Date of Report: May 1, 2000.

LCMR Final Work Program Update Report

I. Atmospheric Mercury Emissions, Deposition, and Environmental Cost Evaluation.

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A. Legal Citation: ML 95, Chp. 220, Sec. 19, Subd. 5(f).
Total biennial LCMR appropriation: $575,000
Balance: $zero

Appropriation Language: This appropriation is from the Future Resources Fund to the Commissioner of the Pollution Control Agency for a mercury emission inventory and quantification of mercury atmospheric deposition. $50,000 is for an evaluation of the external costs of mercury emissions from Minnesota sources.

B. Status of Match Requirement: N/A

This project is not being matched in a formal sense, but additional funding has been found to enhance objective C, "Economic Analysis of the Benefits of Reduced Mercury Deposition." The Hazardous Waste Division of the MPCA obtained a grant from the U.S. EPA, of which $60,000 was used to augment the $50,000 recommended for funding by the LCMR.

II. Project Summary: This project consists of three parts, which together will yield information critical to Minnesota's strategy to reduce mercury contamination. The project focuses on the atmosphere because virtually all of the mercury in Minnesota lakes is delivered by air. The project examines (A) additional information on sources of mercury to the atmosphere, (B) how far mercury is transported away from sources before it is deposited, and (C) the economic benefit of reduced mercury deposition.

Because most atmospheric deposition occurs to soil, there is an emphasis in this project on soil as a secondary source of mercury back to the atmosphere and as a source to lakes through both wind and water erosion.

The importance of the loading rate of soil mercury as well as atmospheric mercury will be evaluated by comparing to known correlates of fish tissue mercury, such as alkalinity, pH, and dissolved organic matter. However, the main reason for determining the mercury introduced by soil erosion is to be able to subtract it from total loading so that atmospheric deposition alone can be calculated, and the hypothesis of enhanced local deposition evaluated. The biological availability of eroded mercury will be examined by measuring methyl mercury in lake sediment stratigraphy and expressing it as a percentage of total mercury.

Other Minnesota emissions will be quantified that national mercury studies are not covering: taconite processing, wood combustion, in-state oil refining, and, because of our unusually high dependence on incineration, mercury in plastics, pigments, and other products.

Finally, the project will estimate the economic benefit of reduced mercury deposition. Mercury reductions make sense to implement if the cost of reduction is less than the economic benefit.

III. Final Work Program Update Summary:

The project, although slow to complete, achieved all of its goals. The data and conclusions were used during the policy discussion conducted from May 1997 to March 1999. In the spring of 1999 the Minnesota Legislature passed legislation, which the governor signed, that put reduction goals into law. These goals were supported by the background material produced under this project (Report on the Mercury Contamination Reuduction Initiative Advisory Council's Results and Recommendations 1999).

IV. Statement of Objectives:

A. Mercury Analyses and Emission Calculations ($242,000 budgeted)

	7/95	1/96	6/96	1/97	6/97
Literature review on mercury in wood	xxx				
Mercury in Wood report		xxxxxxxxxx			
Soil volatilization report		xxxxxxxxxx			
Taconite emissions report		xxxxxxxxxx			
Mercury in oil refining report				xxxxxxxxxx	
Mercury in Products report				xxxxxxxxxx	
Synthesize emission inventory				xxxxxxxxxxxxxxxxxx	

This objective obtains data on the mercury content of materials so that potential mercury emissions from Minnesota can be better calculated. For instance, the amount of wood that is burned in Minnesota is known, but the mercury concentration in the wood is unknown. The mercury concentration of wood will put an upper bound on the potential emission from this source. Similarly, analyses of taconite raw materials, crude oil, paper, and products in the waste stream will allow us to calculate potential emissions and better formulate strategies for reducing mercury contamination.

B. Atmospheric Deposition of Mercury Across Minnesota ($283,000 budgeted)

	7/95	1/96	6/96	1/97	6/97
Site Selection	xxxx				
Core Collection	xxxxxxx				
Lake Water analysis		xxxxxxxxxxx			
GIS Mapping		xxxxxxxxxx			
Lead-210 dating of sediment cores			xxxxxxxxxxxxx		
Analysis of lake sediment			xxxxxxxxxxxxxxxxxxxx		
Data Analysis				xxxxxxxx	
Final Report					xxxxxxx

This objective reconstructs from sediment cores the history of mercury inputs to a large number of Minnesota lakes to determine:

(1) whether lakes near mercury-emitting facilities receive significant local atmospheric deposition
(2) if erosion of soils from agriculture and urbanization contributes to greater inputs of mercury to lakes
(3) whether higher mercury inputs (from local deposition or soil erosion) contribute to higher mercury content of fish

C. Economic Analysis of the Benefits of Reduced Mercury Deposition ($50,000 budgeted)

	7/95	1/96	6/96	1/97	6/97
Survey design	xxxxxxxxxxxxxxx				
Survey execution		xxxxxx			
Statistical analysis and report prep			xxxxxxxxxxxxxxxxxxx		

This objective estimates the economic benefit of reduced mercury deposition through the contingent valuation method. In the case of changes in environmental quality, there are economic benefits for which there are not private, market transactions. The contingent valuation method is in wide use in the field of economics, in part, because of its capability of estimating both market and non-market economic benefits.

V. Objectives/Outcomes

A. Title of Objectives/Outcomes: Mercury Analyses and Emission Calculations

A.1 Activity: Mercury in wood & wind-blown particulates: concentrations & sources (Cooperators: David Grigal and Ed Nater, University of Minnesota)

A.1.a Context within the project:
About three million tons of wood are burned in Minnesota yearly, but the mercury content of the wood is unknown. In addition, wood products such as paper and cardboard constitute a major portion of the solid waste incinerated in Minnesota, yet the mercury content of those products is unknown (but will be determined in Activity A.5, below: "Mercury in Products".).

The major present use of wood and woody residues for energy are by boilers within the forest products industry and by residential firewood use. A potential future use of woody biomass is by projected "whole-tree-energy" combustion systems by electric utilities. It is important to differentiate these uses because each consumes a different suite of species and tree components. The study will sample and analyze the most-used components of the important species and locations. These samples will be collected directly from wood piles, chip piles, boiler feed, etc. The samples will include whatever "contamination" (particularly by surface soil) that accompanies the material that is actually burned. Other samples will be obtained "clean" so that the source of mercury associated with wood can be determined.

The data collected will assess potential mercury emissions, but will not clearly identify the source of the mercury in woody materials. There are three possible sources of mercury to woody materials used for fuel. They include (1) soil contamination during harvest, (2) root uptake, and (3) atmospheric deposition. Atmospheric deposition may further be divided into global sources and regional sources; the latter into materials from fossil-fuel combustion or from wind-blown dust from surface soils.

It is important to find out what the source of mercury associated with wood for several reasons. First, it may be possible to greatly reduce the mercury content if the mercury is soil contamination. Second, the environmental cost of mercury associated with wood may vary depending on the source: if the mercury is derived from air pollution, then wood combustion merely recycles mercury that is already in atmospheric circulation, which presumably has a lower environmental impact (and cost) than mercury mobilized by roots from subsurface soil.

A.1.b Methods:
Trees will be analyzed by geographic region, species, and part of the tree (wood, leaves, and bark). The mercury concentration of paper from mills processing Minnesota wood will be compared to the mercury concentration of the raw materials.

To test the hypothesis the primary source of mercury contamination of wood fuels is by soil contamination, we will sample and analyze the wood and bark of important species as they occur in the forest and compare to fuel from the same species. The hypothesis of root uptake as the main source of mercury will be carried out by sampling a single tree species (red pine, which has little genetic diversity) on soils that differ greatly in mercury concentration. but are near each other and hence receive similar atmospheric mercury deposition. Air concentrations of elemental mercury will also be measured in the canopy to help discriminate between stomatal uptake and particulate deposition. The hypothesis of the atmosphere as the source of mercury to trees will be evaluated at one or two intensive sites, either Cedar Creek Natural History area, or Marcell Experimental Forest. Both sites have been the subject of intensive mercury investigations. Stomatal uptake will be evaluated by sampling leaves of the same group of trees through he growing season. A literature review on this topic will be conducted and written prior to the physical field work, so that the experience of others will enhance this project.

The magnitude of the input via particulate sources will be evaluated through rainfall collection in the open and under forest canopies. The Swedish IVL sampler will be used to quantify mercury deposition on an event basis.

The rainfall will be analyzed for mercury and other chemical species including calcium, aluminum, iron, magnesium and potassium. Through the use of multivariate statistical analyses we will be able to determine those elements that co-vary with mercury. Based on complete chemical analyses of samples of fly ash (from fossil fuel combustion) and of soil materials, we will associate the mercury-related suite of elements to one of those two sources. The possibility of using electron microscopy to identify particles associated with coal-fired plants will be explored. It is important to differentiate these sources because the appropriate response differs dramatically depending on what the answer is. If wind-blown soil is a major source, then addressing agricultural practices as sources of soil erosion might well be appropriate. If the major source is flyash, then enhanced particulate control on power plants would be appropriate. Source attribution by element analysis of soil and fly ash can be a challenging task, but the cooperators for this activity have experience with this method and are confident that it can differentiate soil from fly ash. Wind-blown soil not only is an issue for wood, but for directly enhanced mercury loading to lakes. Results of this study will be compared to the NADP mercury samplers at Marcell and the atmospheric particulate sampler operated by Jerry Keeler at Cedar Creek.

