospheric loading component.
3. Information from sediment core samples from Narraguinnep reservoir is also expected to be forthcoming. These data will provide an historical perspective on temporal trends in mercury deposition to the reservoir.
4. Dry deposition samples will be collected by Frontier Geoscience during 2002 on surrogate surfaces at the Mesa Verde site, in an attempt to characterize this fraction of mercury deposition.

7.3 Additional Data Collection Summary

The additional data collection and analysis that need to be completed as part of Phase 2 of this TMDL are outlined in Table 7-1.

Table 7-1. Summary of data collection and analyses to be completed in Phase 2.

Action
1. Estimation of Loading Capacity of the Reservoirs - Collect data on fish community structure, age/weight relationships, trophic status, and bioenergetics (if possible) from both reservoirs. - Collect information on trophic relationships and mercury levels in forage fish, benthos, and other trophic levels (where possible) from both reservoirs. - Collect additional sediment chemistry data, particularly from Narraguinnep reservoir. - Collect additional water chemistry data (especially vertical profiles) to better characterize the annual mercury cycle in the reservoir. - Generate a lake mercury model for Narraguinnep and revise the model for McPhee based on the new information (thus allowing a more accurate estimate of loading capacity of both reservoirs).
2. Estimation of External Loads - Collect sediment and water chemistry data from the 10 new sites proposed in Section 7.2. - Collect additional sediment and water chemistry data from the 7 existing sites that need additional data (identified in Section 7.2). - Collect mercury deposition data from the new MDN monitoring station in Mesa Verde, CO. - Collect additional data on mercury concentrations in snowpack within the McPhee watershed from USGS studies. - Collect additional data from sediment cores from Narraguinnep reservoir from USGS studies.
3. Data Analysis - Review and analyze new information collected combined with data previously collected to derive new loading and allocation estimates as necessary. - Produce a model for Narraguinnep reservoir using new data.
4. TMDL Review and Revision - Revise TMDL as necessary based on new information and analyses. - Review TMDL progress consistent with monitoring plan.

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APPENDIX A

FIGURES