Physical, Chemical, and Biological Characteristics of Mississippi, Minnesota, and St. Croix River Bed Sediments in the Twin Cities, MN Area during a 1998-2001 Survey

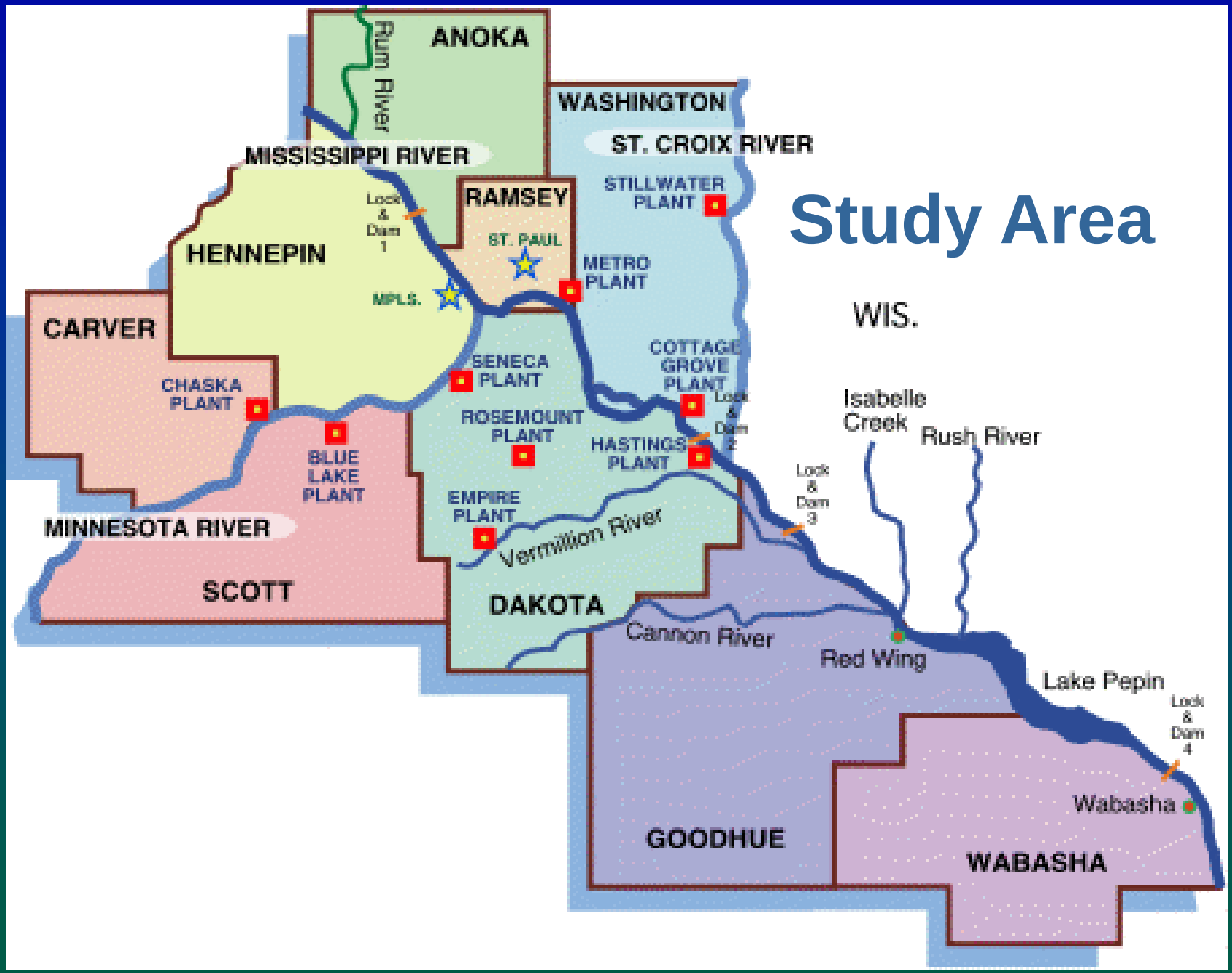
Garry Durland, Tim Pattock, and D. Kent Johnson

Environmental Monitoring and Assessment Section
Metropolitan Council Environmental Services