Quality Assurance: Accuracy of all measurements will be checked using spikes of known concentrations and certified samples when available. Precision of all measurements will be checked by at least 10% replication of sample collection and 10% duplication of laboratory measurements. Split samples will be provided to other interested investigators and archived by freezing for quality assurance checks and for future analysis of other components.

Data management: All field measurements and sample history will be recorded in standard bound notebooks in the field. Each entry will include the date of sampling, the site location, field measurements, and the names of the people who performed the sampling. Any sampling problems that may cause sample contamination or affect sample integrity will also be recorded in the field notebook as well as reported to the project manager upon return from the field. After field work is completed, the notebooks will be archived in a designated area. Relevant field notebook entries will be included in a computer database that will be part of the report to the MPCA. The researchers conducting the study will have the prerogative to publish the results within a reasonable time period after the end of the project, but all the data is public information. Environmental data will be stored in standard public databases as appropriate, such as STORET.

A.1.c Materials:
Materials will consist largely of sample containers and normal laboratory supplies.

A.1.d Budget:

Total Biennial LCMR Budget:	$ 75,000
LCMR Balance:	$ 0
Match:	$ 0
Match Balance:	$ 0

A.1.e Timeline:

	7/95	**1/96**	**6/96**	**1/97**	**6/97**
Literature review	xxx				
Study design	xxxxxxx				
Sample collection		xxxxxxxxxx			
Sample analysis			xxxxxxxxxxxxxx		
Report Preparation			xxxxxxxxxx		

A.1.f Workprogram Update:
May 1, 2000 Update:
All tasks in this activity were carried out successfully and reports were received by the MPCA (Fleck et al. 1999; Pang 1997).

A.2 Activity: Mercury in soil: emission

(Cooperators: David Grigal and Ed Nater, University of Minnesota)

A.2.a Context within the project:
Most atmospheric deposition of mercury in Minnesota is to soils. The organic matter in soil has a high chemical affinity for mercury, and holds mercury tightly over the short term. However, over the long term (decades), only a few percent of atmospherically deposited mercury is held by soil. It is likely that much of the mercury volatilizes back to the atmosphere. How much is re-emitted to the atmosphere?

A.2.b Methods:
Techniques will be developed to measure volatilization of mercury from soil. Volatilization will be measured as a function of temperature, moisture, and metabolic rate of soil microorganisms. Enrichment experiments will be conducted. Rates will be quantified from a variety of soils around Minnesota, including soil that has received sewage sludge amendments.

Quality Assurance: Accuracy of all measurements will be checked using spikes of known concentrations and certified samples when available. Precision of all measurements will be checked by at least 10% replication of sample collection and 10% duplication of laboratory measurements. Split samples will be provided to other interested investigators and archived by freezing for quality assurance checks and for future analysis of other components.

Data management: All field measurements and sample history will be recorded in standard bound notebooks in the field. Each entry will include the date of sampling, the site location, field measurements, and the names of the people who performed the sampling. Any sampling problems that may cause sample contamination or affect sample integrity will also be recorded in the field notebook as well as reported to the project manager upon return from the field. After field work is completed, the notebooks will be archived in a designated area. Relevant field notebook entries will be included in a computer database that will be part of the report to the MPCA. The researchers conducting the study will have the prerogative to publish the results within a reasonable time period after the end of the project, but all the data is public information. Environmental data will be stored in standard public databases as appropriate, such as STORET.

A.2.c Materials:
Materials will consist of jars for incubating soil samples in the laboratory, modified so that headspace gases can be withdrawn for the analysis of mercury, humidity, and carbon dioxide production.

A.2.d Budget:
This activity will continue a cooperative project begun September 1994 in the University of Minnesota soil laboratories of Professors Nater and Grigal, funded jointly by the U.S. Forest Service (USFS) and the states of Minnesota and Wisconsin ($32,000 total). There is a strong possibility that LCMR funds can again be matched by the USFS and/or Wisconsin.

Total Biennial LCMR Budget:	$ 20,000
LCMR Balance:	$ 0
Match:	$ 0
Match Balance:	$ 0

A.2.e Timeline:

	7/95	1/96	6/96	1/97	6/97
Study design	xxxxxxxxxx				
Sample collection & analysis	xxxxxxxxxxxxxxxxx				
Report Preparation		xxxxxxxxxx			

A.2.f Workprogram Update:
May 1, 2000 Update:

All tasks in this activity were carried out successfully and reports were received by the MPCA (Nater and Grigal 1998).

A.3 Activity: Mercury emissions from taconite production
(Cooperator: Rod Bleifuss, Coleraine Minerals Research Lab, NRRI)

A.3.a Context within the project:
Mercury emissions are a function of both the concentration in materials and quantity of materials. Although it is likely that the mercury concentration of the raw materials in the taconite industry is very low, the tremendous quantity of product could make this industry a significant source of mercury emissions. The study will also include a preliminary estimate of the mercury currently being released to the environment in the pelletizing process.

A.3.b Methods:
The type and source of raw materials used in the manufacture of taconite pellets will be studied and representative samples analyzed. There are currently seven taconite operations on the Minnesota iron range, and they differ somewhat both in technology and raw materials. For instance, the easternmost ores are affected by metamorphic processes. Some taconite pellets are made with bentonite as a binder, whereas some use an organic polymer. Four operations chosen to be representative of the seven different taconite operations will be studied under this project. The mercury emission potential of the entire taconite process will be evaluated, ranging from the mercury content of explosives, to the ore, flux, binder, and energy source (coal, oil, wood chips). In addition to assessing the mercury emission potential we will also make a preliminary assessment of current mercury release to the environment from pelletizing by sampling the pellets, scrubber water, and dust collector products. These data can be used to estimate the mercury level in stack emissions. In addition, the history of mercury emissions from the iron range will be studied and estimated, so that comparison can be made with the stratigraphic data obtained from the lake sediment studies in Objective B.

Quality Assurance: Accuracy of all measurements will be checked using spikes of known concentrations and certified samples when available. Precision of all measurements will be checked by at least 10% replication of sample collection and 10% duplication of laboratory measurements. Split samples will be provided to other interested investigators and archived by freezing for quality assurance checks and for future analysis of other components.

Data management: All field measurements and sample history will be recorded in standard bound notebooks in the field. Each entry will include the date of sampling, the site location, field measurements, and the names of the people who performed the sampling. Any sampling problems that may cause sample contamination or affect sample integrity will also be recorded in the field notebook as well as reported to the project manager upon return from the field. After field work is completed, the notebooks will be archived in a designated area. Relevant field notebook entries will be included in a computer database that will be part of the report to the MPCA. The researchers conducting the study will have the prerogative to publish the results within a reasonable time period after the end of the project, but all the data is public information. Environmental data will be stored in standard public databases as appropriate, such as STORET.

A.3.c Materials:
Materials will consist largely of sample containers and normal laboratory supplies.

A.3.d Budget:

Total Biennial LCMR Budget:	$ 45,000
LCMR Balance:	$ 0
Match:	$ 0
Match Balance:	$ 0

A.3.e Timeline:

	7/95	1/96	6/96	1/97	6/97
Study design	xxxxxxx				
Sample collection	xxxxxxxxxx				
Sample analysis		xxxxxxxxx			
Historical Research		xxxxxxxx			
Report Preparation		xxxxxxxxxx			

A.3.f Workprogram Update:
May 1, 2000 Update:
All tasks in this activity were carried out successfully and reports were received by the MPCA (NRRI 1997). The results showed that although iron ore contains mercury in very low concentrations, the vast quantities of ore that are processed yields a significant contribution of mercury to the atmosphere. A great deal of additional investigation on mercury emissions will be conducted by the iron ore industry.

A.4 Activity: Mercury in Minnesota oil refining
(This activity will be carried out by MPCA personnel.)

A.4.a Context within the project:
Crude oil contains mercury in unknown concentrations. It is likely that gasoline is low in mercury because heating during distillation probably releases mercury to the atmosphere. What is the concentration in the crude oil, and what happens to this mercury?

A.4.b Methods:
A literature review of information relating to mercury in these materials will be conducted, and the manufacturing processes will be studied so that appropriate analyses can be made. Both Minnesota refineries (Ashland and Koch) will be studied. The two refineries process very different crudes, so it is important to evaluate both. In order to understand the fate of mercury contained in crude oil, the following fractions will be studied: gasoline, diesel fuel, residual oil, and distillate oil.

Quality Assurance: Accuracy of all measurements will be checked using spikes of known concentrations and certified samples when available. Precision of all measurements will be checked by at least 10% replication of sample collection and 10% duplication of laboratory measurements. Split samples will be provided to other interested investigators and archived by freezing for quality assurance checks and for future analysis of other components.

