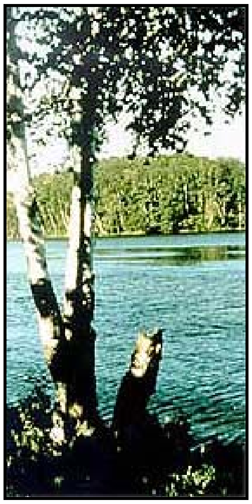  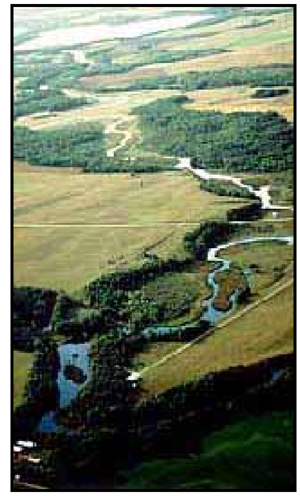

GUIDANCE FOR THE USE AND APPLICATION OF SEDIMENT QUALITY TARGETS FOR THE PROTECTION OF SEDIMENT-DWELLING ORGANISMS IN MINNESOTA

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Minnesota Pollution Control Agency

GUIDANCE FOR THE USE AND APPLICATION OF SEDIMENT QUALITY TARGETS FOR THE PROTECTION OF SEDIMENT-DWELLING ORGANISMS IN MINNESOTA

by

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DISCLAIMER

This guidance is designed to assist Minnesota Pollution Control Agency (MPCA) staff, stakeholders, and businesses with the use and application of numerical sediment quality targets (SQTs) to water bodies within Minnesota. This guidance does not address land-based contaminated soils. The MPCA may change this guidance in the future. For the most recent version of the guidance, refer to the MPCA's Contaminated Sediment Web page at: http://www.pca.state.mn.us/water/sediments/index.html.

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LIST OF ACRONYMS AND ABBREVIATIONS

AOC	Area of Concern
AVS	Acid Volatile Sulfide
BHC	Benzene Hexachloride
BMP	Best Management Practice
CCME	Canadian Council of Ministers of the Environment
CG	Carbonaceous Geosorbents
Cr	Creek
DDD	Dichlorodiphenyldichloroethane
DDE	Dichlorodiphenylethylene
DDT	Dichlorodiphenyltrichloroethane
DL	Detection Limit
DW	Dry Weight
EPA	Environmental Protection Agency
ERA	Ecological Risk Assessment
GIS	Geographic Information System
HPAHs	High Molecular Weight PAHs
IJC	International Joint Commission
LPAHs	Low Molecular Weight PAHs
MDH	Minnesota Department of Health
MEC	Midpoint Effect Concentration
MGP	Manufactured Gas Plant
MLE	Maximum Likelihood Estimation
MN	Minnesota
MPCA	Minnesota Pollution Control Agency
ND	Nondetect
NYSDEC	New York State Department of Environmental Conservation
PAHs	Polycyclic Aromatic Hydrocarbons
PCBs	Polychlorinated Biphenyls
PCDD/Fs	Polychlorinated Dibenzo-*p*-dioxins/Dibenzo Furans
PEC	Probable Effect Concentration
PEC-Q	Probable Effect Concentration Quotient
R-EMAP	Regional Environmental Monitoring and Assessment Program
SEM	Simultaneously Extractable Metal
SLRIDT	St. Louis River Interlake/Duluth Tar
SQG	Sediment Quality Guideline
SQRT	Sediment Quality Remediation Target
SQT	Sediment Quality Target
TEC	Threshold Effect Concentration
TEF	Toxic Equivalency Factor
TEQ	Toxic Equivalent
TOC	Total Organic Carbon
TU	Toxic Unit
US	United States

LIST OF ACRONYMS AND ABBREVIATIONS (continued)

USEPA	United States Environmental Protection Agency
USGS	U.S. Geological Survey
USS	U.S. Steel
UV	Ultraviolet
WDNR	Wisconsin Department of Natural Resources
WI	Wisconsin
WLSSD	Western Lake Superior Sanitary District
XRF	X-ray Fluorescence

GLOSSARY

Acute toxicity **–** The immediate or short-term response of an organism to a chemical substance. Lethality is the response that is most commonly measured in acute toxicity tests.

Anthropogenic **–** Pertains to the influence of human activities.

Aquatic ecosystem **–** All the living and nonliving material interacting within an aquatic system (e.g., pond, lake, river, ocean).

Aquatic organisms **–** All of the species that utilize habitats within aquatic ecosystems (e.g., aquatic plants, invertebrates, fish, and amphibians).

Area of Concern **–** One of 43 Areas of Concern designated in the Great Lakes basin by the International Joint Commission. Each AOC must go through a multi-stage remedial action plan process.

Benthic invertebrate community **–** The assemblages of various species of sediment-dwelling organisms that are found within an aquatic ecosystem.

Bioaccumulation **–** The net accumulation of a chemical substance by an organism as a result of uptake from all environmental sources.

Bioavailability **–** The availability of a substance to be taken up by biological organisms.

Biodiversity **–** The presence of many species of organisms, plant and animal.

Bioturbation **–** The mixing of sediments by living organisms such as worms, clams, or arthropods that make burrows in soft sediment. Their activities mix the sediment layers and may cause substantial sediment resuspension.

Black carbon **–** The residual elemental carbonaceous products of biomass (e.g., forest fires, residential wood burning) and fuel combustion (e.g., traffic, industry, coal, oil) that may end up in soil, sediment, and the air. Black carbon is composed of soot and char; hydrophobic organic chemicals may sorb strongly to it, affecting their bioavailability to organisms.

Bulk sediment **–** Sediment and associated porewater.

Carbonaceous geosorbents **–** Material in sediments composed of black carbon, coal, and kerogen, which increases the sorption of hydrophobic organic contaminants.

Chemical benchmark **–** Guidelines for water or sediment quality which define the concentration of contaminants that are associated with high or low probabilities of observing harmful biological effects, depending on the narrative intent of the guideline.

GLOSSARY (continued)

***Chemicals of potential concern* –** The concentrations of chemical substances that are elevated above anthropogenic background and for which sources of these chemicals can be identified in the watershed (also called potential chemicals of concern).

***Chronic toxicity* –** The response of an organism to long-term exposure to a chemical substance. Among others, the responses that are typically measured in chronic toxicity tests include lethality, decreased growth, and impaired reproduction.

***Consensus-based PECs* –** The probable effect concentrations that were developed from published sediment quality guidelines of similar narrative intent.

***Consensus-based TECs* –** The threshold effect concentrations that were developed from published sediment quality guidelines of similar narrative intent.

***Contaminants of concern* –** The chemical substances that occur in sediments at levels that could harm sediment-dwelling organisms, wildlife, or human health (also called chemicals of concern).

***Contaminated sediment* –** Sediment containing chemical substances at concentrations that pose a known or suspected threat to environmental or human health.

***Dredging* –** Removal of material from the bottom of a water body by excavation or similar removal activity.

***Ecosystem* –** All the living (e.g., plants, animals, and humans) and nonliving (rocks, sediments, soil, water, and air) material interacting within a specified location in time and space.

***Endpoint* –** The response measured in a toxicity test.

***Epibenthic organisms* –** The organisms that live on the surface of bottom sediments.

***Exposure* –** Co-occurrence of, or contact between, a stressor (e.g., chemical substance) and an ecological component (e.g., aquatic organism).

***Hot spot* –** An area of elevated sediment contamination.

***Hydrophobic organic chemical* –** Hydrophobic refers to the tendency of a substance to repel water or to be incapable of completely dissolving in water. Hydrophobic organic chemicals (e.g., PAHs, PCBs, and organochlorine pesticides) are readily soluble in many nonpolar solvents, such as octanol, but only sparingly soluble in water, a polar solvent. These chemicals tend to accumulate in lipids and organic carbon.

GLOSSARY (continued)

Indicators – Provide a sign of ecosystem health. Indicators should adequately represent the ecosystem goals and objectives that have been established.

Infaunal organisms – The organisms that live in bottom sediments.

Kerogen – The solid, insoluble organic matter that occurs in source rocks which can yield oil upon heating.

Level I SQT – Chemical concentrations which will provide a high level of protection for benthic invertebrates.

Level II SQT – Chemical concentration which will provide a moderate level of protection for benthic invertebrates.

Mean PEC-Q – A screening tool to compare sediment quality between sites. In interpreting the results, though, one must consider whether other contaminants of concern contribute to risk and whether the extent and magnitude of contamination has been adequately characterized. The mean PEC-Qs have been shown to provide a reliable basis for classifying sediments as toxic or not toxic in the St. Louis River Area of Concern, and this relationship may hold for other Minnesota waters.

Metals – Metals include elements with a metallic luster and are found on and beneath the earth's surface, such as iron, manganese, lead, cadmium, zinc, nickel, and mercury.

Nonpoint source pollution – Pollution sources that are diffuse, without a single identifiable point of origin, including runoff from agriculture, forestry, and construction sites.

Nutrients – Substances such as nitrogen and phosphorus compounds necessary for growth and survival. Elevated concentrations can cause unwanted growth of algae, and can result in the lowering of the amount of oxygen in the water when the algae die and decay.

Pesticides – A class of hazardous substances (either naturally occurring or chemically synthesized) that are used to kill pests. This class includes insecticides (which kill insects), herbicides (which kill weeds), fungicides (which kill fungus and molds), algicides (which kill algae), and rodenticides (which kill rodents such as rats and mice). Pesticides can accumulate in the food chain and/or contaminate the environment if misused.

Polychlorinated biphenyls (PCBs) – PCBs are a mixture of up to 209 hydrophobic organic chemicals produced by chlorination of biphenyl. PCBs were used for a variety of purposes including electrical applications, carbonless copy paper, adhesives, hydraulic fluids, and caulking compounds. Due to their accumulation in the food chain, production

of PCBs was halted world-wide at the beginning of the 1980s. However, these chemicals still persist in the environment.

***Polycyclic aromatic hydrocarbons (PAHs)* –** PAHs are ubiquitous environmental contaminants that are formed by the incomplete combustion of organic materials, such as wood or fossil fuels. PAH molecules are made up of three or more benzene rings. PAHs form a large and heterogeneous group, but the most toxic ones are PAH molecules that have four to seven rings. The higher molecular weight PAHs [e.g., fluoranthene, benzo(a)pyrene] are products of combustion. The lower molecular weight PAHs (e.g., naphthalene, fluorene) are generally derived from unburned petroleum sources and alkylated PAHs.

***Porewater* –** The water that occupies the spaces between sediment particles.

***Sediment* –** Loose particles of sand, clay, silt, and other substances that settle at the bottom of a body of water. Sediment can come from the erosion of soil or from the decomposition of plants and animals. Wind, water, and ice often carry these particles great distances.

***Sediment-associated contaminants* –** Contaminants that can be or are present in sediments, including bulk sediments and/or porewater.

***Sediment chemistry data* –** Information on the concentrations of chemical substances in bulk sediments or porewater.

***Sediment-dwelling organisms* –** The organisms that live in, on, or near bottom sediments, including both epibenthic and infaunal species.

***Sediment quality guideline* –** Chemical benchmark that is intended to define the concentration of a sediment-associated contaminant that is associated with a high or a low probability of observing harmful biological effects or unacceptable levels of bioaccumulation, depending on its purpose and narrative intent.

***Sediment quality target* –** Chemical benchmarks for the St. Louis River AOC that have been adopted for use throughout Minnesota. See Level I SQT and Level II SQT.

Sediment Quality Triad - A tool based on associations between sediment chemistry, sediment toxicity tests, and *in situ* biological effects.

***Wildlife* –** The reptiles, amphibians, birds, and mammals that are associated with aquatic ecosystems [e.g., piscivorous (fish eating) wildlife].

CHAPTER 1

INTRODUCTION

In Minnesota, contaminated sediments represent one of several nonpoint sources of nutrients and toxic chemicals to the overlying water of stormwater ponds, wetlands, lakes, harbors, and rivers. In affected sediments, complex chemical and physical interactions affect the mobility and bioavailability of contaminants to bottom-feeding (i.e., benthic) organisms (Figures 1 - 3). The results may be severe at some sites, and include:

- Tumors and other deformities in bottom-dwelling fish;
- Degraded benthic communities, which result in less fish food;
- Degraded fish and wildlife habitats;
- Bioaccumulation of contaminants up the food chain, that may result in fish and wildlife consumption advisories;
- Potential human health risks from exposure to sediment-derived contaminants;
- Aesthetic impairments; and
- Restrictions on navigational dredging and beneficial re-use of dredged material.

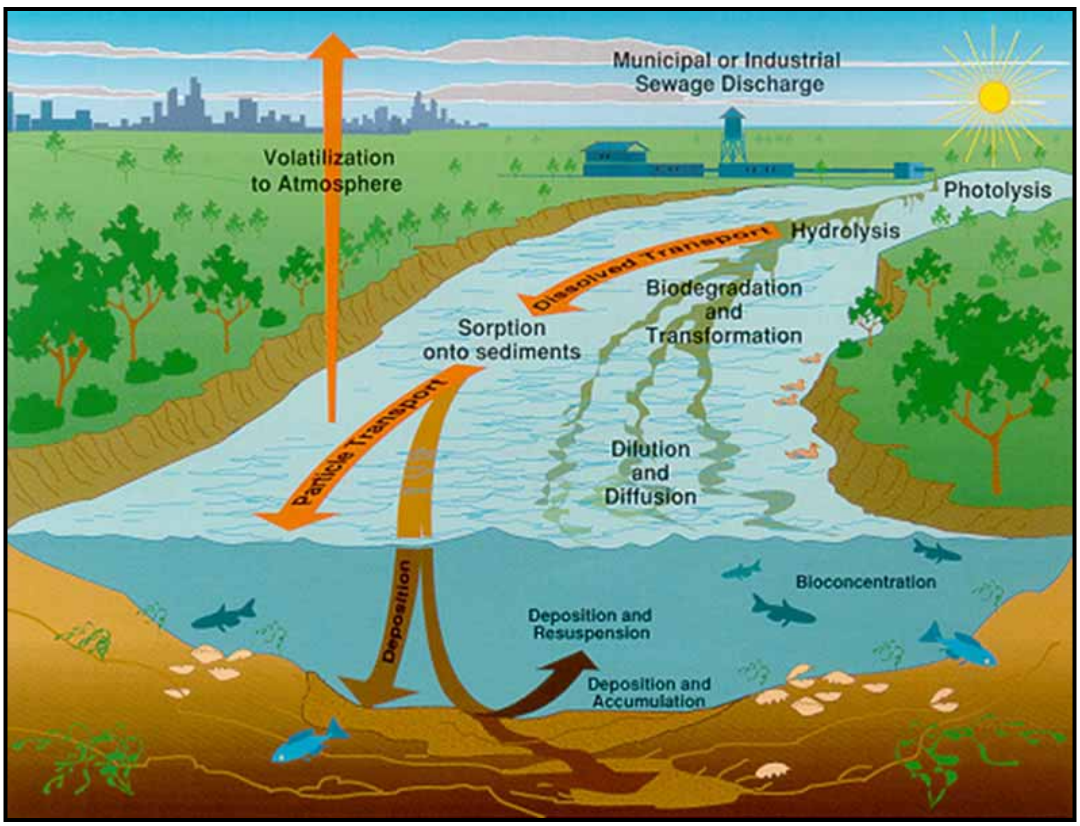

Figure 1. Processes controlling the fate of hydrophobic organic contaminants in freshwater systems (Barber, II, *et al*. 1995).