Metropolitan Council
Environmental Services

Metropolitan Council Environmental Services

- Owns and operates 8 municipal wastewater treatment plants (WWTPs) in the Twin Cities Metropolitan Area (TCMA)
- Each WWTP discharges into 1 of 4 TCMA rivers: Mississippi, Minnesota, St. Croix, and Vermillion
- EMA Section monitors impacts of WWTPs and nonpoint sources of pollution on 150 miles of TCMA rivers
- Water, bed sediment, and biological samples are analyzed to assess river health
- See: www.metrocouncil.org/environment/RiversLakes/Rivers/index.htm


Study Area
ANOKA
Rum River
WASHINGTON
ST. CROIX RIVER
MISSISSIPPI RIVER
RAMSEY
STILLWATER PLANT
Lock & Dam 1
HENNEPIN
ST. PAUL
METRO PLANT
MPLS.
WIS.
CARVER
SENECA PLANT
COTTAGE GROVE PLANT
CHASKA PLANT
ROSEMOUNT PLANT
Lock & Dam 2
Isabelle Creek
Rush River
HASTINGS PLANT
BLUE LAKE PLANT
Lock & Dam 3
EMPIRE PLANT
Vermillion River
MINNESOTA RIVER
SCOTT
DAKOTA
Cannon River
Red Wing
Lake Pepin
Lock & Dam 4
Wabasha
GOODHUE
WABASHA

Metropolitan Wastewater Treatment Plant, 2003

Metro Plant, Treated Wastewater: 200 mgd

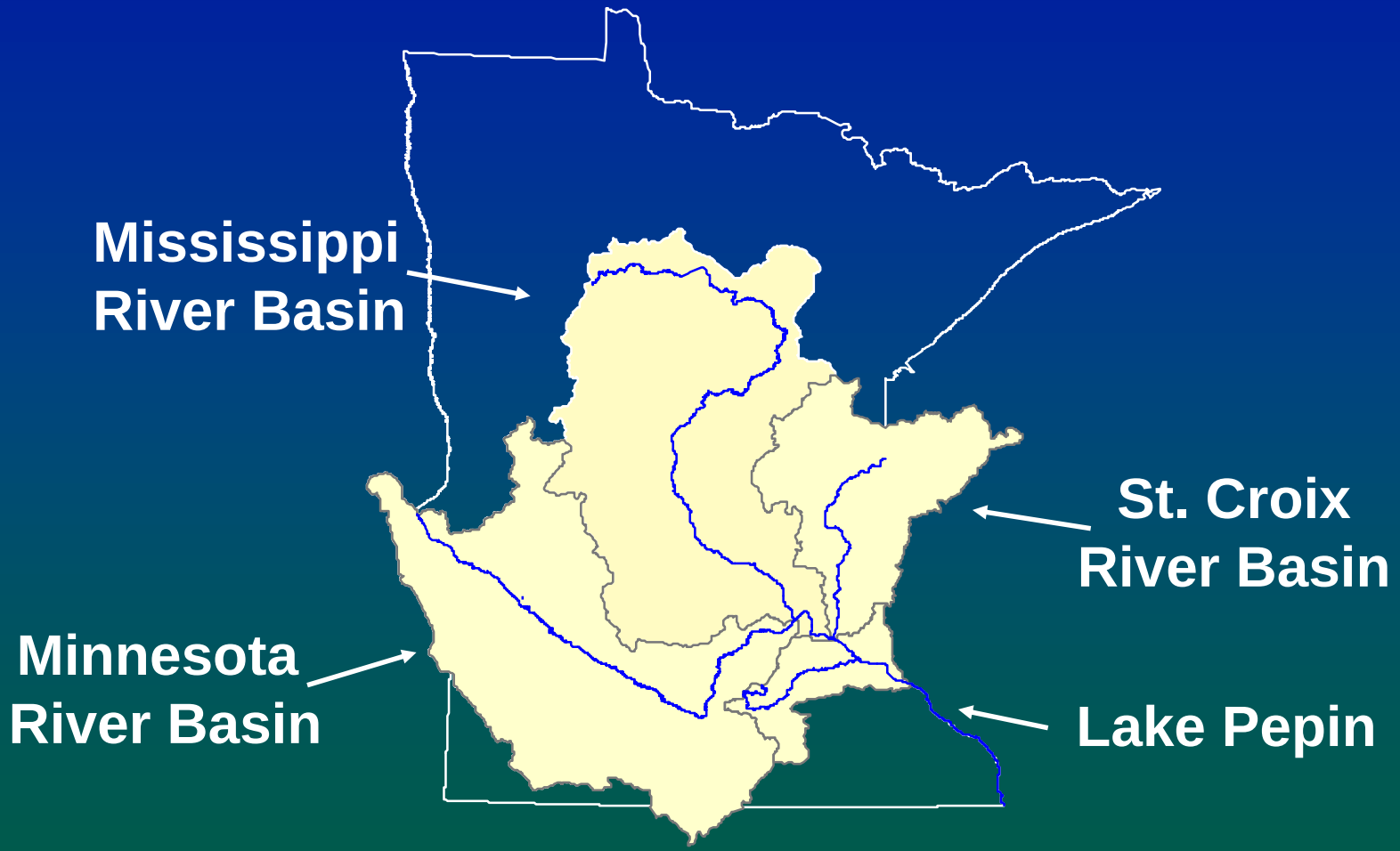
Metropolitan Wastewater Treatment Plant (Metro Plant)