Data management: All field measurements and sample history will be recorded in standard bound notebooks in the field. Each entry will include the date of sampling, the site location, field measurements, and the names of the people who performed the sampling. Any sampling problems that may cause sample contamination or affect sample integrity will also be recorded in the field notebook as well as reported to the project manager upon return from the field. After field work is completed, the notebooks will be archived in a designated area. Relevant field notebook entries will be included in a computer database that will be part of the report to the MPCA. The researchers conducting the study will have the prerogative to publish the results within a reasonable time period after the end of the project, but all the data is public information. Environmental data will be stored in standard public databases as appropriate, such as STORET.

A,4.c Materials:
Materials will consist largely of sample containers and normal laboratory supplies.

A.4.d Budget:

Total Biennial LCMR Budget:	$28,000
LCMR Balance:	$0
Match:	$ 0

Match Balance: $0

A.4.e Timeline:

	7/95	1/96	6/96	1/97	6/97
Study design	xxxxxxx				
Sample collection	xxxxxxxxxx				
Sample analysis		xxxxxxxxx			
Report Preparation		xxxxxxxxxx			

A.4.f Workprogram Update:
May 1, 2000 Update:
All tasks in this activity were carried out successfully and a report was by the MPCA (Gilkeson 1999).

A.5 Activity: Mercury in products.
(This activity will be coordinated with a similar activity in the Hazardous Waste Division of the MPCA).

A.5.a Context within the project:
Incinerators are a major source of mercury emissions to the atmosphere. Minnesota laws and rules have addressed mercury in products where the mercury is obviously present, such as batteries, electrical switches, fluorescent lamps, and thermostats. But mercury can also be invisibly present in significant quantities as pigments in paper, plastics, and rubber, or as a chemical additives to plastics such as polyurethane, where it is sometimes used as a catalyst in manufacturing. It is essential to detect this mercury so that strategies can be devised for reducing or eliminating these sources of mercury.

A.5.b Methods:
The literature will be reviewed concerning the range of products that may contain added mercury. Representative products will be obtained and analyzed. An effort will be made to match analytical effort with the probability that the product could potentially be responsible for significant mercury emissions. Data from earlier Minnesota studies of the composition of the solid waste stream (MPCA 1992, 1993) and medical waste stream (Torkelson 1991) will be used to calculate potential emissions.

Quality Assurance: Accuracy of all measurements will be checked using spikes of known concentrations and certified samples when available. Precision of all measurements will be checked by at least 10% replication of sample collection and 10% duplication of laboratory measurements. Split samples will be provided to other interested investigators and archived by freezing for quality assurance checks and for future analysis of other components.

Data management: All field measurements and sample history will be recorded in standard bound notebooks in the field. Each entry will include the date of sampling, the site location, field measurements, and the names of the people who performed the sampling. Any sampling problems that may cause sample contamination or affect sample integrity will also be recorded in the field notebook as well as reported to the project manager upon return from the field. After field work is completed, the notebooks will be archived in a designated area. Relevant field notebook entries will be included in a computer database that will be part of the report to the MPCA. The researchers conducting the study will have the prerogative to publish the results within a reasonable time period after the end of the project, but all the data is public information. Environmental data will be stored in standard public databases as appropriate, such as STORET.

A.5.c Materials:
Materials will consist largely of sample containers and normal laboratory supplies.

A.5.d Budget:

Total Biennial LCMR Budget: $ 7,000

LCMR Balance:	$ 0
Match:	$ 0
Match Balance:	$ 0

A.5.e Timeline:

	7/95	1/96	6/96	1/97	6/97
Study design	xxxxxxx				
Sample collection	xxxxxxxxxx				
Sample analysis			xxxxxxxxx		
Report Preparation			xxxxxxxxxx		

A.5.f Workprogram Update:
May 1, 2000 Update:
All tasks in this activity were carried out successfully and the data was incorporated in a PCA report (Source Reduction Feasibility and Reduction Strategies (SRFRS) Committee 2000).

A.6 Activity: Coordination and Emission Inventory Preparation

A.6.a Context within the project:
Although all of the above activities will be contracted out, there will still be considerable need for MPCA staff to coordinate activities, help obtain samples, and synthesize the information into a revised mercury emission inventory (the earlier effort to inventory sources of mercury emissions, White and Jackson (1992), will be updated).

A.6.b Methods:
A half-time MPCA staff position will be devoted to coordinating emission inventory activities, helping to obtain samples, and writing a synthesis inventory report when the data are available.

A.6.c Materials:
Salary, travel, telephone, and computer time are necessary materials for this activity.

A.6.d Budget:

Total Biennial LCMR Budget:	$67,000
LCMR Balance:	$0
Match:	$ 0
Match Balance:	$ 0

A.6.e Timeline:

	7/95	1/96	6/96	1/97	6/97
Coordinate	xxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxx				
Study design	xxxxxxxxxxxx				
Help collect samples	xxxxxxxxxxxxxxxxx				
Synthesize emission inventory				xxxxxxxxxxxxxxxxxx	

A.6.f Workprogram Update:
May 1, 2000 Update:
All tasks in this activity were carried out successfully and the data was incorporated in a PCA report (Source Reduction Feasibility and Reduction Strategies (SRFRS) Committee 2000).

B. Title of Objectives/Outcomes:
Atmospheric Deposition of Mercury Across Minnesota
(Cooperator: Daniel Engstrom)

B.1 Activity: Site Selection, Coring, and Mapping

B.1.a Context within the project:
A total of 50 lake sites from two regions in Minnesota will be selected for sediment coring work to assess historic trends in mercury deposition over the last 150 years. From this array of 50 sites we will determine the relative changes in mercury inputs between preindustrial and modern times and compare these increases among lakes at different distances from local emission sources and with different levels of land-use in their watersheds.

B.1.b Methods:
The two study regions will include the Twin Cities metropolitan area and an out-state region in which a large point-source mercury emitter (power plant or incinerator) is located. We will use the Twin Cities region to explore local mercury deposition in an urban setting containing multiple emission sources and the rural transect to assess the local impacts of an isolated large emitter. Lake sites will be arrayed up- and down-wind of the mercury emission source so as to provide a spatial assessment of long-term mercury deposition. These transects will span a distance of 50–100 km -- the scale over which local mercury deposition is thought to occur. Most sites within the Twin Cities area will be located within the 7-county metropolitan area, however several lakes in western Wisconsin may be needed to complete the down-wind distal side of the transect. Additional lakes may be cored around emission sources in Wisconsin or Michigan if collaboration with researchers in those states would be particularly productive

Lakes with different degrees of watershed development will be selected at varying distances along the transects to explore the impact of land-use changes on mercury transport to lakes. Other criteria for site selection will include the availability of fish-mercury data and water quality data; these complimentary data will be used to compare mercury accumulation rates from sediment cores with contamination levels in fish. Lake selection and sampling will be coordinated with researchers from the University of Minnesota-Duluth, who are conducting a study of mercury concentrations in fish tissue from Minnesota Lakes (LCMR project number I-11). Watershed land-use will be characterized by GIS technology from existing imagery available from the University of Minnesota Map Library.

A single sediment core spanning the last 200-300 years of lake history will be collected from the deeper regions of each lake. The cores will be collected during the open-water season by means of a piston-corer fitted with a clear plastic core barrel and operated from the lake surface by rigid drive-rods. The sediments will be extruded vertically from the top of the tube at 1-4 cm intervals and stored under refrigeration until subsampled for various analyses.

B.1.c Materials:
Field supplies including sample containers, coring tubes, coolers and the fabrication of a new sediment corer: $3,000 budgeted

B.1.d Budget:

Total Biennial LCMR Budget:	$ 56,000
LCMR Balance:	$ 0
Match:	$ 0
Match Balance:	$ 0

B.1.e Timeline:

	7/95	1/96	6/96	1/97	6/97
Site Selection	xxxx				
Core Collection	xxxxxxx				
GIS Mapping		xxxxxxxxxx			

B.1.f Workprogram Update:
May 1, 2000 Update:
All tasks in this activity were carried out successfully and the GIS analysis is complete (Post 1996).

B.2 Activity: Sediment Dating

B.2.a Context within the project:
All sediment cores collected during the course of the project (section B.1) will be dated by lead-210 methods to provide a detailed chronology and sediment accumulation rates. These data are required to assess changes in mercury inputs from atmospheric deposition and watershed erosion.

B.2.b Methods:
Sediments will be dated by ^{210}Pb methods to determine age and sediment accumulation rates for the past 150-200 years. Lead-210 will be measured by ^{210}Po distillation and alpha spectroscopy, and dates will be calculated by the constant rate of supply (c.r.s.) model.

B.2.c Materials:
All material costs for dating supplies are subsumed in a standard analytical fee of $50 per sample. These costs include laboratory reagents, isotope standards and spikes, silver planchets, and instrument operation and maintenance fees.