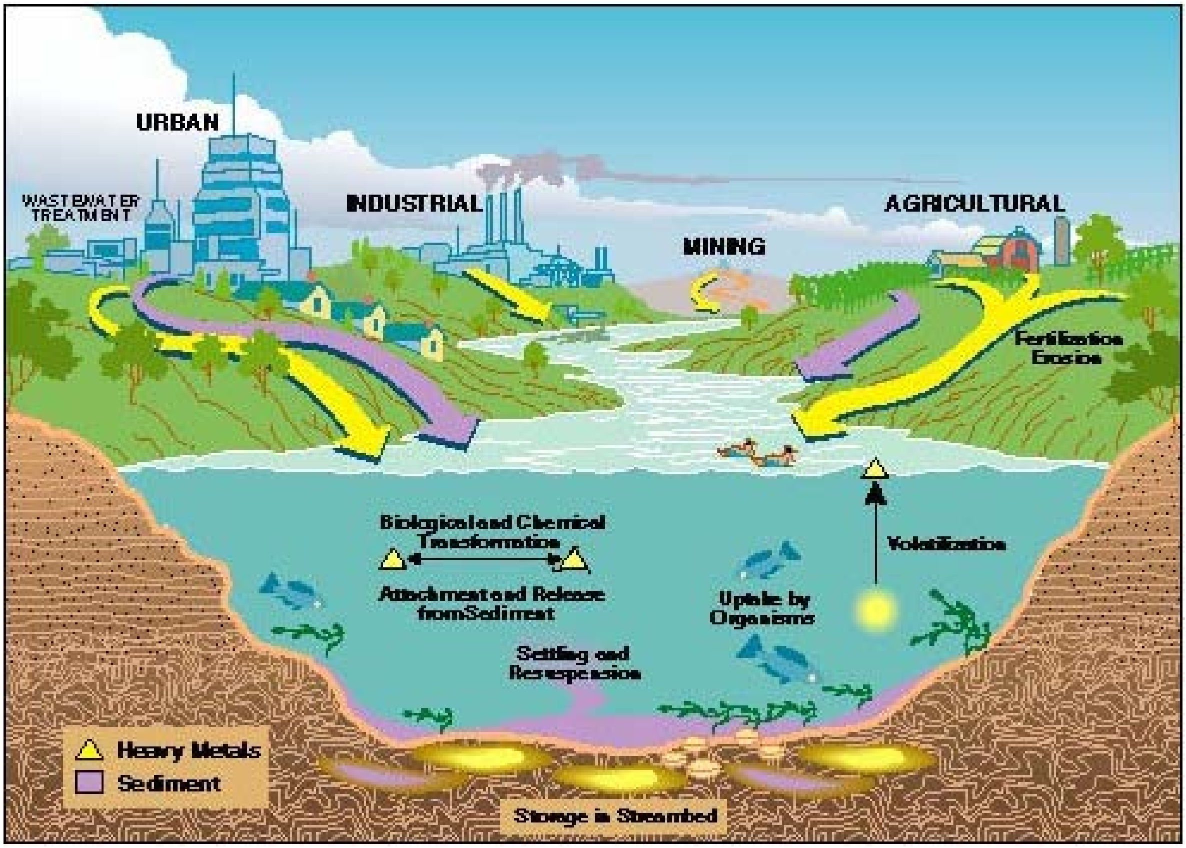

Figure 2. Sources and sinks of heavy metals in freshwater systems (Garbarino *et al*. 1995).

The Minnesota Pollution Control Agency (MPCA) is responsible for the assessment, management and remediation, or cleanup, of contaminated sediment sites in Minnesota. Staff members from several programs within the MPCA are involved in this effort. The goals are to protect human health and the environment, to restore water bodies to unimpaired uses, and to achieve applicable water quality standards. Currently, the MPCA does not have sediment quality standards.

Specific indicators (e.g., sediment chemistry) can be used to determine if the designated uses of the aquatic ecosystem are being protected, and where necessary, restored. A suite of sediment quality indicators were developed for the St. Louis River Area of Concern (AOC) in northeastern Minnesota (Crane *et al.* 2000). These indicators can be used in other areas of Minnesota to assess sediment quality. These indicators include:

- Sediment chemistry;
- Sediment toxicity;
- Benthic invertebrate community structure;
- Sediment Quality Triad (a tool based on associations between sediment chemistry, sediment toxicity tests, and *in situ* biological effects);
- Physical characteristics (e.g., particle size, sedimentation rate);

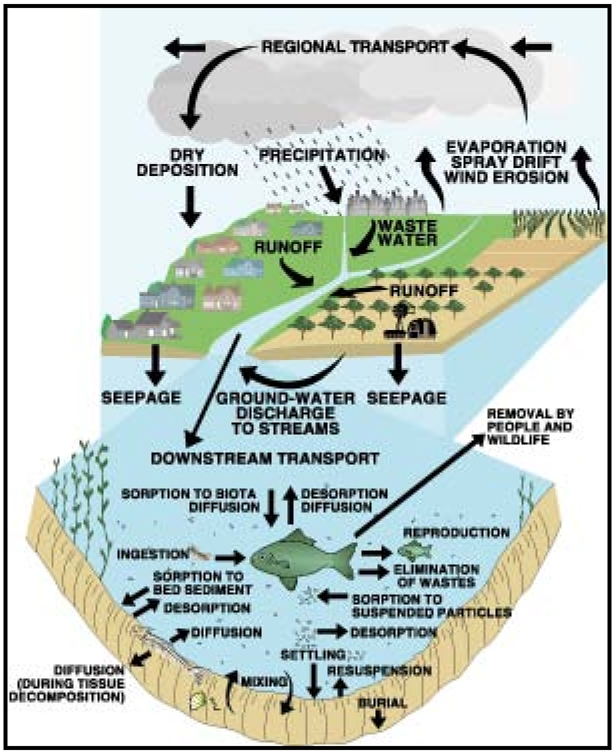

Figure 3. Fate and transport of pesticides in a watershed, including sediment processes [modified from Majewski and Capel (1995) as cited in USGS (2000)].

- Tissue chemistry (including bioaccumulation studies);
- Water chemistry;
- Pore water toxicity (i.e., exposure of aquatic plants, invertebrates, and/or fish larvae to water extracted from the sediments);
- Fish health (e.g., incidence of tumors, fin rot); and
- Water column and elutriate toxicity, where the term elutriate refers to dilutions of sediment material.

The sediment quality indicators are composed of distinct measurements called metrics (Crane *et al*. 2000). An example of a metric important to sediment chemistry is the dry weight concentration of a contaminant (e.g., mercury). While the metrics provide information that can be used to directly assess trends in sediment quality conditions, comparisons of the metrics to numerical targets provides valuable information for sediment quality assessments.

Numerical sediment quality targets (SQTs), adopted for use in the St. Louis River AOC to protect benthic invertebrates (Crane *et al*. 2000, 2002a; Crane and MacDonald 2003), can be used throughout the state as benchmark values for making comparisons to surficial sediment chemistry measurements. The SQTs are a type of sediment quality guideline (SQG) that provide useful tools for making sediment management decisions, especially when considered as part of a weight-of-evidence approach that includes other sediment quality indicators, such as

geochemical characteristics (e.g., particle size), sediment toxicity, benthic invertebrate community structure, and tissue residue chemistry (Crane *et al*. 2000, 2002a; Crane and MacDonald 2003).

The purpose of this document is to provide a quick resource to the SQTs, as well as to provide further guidance on their use and application in Minnesota waterways. In addition, this report includes responses to frequently asked questions regarding the use and application of the SQTs. Finally, this document provides a case study of how the SQTs have been applied in the St. Louis River AOC. The techniques used in this case study can be easily applied to other contaminated waterways within Minnesota, as well as to general assessments of sediment quality in waters of the state.

For additional background information about contaminated sediments, refer to the U.S. Environmental Protection Agency (EPA) fact sheet in Appendix A. For further information about the contents of this document, please contact either:

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CHAPTER 2

SEDIMENT QUALITY TARGETS FOR MINNESOTA WATERS

2.1 ESTABLISHMENT OF NARRATIVE SEDIMENT QUALITY TARGETS

In recognition of the challenges that are associated with sediment management in the St. Louis River AOC, two types of narrative SQTs were established by the MPCA and its collaborators (Crane *et al*. 2000).

- The Level I SQTs are intended to identify contaminant concentrations below which harmful effects on sediment-dwelling organisms (i.e., benthic invertebrates) are unlikely to be observed.
- The Level II SQTs are intended to identify contaminant concentrations above which harmful effects on sediment-dwelling organisms are likely to be observed.

These narrative objectives are also applicable to other water bodies within Minnesota. The narrative objectives for both levels of SQTs do not address the potential for bioaccumulation nor the associated effects on those species that consume aquatic organisms (i.e., wildlife and humans; Crane *et al*. 2000).

2.2 SELECTION OF SEDIMENT QUALITY TARGETS

After a review of both theoretical and empirical approaches used to derive numerical SQGs for freshwater ecosystems, the following strategy was used to recommend numerical SQTs for the protection of sediment-dwelling organisms in the St. Louis River AOC (Crane *et al.* 2000). First, the consensus-based SQGs, derived by MacDonald *et al*. (2000), were adopted for all of the substances for which they were available. The rationale by which the consensus-based SQGs were selected is provided in Crane *et al*. (2000). The consensus-based SQGs consisted of threshold effect concentrations (TECs), which were consistent with the narrative intent of the Level I SQTs, and probable effect concentrations (PECs), which were consistent with the narrative intent of the Level II SQTs. Second, the most reliable of the other effects-based freshwater SQGs that have been published (CCME 1999; NYSDEC 1999) were adopted for those chemicals for which consensus-based SQGs were not available. In this context, the term reliable is defined as the ability of the SQGs to correctly classify sediments as toxic or nontoxic based on the data used to derive the guidelines (Long and MacDonald 1998).

The strategy for identifying effects-based SQTs for the protection of sediment-dwelling organisms yielded Level I and Level II SQTs for 8 trace metals, 13 individual polycyclic aromatic hydrocarbons (PAHs), total PAHs, total polychlorinated biphenyls (PCBs), and 10 organochlorine pesticides (Table 1; Crane *et al*. 2000, 2002a). In addition, SQGs for polychlorinated dibenzo-*p*-dioxins/dibenzo furans (PCDD/Fs; CCME 1999) were recently adopted as additional SQTs (Table 2). The consensus-based SQGs (MacDonald *et al.* 2000), for which many of the SQTs were adopted from, are also being used by the Wisconsin Department

Table 1. Recommended Level I and Level II Sediment Quality Targets for the Protection of Sediment-dwelling Organisms (Crane *et al*. 2000, 2002a)

Chemical	Aquatic Life		
	Level I SQT	Level II SQT	Source[†]
Metals (in mg/kg DW)			
Arsenic[§]	9.8	33	MacDonald *et al*. (2000)
Cadmium*[§]	0.99	5.0	MacDonald *et al*. (2000)
Chromium[§]	43	110	MacDonald *et al*. (2000)
Copper*[§]	32	150	MacDonald *et al*. (2000)
Lead*[§]	36	130	MacDonald *et al*. (2000)
Mercury	0.18	1.1	MacDonald *et al*. (2000)
Nickel[§]	23	49	MacDonald *et al*. (2000)
Zinc*[§]	120	460	MacDonald *et al*. (2000)
PAHs (in µg/kg DW)			
2-Methylnaphthalene	20	200	CCME (1999)
Acenaphthene	6.7	89	CCME (1999)
Acenaphthylene	5.9	130	CCME (1999)
Anthracene*	57	850	MacDonald *et al*. (2000)
Fluorene	77	540	MacDonald *et al*. (2000)
Naphthalene*[§]	180	560	MacDonald *et al*. (2000)
Phenanthrene*[§]	200	1200	MacDonald *et al*. (2000)
Benz(a)anthracene*[§]	110	1100	MacDonald *et al*. (2000)
Benzo(a)pyrene*[§]	150	1500	MacDonald *et al*. (2000)
Chrysene*[§]	170	1300	MacDonald *et al*. (2000)
Dibenz(a,h)anthracene	33	140	MacDonald *et al*. (2000); CCME (1999)
Fluoranthene*	420	2200	MacDonald *et al*. (2000)
Pyrene*[§]	200	1500	MacDonald *et al*. (2000)
Total PAHs*[§]	1600	23000	MacDonald *et al*. (2000)
PCBs (in µg/kg DW)			
Total PCBs*[§]	60	680	MacDonald *et al*. (2000)
Pesticides (in µg/kg DW)			
Chlordane*	3.2	18	MacDonald *et al*. (2000)
Dieldrin*	1.9	62	MacDonald *et al*. (2000)
Sum DDD*	4.9	28	MacDonald *et al*. (2000)

Table 1. Continued

Chemical	Aquatic Life Level I SQT	Aquatic Life Level II SQT	Source[†]
Pesticides (continued)			
Sum DDE*[§]	3.2	31	MacDonald *et al*. (2000)
Sum DDT*	4.2	63	MacDonald *et al*. (2000)
Total DDT*	5.3	570	MacDonald *et al*. (2000)
Endrin	2.2	210	MacDonald *et al*. (2000)
Heptachlor epoxide*	2.5	16	MacDonald *et al*. (2000)
Lindane (gamma-BHC)	2.4	5	MacDonald *et al*. (2000)
Toxaphene	0.1	32	NYSDEC (1999)[¥]
Mean PEC-Q	0.1	0.6	USEPA 2000

SQT = sediment quality target; PEC-Q = probable effect concentration quotient; DW = dry weight.

[†] Some SQT values were rounded to two significant figures from the original source.
* Reliable consensus-based threshold effect concentration (TEC) values that were adopted as Level I SQTs [i.e., predictive ability ≥75% and ≥20 samples below the TEC (MacDonald *et al.* 2000)].
[§] Reliable consensus-based probable effect concentration (PEC) values that were adopted as Level II SQTs [i.e., predictive ability ≥75% and ≥20 samples predicted to be toxic (MacDonald *et al.* 2000)].
[¥] originally based on μg/g organic carbon; assumed total organic carbon (TOC) = 1%.

Table 2. Additional Recommended Level I and Level II SQTs for Chemicals of Interest

Chemical	Aquatic Life Level I SQT	Aquatic Life Level II SQT	Source
Polychlorinated dibenzo-p-dioxins/ dibenzo furans (in ng TEQ/kg DW)			
PCDD/Fs*	0.85	21.5	CCME 1999

SQT = sediment quality target; TEQ = toxic equivalent; DW = dry weight.
* Values are expressed as TEQ units, based on van den Berg *et al.*'s (1998) toxic equivalency factor (TEF) values for fish. There is currently insufficient information to determine TEFs for invertebrates.