- Owned and operated by MCES
- 200 mgd facility in St. Paul, MN
- Largest WWTP in Minnesota
- Treats half of state's municipal wastewater
- Fifty miles upstream of Lake Pepin
- Upgraded to advanced secondary treatment in 1986
- State-of-the-art technology for pollutant removal (TSS, BOD, NH3, TP)
- Effective pre-treatment program for trace metals reduction (1982)

Confluence of the Mississippi and Minnesota Rivers
St. Paul, MN

Confluence of the Mississippi and St. Croix Rivers
Prescott, WI

Lake Pepin Watershed



1998-2001 Sediment Survey: Sediment Quality Triad Approach

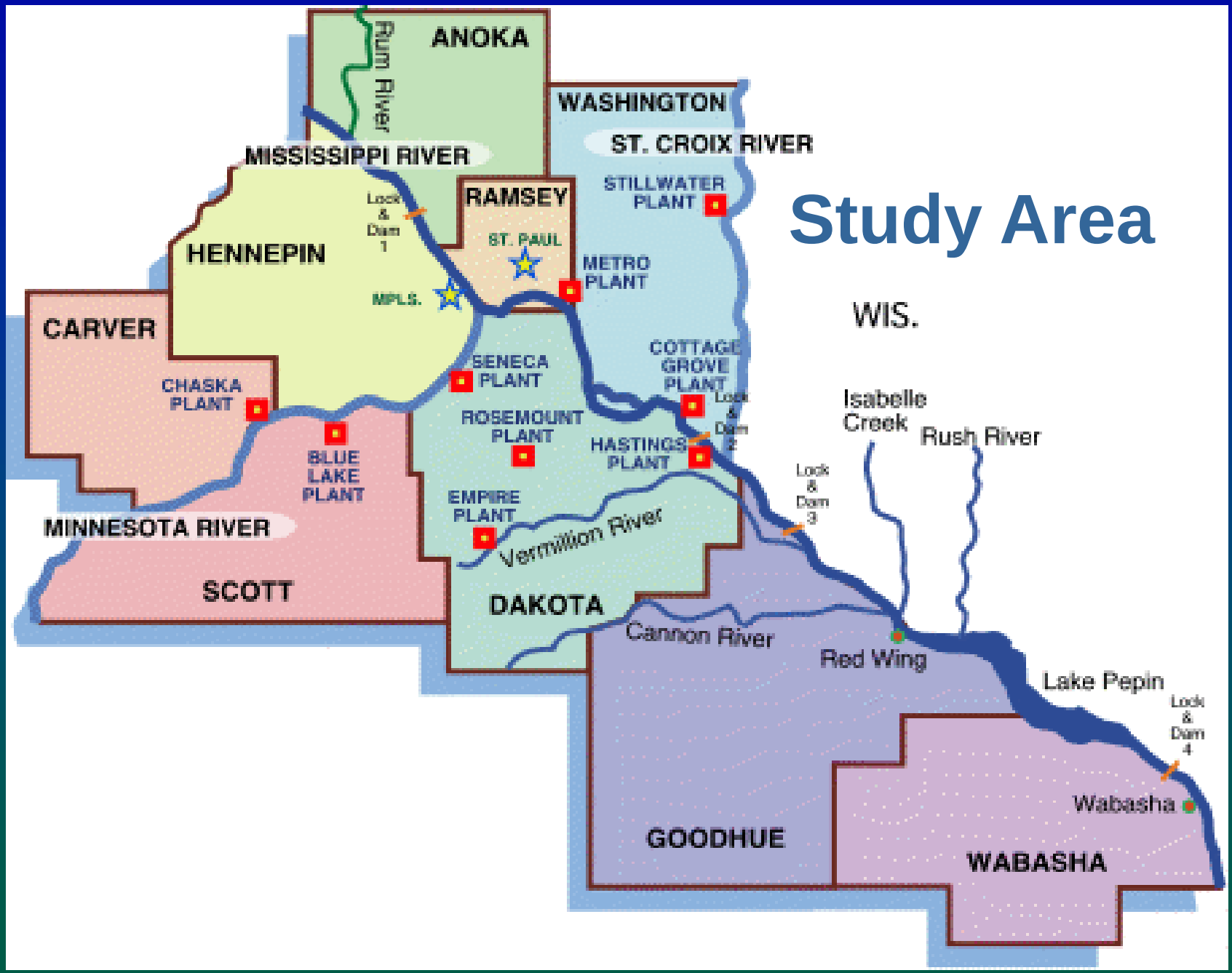
- Physical and chemical analysis of sediment
- Benthic macroinvertebrate analysis
- Sediment toxicity-testing