B.2.d Budget:

Total Biennial LCMR Budget:	$ 83,750
LCMR Balance:	$0
Match:	$ 0
Match Balance:	$ 0

B.2.e Timeline:

	7/95	1/96	6/96	1/97	6/97
^{210}Pb Analytical		xxxxxxxxxxxxxxxxxxxxxx			
^{210}Pb Modeling			xxxxxxxxxxxxx		

B.2.f Workprogram Update:

May 1, 2000 Update:
All tasks in this activity were carried out successfully and the data was incorporated in a report to the MPCA (Engstrom et al. 1999).

B.3 Activity: Sediment Chemistry

B.3.a Context within the project:
Sediments will be analyzed for mercury content, bulk density, and the content of inorganic material derived from erosion of watershed soils. These data in combination with results from ^{210}Pb dating (B.2) will be used to reconstruct time-trends in mercury inputs and watershed erosion.

B.3.b Methods:
The concentration of total mercury will be measured at 15 stratigraphic levels in each dated core. Sampling intervals will be spaced according to dating results to provide maximum detail for the 20th century and coarser resolution for the previous 100 years. The concentration of methyl mercury will be analyzed from a selection of 20 cores at the same stratigraphic levels analyzed for total mercury. These cores will be selected to provide a comparison of lakes with (a) high and low rates of watershed erosion (b) high and low impact from urban emission sources, and (c) high and low alkalinity. Results from sediment dating, total mercury, and geochemical measurements will be used to select the best sites for methyl mercury analysis. Total and methyl mercury will be measured by cold-vapor atomic fluorescence using state-of-art instrumentation and clean-lab techniques.

Bulk density, organic matter, and carbonate content of all sediment samples will determined by standard loss-on-ignition techniques. Characteristic changes in sediment lithology (including texture and color) marking the onset of European settlement will be used as a provisional dating marker to guide sample selection for dating and mercury analysis. Such changes usually involve an increase in inorganic constituents (silts and clays) representing accelerated erosion from land clearance and farming in the mid to late 1800s. Because the inorganic fraction is largely composed of silts and clays (clastic materials), the inorganic content of the sediments is often a good proxy for erosional intensity. Geochemical analysis for elements associated with the erosion of mineral soil (sodium, potassium, titanium, aluminum) will also be conducted to assess watershed disturbance. Selected sediment intervals will be digested by lithium-borate fusion and measured by ICP-MS for a suite of 12 major elements (including the erosion indicators listed above).

Quality Assurance: Accuracy of all measurements will be checked using spikes of known concentrations and certified samples when available. Precision of all measurements will be checked by at least 10% replication of sample collection and 10% duplication of laboratory measurements. Split samples will be provided to other interested investigators and archived by freezing for quality assurance checks and for future analysis of other components.

Data management: All field measurements and sample history will be recorded in standard bound notebooks in the field. Each entry will include the date of sampling, the site location, field measurements, and the names of the people who performed the sampling. Any sampling problems that may cause sample contamination or affect sample integrity will also be recorded in the field notebook as well as reported to the project manager upon return from the field. After field work is completed, the notebooks will be archived in a designated area. Relevant field notebook entries will be included in a computer database that will be part of the report to the MPCA. The researchers conducting the study will have the prerogative to publish the results within a reasonable time period after the end of the project, but all the data is public information. Environmental data will be stored in standard public databases as appropriate, such as STORET.

B.3.c Materials:
All material costs for total-mercury analysis are covered in a standard analytical fee of $35 per sample; the cost of methyl-mercury analyses are projected at $125 per sample. Analytical fees for elemental analysis are budgeted at $30 per sample. Laboratory supplies for sediment digestion and loss-on-ignition include sample containers and analytical reagents; $3,000 budgeted.

B.3.d Budget:

Total Biennial LCMR Budget:	$ 108,250
LCMR Balance:	$ 0
Match:	$ 0
Match Balance:	$ 0

B.3.e Timeline:

	7/95	1/96	6/96	1/97	6/97
Loss-on-Ignition	xxxxxxxxxxx				
Hg Analytical		xxxxxxxxxxxxxxxxxxxx			
Elemental Geochemistry		xxxxxxxxxx			

B.3.f Workprogram Update:
All tasks in this activity were carried out successfully and the data was incorporated in a report to the MPCA (Engstrom et al. 1999).

B.4 Activity: Lake Chemistry

B.3.a Context within the project:
Many of the lakes that are chosen for sediment analysis will have supporting data already available, such as fish tissue analyses and background water chemistry (pH, alkalinity, DOC, chlorophyll, cations, anions). However, some lakes will be chosen for sediment analysis for which their is no reliable supporting data. We will work with the DNR to obtain fish tissue analyses, and water samples will be taken for analysis. Lake chemistry is essential for inclusion in the database for multiple regression analysis of the data (see data interpretation, below).

B.4.b Methods:
Samples will be taken using standard MPCA protocols and submitted for analysis to the NRRI water chemistry laboratory in Duluth, which is accustomed to analyzing dilute waters of northern Minnesota.

Quality Assurance: Accuracy of all measurements will be checked using spikes of known concentrations and certified samples when available. Precision of all measurements will be checked by at least 10% replication of sample collection and 10% duplication of laboratory measurements. Split samples will be provided to other interested investigators and archived by freezing for quality assurance checks and for future analysis of other components.

Data management: All field measurements and sample history will be recorded in standard bound notebooks in the field. Each entry will include the date of sampling, the site location, field measurements, and the names of the people who performed the sampling. Any sampling problems that may cause sample contamination or affect sample integrity will also be recorded in the field notebook as well as reported to the project manager upon return from the field. After field work is completed, the notebooks will be archived in a designated area. Relevant field notebook entries will be included in a computer database that will be part of the report to the MPCA. The researchers conducting the study will have the prerogative to publish the results within a reasonable time period after the end of the project, but all the data is public information. Environmental data will be stored in standard public databases as appropriate, such as STORET.

B.4.c Materials:
All material costs for analyses are covered in a standard analytical fees.

B.4.d Budget:

Total Biennial LCMR Budget:	$8,000
LCMR Balance:	$0
Match:	$ 0

Match Balance: $0

B.4.e Timeline:

	7/95	1/96	6/96	1/97	6/97
Water analysis	xxxxxxxxxxx				

B.4.f Workprogram Update:
All tasks in this activity were carried out successfully and the data have been incorporated in the MPCA permanent database (STORET).

B.5 Activity: Data Interpretation

B.5.a Context within the project:
Trends in mercury accumulation will be compared among lakes within each of the two study regions (metro and out-state) to determine if sites near emission sources are more highly impacted by atmospheric mercury deposition than those more distant and whether such lakes have higher levels of fish contamination. Lakes will be stratified according to watershed impacts and erosion rates to determine whether urbanization, agriculture, and other land use changes increase mercury export from watershed soils.

B.5.b Methods:
Analytical results from sediment dating and mercury analyses will be used to calculate mercury accumulation rates for each core for three time-stratigraphic periods -- (pre-industrial, modern, and peak (1960-1970). The change in mercury accumulation between these periods will provide a relative measure of the increase in mercury inputs to the lakes. It is necessary to use mercury accumulation (as opposed to concentration) in this comparison, because many of the lakes in this study will have experienced increased sedimentation rates (that dilute mercury concentrations) during the last 100 years. The ratio of modern to preindustrial mercury accumulation is also independent of individual lake characteristics (size, chemistry, morphometry, etc.) that otherwise affect the absolute flux of mercury to the core-site and can be compared among lakes to assess spatial trends in atmospheric deposition.

Increased mercury inputs to lakes may result from changes in atmospheric mercury deposition, land-use changes that alter mercury retention in the watershed, or both factors simultaneously. We will use two approaches to disentangle increasing watershed inputs of mercury from spatial and temporal trends in atmospheric deposition. (1) Lakes will be stratified according to land-use cover types to help normalize for different degrees of watershed impacts. Those lakes with little or no watershed development should largely reflect spatial trends in atmospheric deposition; comparisons among nearby lakes with different degrees of watershed impact should reveal the effects of urbanization, agriculture, and other land-use practices on mercury export from watershed soils. (2) Changes in accumulation of inorganic sediment will be used as a proxy for erosional intensity in order to normalize mercury fluxes to different degrees of land-use impact. Lakes may be stratified according to erosional intensity (as above) or mercury accumulation ratios may be numerically corrected for the changes in inorganic accumulation.

Because mercury concentrations and sedimentation rates are spatially variable within a lake basin, mercury accumulation rates at a single core site cannot be automatically extrapolated to the entire lake bottom and actual fluxes to the lake in a mass-balance sense cannot be calculated. Atmospheric deposition rates for mercury can be determined from sediment studies, but such calculations usually require that many cores be analyzed from a single lake (Engstrom *et al.*, 1994) . However, in this study we will explore two new methods for estimating whole-lake mercury fluxes from single cores. In the first approach mercury accumulation rates will be corrected by the inventory of ^{210}Pb in the core to correct for different degrees of sediment focusing among core locations and lakes. In the second method mercury accumulation rates will be normalized to estimates of pre-industrial mercury deposition for the upper Midwest (derived from previous multiple-core studies) with lake-wide inputs corrected for watershed size according to equations in Swain *et al.* (1992). The purpose of this exercise is to derive whole-basin mercury accumulation rates that can be compared with levels of fish contamination (along with other environmental variables -- pH, alkalinity, DOC) using multiple regression methods.