The Level I and Level II SQTs can be used elsewhere in Minnesota in depositional deposits of sediments found in lakes, ponds, wetlands, low gradient rivers and streams, as well as ports and harbors (Crane and MacDonald 2003). Thus, these SQTs can be used as benchmark values for making comparisons to surficial sediment chemistry measurements throughout the State of Minnesota.

of Natural Resources (WDNR) and several other jurisdictions in the United States and abroad. According to Swartz (1999) and MacDonald *et al*. (2000), consensus-based SQGs provide a unifying synthesis of existing SQGs, reflect causal rather than correlative effects, and account for the effects of contaminant mixtures. Therefore, the consensus-based SQGs are likely to provide useful tools for assessing sediment quality conditions in a range of geographic areas.

2.3 PREDICTIVE ABILITY OF THE LEVEL I AND LEVEL II SQTS

Sediment toxicity tests are used to demonstrate whether sediment samples cause significant mortality or sublethal (e.g., growth, reproduction) toxicity to benthic organisms compared to reference or control sediments. These tests are usually done in a laboratory under controlled conditions using test organisms that have been cultured for this purpose. The amphipod, *Hyalella azteca*, and the midge, *Chironomus dilutus* (formally *C. tentans*) are common test organisms. Amphipods and midges are also found in the native benthic invertebrate community of the St. Louis River AOC and elsewhere in Minnesota.

The Level I and Level II SQTs were evaluated by Crane *et al*. (2000) to determine their ability, when used alone, to correctly classify sediment samples from the St. Louis River AOC as toxic or non-toxic. The process by which this was done using a matching sediment chemistry and toxicity database, and the results obtained, were described in Crane *et al*. (2000). In general, the incidence of sediment toxicity increased with increasing concentrations of individual metals and PAHs (refer to Table 9 in Crane *et al*. 2000). These results indicated the Level I SQTs provided an accurate basis for predicting the absence of sediment toxicity in the St. Louis River AOC. In addition, the incidence of sediment toxicity was higher above the Level II SQTs than it was at or below the Level I SQTs (Crane *et al*. 2000).

Sediments often contain mixtures of contaminants. Crane *et al*. (2000, 2002a) further evaluated the predictive ability of the SQTs using a matching sediment chemistry and toxicity data set for the St. Louis River AOC. This evaluation involved determination of the incidence of toxicity to amphipods (*H. azteca*) and midges (*C. tentans*; now referred to as *C. dilutus*) within five ranges of Level II SQT quotients [i.e., mean probable effect concentration quotients (PEC-Qs)]. Mean PEC-Qs provide a sediment assessment tool that distills data from a mixture of contaminants (i.e., certain metals, total PAHs, and/or total PCBs) into one unitless index. Thus, the mean PEC-Qs provide a way to compare sediment quality over time and space (Long *et al*. 2006). For both types of toxicity tests, the incidence of toxicity increased as the mean PEC-Q ranges increased (Crane *et al.* 2000, 2002a). The incidence of toxicity observed in these tests was also compared to that for other geographic areas in the Great Lakes region and in North America for

10- to 14-day amphipod (*H. azteca*) and 10- to 14-day midge (*C. tentans* or *C. riparius*) toxicity tests. In general, the predictive ability of the mean PEC-Qs was similar across geographic areas (Crane *et al*. 2000, 2002a). The results of these predictive ability evaluations indicated that collectively the mean PEC-Qs provide a reliable basis for classifying sediments as toxic or not toxic in the St. Louis River AOC, in the larger geographic areas of the Great Lakes, and elsewhere in North America (Crane *et al.* 2000, 2002a). Thus, similar relationships would be expected throughout Minnesota in other contaminated waterways.

The predictive ability evaluation was updated in 2006 with additional matching sediment chemistry and toxicity data (i.e., 1,464 toxicity test endpoints) for the St. Louis River AOC (Crane 2006a). The results of the predictive ability evaluation indicate that the incidence of acute toxicity to amphipods and midges tends to be low (i.e., 4.3% and 2.1%, respectively) when the concentrations of sediment-associated contaminants are low (i.e., as indicated by mean PEC-Qs of ≤0.1; Table 3). Importantly, the incidence of sediment toxicity in St. Louis River AOC sediments increased with increasing contaminant concentrations in the 10-day amphipod and midge tests, as well as with all non-ultraviolet (UV) tests combined (Table 3). For the 28-day *H. azteca* tests, additional data are needed to evaluate trends in the incidence of sediment toxicity.

On an overall basis, the 10-day amphipod and midge tests had a similar incidence of sediment toxicity (i.e., 16.6% and 18.0%, respectively; Table 3), although these tests were often not toxic to the same samples (Crane 2006a). The combination of all non-UV toxicity tests had a higher incidence of toxicity (30.8%). The overall toxicity observed for the 28-day *H. azteca* toxicity tests (58.6%) was even higher (Table 3). The 28-day *H. azteca* test is more sensitive than either the 10-day amphipod or midge tests (Ingersoll *et al*. 2001), and its use would reduce the potential for false negatives at low mean PEC-Qs.

2.4 PROCEDURES FOR CALCULATING TOTAL CHEMICAL CONCENTRATIONS

Some of the Level I and Level II SQTs are based on total chemical concentrations. In order to apply the SQTs in a consistent way, this section provides guidance on how to treat nondetect data and calculate total chemical concentrations. This guidance was developed primarily from experience gained from creating and compiling a GIS-based sediment quality database for the St. Louis River AOC (Crane and Myre 2006). At the present time, the MPCA does not have a statewide sediment quality database.

2.4.1 Treatment of Nondetect (ND) Data

Nondetect data can be treated multiple ways, depending on the statistical background of the user and on their study objectives. For example, in the Phase IV GIS-based sediment quality database for the St. Louis River AOC, the following rules were used for calculating total chemical concentrations with ND data (Crane and Myre 2006):

- Nondetected results are treated as one-half the detection limit (DL) if there is a mix of ND and detected results (e.g., <5 + 5 = 7.5). If all the results are ND, then the total is calculated by summing the detection limits (e.g., <5 + <5 = 10).

Table 3. Incidence of Toxicity for Mean PEC-Q Ranges as Determined Using Matching Sediment Chemistry and Toxicity Data From the St. Louis River AOC (Crane 2006a)

	Incidence of Toxicity			
Mean PEC-Q Range	**10-day *H. azteca* (Amphipod) Growth or Survival*§**	**10-day *C. dilutus* (Midge) Growth or Survival*§**	**28-day *H. azteca* Growth or Survival***	**All Non-UV Tests Combined (excluding Microtox®)***
≤0.10	4.3% (2 of 46 stations)	2.1% (1 of 48 stations)	0% (0 of 1 station)	7.3% (4 of 55 stations)
>0.10 to ≤0.50	12.8% (12 of 94 stations)	16.5% (17 of 103 stations)	61.5% (8 of 13 stations)	27.0% (34 of 126 stations)
>0.50 to ≤1.0	36.4% (4 of 11 stations)	22.2% (4 of 18 stations)	44.4% (4 of 9 stations)	45.8% (11 of 24 stations)
>1.0 to ≤5.0	41.7% (5 of 12 stations)	33.3% (4 of 12 stations)	83.3% (5 of 6 stations)	61.5% (16 of 26 stations)
>5.0	83.3% (5 of 6 stations)	100% (8 of 8 stations)	No Data	100% (9 of 9 stations)
Overall	16.6% (28 of 169 stations)	18.0% (34 of 189 stations)	58.6% (17 of 29 stations)	30.8% (74 of 240 stations)

PEC-Q = probable effect concentration quotient; UV = ultraviolet.

* Excluded UV-exposed toxicity test results.
§ Sites 102-TR and 044-TR, from the R-EMAP study (Breneman *et al*. 2000), were removed from the incidence of toxicity calculations due to incomplete sediment chemistry data (i.e., PAHs, PCBs) for these known contaminated areas.

- High ND data are screened out by excluding less-than-detect results that have detection limits greater than the corresponding Level II SQT value. In the Phase IV St. Louis River AOC sediment quality database, these results are identified with an "X" in the "MESL_EXCLUDE HIGH ND" field.

For other ND sediment chemistry data in the GIS-based sediment quality database for the St. Louis River AOC, a user-friendly query interface was designed with four data treatment options for censoring nondetected data (Crane and Myre 2005).

- Substitute nondetected values with one-half the detection limit;
- Delete nondetected values;
- Substitute nondetected values with the detection limit; and
- Exclude nondetected values with high detection limits.

For other Minnesota sediment chemistry data sets, users may either consider the above options or use more advanced data treatment options. Nondetects are labeled as left-censored data since their values lie somewhere to the left of the detection limit threshold. Users should be aware that bias may be introduced into the results when the above data treatment options are used. Users interested in better approaches for analyzing censored data should consider using maximum likelihood estimation (MLE), imputation, or the Kaplan-Meier method (Helsel 2005a). MLE solves a "likelihood equation" to find the values for mean and standard deviation that are most likely to have produced both nondetect and detected data (Helsel 2005a). Imputation methods fill in values for censored or missing observations without assigning them all the same value (Helsel 2005a). Kaplan-Meier is a nonparametric method designed to incorporate data with multiple censoring levels and does not require specification of an assumed distribution (Helsel 2005a). Additional information about these methods is available in Helsel (2005a,b).

2.4.2 Total PAHs

Only the 13 priority PAHs are included in the calculation of total PAHs for comparison to the Level I and Level II SQTs for total PAHs. These priority PAHs include 7 low molecular weight PAHs (LPAHs) and 6 high molecular weight PAHs (HPAHs).

- The individual compounds included in the LPAH total (if measured in the study) are:
    - acenaphthene
    - acenaphthylene
    - anthracene
    - fluorene
    - 2-methylnaphthalene
    - naphthalene
    - phenanthrene

- The individual compounds included in the HPAH total (if measured in the study) are:
    - benz(a)anthracene
    - benzo(a)pyrene
    - chrysene

- dibenz(a,h)anthracene
- fluoranthene
- pyrene

If users want to develop a more conservative estimate of total PAHs at a site to compare to the Level I and Level II SQTs, they may include additional PAHs [e.g., benzo(b&j)fluoranthene] in the calculation of total PAHs. However, they should add a subscript of the number of PAHs used in the calculation (e.g., total PAH_{16}) to clarify their intent. For further guidance on the calculation of total PAHs, contact either Judy Crane [651-297-4068 (voice); judy.crane@state.mn.us] or Steve Hennes [651-296-7830 (voice); steven.hennes@pca.state.mn.us].

2.4.3 Total PCBs

For comparisons to the Level I and Level II SQTs, total PCBs should be determined as follows:

- PCB congeners are used preferentially over PCB Aroclors (i.e., include all available congeners in the total).
- All congeners are summed.
- If only Aroclors are measured, then sum all Aroclor concentrations.

When planning a field study, PCB congeners will provide more useful information than Aroclor data.

2.4.4 Total DDTs

DDT (dichlorodiphenyltrichloroethane) commonly degrades to DDE (dichlorodiphenylethylene), as well as DDD (dichlorodiphenyldichloroethane) in the environment. Each component is summed as follows:

- DDD_{sum} = o,p'DDD + p,p'DDD
- DDE_{sum} = o,p'DDE + p,p'DDE
- DDT_{sum} = o,p'DDT + p,p'DDT
- $DDT_{total} = DDD_{sum} + DDE_{sum} + DDT_{sum}$

2.4.5 Total Chlordane

Total Chlordane equals the sum of the below compounds:

- cis-Nonachlor,
- trans-Nonachlor,
- cis-Chlordane,
- trans-Chlordane, and
- gamma-Chlordane.

2.5 PROCEDURE FOR CALCULATING MEAN PEC-Qs

The steps for calculating mean PEC-Qs are provided in the below text box.

Procedure for Calculating Mean PEC-Qs for Chemicals with Reliable PECs (USEPA 2000)

Step 1. Calculate the individual PEC-Qs for chemicals with reliable PECs (i.e., metals, total PAHs, and total PCBs). Note: the PEC for total PAHs (instead of the PECs for individual PAHs) is used in the calculation to avoid double counting the individual PAH concentration data.

$$\text{PEC-Q} = \frac{\text{chemical concentration (in dry wt.)}}{\text{corresponding PEC value}}$$

Step 2. Calculate the mean PEC-Q for the metals with reliable PECs (i.e., arsenic, cadmium, chromium, copper, lead, nickel, and zinc).

$$\text{mean PEC-Q}_{metals} = \frac{\Sigma \text{ individual metal PEC-Qs}}{n}$$

where n = number of metals with reliable PECs for which sediment chemistry data are available (i.e., 1 to 7).

Step 3. Calculate the mean PEC-Q for the three main classes of chemicals with reliable PECs.

$$\text{mean PEC-Q} = \frac{(\text{mean PEC-Q}_{metals} + \text{PEC-Q}_{T.\ PAHs} + \text{PEC-Q}_{T.\ PCBs})}{n}$$

where n = number of classes of chemicals for which sediment chemistry data are available (i.e., 1 to 3).

Additional guidance on calculating mean PEC-Qs is given below:

- Nondetect data are treated as one-half the detection limit.
- Nondetect data that have detection limits greater than the Level II SQTs must be excluded from the mean PEC-Q calculation. For example, these data are denoted with an “X” in the “MESL EXCLUDE HIGH ND” field in the Phase IV GIS-based sediment quality database for the St. Louis River AOC (Crane and Myre 2006).
- Total metals (i.e., arsenic, cadmium, chromium, copper, lead, nickel, and zinc) are included in the calculation instead of corresponding simultaneously extractable metals (SEM) data. SEM data are included in the calculation only if the sample does not have results for total metals. In this case, SEM concentrations are assumed to be equivalent to total metal concentrations as a conservative estimate. This assumption

was based on an evaluation of corresponding SEM and total metal data sets in a nation-wide sediment quality database.

- Only chemicals with reliable PECs are used in the calculation (USEPA 2000).
- Mean PEC-Qs are calculated using the procedure of USEPA (2000), which is based on the reliable SQTs for the average metals quotient, total PAH quotient, and/or total PCB quotient (n = 1 to 3 quotients/sample); see the accompanying text box.
- The reported totals for PAHs and PCBs are only used if a calculated total is not available.
- PCB congeners are used preferentially, rather than PCB Aroclors, to calculate total PCBs.
- The mean PEC-Q calculation is based on dry weight concentrations of contaminants because previous studies have demonstrated that normalization of SQGs for PAHs or PCBs to TOC (Barrick *et al*. 1988; Long *et al*. 1995; USEPA 1996) or normalization of SEM concentrations to acid volatile sulfide (AVS) concentrations (Long *et al*. 1998) did not improve the predictions of toxicity in field collected sediments.
- Only conventional, measured analytical data are used in the calculation of mean PEC-Qs. Thus, estimated data from screening-level analytical procedures [e.g., PAH fluorescence technique, immunoassays, X-ray fluorescence (XRF) for metals] are not used in the calculation of mean PEC-Qs.