Evaluation of Bed Sediment Samples

- Grain size (particle size) analysis of bed sediment
- Chemical analysis of bed sediment and sediment pore water for trace metals, organochlorine compounds (OCs), and polycyclic aromatic hydrocarbons (PAHs)
- Benthic macroinvertebrate analysis
- Bed sediment toxicity-testing (10-day survival and growth)
- Sediment pore water toxicity-testing (1-day survival)

Sediment Monitoring Sites

- 13 Mississippi River sites along an 80-mile river reach
  - 7 mainstem sites from Lock and Dam 1 - Lock and Dam 3
  - 3 sites in Pig's Eye Lake
  - 3 sites in Lake Pepin
- 2 Minnesota River sites along a 40-mile river reach
  - Jordan and Ft. Snelling
- 2 St. Croix River sites along a 23-mile river reach
  - Stillwater and Prescott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DAKOTA
Cannon River
Red Wing
Lake Pepin
Lock & Dam 4
Wabasha
GOODHUE
WABASHA

Sediment Sample Collection and Analysis

- Bed sediment samples obtained with a stainless steel Ponar grab sampler
- 3 samples per site, on a cross-channel transect; 1 equal-volume composite sample formed from portions of the 3 discrete samples
- Sample-splitting in the field, for grain size analysis, chemical analysis, and toxicity-testing
- Separate benthic macroinvertebrate samples obtained at the 3 transect locations per site
- All samples analyzed in the MCES Laboratory, St. Paul, MN

Field Collection of Bed Sediment Samples

Grain Size Analysis of Bed Sediment

- Fine clay: <0.08 micron
- Medium clay: 0.08-0.2 micron
- Coarse clay: 0.2-2 microns
- Fine silt: 2-5 microns
- Medium silt: 5-20 microns
- Coarse silt: 20-53 microns
- Fine sand: 53-125 microns
- Medium sand: 125-177 microns
- Coarse sand: 177-250 microns
- Fine gravel: 250-500 microns
- Coarse gravel: 500-2000 microns
- Larger than coarse gravel: >2000 microns

Trace Metals Analyzed in Bed Sediment and Pore Water

Antimony (Sb)
Arsenic (As)
Beryllium (Be)
Cadmium (Cd)
Chromium (Cr)
Copper (Cu)
Lead (Pb)
Manganese (Mn)
Mercury (Hg)
Nickel (Ni)
Selenium (Se)
Silver (Ag)
Thallium (Tl)
Zinc (Zn)

OC Pesticides Analyzed in Bed Sediment and Pore Water

Aldrin
a-BHC
b-BHC
g-BHC
d-BHC
Chlordane
4,4’-DDD
4,4’-DDE
4,4’-DDT
Dieldrin
Endosulfan I
Endosulfan II
Endosulfan Sulfate
Endrin
Endrin Aldehyde
Heptachlor
Heptachlor Epoxide
Toxaphene
PCB 1016
PCB 1221
PCB 1232
PCB 1242
PCB 1248
PCB 1254
PCB 1260