Recent research indicates that methyl mercury (the toxic form taken up by aquatic organisms) is preserved in lake sediments in proportion to its production within the lake. Sediment profiles may thus provide an historic account of both inorganic and biologically active mercury species. A comparison of trends for total and methyl-mercury should help determine whether inputs from watershed erosion are available for methylation to the same extent as direct atmospheric deposition, or whether mercury inputs to urban lakes are more or less likely to be methylated than inputs to rural lakes. Methyl mercury fluxes may also be compared between low and high alkalinity lakes (low alkalinity lakes tend to have higher mercury levels in fish), to determine whether a larger portion of incoming mercury is methylated in those lakes with higher fish mercury. Methyl-mercury trends will be compared among several groups of lakes in a manner similar to that described for total-mercury. In addition, the ratio of methyl/total mercury will provide a critical measure of historic changes in the availability of mercury inputs for methylation. Comparisons will be made between four groups of lakes (five lakes in each group) according to the following scheme:

Group	Location	Erosion	Alkalinity
Control	rural	low	high
Disturbed Watershed	rural	high	high
Urban Emission	downwind of Metro	low	high
Low Alkalinity	rural	low	low

B.5.c Materials:
Office and computer supplies for data analysis, manuscript preparation, and publication are included: $2,000 budgeted

B.5.d Budget:

Total Biennial LCMR Budget:	$27,000
LCMR Balance:	$0
Match:	$ 0
Match Balance:	$ 0

B.5.e Timeline:

	7/95	1/96	6/96	1/97	6/97
Data Analysis				xxxxxxxx	
Final Report					xxxxxxx

B.5.f Workprogram Update:

All tasks in this activity were carried out successfully and the data was incorporated in a report to the MPCA (Engstrom et al. 1999).

C. Title of Objectives/Outcomes:
Economic Analysis of the Benefits of Reduced Mercury Deposition
(Cooperators: Jim Vincent, University of St. Thomas and Patrick Welle, Bemidji State University)

This component of the project will involve the estimation of economic benefits that result from reduced mercury deposition. When potential improvements are made to environmental quality, then there will typically be economic benefits that accrue to some individuals. Some of these benefits may be reflected in market transactions, such as increased spending for recreational fishing. In many cases, however, the benefits people receive are not reflected in market transactions. In these circumstances people may receive benefits from keeping open the option to visit a resource that has been preserved, they may derive satisfaction simply from knowing that the integrity of an ecosystem has been preserved or enhanced or they may benefit from reduced health risks. The economic benefits derived in these "passive" manners typically cannot be estimated from conventional data on prices and costs.

Estimation of the total economic value of a potential environmental improvement thus requires a technique which has the capacity to measure the value that accrues to all who enjoy improvements in environmental quality. The contingent valuation method (CVM) is one of the principal techniques employed in order to obtain a measure of the willingness of the public to pay for such improvements. The CVM employs a sophisticated survey procedure designed to elicit from respondents their maximum willingness to pay for a specific environmental improvement. After aggregating across the study population an estimate of the average Minnesota household willingness to pay can be derived.

It should be noted that not all contingent valuation studies are regarded as being effective at deriving valid estimates of willingness to pay. The state of the art regarding proper study design is continuously evolving, and only those studies that reflect proper design protocols are able to yield credible and defensible results. (A more complete description of the CVM is provided below in Section VII. Also included in Section VII is an analysis of the potential usefulness of contingent valuation results as well as a review of the weaknesses and criticisms of the method.)

This project can be partitioned into two phases. Phase I will involve the design and peer-review of the contingent valuation survey instrument. In Phase II the survey is implemented (by telephone, personal-interview and mail), data are collected and analyzed, and a final interpretive report is completed.

C.1 Activity: Estimation through the Contingent Valuation Method

C.1.a. Context within the project:
It is recognized that measures to reduce mercury deposition may impose costs on society. These costs are most likely to be borne in the form of higher prices for goods and services. In order to determine the cost that the public is willing to bear it is necessary to have information on the potential economic benefits they will receive in exchange. In addition, distributional issues can be explored. Hypotheses can be tested regarding whether benefits of mercury control (regardless of how big or small they may be in the aggregate) accrue predominantly to a particular socio-economic group (e.g., higher-income, better-educated households) or to a particular region of the state. This information will assist policy-makers in determining the appropriate control measures.

C.1.b. Methods:
A contingent-valuation survey will be employed to estimate the potential economic benefits of mercury control measures. Responses will be obtained from a random sample of Minnesota households. This study will employ a "willingness-to-pay" perspective for the definition of economic benefits. This particular application of CVM will reflect the design recommendations of the NOAA Panel (see the discussion in Section VII) as well as reflecting subsequent research developments.

The information provided to respondents will be in the form of policy scenarios developed in consultation with the Minnesota Pollution Control Agency (MPCA). A policy scenario consists of a description of a possible policy action (at either the federal or state levels) and the potential environmental effects of that action. Dr. Edward Swain of the MPCA will be the lead scientist in the development of the policy scenarios employed in this study. It is anticipated that experts on the environmental effects of mercury emissions will be engaged as subcontractors for this phase of the project. This will enable Dr. Swain to develop credible and defensible policy scenarios which are based on the most up-to-date research findings and modeling results.

It should be recognized that the use of the CVM does not require that we know with certainty the effects of mercury-control actions. Many policy decisions are made in an environment of uncertainty, as are many consumers' decisions. Of great interest in a study of this type is how an accurate portrayal of scientific uncertainty affects respondents' views of the economic benefits of a policy action.

The survey responses used for benefits estimation will be obtained by three separate response-elicitation techniques. Personal (face-to-face) interviews of 250 Minnesota adults will be conducted. This type of interview process enables the greatest amount of information to be collected on respondent motivation. This in turn allows for more decisive interpretation of responses as reflecting true willingness to pay. The use of personal interviews in this study reflects the importance attached to interviews in the NOAA-panel recommendations.

The personal-interview method, however, has been subject to criticism due to the limitations imposed on sample sizes due to the high cost of professionally executed interviews. To ameliorate this problem the sample will be augmented in a cost-effective fashion through two additional sub-samples. One sub-sample will consist of responses to telephone interviews conducted with a random sample of 250 Minnesota adults. These interviewees will have received background information on the proposed policy scenarios prior to the phone interview (see Hanemann (1994) for a discussion of this approach--note: all references are located at the end of section VII). The third sub-sample will involve a mail survey distributed to a random sample of 2,000 Minnesota households.

This system of three different elicitation techniques also provides for the capability to test for respondents' sensitivity to the scope ("quantity" of potential effects) of mercury pollution reductions. (The issue of sensitivity to scope and embedding bias are discussed below in Section VII.) This is an important test for internal consistency of responses, and can help to determine if biases are present in the estimation of willingness to pay.

Each sub-sample (as defined by elicitation technique) will be subdivided, with a different policy scenario being described to the different groups. For example, each sub-sample may be split in two, with half of the group receiving a policy scenario describing actions taken by the State of Minnesota alone to reduce mercury emissions. The other half will receive a policy scenario in which Minnesota considers taking action as a part of a larger nationwide control effort. This approach is valuable for two reasons. First, it may be of intrinsic interest to policy-makers how the willingness of Minnesota households to pay for mercury control may differ between the smaller-scale state-level effort and the larger-scale national effort. Secondly, it enables the investigators to conduct an additional test for possible insensitivity to scope. The latter is important in evaluating the validity of the results produced by the study.

The structure of the survey instrument will be what is known in the discipline as a "dichotomous-choice, referendum-style" survey. The CV researcher must provide respondents with a realistic portrayal of the policy options, and describe the cost burden to their household. The cost burden is defined both in terms of its magnitude and the vehicle through which these costs will be paid (e.g., higher prices for products or higher taxes, etc.). In a dichotomous-choice, referendum format, the respondents reveal how they would "vote" in a referendum on the policy, given the policy's cost to their household. From such responses, an average household willingness to pay can be estimated (using an econometric technique known as censored logistic regression).

Additional questions about households' characteristics allow for a fuller understanding of how such characteristics affect respondents' willingness to pay. This type of information is important for the purposes of accurate statistical estimation, but also allows for exploring other issues of importance. For example, with such information hypotheses regarding whether economic benefits of mercury control accrue predominantly to higher-income households, to higher-educated households or to specific regions can be tested. These distributional issues, in addition to the overall willingness to pay, are of concern to policy-makers.

Further analysis of the benefits of reduced mercury deposition will be conducted based on responses to questions designed to determine the various motivations underlying willingness to pay. One component of value is the benefit attached to reduced pollution as "an insurance policy" against damages that are not known with certainty (option value). Given the scientific uncertainty about the effects of mercury deposition this analysis will generate useful information on social preferences for reducing the risks imposed by mercury pollution.