CHAPTER 3

RECOMMENDED USES AND APPLICATIONS OF SQTS

3.1 OVERVIEW

This chapter describes the recommended uses of the Level I and Level II SQTs in Minnesota waterways, including their applications for assisting people with designing monitoring programs, interpreting sediment chemistry data, conducting ecological risk assessments, and/or developing site-specific sediment quality remediation targets for small, uncomplicated sites where adverse biological effects are likely (Table 4; Crane *et al*. 2000; Crane and MacDonald 2003). The applicability of the SQTs in sediment assessments is increased when used in conjunction with other sediment assessment tools such as sediment chemistry, sediment toxicity testing, bioaccumulation studies, and effects on *in situ* benthic invertebrates (Chapman *et al*. 1987; Wenning and Ingersoll 2002). Much of this chapter was adapted from previous publications on this subject (Crane *et al*. 2000; Crane and MacDonald 2003).

> Important: The Level I and Level II SQTs are not to be used as "pollute up to" concentrations.

3.2 DESIGN OF MONITORING PROGRAMS

Sediment quality monitoring programs may be conducted for status and trends assessment, impact assessment, or to ensure compliance with enforcement or remediation activities. A well focused program that addresses the management questions for the area will yield the most useful results.

The numerical SQTs contribute to the design of sediment quality monitoring programs in several ways. First, comparison of existing sediment chemistry data with the Level I and Level II SQTs provides a systematic basis for identifying high priority areas for conducting further monitoring activities, such as delineating the spatial extent of contamination and assessing biological effects (i.e., through sediment toxicity tests, benthic invertebrate community surveys, and/or bioaccumulation assessments). Second, when used in conjunction with existing sediment chemistry data, the SQTs may be utilized to identify chemicals of concern within a study area. By considering the potential sources of these contaminants, it may be possible to further identify priority sites for investigation. The SQTs can also be used in the design of monitoring programs by establishing target detection limits for each substance (e.g., 0.5 x Level I SQT).

3.3 INTERPRETATION OF SEDIMENT CHEMISTRY DATA

Numerical SQTs provide practical assessment tools, or scientific benchmarks, against which the biological importance of sediment chemistry data can be assessed. More specifically, individual

Table 4. Recommended Uses of the Level I and Level II SQTs in Minnesota Waterways (Crane and MacDonald 2003)

Recommended Uses of Numerical SQTs
Design Monitoring Programs • Identify chemicals of potential concern in conjunction with existing sediment chemistry data; • Identify high priority areas (e.g., hot spot sites) for conducting further monitoring activities;
Interpret Sediment Chemistry Data • Identify, rank, and prioritize sediment-associated contaminants; • Evaluate spatial patterns of sediment contamination;
Incorporate in Ecological Risk Assessments • Formulate problem; • Assess effects; • Characterize risks;
Develop Sediment Quality Remediation Targets • Use individual SQTs or mean PEC-Qs as remediation goals at small and uncomplicated sites; • Use SQTs as screening tools in preliminary assessments of data at larger sites; and • Use SQTs in conjunction with other tools (e.g., sediment toxicity tests, benthological surveys, bioaccumulation assessments) at complex sites.

SQTs may be used as screening tools to evaluate the quality of dredged material and to identify reference areas and areas of contaminated sediments.

The MPCA's Stormwater Manual (Minnesota Stormwater Steering Committee 2006) refers to the SQTs as the state benchmark values for making comparisons to surficial sediment chemistry measurements. In addition, it encourages anyone interested in removing sediments from a best management practice (BMP) structure (e.g., stormwater ponds, pre-treatment supplements such as forebays and proprietary chambers, and non-clogging catch-basin inserts) who is not knowledgeable about the character of the material being removed to contact the MPCA via its Contaminated Sediment Web page (http://www.pca.state.mn.us/water/sediments/index.html). This manual also refers users to this web site for guidance on sampling suspected contaminated sediment from BMPs.

3.3.1 Identify, Rank, and Prioritize Sediment-associated Contaminants

The numerical SQTs can be used to identify, rank, and prioritize sediment-associated contaminants within a study area. In this application, the concentration of each chemical substance in each sediment sample is compared to the corresponding SQT value. This comparison can be based on a unique sediment chemistry value or a statistical distribution of values [e.g., mean, median, minimum, 10th percentile, 90th percentile, maximum; see Crane (2006a) for example comparisons to a statistical distribution of sediment chemistry values]. Note that sediment chemistry data should be assessed for normality and skewness, as well.

Those chemicals that occur at concentrations below the Level I SQTs should be considered to be of relatively low priority. Those substances that occur at concentrations above the Level I SQTs, but below the Level II SQTs, should be considered to be of moderate concern. Those substances that are present at concentrations in excess of the Level II SQTs should be considered to be of relatively high concern. The relative priority assigned to each chemical substance can be determined by evaluating the magnitude and frequency of exceedance of the SQTs. Chemicals that exceed the Level II SQTs frequently, or by large margins, should be viewed as the chemicals of greatest concern (Long and MacDonald 1998; MacDonald *et al*. 2000; Ingersoll *et al*. 2001).

In conducting such assessments, it is important to note that certain chemicals can be present in relatively unavailable forms (such as in slag, paint chips, and tar). The SQTs should be used with caution for evaluating sediment samples that contain a large proportion of these relatively inert materials. The SQTs are most applicable for soft sediment samples in depositional areas that have small quantities of these types of materials. Due to uncertainties associated with bioavailability, there is not 100% certainty that samples with chemical concentrations in excess of the Level II SQTs will actually be toxic to sediment-dwelling organisms. The reliability of the SQTs should also be considered when conducting evaluations of sediment chemistry data, with the greatest weight assigned to those SQTs that have been shown to be reliable (Ingersoll *et al*. 1996; MacDonald *et al*. 2000).

Collecting ancillary sediment quality information can increase the degree of confidence that can be placed in determinations of chemicals of concern. Specifically, data on regional background concentrations of sediment-associated contaminants can be used to identify substances of relatively low concern with respect to anthropogenic activities (i.e., those substances that occur at or below background levels). Data from toxicity tests can also be used to support the identification of chemicals of concern. More specifically, matching sediment chemistry and toxicity data provide a basis for evaluating the degree of concordance between the concentrations of specific contaminants and measured adverse effects (i.e., using correlation analyses and regression plots; Carr *et al*. 1996). Those substances that are present at elevated concentrations (i.e., as indicated by exceedances of the Level II SQTs) in toxic samples should be identified as the chemicals of highest concern (Long and MacDonald 1998; MacDonald *et al*. 2000). Those chemicals that are not positively correlated to the results of toxicity tests should be viewed as relatively lower priority contaminants. These types of analyses can be conducted on a site-specific basis.

The numerical SQTs can also be used to identify sites of potential concern with respect to the potential for observing adverse biological effects. In this application, the concentrations of sediment-associated contaminants should be compared to the corresponding SQTs. Sediments in which none of the measured chemical concentrations exceed the Level I SQTs should be considered to have the lowest potential for adversely affecting sediment-dwelling organisms and could be considered reference areas (Long and Wilson 1997). However, the potential for unmeasured contaminants to be present at levels of toxicological concern cannot be dismissed without detailed information on land and water uses within the watershed or the results of sediment toxicity tests. Those sediments that have concentrations of one or more contaminants between the Level I and Level II SQTs should be considered to be of moderate priority, while those sediments with contaminant concentrations in excess of one or more Level II SQTs should be considered to be of relatively high concern. Once again, the magnitude and frequency of exceedances of the Level II SQTs provide a basis for assigning relative priority ratings to contaminated sediment sites.

3.3.2 Evaluate Spatial Patterns of Sediment Contamination

The numerical SQTs provide consistent tools for evaluating spatial patterns in chemical contamination such as in Regional Environmental Monitoring and Assessment Program (R-EMAP) studies (Crane *et al*. 2005). More specifically, the SQTs can be used to compare and rank sediment quality conditions among sites located within a geographic area (see Chapter 5 for an example). This type of comparison can be done for sediments collected from different habitat types (e.g., navigation channels versus shallow water areas), different contaminated sites, or inclusive of all of the sediment chemistry data collected from a geographic area. For the St. Louis River AOC, this type of analysis can be easily accomplished through use of the Phase IV GIS-based sediment quality database which contains the Level I and Level II SQTs provided in Table 1 (Crane and Myre 2006).

Most of the Level II SQTs correspond to the consensus-based PECs (MacDonald *et al*. 2000). The calculation of mean PEC-Qs for the three main classes of chemicals with reliable PECs (i.e., metals, total PAHs, and total PCBs) provides a way of ranking complex mixtures of contaminants in the sediment (Ingersoll *et al.* 2001). For example, mean PEC-Qs are available in the Phase IV GIS-based sediment quality database for the St. Louis River AOC. These data are easily queried from the database using a user-friendly query interface. These data can then be spatially represented and ranked on GIS maps showing the mean PEC-Q ranges for surficial sites in the St. Louis River AOC (see Chapter 5 for an example). Similar maps could be generated for deeper core segments to give a better indication of the temporal distribution of contaminants.

If a stratified random sampling design is used in a monitoring program, then the SQTs provide a basis for calculating the spatial extent of potentially toxic sediments. In hot spot areas, further investigations would typically be implemented to identify contaminant sources, assess the areal extent and severity of actual sediment toxicity and benthic community effects, evaluate the potential for bioaccumulation, and/or determine the need for source control measures or other remedial measures. The SQTs can also be used, in combination with sediment chemistry data, sediment toxicity tests, benthic invertebrate community surveys, bioaccumulation assessments, and/or fish health biomarkers and fish community assessments, to evaluate the success of

regulatory actions that are implemented at the site (e.g., to evaluate post-remediation monitoring data).

3.4 INCORPORATION IN ECOLOGICAL RISK ASSESSMENTS

Ecological risks assessment (ERA) is a paradigm by which the likelihood of undesired effects of human actions or natural events on nonhuman organisms, populations, and ecosystems are estimated (Suter 1997). The risk characterization involves the integration of the magnitude of exposure with the effects associated with varying levels of exposure. Although environmental monitoring determines status and trends in indicators to determine whether the environment is improving, ERA estimates effects of stressors on endpoint attributes to support decision-making (Suter 2001). Integrating the watershed approach with ERA increases the use of environmental monitoring and assessment data in decision-making (Serveiss 2002). Sediment quality targets can be used, with sufficient certainty in ecological risk assessments (Chapman *et al*. 1997).

3.4.1 Problem Formulation

Numerical SQTs can contribute directly to several stages of the ecological risk assessment process, including problem formulation, effects assessment, and risk characterization. During problem formulation, background information and preliminary sampling data are used to identify the problem and define the issues that need to be addressed at contaminated sites (Chapman *et al*. 1997). At the problem-formulation stage, SQTs can be used in conjunction with existing sediment chemistry data to identify the chemicals and areas of concern with respect to sediment contamination (Long and MacDonald 1998). In turn, this information can be used to scope out the nature and extent of the problem and to identify probable sources of sediment contamination at the site. In addition, the SQTs (i.e., less than Level I SQTs) provide a consistent basis for identifying appropriate reference areas that can be used in subsequent assessments of the contaminated site (Menzie 1997). Furthermore, the underlying data (i.e., the matching sediment chemistry and biological effects data) provide a scientific basis for identifying appropriate assessment endpoints (i.e., receptors and ecosystem functions to be protected) and measurement endpoints (i.e., metrics for the assessment endpoints) that can be used at subsequent stages of the assessment.

3.4.2 Effects Assessment

Numerical SQTs also represent effective tools that can be used to assess the effects of sediment-associated contaminants (i.e., during the effects assessment of the ERA). The goal of the effects assessment is to provide information on the toxicity, or other effects, that are likely to occur in response to exposure to contaminated sediments. The results of recent evaluations of their reliability and predictive ability substantially increase the level of confidence that can be placed in the consensus-based SQGs for which most of the Level I and Level II SQTs are based on (Crane *et al*. 2000, 2002a; MacDonald *et al.* 2000). For example, there is a low probability of observing sediment toxicity (i.e., <10%) in North American sediments with mean PEC-Qs ≤0.1 (i.e., based on the results of 28- to 42-day toxicity tests with amphipods; Ingersoll *et al*. 2001). In contrast, the probability of observing sediment toxicity increases at mean PEC-Qs of >0.5 to ≤1.0 (56% incidence of toxicity) and >1.0 (97% incidence of toxicity: i.e., based on the results

of 28- to 42-day toxicity tests with amphipods on North American sediments; Ingersoll *et al*. 2001). For 10-day amphipod (*H. azteca*) and midge (*C. tentans*) toxicity tests conducted on surficial sediments collected from the St. Louis River AOC, the incidence of toxicity increased as the mean PEC-Q range increased (Crane *et al*. 2002a; Crane 2006a). Thus, the SQTs (as mean PEC-Qs) provide an effective basis for classifying sediments as toxic or not toxic when used in conjunction with sediment chemistry data (Ingersoll *et al*. 1996, 2001, 2002; MacDonald *et al*. 1996, 2000; Crane *et al*. 2002a; Crane 2006a). The case study of the St. Louis River AOC presented in Chapter 5 illustrates how mean PEC-Qs can be used to predict sediment toxicity, as well as to compare sediment quality of complex mixtures of sediment contaminants between sites. The approach used in this case study can be adopted at other sites. The applicability of the SQTs in effects assessments is increased when used in conjunction with other tools, including those that facilitate determinations of background concentrations of contaminants, sediment toxicity tests, bioaccumulation tests, and benthic invertebrate community assessments (Chapman *et al*. 1987).

3.4.3 Risk Characterization

The primary purpose of the risk characterization stage of an ERA is to estimate the nature and extent of the risk at a contaminated sediment site and to evaluate the level of uncertainty associated with the estimate (Chapman *et al*. 1997). The SQTs are particularly useful at this stage of the process because they provide a consistent, quantitative basis for evaluating the potential for observing adverse effects in contaminated sediments, for determining the spatial extent of unacceptable levels of sediment contamination (i.e., sediments that exceed prescribed limits of risk to sediment-dwelling organisms), and for estimating the uncertainty in the risk determinations (i.e., the potential for Type I and Type II errors). Importantly, calculation of the frequency of exceedance of the Level II SQTs and specified mean PEC-Qs enables risk assessors to estimate the probability that contaminated sediments will be toxic to sediment-dwelling organisms (Long *et al*. 1998; Field *et al*. 1999; Ingersoll *et al*. 2001). These procedures facilitate determination of the cumulative effects of contaminants arising from multiple sources (i.e., in addition to the contaminated site) and the potential for off-site impacts when appropriate sediment chemistry data are available.

The uncertainty associated with the application of the SQTs at this stage of the ERA can be effectively reduced by using the sediment chemistry data and SQTs in conjunction with other indicators, such as results of sediment toxicity tests and benthic invertebrate community assessments. Uncertainty associated with establishing cause and effect relationships between SQTs and observed toxicity can be reduced by conducting spiked-sediment exposures and toxicity identification evaluation procedures on sediment samples (Ingersoll *et al*. 1997).

3.5 DEVELOPMENT OF SEDIMENT QUALITY REMEDIATION TARGETS

The development of sediment quality remediation targets (SQRTs) provides a common yardstick against which the efficacy of a range of sediment management initiatives can be measured. The narrative intent of the SQRTs needs to include socio-economic and political factors. Numerical SQTs can be used in several ways to support the derivation of SQRTs. Specifically, the Level II SQTs for trace metals, PAHs, and PCBs, in the form of mean PEC-Qs, provide a means of

establishing SQRTs that fulfill the narrative use protection objections for the site. For example, SQRTs could be set at mean PEC-Qs ≤0.1 if the site management goal is to provide a high level of protection for sediment-dwelling organisms (Crane *et al*. 2002a).