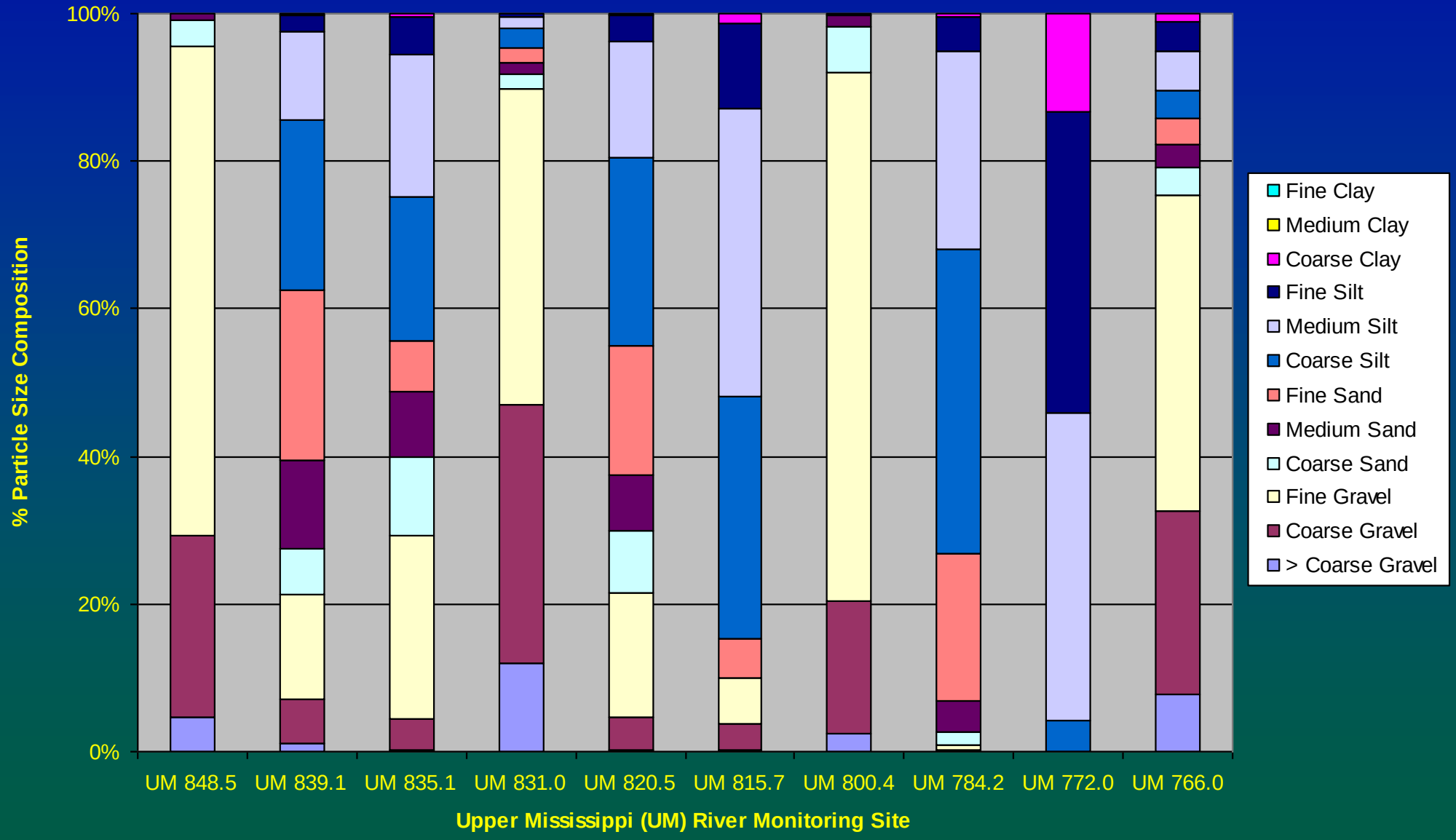
PAHs Analyzed in Bed Sediment and Pore Water

Acenapthene
Acenaphthylene
Anthracene
Benzidine
Benzo(a)anthracene
Benzo(b)fluoranthene
Benzo(k)fluoranthene
Benzo(g,h,i)perylene
Benzo(a)pyrene
Bis (2-chloroethyl) ether
Bis (2-chloro-isopropyl) ether
Bis (2-chloroethoxy) methane
Bis (2-ethylhexyl) phthalate
4-Bromophenyl phenyl ether
Butylbenzylphthalate
4-Chloro-3-Methylphenol
2-Chloronaphthalene
2-Chlorophenol
4-Chlorophenyl phenyl ether
Chrysene
Dibenzo(a,h)anthracene
Di-N-butyl-phthalate
1,2-Dichlorobenzene
1,3-Dichlorobenzene
1,4-Dichlorobenzene
3,3'-Dichlorobenzidine
2,4-Dichlorophenol
Diethylphthalate
2,4-Dimethylphenol
Dimethylphthalate
2,4-Dinitrophenol
2,4-Dinitrotoluene
2,6-Dinitrotoluene
Di-N-octylphthalate
1,2-Diphenylhydrazine
Fluoranthene
Fluorene
Hexachlorobenzene
Hexachlorobutadiene
Hexachlorocylopentadiene
Hexachloroethane
Indeno (1,2,3-c-d) pyrene
Isophorone
2-Methyl-4,6-Dinitrophenol
Naphthalene
Nitrobenzene
2-Nitrophenol
4-Nitrophenol
N-Nitrosodimethyl amine
N-Nitroso-diphenylamine
N-Nitrosodi-N-propylamine
Pentachlorophenol
Phenanthrene
Phenol
Pyrene
1,2,4-Trichlorobenzene
2,4,6-Trichlorophenol