Other questions will also be designed to distinguish between the motives of respondents for reducing mercury deposition, most importantly to examine the relative importance of use values versus non-use (often referred to as passive-use) values. For example, use values would include perceived benefits from fishing in lakes that were not subject to fish consumption advisories. Also to be explored are respondents preferences for perceived reductions in health risks. The procedures employed to discriminate among motivations for willingness to pay will build upon and extend the work done by these investigators in previous work performed for the MPCA on acid deposition (Welle (1986)) and toxic air pollution (Welle, Vincent and Hagen (1992)).

A critical part of the development of the contingent valuation survey instrument is the pretesting process. Three types of pretests recommended in the literature will be employed: (1) peer review among experts on CVM and survey research, (2) trial delivery of the survey instruments with people from the survey population (including multiple focus groups), and (3) review by personnel who will use the empirical results (e.g., the MPCA staff) to ensure that the evidence generated will be in a form useful for policy purposes.

A subsequent pretesting step is employed in order to enhance the statistical accuracy of the results. After the survey instrument is developed it is implemented with a fraction (approximately 10%) of the sample population. The responses are then used to estimate a preliminary version of the willingness-to-pay function. This function is then used to compute the distribution of "household cost" values which are employed in the dichotomous-choice referendum. This approach has been demonstrated to improve statistical confidence (see Duffield and Patterson (1991) and Bishop and Heberlein (1990)).

This team of investigators has extensive experience in these methods and have conducted nationally recognized research on the implementation and on the validity of CVM (see Sections VII and XIII). Previous CVM research conducted by these researchers have been performed with the assistance of Bemidji State University's Center for Social Research. The Center has a qualified staff with experience in both CVM and general survey research methods. It is anticipated that the BSU Center for Social Research will be engaged for the interviewing process as well as for the technical implementation of the mail survey.

C.1.c. Materials:
Printing of Survey: $1500
Postage (for multiple mailings): $4000
Purchase of phone list & long-distance phone charges (for follow-up calls): $2500

C.1.d. Budget:

Phase I (funded by EPA grant to MPCA): $60,000
(Survey instrument design and peer-review of survey instrument)

Phase II (funded by LCMR):
(Survey instrument pretesting, implementation, analysis of results, and final report)

Total Biennial LCMR Budget:	$ 50,000
LCMR Balance:	$ 0
Match:	$ 0
Match Balance:	$ 0

C.1.e. Timeline:

	7/95	1/96	6/96	1/97	6/97
Survey design	xxxxxxxxxxxxxxx				
Survey execution		xxxxxx			
Statistical analysis and report			xxxxxxxxxxxxxxxxxxx		

Survey design xxxxxxxxxxxxxxx
This phase of the activity will involve the design and pretesting of the survey instrument. The product will be the completed survey instrument.

Survey execution xxxxxx
The second phase of the activity will be the execution of the survey and data collection. This process takes approximately two months. The product will be a data set which will enable the estimation of willingness to pay for mercury reduction.

Statistical analysis and report xxxxxxxxxxxxxxxxxxx
The third phase of the activity will be the analysis and interpretation of the data. The results of the study and the methods employed will be fully explained in an extensive final report. The implications and reliability of the results for policy-making purposes will be addressed.

C.1.f Workprogram Update:
All tasks in this activity were carried out successfully and the data was incorporated in a report to the MPCA (Hagen, Vincent, and Welle 1999).

VI. Evaluation

The project as a whole will be successful if the three components substantially enhance our ability to implement strategies to reduce mercury contamination in Minnesota, as outlined by the MPCA Mercury Task Force (1994). Because the three components of this project are being pursued in different ways, the success of each component has to be judged independently.

A. Mercury Analyses and Emission Calculations

Because there is measurable mercury in virtually all natural and manufactured materials, it will be possible to determine the potential emissions for combustion of wood, wood products, consumer products, and liquid fuels such as gasoline and ethanol. QA/QC procedures will be devised so that the utility of the data can be confirmed. Careful study of refineries and ethanol production will reveal where any mercury emissions occur in those processes.

B. Atmospheric Deposition of Mercury Across Minnesota

Currently there is no data on the degree of enhanced mercury accumulation in lakes around urban areas or point sources such as an incinerator. Similarly, there is no information on how much mercury loading is increased by wind- or water-borne soil erosion. If this component can delineate the range of each of these, then it will have been successful. Even knowing just the range of these effects will allow us to allocate resources to mercury reduction.

C. Economic Analysis of the Benefits of Reduced Mercury Deposition

Contingent valuation studies are evaluated at several stages. (This subject is discussed in more detain in Section V.C.1.b.) The survey instrument itself is subject to a rigorous review process by experts in the discipline, by policy-makers who may rely on the information gathered, and by potential respondents. After implementation of the survey there are several tests for internal consistency which must be conducted. This is made possible in part by an array of background questions asked of respondents. These enable a determination of whether survey respondents' were seriously considering the potential financial impacts they would feel if additional regulatory controls were adopted. If their responses are consistent with the predictions of economic theory, then there is a higher degree of confidence that meaningful estimates of household willingness-to-pay can be obtained. The structure of the survey instrument proposed in this study design enables tests for sensitivity to scope along several dimensions. Such tests can be made across elicitation methods and within each elicitation sub-sample but across the different policy scenarios presented.

A final mode of review is that of peers. This study will employ state-of-the-art design protocols and will also contain novel diagnostic techniques. It is anticipated that this will enable the production of conference papers and journal articles. The scrutiny given to the study design and results under these conditions will offer an additional critical perspective on its usefulness.

VII. Context within field:

A. Mercury Analyses and Emission Calculations

It is simply not possible to implement effective mercury reduction strategies unless the sources of mercury to the atmosphere are known and quantified. For instance, many people are under the impression that fuel oil is a preferable energy source compared to coal for electrical production, in terms of mercury emissions. Yet, this assumption may not hold up if losses during refining were included. Similarly, there is a wide-spread assumption that biomass combustion must be cleaner than fossil fuel. But, there is little data to address this assumption, and few people keep in mind that the mercury content per B.t.u. is the pertinent issue, rather than the mercury concentration.

The fate of mercury in soil represents the most challenging activity here. It may be difficult to show that volatilization of mercury under laboratory conditions are representative of field conditions. It also may be difficult to devise a technique to quantity the mercury content of wind-blown soil and quantify its movement. Although soil is the biggest challenge, it is also the most important category to understand, because soils contain the largest pool of mercury in Minnesota, and the world, that is available to aquatic systems.

B. Atmospheric Deposition of Mercury Across Minnesota

One of the central questions surrounding atmospheric mercury pollution is the relationship between mercury emission sources and the deposition that occurs at a given location. In Minnesota (and elsewhere) we currently do not know how much deposition results from local emissions and how much comes from long-distance transport from regional and global sources. In previous studies funded by the LCMR we learned that mercury deposition in out-state Minnesota is elevated four-fold over natural (pre-industrial levels) and that in pristine (forested and undeveloped) watersheds, about 20% of incoming mercury is washed into lakes; the remainder is retained in the soils or re-emitted to the atmosphere (Swain *et al.*, 1992) . More recently our studies of the Minneapolis chain of lakes show that peak mercury inputs to these sites were elevated 9-16 times above background (pre-industrial) levels -- well above the increase in out-state Minnesota (unpublished data). These results suggest that mercury deposition in the Twin Cities area may be higher than in rural areas or that urbanized watersheds are much less effective in retaining mercury than are forested ones. Both factors may actually contribute excess mercury to Twin Cities lakes, which may account for the unexpectedly high levels of mercury found in fish from some of these sites (DNR data).

Direct monitoring of mercury deposition has been conducted at several locations in Minnesota over the last 3-4 years, but because mercury deposition is highly variable in space and time (especially near emission sources), the available data are not adequate to answer the question of spatial trends, nor can they address the fate of mercury once it falls on the landscape. The use of lake sediment cores to document deposition patterns has several advantages over direct monitoring: (1) sediment records integrate short-term variations in mercury deposition, (2) they provide a historic record of changes in mercury input, (3) they provide information on watershed contributions, and (4) the lakes themselves are the receptor of interest where rates of mercury input have a direct bearing on contamination levels in the biota.

Clearly mercury loading rates are not the only factor limiting mercury residues in fish. The production of methylmercury is probably the critical process controlling mercury bioaccumulation, but factors affecting methylation are not well understood. Empirical observations have identified pH, alkalinity, and dissolved organic carbon (DOC) as significant correlates of mercury in fish (Swain & Helwig, 1989) . Nonetheless, methylmercury production can be proportion to mercury concentration, such that an increase in total mercury deposition could produce an equivalent response in mercury bioaccumulation, all other factors being equal. In Minnesota over 500 lakes have been assessed for mercury levels in fish, but previous efforts to relate contamination levels to water-chemistry and geographic variables have not included mercury loading among the various environmental correlates, because such data were unavailable on a lake-by-lake basis. Results from this study will provide an assessment of mercury inputs -- from direct deposition and soil erosion -- that may be compared along with other environmental data to levels of fish contamination.

C. Economic Analysis of the Benefits of Reduced Mercury Deposition

The use of the CVM in economic analysis can best be understood after a brief review of the types of economic value of relevance in economic theory. Use value is said to be obtained when someone gets enjoyment from some form of direct interaction with the resource. For example, people may engage in recreational activities such as hiking, hunting, wildlife watching or fishing. Health-related use value may be derived if people perceive a cleaner environment as offering lower health risks.