Alternatively, the SQRTs could be set at a mean PEC-Q of 0.6 if the immediate goal for the site is to reduce the potential for acute toxicity and permit natural recovery processes to further reduce contaminant concentrations (Crane *et al.* 2002a). In addition, mean PEC-Qs and evaluations of their predictive ability provide information that may be used to evaluate the costs and benefits associated with various remediation options. The SQTs can also be used in follow-up assessment studies after the remediation action to monitor the long-term effectiveness of remediation and to determine if the status and trends of chemical indicators are improving.

It is important to note that numerical SQTs should not be regarded as blanket values for regional sediment quality. Variations in environmental conditions among sites could affect sediment quality in different ways and, hence necessitate the modification of the SQTs to reflect local conditions. MacDonald and Sobolewski (1993) provided interim guidance on the development of site-specific sediment quality remediation objectives for Environment Canada. In addition, the results of sediment quality triad investigations at the site under investigation can be used to evaluate the applicability of numerical SQTs and to refine these SQTs to make them more directly applicable to the site, if necessary. MacDonald and Ingersoll (2000, 2002) provided detailed information on the design and implementation of triad investigations for assessing the predictive ability of SQGs.

Importantly, the weight-of-evidence generated should be proportional to the weight of the decision in the management of contaminated sediments. At small and uncomplicated sites (e.g., boat slips) where adverse biological effects are likely, the costs associated with detailed site investigations are likely to exceed the costs associated with the removal and disposal of contaminated sediments. In these cases, the Level II SQTs, incorporated into mean PEC-Qs, represent cost-effective tools for establishing clean-up targets and developing remediation requirements (Wenning and Ingersoll 2002). For larger sites, SQTs should be used as screening tools in preliminary assessments of data. For complex sites in which additional sediment assessment phases are conducted, SQTs are used in conjunction with other tools (e.g., sediment toxicity tests, benthological surveys, bioaccumulation assessments) to make decisions about the spatial and temporal extent of contamination and the need for remediation (Wenning and Ingersoll 2002).

Application of toxicity identification evaluation procedures and/or sediment spiking studies provides a basis of confirming the identity of the substances that are causing or substantially contributing to sediment toxicity. In this way, it is possible to design remediation requirements that are most likely to achieve the desired outcomes at the site (i.e., restoration of beneficial uses).

3.6 CAVEATS ON THE USE AND APPLICATION OF SQTS

Users of the SQTs must take into consideration variations in physical, chemical, and biological factors in the sediment environment that may complicate and introduce uncertainty into the

application of these values and other sediment assessment tools. In general, uncertainty will be higher when applying the SQTs in depositional wetlands (due to high organic matter and sulfides), oil and gas production environments, in highly modified depositional systems, and in nondepositional and erosional systems (Wenning and Ingersoll 2002). Sediments are often heterogeneous, resulting in patchy distributions of contaminants, grain size, sulfide levels, organic carbon, and black carbon type at varying levels of scale. In addition, benthic and epibenthic organisms can be exposed to sediment-associated contaminants by different exposure routes, and species-specific differences in physiology, biochemistry, and behavior can result in different responses to contaminants (Wenning and Ingersoll 2002). None of these factors, though, preclude the general applications of the Level I and Level II SQTs to most sediment conditions in Minnesota.

The Level I and Level II SQTs are intended for the protection of sediment-dwelling organisms only. They do not address effects in fish, wildlife, or humans. Risk to fish or wildlife is usually evaluated through food web modeling. At sites where human exposure to sediment contaminants may be a concern, the human health screening values developed by the Minnesota Department of Health (MDH) for the St. Louis River AOC (MDH 2005) may be used throughout the state. These MDH values supersede the Level I and Level II SQTs for the protection of human health provided in Crane *et al.* (2000). Contact Carl Herbrandson (MDH) at 651-215-0925 (voice) or carl.herbrandson@state.mn.us for a copy of the MDH human health screening values. The wildlife SQTs provided in Crane *et al*. (2000) can still be used throughout Minnesota; contact Steve Hennes at 651-296-7830 (voice) or steven.hennes@state.mn.us for wildlife SQGs for other chemicals not listed in Crane *et al*. (2000).

CHAPTER 4

FREQUENTLY ASKED QUESTIONS

The Level I and Level II SQTs have been used by the MPCA since 2000. During this time, several issues have arisen on their use and application to sediments in Minnesota waterways. This section provides a compilation of frequently asked questions and responses regarding the use and application of the Level I and Level II SQTs, as well as mean PEC-Qs, in Minnesota waterways.

1. What is the difference between a SQG and a SQT?

Answer: Sediment quality guidelines are scientific tools that synthesize information regarding the relationships between the sediment concentrations of chemicals and any adverse biological effects resulting from exposure to these chemicals (Environment Canada 2004). The SQTs are a type of SQG. The SQT terminology is consistent with establishing metrics and numerical targets for each of the priority ecosystem health indicators recommended for the St. Louis River AOC (Crane *et al*. 2000). Thus, sediment chemistry is an ecosystem health indicator for which one of the metrics is concentration of contaminants of concern. The SQTs provide the numerical targets for contaminants of concern. Other jurisdictions use SQGs in the same manner the MPCA uses SQTs.

2. Are there SQGs available for contaminants not listed in Tables 1 and 2?

Answer: Yes, there are SQGs available for additional contaminants from a variety of sources and jurisdictions (refer to SQG information available at: http://www.pca.state.mn.us/water/sediments/links-assessment.html#guidelines). These other SQGs have not been tested for reliability in Minnesota like the SQTs in Table 1, but may be considered for use on a case-by-case basis. Contact either Judy Crane [651-297-4068 (voice) or judy.crane@pca.state.mn.us] or Steve Hennes [651-296-7830 (voice) or steven.hennes@pca.state.mn.us] for guidance on other SQGs that can be used to make benchmark comparisons against other contaminants.

3. Should the SQTs for nonionic organic compounds, such as PAHs, be normalized to organic carbon if TOC data are available?

Answer: No, the SQTs are expressed on a bulk sediment dry weight basis, and should not be adjusted or normalized for organic carbon. The consensus-based SQGs and Canadian SQGs, which are the basis for all but one of the SQTs, are expressed as dry weight concentrations in the original publications (CCME 1999; MacDonald *et al.* 2000). In theory, normalization to organic carbon to adjust for potential decreased bioavailability is appropriate. However, the results of previous studies have shown that dry weight-normalized SQGs predicted sediment toxicity as well or better than organic carbon-normalized SQGs in field-collected sediments (Barrick *et al*. 1988; Long *et al.* 1995; Ingersoll *et al*. 1996; USEPA 1996; MacDonald 1997). Sorption to sediments is a complex and variable phenomenon, which cannot be captured by simple TOC normalization.

4. **How can toxic units be used to predict the toxicity of PAHs to benthic invertebrates?**

   Answer: The U.S. EPA's narcosis model requires the measurement of 18 parent and 16 groups of alkyl PAHs (i.e., group of 34 PAHs) in sediments to calculate the number of PAH toxic units (TUs) available to benthic organisms (USEPA 2003). Sediment concentrations of the 34 PAHs are used along with their expected sediment/water/lipid partitioning behavior to calculate a hazard quotient, referred to as a TU, which is used as a benchmark for predicting the toxicity of PAHs to benthic invertebrates (Hawthorne *et al*. 2006). If data for the 34 PAHs are not available, the U.S. EPA proposes estimating the risk by multiplying the TU for 13 parent PAHs by 11.5 (95% confidence interval) based on data from 488 sediments (USEPA 2003). Hawthorne *et al*. (2006) suggest this estimate is overly conservative for PAHs from pyrogenic manufactured gas plant (MGP) processes based on the analysis of 45 sediments from six sites; they demonstrated that a factor of 4.2 (rather than 11.5) is sufficient to estimate total TU within a 95% confidence level for MGP sites.

5. **Can mean PEC-Qs be calculated if sediment chemistry data are lacking for one or two groups of chemicals (i.e., reliable metals, total PAHs, or total PCBs)?**

   Answer: Yes. While it would be ideal to have data on all three classes of chemicals, the mean PEC-Qs can still be an effective screening tool [especially if the chemical class(es) measured is/are the primary contaminant(s) of concern at a site]. Be sure to note in the interpretation of the data the chemical classes missing from the mean PEC-Q calculation.

6. **To what depth interval should the Level I and Level II SQTs be used to assess sediment quality?**

   Answer: The SQTs are most applicable to use in the bioactive zone of sediments. This zone encompasses the burrowing depth of the range of benthic organisms present, as well as the rooting depth of aquatic vegetation in nearshore areas. The bioactive zone will vary between areas. Based on previous work done at the St. Louis River Interlake/Duluth Tar Superfund site, the MPCA generally assumes the bioactive zone extends from the surface of the sediments (i.e., 0 m) to 1 m in depth. The selection of this depth interval is also supported by work done in British Columbia to select sediment quality criteria for contaminated sediment sites (Macfarlane *et al*. 2003). The SQTs can also be used in deeper core segments as a way to statistically compare sediment quality between deeper and upper core segments (i.e., to determine if upper sediments are more or less contaminated than deeper sediments; Crane 2006a,b). In addition, where sediments will be excavated, the SQTs can be used to evaluate the proposed new bed surface.

7. **Can the Level I and Level II SQTs be used for the disposal of dredged material on land?**

   Answer: No. The Level I and Level II SQTs are not designed to be protective of terrestrial invertebrates. Instead, refer to the MPCA's draft document on "Managing Dredged Materials in the State of Minnesota" (MPCA 2006) for guidance on using soil reference values to assess the quality of the dredged material for potential land disposal; this document is available from Julianne Rantala at 651-297-8332 (voice) or julianne.rantala@pca.state.mn.us.

8. Can the Level I and Level II SQTs be used to assess sediment quality for the open water disposal of dredged material?

Answer: The MPCA does not allow for deep water disposal of dredged material, except for the creation of beneficial uses such as beach nourishment and habitat creation (MPCA 2006). Under those circumstances, the SQTs could be used to screen the quality of the sediment to be used for beneficial uses within the water.

9. Has the MPCA determined anthropogenic background concentrations of chemicals with SQTs that are representative of surficial sediments in Minnesota?

Answer: No. Currently, background concentrations have to be determined on a site-by-site basis. For further information, please contact either Judy Crane [651-297-4068 (voice) or judy.crane@state.mn.us] or Steve Hennes [651-296-7830 (voice) steven.hennes@pca.state.mn.us].

10. Are there situations where the SQTs may not be adequately protective?

Answer: Yes. For example, enhanced toxicity can occur if PAH-exposed organisms are simultaneously exposed to UV light (USEPA 2003), which is not factored into the SQTs. Field collected amphipods (scuds) from the lower St. Louis River and Duluth Harbor were exposed to UV light, and the results indicated that organisms residing in PAH-contaminated environments can accumulate PAH concentrations sufficient to be at risk for photoactivated toxicity (Diamond *et al*. 2003). In a different laboratory experiment, the spectral characteristics of UV light were shown to be an important factor in predicting photoinduced sediment toxicity from exposure to PAH compounds (Diamond *et al*. 2000). Thus, in environments where significant sunlight penetrates to the sediment and benthic organisms are exposed to UV light, the SQTs may be underprotective.

11. Are there conditions which may result in the SQTs being overly protective?

Answer: Yes, if soot carbon (i.e., black carbon), coal particles, and kerogen are present in the sediment. Black carbon (i.e., soot and char from charcoal) is formed by the combustion of biomass and fuel, and it may end up in soil, sediment, and the air (Pignatello *et al*. 2006). Black carbon increases the sorption of hydrophobic organic chemicals like PAHs and PCBs. Black carbon, along with coal and kerogen, are collectively termed “carbonaceous geosorbents” (CG). The presence of CG can explain: 1) sorption to sediments being up to two orders of magnitude higher than expected on the basis of sorption to amorphous organic matter only, 2) low and variable biota-to-sediment accumulation factors (i.e., lower bioavailability than expected), and 3) limited potential for microbial degradation (Cornelissen *et al.* 2005). Consequently, PAHs and PCBs may partition less to interstitial water in sediments that contain soot, coal particles, and/or kerogen than would be expected with typical organic carbon partitioning. This could cause the SQTs to be overprotective. These conditions cannot be assumed, but need to be evaluated on a site-specific basis.

Another situation where SQTs may be overprotective is when metals are contaminants of concern, and high concentrations of sulfides are present in the sediments. Sulfides bind to metals and form insoluble precipitates, reducing their bioavailability. This condition can be assessed by measuring AVS and SEM in the sediments, or more directly by

measuring pore water concentrations and conducting sediment toxicity tests. See U.S. EPA (2005) for details on the application of these methods.

12. How do the Level I SQTs and Level II SQTs compare to the SQGs used by other jurisdictions [e.g., the Wisconsin Department of Natural Resources (WDNR)]?

Answer: Several other states (e.g., Georgia, Florida, Indiana, Massachusetts, Michigan, Pennsylvania, and Wisconsin), and the Colville Nation of Washington state use consensus-based SQGs in their freshwater sediment quality management programs (Crane and MacDonald 2003). For example, the WDNR adopted the consensus-based SQGs of MacDonald *et al*. (2000), as well as other reliable effects-based SQGs that were either published in the scientific literature or in WDNR Water Quality Standards Section development memos (WDNR 2003). Some of the Minnesota SQTs were rounded to two significant digits from their original source, whereas the WDNR retained the number of significant digits used by the original source. The WDNR also developed a qualitative descriptor system to be used to provide a common basis of expressing relative levels of concern with increasing contaminant concentrations (WDNR 2003). The resulting levels of concern can be used to rank and prioritize sites for additional investigation phases as shown below. To this end, the WDNR developed the qualitative midpoint effect concentration (MEC), which is the concentration midway between the consensus-based TEC and PEC concentrations (as shown below).

Level of Concern	TEC (MacDonald *et al*. 2000)	Level of Concern	Midpoint Effect Concentration (MEC)	Level of Concern	PEC (MacDonald *et al*. 2000)	Level of Concern
Level 1		Level 2	(TEC+PEC)/2	Level 3		Level 4
≤ TEC		>TEC≤MEC	= MEC	>MEC≤PEC		>PEC

The WDNR further made the assumption that the SQGs for nonionic organic compounds (e.g., PAHs, PCBs, pesticides) are based on 1% TOC, although the consensus-based SQGs are expressed as dry weight in the original publication (MacDonald *et al*. 2000). The WDNR also includes the normalization of total PAHs and total PCBs to 1% organic carbon in the calculation of mean PEC-Qs. The MPCA assumes dry weight values and does not normalize nonionic organic compounds to organic carbon. For the St. Louis River AOC, the WDNR agreed in December 2005 to follow the MPCA's procedures for calculating mean PEC-Qs and utilizing the consensus-based TECs and PECs without normalizing them to TOC (J. Crane, personal communication, December 2005). Thus, the consensus-based SQGs and mean PEC-Qs will be used in a uniform manner by both agencies in the St. Louis River AOC, although the WDNR will still use the qualitative MEC value for Wisconsin sites along the St. Louis River AOC.