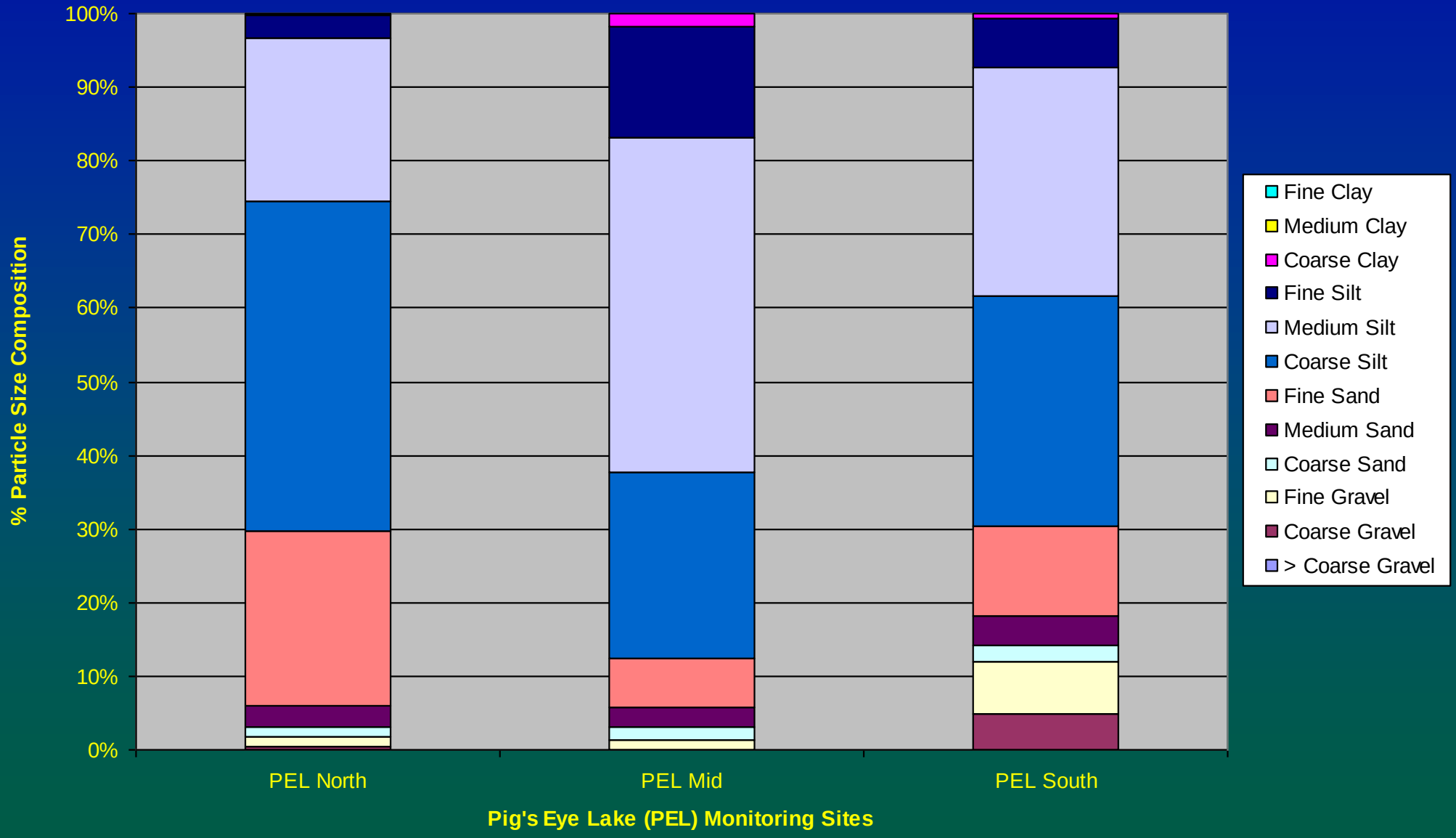
Toxicity-Testing of Bed Sediment and Pore Water