Passive-use value, on the other hand, can be derived without any direct interaction with the resource. Passive-use value can take three distinct forms: existence value, option value and quasi-option value. In the case of existence value, a person derives satisfaction simply from knowing that a resource (such as a species or pristine ecosystem) exists. There are several possible motives underlying existence value. These may include altruism, the desire to leave a bequest to future generations, or perhaps the capacity of people to derive satisfaction directly from the knowledge of the existence of certain intact ecosystems. Existence value has been identified in a variety of contexts, including natural resources, places of historic significance, and great works of art.

Another form of passive-use value is option demand. Resource preservation can give rise to option value when some people are uncertain about their future demand for visitation (use) of the resource. As a result, these individuals may be willing to pay to have the resource preserved, thus keeping open their option to visit it. Option value is analogous to an insurance premium that someone would be willing to pay to guarantee that the resource exists should they decide to visit it in the future. Option value, by this definition, represents a willingness to pay for resource preservation over and above any expected consumer benefit that the person would receive from future use of the resource. Although option value is related to use, in a formal sense it is a passive-use value since the benefit of keeping one's option open can occur in complete isolation from the resource, and occurs simply because of the fact that the resource exists.

A third type of passive-use value is quasi-option value. Quasi-option value arises because there is uncertainty about the future value of many natural resources. For example, some resources (predominantly plant and animal species) may have medicinal properties about which we are currently unaware. Information about the value of such resources is revealed only with the passage of time and the accumulation of knowledge. As information accumulates, more accurate assessments of the value of natural resources can be made. If we take irreversible actions (such as ecosystem alterations which reduce biological diversity), we lose our ability to study the lost resource for potential use. In contrast, by preserving such a resource we afford ourselves the opportunity to obtain additional information about its potential uses, while maintaining the opportunity to use the resource in any way we see fit in the future. This expected value of this opportunity is positive.

In addition to the distinction between use and passive-use value, a distinction can be drawn between market and non-market goods. When goods are traded in markets people register their economic valuation--that is, they "vote" with their dollars. Market price data thus provide information which can be used to calculate the economic value consumers place on such goods. There are many goods, however, which are not traded in markets. For some of these goods no price-based valuation information exists. Many of the goods provided by natural resources fall into this category. One reason for this is that many environmental goods are "public" goods, as is explained below.

In the case of private, market-traded goods the value of a unit of the good is obtained only by a single consumer. For example, consumption of a slice of pizza by an individual consumer precludes the consumption of that slice by other consumers. In contrast, a person's consumption of a public good (such the existence of an intact ecosystem) does not preclude the consumption of that good by others. This characteristic, called non-rival consumption, renders the economically efficient provision of public goods incompatible with private markets.

This characteristic also implies that the economic value of a unit of the good is the sum of all consumers' values. In the case of a private good, such as a slice of pizza, it makes economic sense to produce it only if there is a person who values it sufficiently highly to pay for the cost of production. In the case of public goods, provision is economically efficient if the sum of all consumers' values is sufficient to cover the cost of production, since consumption is non-rival. The passive-use goods provided by the preservation of healthy forest ecosystems have the characteristics of public goods. The enjoyment of such a good by one individual does not diminish the ability of others to enjoy the same good.

This economic-theoretic framework has two very important implications. Goods which are public in nature are likely to be under-provided by private markets or by policy decisions which rely solely on market-produced data. An additional implication is that the value of each unit of the public good is the sum of values placed on it by each potential consumer. The total economic value of the passive-use goods is thus the sum of the values of each consumer places on these goods.

The Contingent Valuation Method

There are some significant methodological differences in the estimation of use value and passive-use value. Use value is typically associated with some potentially observable activity on the part of the consumer, most notably travel to a recreation site. The expenditures associated with engaging in recreation, for example, can be used in the estimation of what consumers are willing to pay to use the resource. Many studies of recreation demand have employed the travel-cost method (TCM) to estimate willingness to pay for improvements in environmental quality, in which travel costs (including the value of personal time) are used to estimate the strength of demand for visitation.

The problem confronting researchers in the estimation of total economic value (use value plus passive-use value) is that passive consumption for the most part does not generate observable behavior. Thus there are not the associated expenditures from which strength of demand can be inferred. The recognition that passive-use values are an integral part of economic value combined with the lack of observable economic behavior has led to a direct method for eliciting consumers' willingness to pay for potential environmental improvements. This technique is known as the contingent valuation method.

The contingent-valuation method (CVM) is widely applied to the problem of estimating the economic value of goods and services which are not traded in markets and for which no economic behavior is observable. These non-market characteristics are present when the "good" in question is in the form of an environmental amenity. As a result, contingent valuation is receiving increasing use for estimating the economic value of environmental goods. These applications include the estimation of economic damages from oil spills, the value associated with ecosystem preservation, and the benefits of reduced exposure to pollutants.

The contingent valuation method utilizes survey methodology to reveal the monetary values respondents place on goods. The CV researcher must provide respondents with a realistic portrayal of the policy options (e.g., management alternatives for a given area of forestland), and describe the cost burden to their household. The cost burden is defined both in terms of its magnitude and the vehicle through which these costs will be paid (e.g., higher prices for products, higher taxes, etc.). A valuation question then typically follows, in which respondents reveal either directly or indirectly their willingness-to-pay (WTP) for the stated good. For example, with a valuation question in a dichotomous-choice (or referendum) format, the respondents reveal how they would "vote" in a referendum on the policy, given the policy's cost to their household. From such responses, a mean WTP can be estimated. Alternatively, the valuation question can have an open-ended or payment-card format. (See Mitchell and Carson, 1989, for an extensive discussion of these approaches.)

The credibility accorded to the results of contingent-valuation studies is evidenced, in part, by the increasing support for its use as a method for estimating the economic benefits associated with policy proposals. For example, it is included in the federal government's prescribed procedures for analysis (Water Resources Council, 1979, 1989 and Department of the Interior, 1986.) In addition, results from contingent-valuation studies were granted the status of rebuttable presumption in environmental-damage litigation cases by a U.S. Circuit Court of Appeals (*State of Ohio vs. the United States Department of Interior*, 880 F.2d 432, D.C. Circuit, 1989). These policy developments provide for the use CVM as an estimation technique to establish compensable environmental damages under the Comprehensive Environmental Response, Compensation, and Liability Act of 1980 (CERCLA). The same now holds true for the Oil Pollution Act of 1990. Along with this increasing use has come increasing scrutiny.

In recent years economists, psychologists and survey researchers have vigorously debated the validity of using the contingent valuation method to estimate the economic value of goods which are not traded in markets. A recent analysis of CVM was conducted by a high-profile panel appointed by the National Oceanic and Atmospheric Administration (NOAA). This panel assessed the usefulness of the method and recommended research protocols to improve the tool's performance. The conclusions reached by the panel were used by NOAA in its rulemaking under the Oil Pollution Act of 1990. The panel consisted of five distinguished researchers, and was co-chaired by two Nobel laureates in Economics, Kenneth Arrow and Robert Solow. One of the its members describes the task given to the panel as addressing the following question: "Is the contingent valuation method capable of providing estimates of lost nonuse or existence values that are reliable enough to be used in natural resource damage assessments?" (Portney, 1994, p. 8).

Summaries of many of the issues can be found in surveys of the literature produced by Cummings, Brookshire, and Schulze (1986) and by Mitchell and Carson (1989). Recently Carson et al. (1994) assembled a bibliography on CVM that contains 1,672 references. The studies referenced include applications of CVM as well as diagnostic research designed to assess its validity and reliability.

Much of the research on CVM has focused on the extent to which it is subject to random error (imprecision) or systematic error (biased results). The most serious concerns have related to the possibility of bias (systematic over- or underestimation). Most of the investigation has focused on the following categories of potential bias: (a) incentives for strategic responses, or strategic bias, (b) error based on the information which is conveyed, or information bias, (c) error due to the hypothetical nature of the CV market, or hypothetical bias, (d) the influence of cost information presented in the survey on respondents' stated monetary valuation, or starting-point bias, and (e) embedding bias. Surveys of this research can be found in Cummings, et al., (1986) and Mitchell and Carson (1989).

Among the most interesting methodological studies are those designed to compare CV results to the values generated in simulated markets in which actual (as opposed to hypothetical) monetary transactions are made. Some of the most revealing work in this area is that by Bishop and Heberlein on the exchange of hunting permits (Bishop and Heberlein, 1979, 1990 and Bishop, et al., 1983). Contingent values on willingness to pay were statistically quite close to those revealed in actual cash transactions. Contingent values generated from a sealed-bid auction were 33% higher than cash-transactions values. When the CV questions were in the dichotomous choice format (in which the respondent must agree or refuse to pay a specified price for the good), the CV results for willingness to pay exceeded the values from the simulated market by 13%. In neither case were the differences statistically significant.