CHAPTER 5

CASE STUDY: ST. LOUIS RIVER AREA OF CONCERN

5.1 CASE STUDY APPROACH

A case study is included in this document to illustrate how the Level I and Level II SQTs, as well as mean PEC-Qs, can be used to assess sediment quality at a site within Minnesota. In particular, the MPCA has conducted 15 years of sediment investigations in the St. Louis River AOC (Figure 4). The sediment quality data from these investigations, and other stakeholder studies, have been assembled into the Phase IV GIS-based sediment quality database for the St. Louis River AOC (Crane 2006c; Crane and Myre 2006). As part of this database effort, an evaluation of sediment quality conditions in the St. Louis River AOC was conducted. The case study presented below resulted from this evaluation (Crane 2006a,b).

Figure 4. Collection of sediment samples from the St. Louis River AOC [left to right: collection of a sediment core from Slip C, collection of sediment for enumeration of benthic invertebrates, and collection of sediment for bioaccumulation testing (note the oil sheen)].

5.2 BACKGROUND

The lower St. Louis River has special significance due to its geographic boundary shared by Minnesota and Wisconsin, proximity to Lake Superior, and economic, social, and recreational importance to the area (Figure 5). In particular, this waterway provides critical habitat to benthic invertebrates, fish, and waterfowl species and provides an economic venue for Great Lakes shipping and business in the Duluth-Superior Harbor. Economic development of this area over the past 130 years has contributed a mixture of contaminants to this waterway, including PAHs, mercury and other metals, and PCBs. Some of these contaminants have accumulated in the sediments over time, resulting in concern about their potential ecological and human health effects.

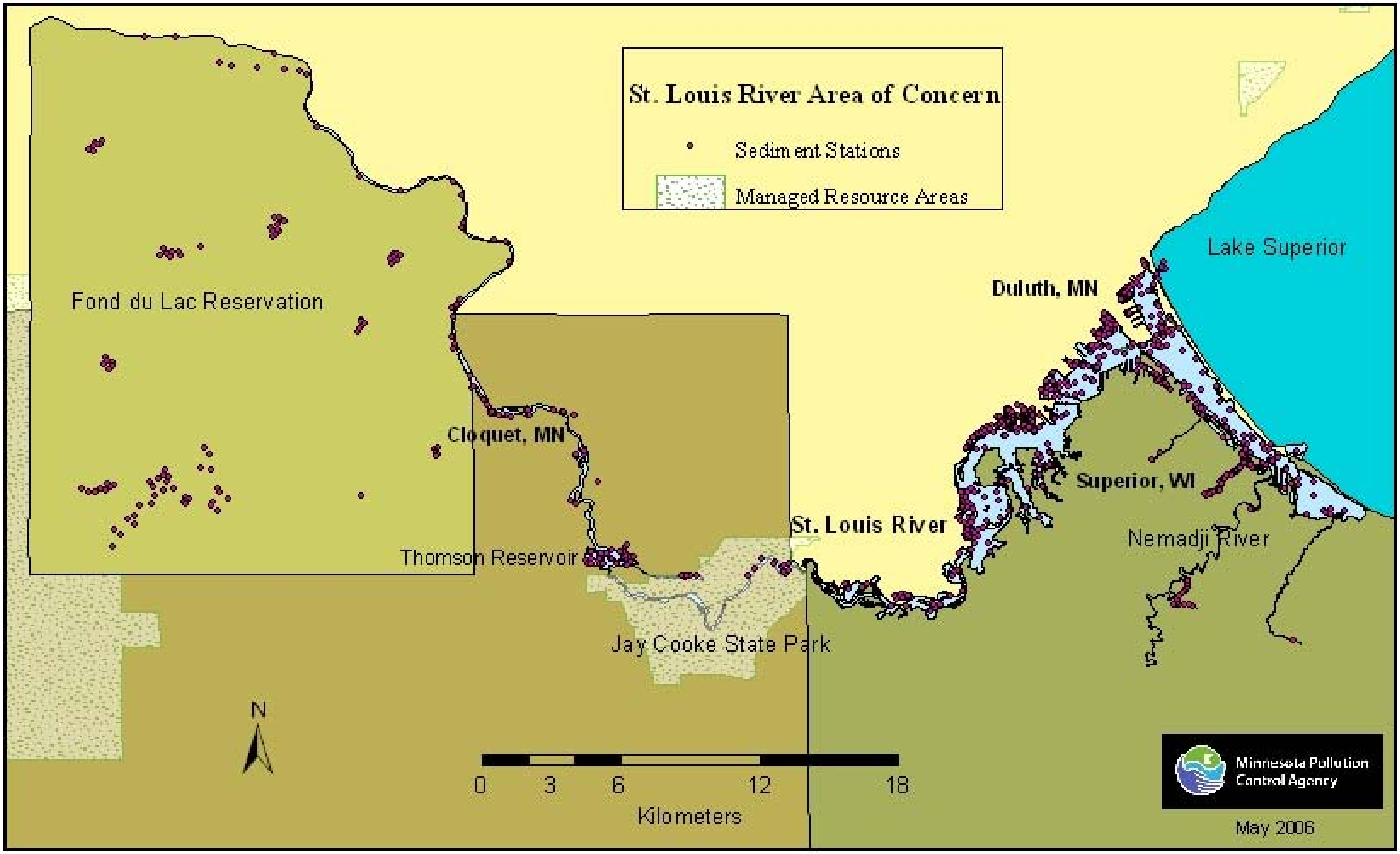

Figure 5. Map of the St. Louis River AOC.

Contaminated sediments contribute to fish consumption advisories, restrictions on dredging, and habitat impairments to bottom-feeding organisms in the lower St. Louis River. These use impairments were a factor in the International Joint Commission's decision to designate this waterway as one of 43 AOCs in the Great Lakes basin in 1987 (IJC 1989). The boundaries of this AOC include 72 nautical kilometers from Cloquet, MN to the Duluth, MN and Superior, WI entries to Lake Superior. Several sediment quality and fish tissue studies have been conducted to delineate the extent and magnitude of contaminants of potential concern and to assess the potential for ecological and human health effects. Sediment quality issues in this AOC are of interest to local and state agencies in Minnesota and Wisconsin, as well as to federal agencies, tribal groups, responsible parties, nonprofit groups, and concerned stakeholders.

A number of ecosystem health indicators have been selected to support the assessment of sediment quality conditions within the lower St. Louis River AOC, including sediment chemistry, sediment toxicity, benthic invertebrate community structure, tissue chemistry, sediment quality targets, physical parameters, and biomarkers in fish. Investigations conducted using data on multiple indicators provide a weight-of-evidence approach for assessing the effects of contaminated sediments on the beneficial uses of this aquatic ecosystem.

Sediments in the lower St. Louis River AOC usually contain a mixture of contaminants (e.g., PAHs, PCBs, mercury, and other metals). These contaminants may not always be bioavailable to benthic invertebrates living in the surface sediments. In addition, contaminants in deeper sediments are permanently buried (i.e., cannot be resuspended due to wave action, currents, or bioturbation from aquatic worms), and benthic organisms are not exposed to them unless navigational dredging or in-water construction activities disturb the sediments.

5.3 USE OF MEAN PEC-Qs FOR ASSESSING SEDIMENT QUALITY

Mean PEC-Qs provide a sediment assessment tool that distills data from a mixture of contaminants into one unitless index. Table 5 shows the number of chemical classes used in the calculation of mean PEC-Qs for sediment samples in the Phase IV GIS-based sediment quality database for the St. Louis River AOC. At mean PEC-Q values less than 0.1, harmful effects on benthic invertebrates are unlikely to be observed. At mean PEC-Qs greater than 0.6, harmful effects on sediment-dwelling organisms are likely to be frequently or always observed.

The mean PEC-Qs provide a way to compare sediment quality between sites (Table 6). Due to the non-normal distribution of mean PEC-Qs in the data set, it is more appropriate to examine summary median values rather than arithmetic average values. In interpreting the data in Table 6, one must consider whether other contaminants of concern contribute to risk and whether the extent and magnitude of contamination has been adequately characterized at a site.

Minnesota Slip and the St. Louis River Interlake/Duluth Tar (SLRIDT) Superfund site have the greatest proportion of surface sediments likely to present a high risk to benthic invertebrates (Table 7 and Figure 6). Sediment remediation of the SLRIDT Superfund site began June 2006 and is expected to be completed by 2009. A focused feasibility study of remediation options for Minnesota Slip was completed November 2005 (Bay West, Inc. 2005). Sediments from Superior

Table 5. Number of Chemical Classes Used in the Calculation of Mean PEC-Qs for Sediment Samples Included in the Phase IV GIS-based Sediment Quality Database (Crane 2006a,b)

		Number of Chemical Classes*	
Depth Interval	**1**	**2**	**3**
0-30 cm, inclusive	486	468	83
>30 cm, inclusive	495	177	28
Other Depths	144	178	76

* Chemical classes include mean metals (i.e., arsenic, cadmium, chromium, copper, lead, nickel, and zinc), total PAHs, and total PCBs.

Bay present the lowest risk to benthic invertebrates; part of this bay is regularly dredged to maintain the federal navigation channel. Howard's Bay has the highest percentage of moderately contaminated surface sediments. The pre-remediation data for Hog Island Inlet and Newton Creek also indicates this site had a high percentage of moderately contaminated sediments. Diesel range organics and alkylated PAHs were other contaminants of concern at this site that are not considered in the calculation of mean PEC-Qs. Sediment remediation of Hog Island Inlet/Newton Creek was completed November 2005, and post-remediation sediment chemistry data were not available in time for this analysis of data.

5.4 SEDIMENT TOXICITY TESTS

The Phase IV sediment quality database contains data on 1,464 toxicity test endpoints (Crane and Myre 2006). Data were queried from the database to obtain toxicity test data that had matching sediment chemistry results in the form of mean PEC-Qs. The term "matching" is used to mean the sediment sample was homogenized and split in the field so that part of the sample was used for sediment toxicity testing and the remainder for sediment chemistry analyses. Sediment samples were designated as toxic if one or more toxicity test endpoints were significantly depressed from the responses observed in the reference or control sediment.

The incidence of toxicity for the mean PEC-Q ranges shown in Table 8 was calculated. The incidence of toxicity was low (i.e., 7.3%) when the concentrations of sediment-associated contaminants were low (i.e., as indicated by mean PEC-Qs of $\leq$0.1). Toxicity increased as the sediments became more contaminated with the classes of chemicals used to calculate mean PEC-Q values. The incidence of sediment toxicity was 100% when the mean PEC-Qs exceeded five; however; these results should be evaluated with caution since this observation was only based on nine samples.

Table 6. Distribution of Mean PEC-Qs in Surface Sediments (i.e., upper 30 cm) of Selected Locations with More than Twenty Sediment Samples (Crane 2006a,b)

Location Description	**N**	**10th Percentile**	**Median**	**90th Percentile**
Hog Island Inlet/Newton Creek*	189	0.054	*0.19*	*0.39*
Howard's Bay	30	*0.14*	*0.37*	***0.61***
Lower St. Louis River	46	0.051	*0.16*	*0.46*
Minnesota Slip	62	*0.3*	***1.1***	***1.9***
Slip C	48	0.066	*0.49*	***1.2***
SLRIDT Superfund Site	214	*0.19*	***1.3***	***21.4***
Superior Bay	41	0.013	*0.11*	*0.28*
Thomson Reservoir	23	0.082	*0.15*	*0.18*
USS Superfund Site	36	0.028	*0.17*	***4.8***
WLSSD, Miller Cr. & Coffee Cr. Embayment	42	0.021	*0.33*	***0.80***
St. Louis River AOC**	910	0.052	*0.25*	***2.3***

* Pre-remediation data for this site; sediment remediation was completed November 2005.
** Includes pre-remediation data for Hog Island Inlet and Newton Creek.

PEC-Q = probable effect concentration quotient; AOC = Area of Concern; N = number of sediment samples; SLRIDT = St. Louis River Interlake/Duluth Tar; USS = U.S. Steel; Cr. = creek; WLSSD = Western Lake Superior Sanitary District.
Values in italics and yellow shading exceed the Level I SQT of 0.1 for mean PEC-Qs.
Values in bold italics and orange shading exceed the Level II SQT of 0.6 for mean PEC-Qs.

Sediments in the St. Louis River AOC generally contain complex mixtures of contaminants. The results of this evaluation indicate that, collectively, the mean PEC-Qs provide a reliable basis for classifying sediments as toxic or not toxic. For this reason, assessments of sediment quality conditions relative to the protection of sediment-dwelling organisms should be conducted using mean PEC-Qs.

5.5 APPLICATION TO OTHER MINNESOTA SITES

The approach used in this case study can be applied to other sites in Minnesota exhibiting a range of sediment quality conditions. Comparisons of individual chemical concentrations to the corresponding Level I and Level II SQTs can be used to determine contaminants of concern at a

Table 7. Frequency of Low, Moderate, and High Risk Samples in Surface Sediments from the Lower St. Louis River AOC (Crane 2006a,b)

			Percentage of Samples Within Ranges of Mean PEC-Qs	
		<0.1	**0.1 to 0.6**	**>0.6**
Location Description	**N**	**(Low)**	**(Moderate)**	**(High)**
Hog Island Inlet/Newton Creek*	189	19	78	3
Howard's Bay	30	7	83	10
Lower St. Louis River	46	33	61	6
Minnesota Slip	62	2	11	87
Slip C	48	15	46	39
SLRIDT Superfund Site	214	4	25	71
Superior Bay	41	46	54	0
Thomson Reservoir	23	30	70	0
USS Superfund Site	36	30	42	28
WLSSD, Miller Cr. & Coffee Cr. Embayment	42	24	55	21
St. Louis River AOC**	910	21	51	28

* Pre-remediation data for this site; sediment remediation was completed November 2005.
** Includes pre-remediation data for Hog Island Inlet and Newton Creek.

AOC = Area of Concern; N = number of sediment samples; PEC-Q = probable effect concentration quotient; SLRIDT = St. Louis River Interlake/Duluth Tar; USS = U.S. Steel; Cr. = creek; WLSSD = Western Lake Superior Sanitary District.

site. Sediments are frequently contaminated with complex mixtures of chemicals, and the composition of the chemical mixture can vary considerably within a study area or site (Long *et al.* 2006). Thus, the mean PEC-Qs provide a straightforward, effects-based numerical index of the relative degree of chemical contamination of sediment samples. A number of sediment studies in different geographic areas of North America demonstrate that both the incidence and magnitude of sediment toxicity in laboratory tests and the incidence of impairment to natural benthic communities increases incrementally with increasing mean SQG quotients (Long *et al.* 2006). In addition, mapping of the mean PEC-Qs values with important GIS information can provide an easier way to communicate sediment quality issues to managers and stakeholders (see Figure 6 for an example).