- Bed Sediment Toxicity-Testing (EPA, 1994)
  - *Hyalella azteca* 10-Day Survival Test
  - *Chironomus tentans* 10-Day Survival and Growth Test
- Pore Water Toxicity-Testing (EPA, 1993)
  - *Ceriodaphnia dubia* 24-Hour Survival Test

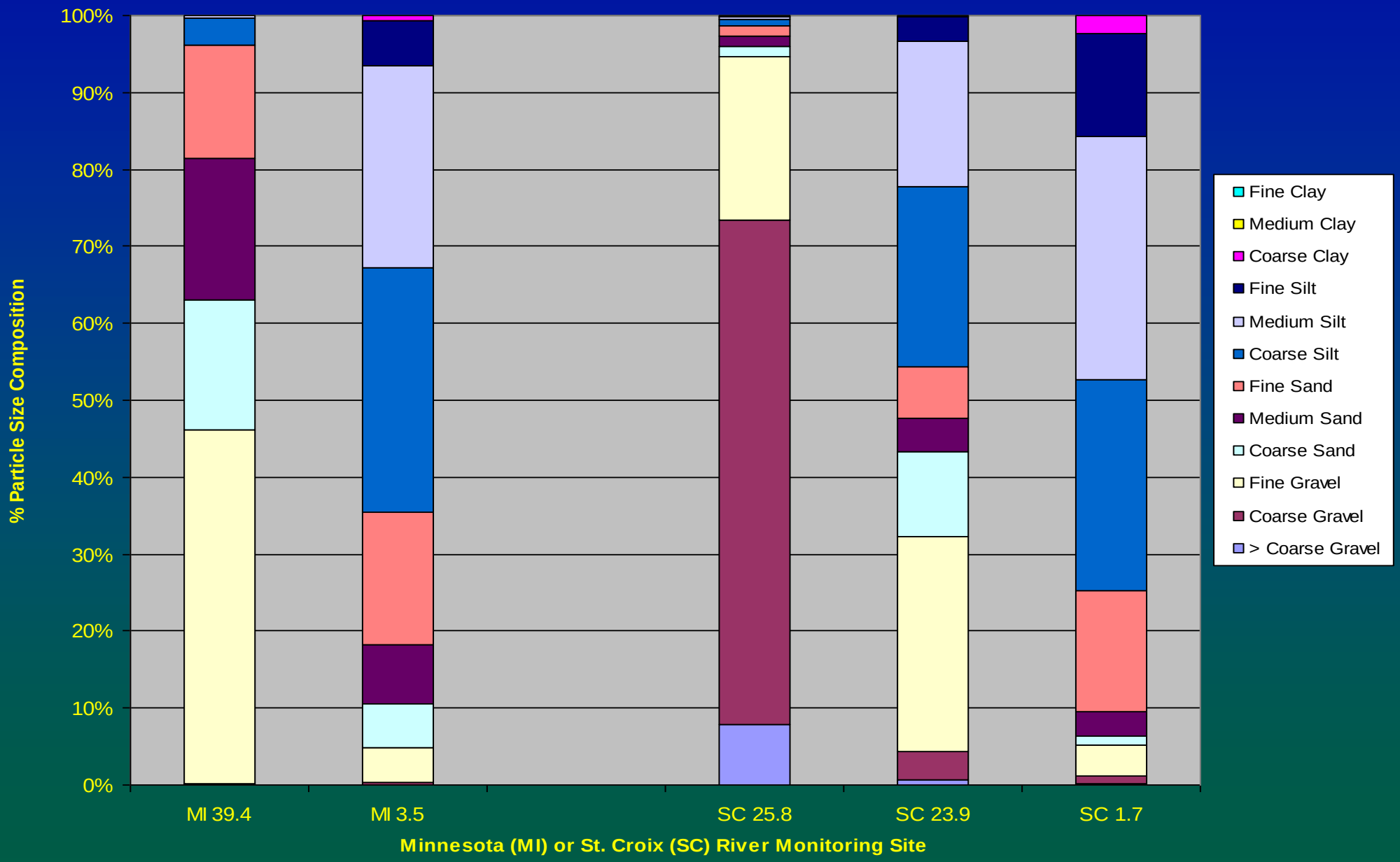
Percent Particle Size Composition at Mississippi River Sediment Monitoring Sites: 1998-2001 Survey