Concern about how a good's characteristics affect the reliability of CV estimates is addressed in research by Kealy, Montgomery, and Dovidio (1990). Their research examined contingent values of two goods "...at polar extremes of the private/public good continuum: a brand-name candy bar and a contribution to a program to alleviate acid rain damage in a major recreational area (Kealy, et al., 1990, p. 259)." They hypothesized "...that contingent values for our public good would be less reliable and less accurate predictors of actual willingness to pay than those for our private good because the private good was more well defined and concrete, and because of respondents' greater familiarity with the private good (p. 259)." Their results, however, contradict this hypothesis. They found comparable reliability and predictive validity for both types of goods.

Recently the research agenda has been dominated by concerns over "embedding" bias in CVM results, a phenomenon which results in respondents exhibiting "insensitivity to scope". Insensitivity to scope would have been exhibited if, for example, respondent revealed the same willingness to pay for a policy which would preserve 1 million acres of forestland as for a policy which would preserve a 2 million acres which includes the original 1 million acres (the 1 million acre reserve being embedded in the larger 2 million acre reserve).

In a widely cited paper, Kahneman and Knetsch (1992) report the results of a CV study in which embedding is found. In a telephone survey respondents in different subsamples were asked what they would be willing to pay for "significant improvements" in "environmental services", "preparedness for disasters", and "availability of equipment and trained personnel for rescue operations". Kahneman and Knetsch consider these to be in descending order of inclusiveness, with environmental services being the most inclusive category and the following two to be successively more embedded. Their survey results show that for the group that was asked initially about their valuation of environmental services (and subsequently asked about the values of the two remaining embedded services) the willingness to pay for environmental services was roughly equal to the willingness to pay for disaster preparedness (for the group that was subsequently asked about the value of the one remaining embedded service). It was observed that the value of the sum of the parts of an inclusive category may widely diverge from the value elicited for the inclusive category as a whole.

From these and other results, Kahneman and Knetsch offer the interpretation that CV results are arbitrary and do not reveal true economic value. Kahneman and Knetsch attribute the insensitivity to scope to respondents' desire to purchase "moral satisfaction" by contributing to a good cause, rather than being motivated by the desire to purchase a specific quantity of an economic good.

Smith (1991) takes issue with Kahneman and Knetsch, arguing that none of their conclusions follow from the results of their study. He argues that their CV study was flawed, in part because the Kahneman and Knetsch CV questions were ineffective in defining and framing the context of the good to be valued. This type of flaw could alone result in responses which would support the conclusion that CV results are arbitrary. As discussed by Mitchell and Carson (1989) and others, careful survey design is essential in order to mitigate embedding bias.

While the research by Kahneman and Knetsch stimulated additional discourse on the embedding issue, concern about this potential bias existed long before their study. Mitchell and Carson (1989) discuss the development of the evidence insensitivity to scope in the context of "part-whole" bias. Part-whole effects can result in insensitivity to scope in situations in which respondents are incapable of or have inadequate information for distinguishing the "part" of benefits provided by a particular policy from the "whole" of benefits which could be ascribed to a broader policy. While this leads to insensitivity to scope as described Kahneman and Knetsch, it is important to note that it results from respondent motivation that is very different from the simple desire to purchase moral satisfaction by contributing to a good cause. It is also important to note that in evaluating biases in the CVM, it is essential to be mindful of similar shortcomings of other estimation techniques, as well as the realities of market behavior. Part-whole bias is not unique to CVM, and exists for other estimation techniques as well. (For a discussion of how this applies to travel cost, hedonic price, and other methods, see Mitchell and Carson (1989), p. 47.)

Recent evidence pertaining to the embedding issue is discussed in Hanemann (1994). Some of the evidence reviewed by Hanemann is evidence contained in the meta-analysis by Walsh, Johnson and McKean (1992) on over 100 CVM recreation studies and in a study by Smith and Osborne (1994) on 10 applications of CVM to air quality. Hanemann discusses at some length the evidence provided in a review by Carson (1994) of 27 papers testing for sensitivity to scope, and notes that only two failed to generate statistical evidence of sensitivity to scope, the one by Kahneman and Knetsch (1992) and the other by Boyle, et al. (1994). That is, only 2 of 27 papers found evidence of this type of embedding behavior. Hanemann notes that critiques of these two studies have pointed to methodological shortcomings which could explain their findings. In summarizing the evidence Hanemann claims, "At any rate, even if one regards these two studies as highly credible evidence that respondents were insensitive to scope, they certainly do not represent the majority finding in the contingent valuation literature regarding the variation of willingness-to-pay with scope" (Hanemann, 1994, p. 35).

The NOAA Panel's conclusions are the most comprehensive and authoritative statements to date. Given that the NOAA panel was considering the use of CVM for environmental damage litigation (in which a single party could be held liable for environmental damages) they were compelled to adopt very strict standards by which to judge the method. After obtaining input critical of CVM, the panel noted, ".... some antagonists of the CV approach go so far as to suggest that there can be no useful information content to CV results. The Panel is unpersuaded by these extreme arguments" (Arrow et al., 1993, 4610). After thorough review of the validity CVM for measuring passive-use values, the preponderance of evidence supports the usefulness of results from carefully performed CV studies. The NOAA panel concludes, ".... the Panel concludes that CV studies can produce estimates reliable enough to be the starting point of a judicial process of damage assessment, including lost passive-use values" (Arrow et al., 1993, 4610).

Although the NOAA panel did express concerns regarding upward bias in CV results, they concluded that contingent valuation studies have the potential to yield useful results. This conclusion, of course, does *not* imply that all CV studies are useful. The evidence clearly indicates that CV results are sensitive to study design. Each study must thus be judged on its own merits.

VIII. Budget Context:
2-year period ending June 30, 1995: No other funds are being spent on these activities by the MPCA.
2-year period beginning July 1, 1995: Objective C is being enhanced by a $40,000 add-on grant from the U.S. Environmental Protection Agency. Objective A5 (Mercury in Products) is supplemented by a $20,000 grant, also from the U.S. EPA.

IX. Dissemination:
Results of Objectives A, "Mercury Analyses and Emission Calculations" and C "Economic Analysis of the Benefits of Reduced Mercury Deposition" will be primarily be publicized through a new edition of the MPCA Mercury Task Force Report, "Strategies for Reducing Mercury in Minnesota."

Results of Objective B, "Atmospheric Deposition of Mercury Across Minnesota" will be published in major peer-review journals and incorporated in MPCA Mercury Task Force reports.

X. Time:
This project will be finished by June 30, 1997.

XI. Cooperation:
Edward Swain, project manager, will spend at least a third of his time managing this project, including supervising a half-time ~~unclassified~~ position hired for this project.

Daniel Engstrom will be contracted with to accomplish Objective B, which will absorb at least a third of his time for two years.

Jim Vincent and Patrick Welle will be contracted with to accomplish Objective C, which will absorb about 25% of their time from 7/1/95 to 1/1/97. Jim Vincent will be on Sabbatical 1995-96 from the University of St. Thomas and Patrick Welle will be on reduced teaching load at Bemidji State University in order to work on the project.

XII. Reporting Requirements: Semiannual six-month Workprogram update reports will be submitted not later than January 1, 1996, July 1, 1996, January 1, 1997, and a final six-month Workprogram update and final report by June 30, 1997.

XIII. Required Attachment:

See attached vitae and Project Staffing Summary.

XIV. Use of Classified Personnel

Objective A.6, "Coordination and Emission Inventory Preparation" requires the hiring of a half-time employee at the MPCA. During preparation of this workplan, no particular employee was identified, so it was stated that an unclassified employee would be hired. However, it has become clear that the best person for this task is now a classified employee of the Office of Environmental Assistance (OEA). For the Federal fiscal year ending October 1, 1995 the employee, John Gilkeson, was on a leave of absence from the OEA and worked in an unclassified position at the MPCA on an EPA-funded project on mercury in products. Mr. Gilkeson is now back in his classified position at OEA. During his year at the MPCA, he learned a great deal about mercury, hard-won knowledge that could be capitalized upon for this LCMR project. Conversely, there would be a learning curve for an unclassified worker unfamiliar with the issues surrounding mercury.

In addition to Objective A6, the half-time employee would help carry out Objectives A4 and A5. Objective A5, "Mercury in Products," is a subject Mr. Gilkeson is particularly suited to pursue, having worked on the subject for a year. Objective A4, "Mercury in Minnesota Oil Refining," involves obtaining samples of petroleum products from Minnesota's two oil refineries. Because Mr. Gilkeson has a degree in engineering, he would be particularly helpful in carrying out a study of the complicated industrial complex of an oil refinery.

Mr. Gilkeson's current duties at OEA consist of working in a non-research mode on mercury issues, taking information on mercury in products and offering assistance to both manufacturers of the products and waste managers to minimize use and disposal of mercury. A major benefit of allowing Mr. Gilkeson to participate in this LCMR project is that the knowledge gained through research will be retained by the state after the project and used on a daily basis in the Office of Environmental Assistance programs.

Update July 15, 1996: Mr. Gilkeson was hired half-time at the MPCA in Februrary 1996 to help on this project.

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