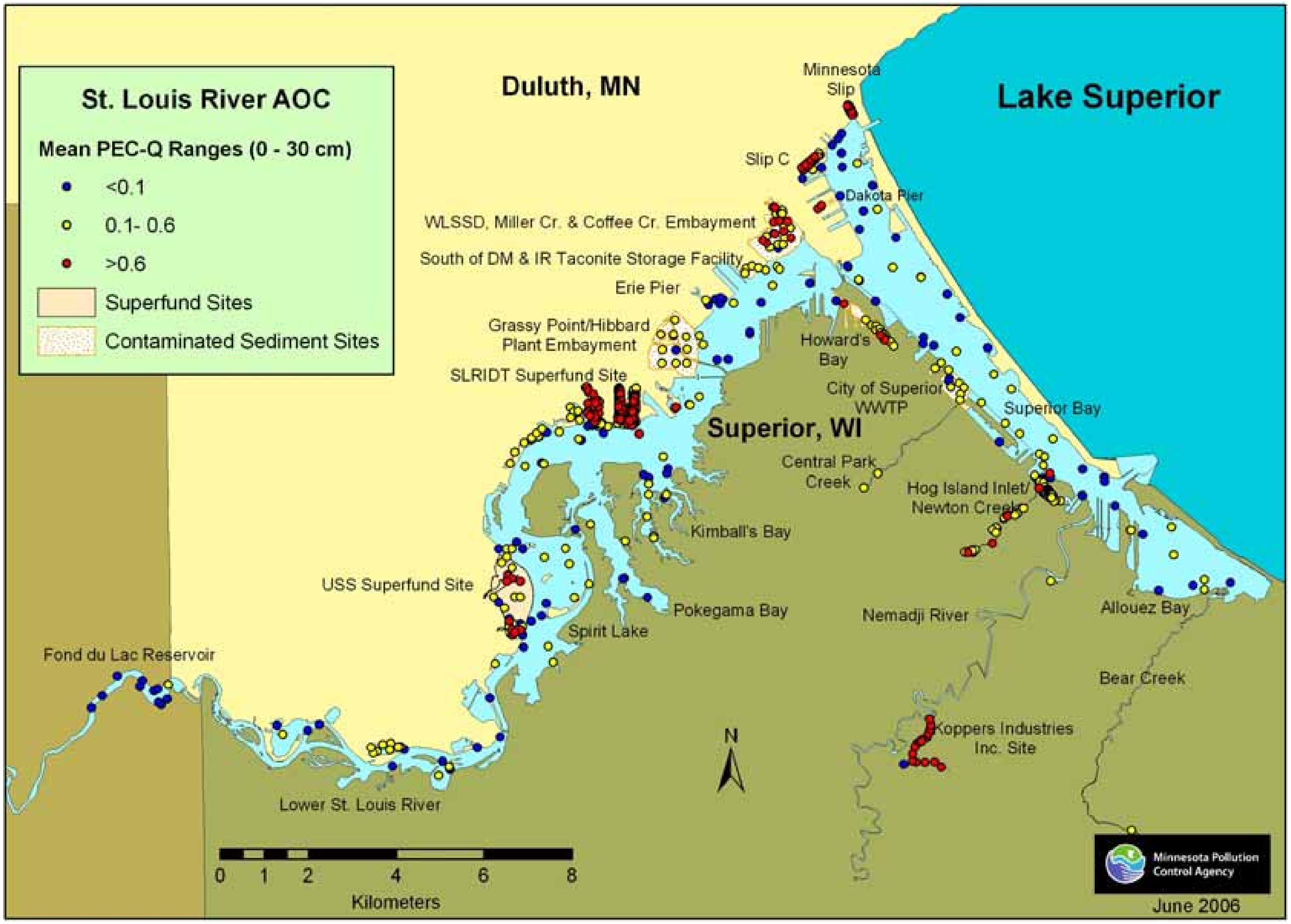

Figure 6. Distribution of mean PEC-Q values in the surface sediments of the lower St. Louis River AOC. The data for Hog Island Inlet and Newton Creek represent pre-remediation conditions (i.e., prior to fall 2005).

Table 8. Incidence of Sediment Toxicity in the St. Louis River AOC for Selected Mean PEC-Q Ranges (Crane 2006a,b)

Mean PEC-Q Range	**N**	**Incidence of Toxicity (%)** All Standard Toxicity Tests (Excluding Bacteria Tests)
≤0.10	55	7.3
>0.10 to ≤0.50	126	27.0
>0.50 to ≤1.0	24	45.8
>1.0 to ≤5.0	26	61.5
>5.0	9	100
Overall	240	30.8

PEC-Q = probable effect concentration quotient
N = number of stations

For further information on the uses, advantages, and limitations of the Level I and Level II SQTs (including mean PEC-Qs), please refer to the papers by Crane *et al*. (2000, 2002a) and Crane and MacDonald (2003). For a critical review of the calculation and uses of mean SQG quotients (including advantages and limitations), refer to the paper by Long *et al*. (2006). For additional information on using the SQTs and other sediment quality indicators (e.g., sediment chemistry, sediment toxicity tests, benthic invertebrate community) in comprehensive sediment quality assessments, refer to Crane *et al*. (2000) and the sediment assessment section of the MPCA's Contaminated Sediments Web page at: http://www.pca.state.mn.us/water/sediments/links-assessment.html. For additional examples of how sediment chemistry data can be displayed in comparison to their corresponding Level I and Level II SQTs, see Appendix B.

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Page 17: Judy Crane, MPCA

APPENDIX A

Basic Information on Contaminated Sediments in Water (U.S. EPA)

From: http://www.epa.gov/waterscience/cs/aboutcs/

U.S. Environmental Protection Agency

Contaminated Sediment in Water

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EPA Home > Water > Contaminated Sediment in Water > Basic Information

Contaminated Sediment in Water Home
Basic Information
Major Contaminants
How to Locate
Species Affected
How to Protect
How to Manage
How to Prevent
Sediment Quality Guidelines
Publications
Related Links
Acronyms

Basic Information

Sediments are loose particles of sand, clay, silt, and other substances that settle at the bottom of a water body. They come from eroding soil and from decomposing plants and animals. Wind, water, and ice often carry these particles great distances.

Many of the sediments in our rivers, lakes, and oceans have been contaminated by pollutants. Some of these pollutants, such as the pesticide DDT and the industrial chemicals known as polychlorinated biphenyls (PCBs), were released into the environment long ago. The use of DDT and PCBs in the United States was banned in the 1970s, but these chemicals persist for many years.

Other contaminants enter our waters every day. Some flow directly from industrial and municipal waste dischargers, while others come from polluted runoff in urban and agricultural areas. Still other contaminants are carried through the air, landing in lakes and streams far from the factories and other facilities that produced them. In cases like this, the sediment may serve as a contaminant reservoir or source of contamination.

Experts believe that contaminated sediments are a widespread and serious problem. Areas of concern are found on the Atlantic and Pacific coasts, in the Gulf of Mexico and the Great Lakes, and along inland waterways.

Contaminated sediments affect small creatures such as worms, crustaceans, and insect larvae that inhabit the bottom of a water body in what is known as the **benthic environment**. Some kinds of toxic sediments kill benthic organisms, reducing the food available to larger animals such as fish.

Some contaminants in the sediment are taken up by benthic organisms in a process called **bioaccumulation**. When larger animals feed on these contaminated organisms, the toxins are taken into their bodies, moving up the food chain in increasing concentrations in a process known as **biomagnification**. As a result, fish and shellfish, waterfowl, and freshwater and marine mammals, as well as benthic organisms, are affected by contaminated sediments.

Species that cannot tolerate the toxic contaminants found in some sediments simply die, reducing the variety of organisms, also known as **biodiversity**, in the affected environment. Animals that survive exposure to contaminated sediments may develop serious health problems, including fin rot, tumors, and reproductive effects.

When contaminants bioaccumulate in trout, salmon, ducks, and other food sources, they pose a threat to human health. In 1998, fish consumption advisories were issued for more than 2,506 bodies of water in the United States. Possible long-term effects of eating contaminated fish include cancer and neurological defects.

Contaminated sediments do not always remain at the bottom of a water body. Anything

that stirs up the water, such as a storm or a boat's propeller, can **resuspend** some sediments. Resuspension may mean that all of the animals in the water, and not just the bottom-dwelling organisms, will be directly exposed to toxic contaminants.

Every year, approximately 300 million cubic yards of sediment are dredged to deepen harbors and clear shipping lanes in the United States. Roughly 3 - 12 million cubic yards of these sediments are so contaminated they require special, and sometimes costly, handling. If dredging to improve navigation cannot be conducted because sediments are contaminated, the volume of shipping on these waterways will decline.

No single government agency is completely responsible for addressing the problem of contaminated sediments. A variety of laws give federal, state, and tribal agencies authority to address sediment quality issues. Private industry and the public also have roles to play in contaminated sediment prevention. Increasing public awareness of the problem is crucial to developing an effective solution.

Major Contaminants
How to Locate
Species Affected
How to Protect
How to Manage
How to Prevent
Glossary
Acronyms

APPENDIX B

Examples of Graphical Displays of Sediment Chemistry Data Compared to the Level I and Level II SQTs

APPENDIX B

This section provides several examples of how sediment chemistry data can be displayed in comparison to their corresponding Level I and Level II SQTs. The examples used in this appendix are from a sediment investigation of Minnesota Slip in the Duluth Harbor (Crane *et al*. 2002b). The locations of sediment sampling sites are provided in Figure B-1. The profile of lead in one sediment core is provided in Figure B-2; from this figure, note the concentrations of lead exceeded the Level II SQT of 130 mg/kg dry weight in each depth interval. In addition, this figure demonstrates the surface sediments are less contaminated than the middle portions of the sediment core. Figure B-3 provides isopleth plots for the distribution of lead in Minnesota Slip for selected depth intervals. In these figures, the Level I and Level II SQTs are used to define the concentration ranges for the isopleth plots. These types of plots can be used for targeting areas for further investigation or action. In addition, isopleth plots provide a good way of communicating the distribution of contaminants to managers, stakeholders, and the public.

Graphical displays of sediment quality data are also enhanced by the addition of GIS data (e.g., data on water uses, land uses, contamination sources) in the vicinity of the sample site. For several examples of sediment quality data plotted on maps displaying a range of GIS data, refer to the 11 by 17 inch color figures provided in the following report: "Overview of Sediment Quality Conditions in the St. Louis River Area of Concern" (Crane 2006a). This report is available on the MPCA's Contaminated Sediment Web page in the following PDF files:

- Report Text: http://www.pca.state.mn.us/publications/tdr-fg06-04a.pdf,
- Report Tables: http://www.pca.state.mn.us/publications/tdr-fg06-04b.pdf,
- Report Figures 1-8: http://www.pca.state.mn.us/publications/tdr-fg06-04c.pdf,
- Report Figure 9: http://www.pca.state.mn.us/publications/tdr-fg06-04d.pdf,
- Report Figures 10-17: http://www.pca.state.mn.us/publications/tdr-fg06-04e.pdf.

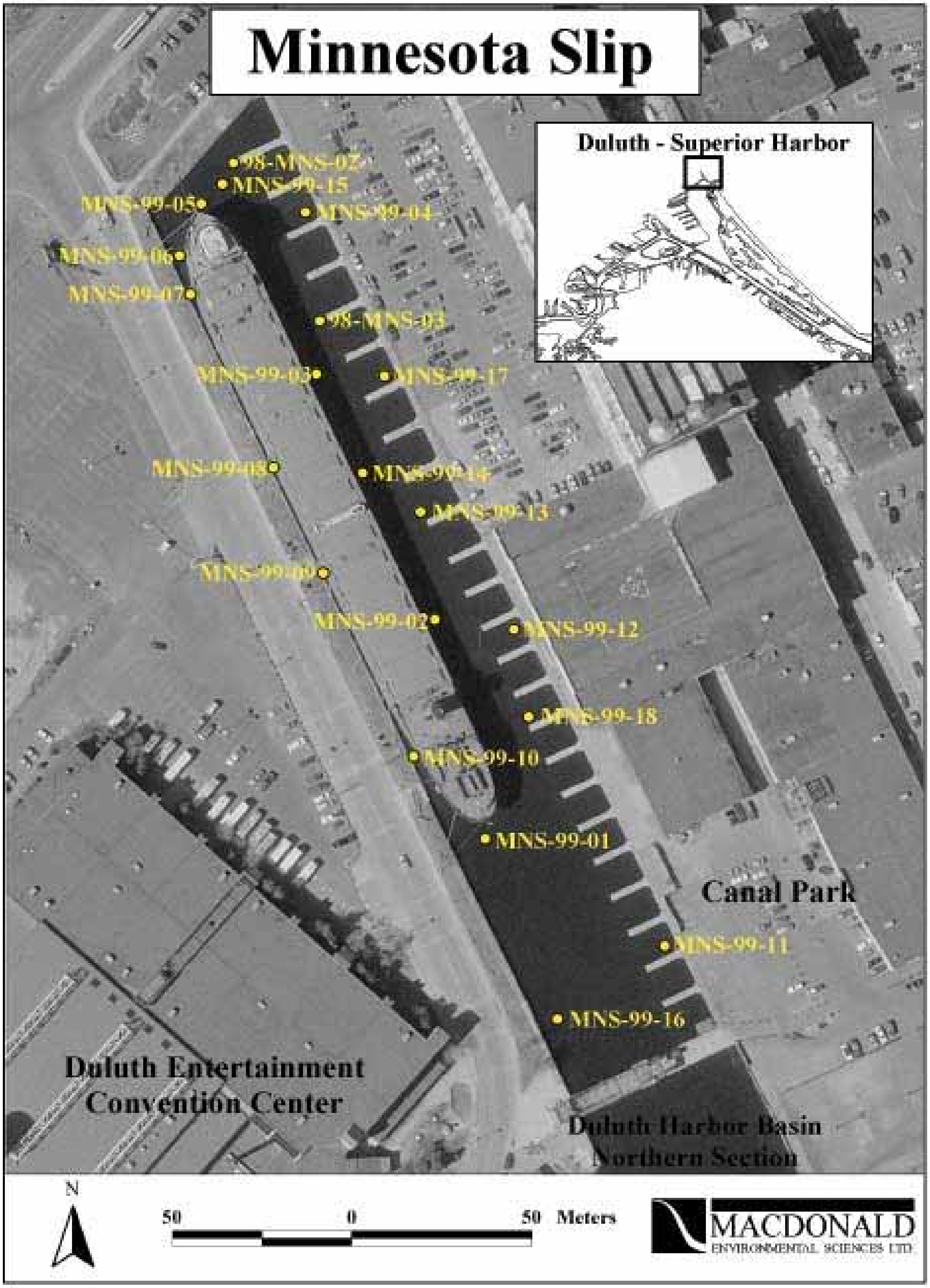

Figure B-1. Location of sediment sampling sites in Minnesota Slip during 1998 and 1999 (Crane *et al*. 2002b).

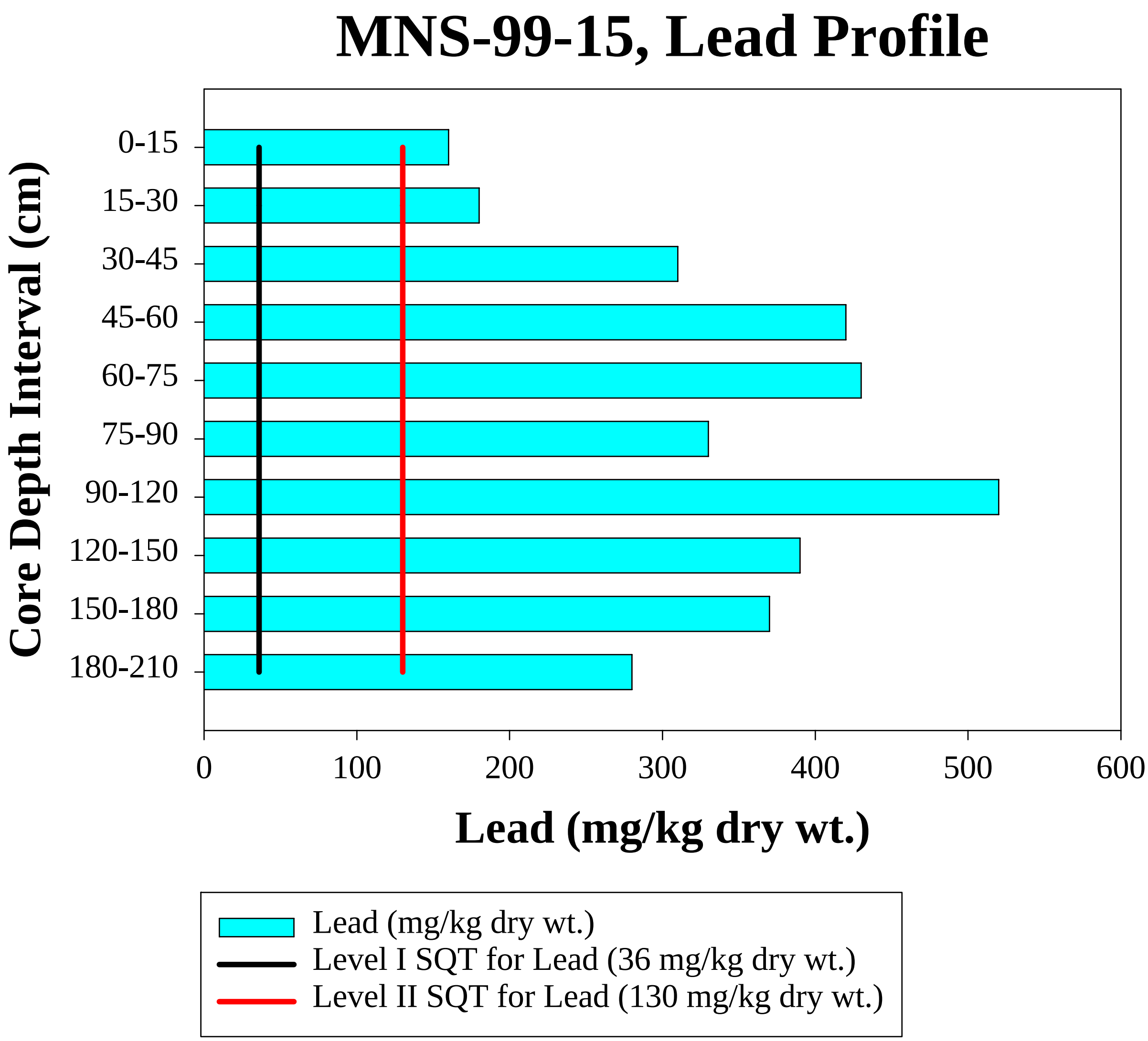

Figure B-2. Historical distribution of lead (mg/kg dry wt.) at site MNS-99-15 (Crane *et al.* 2002b)

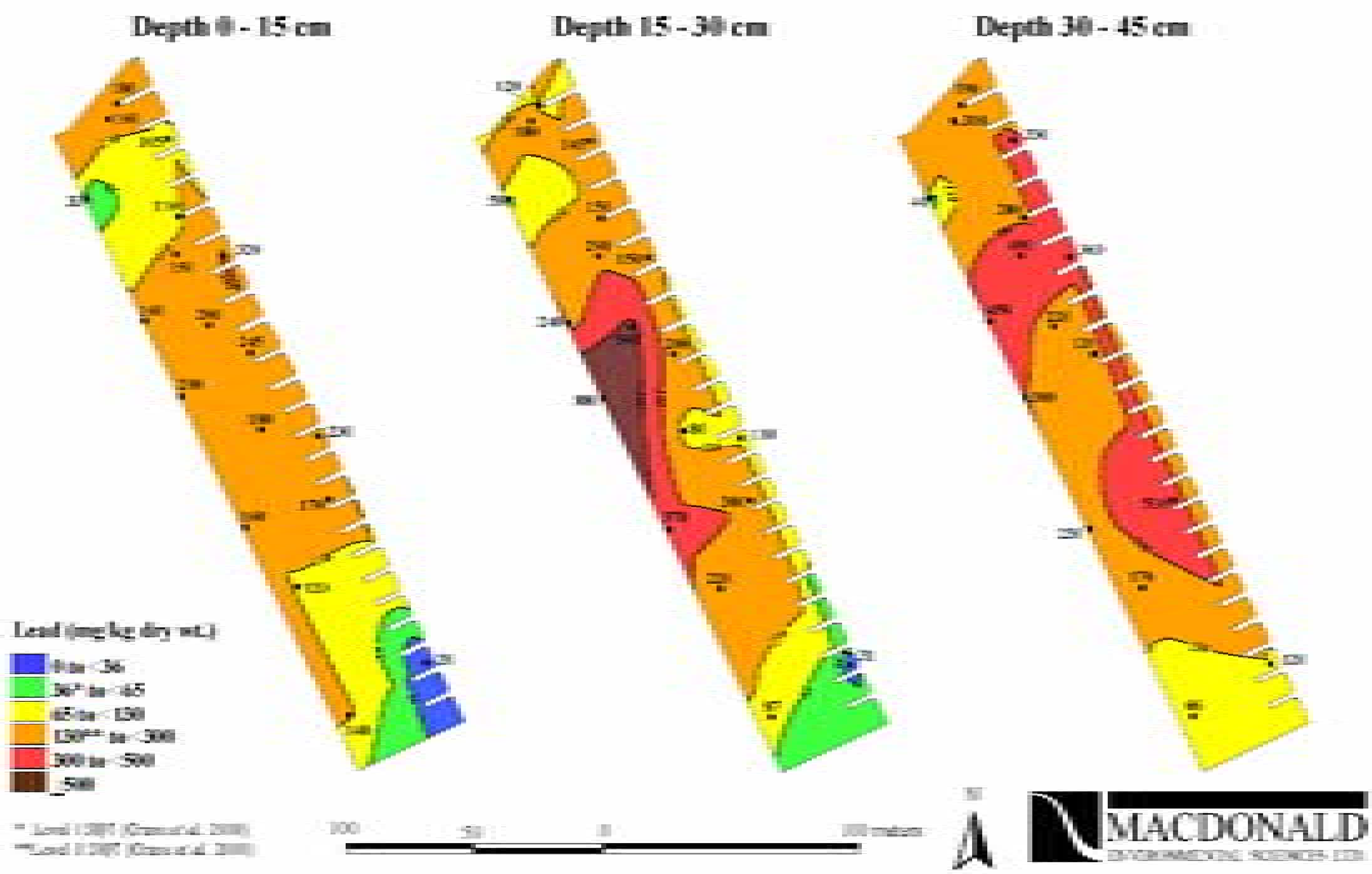

Figure B-3. Isopleth plots for the distribution of lead (mg/kg dry wt.) in Minnesota Slip for selected depth intervals (Crane *et al*. 2002b).

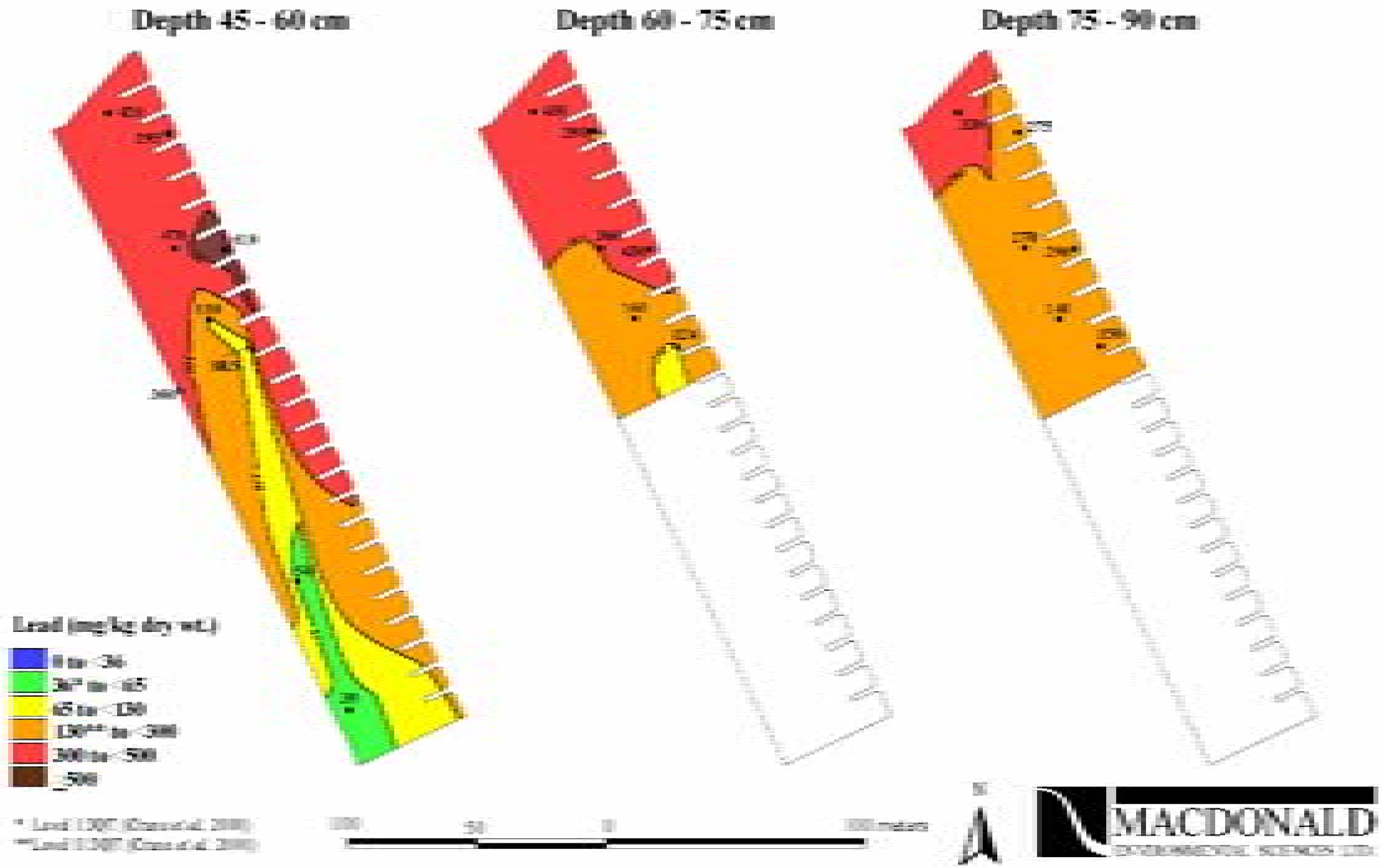

Figure B-3. Continued

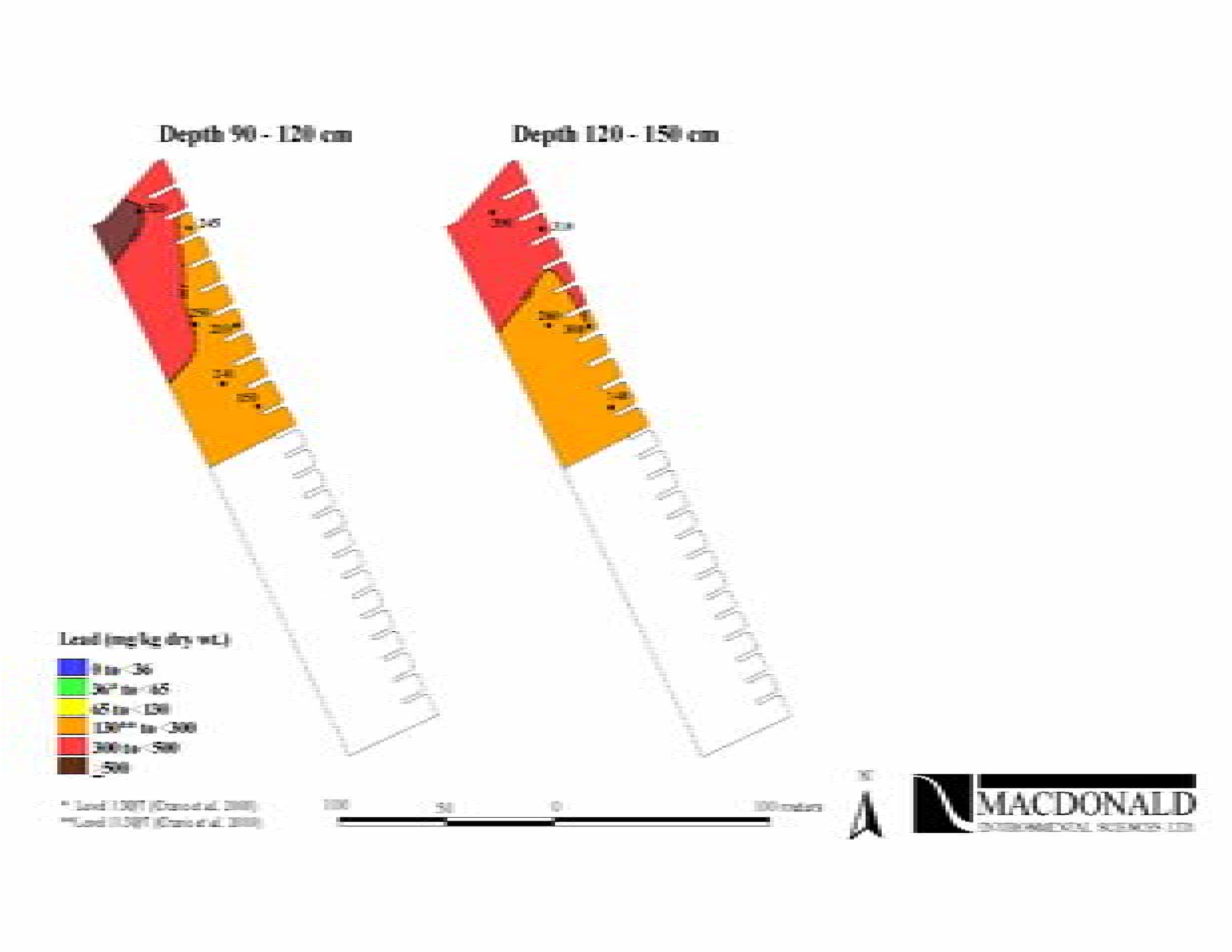

Figure B-3. Continued.