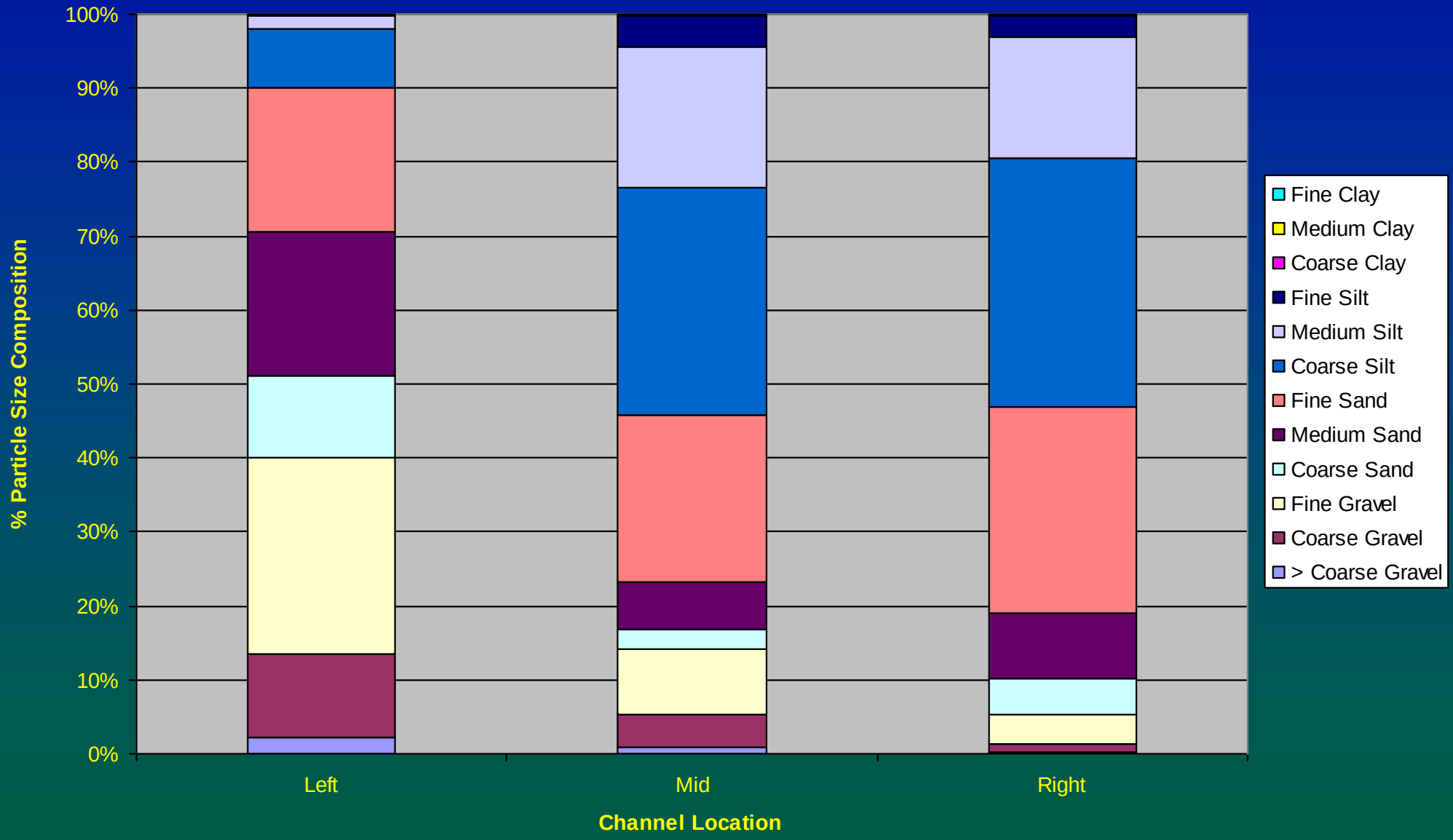
Percent Particle Size Composition at Pig's Eye Lake Sediment Monitoring Sites: 1998-2001 Survey



Percent Particle Size Composition at Minnesota and St. Croix River Monitoring Sites: 1998-2001 Survey



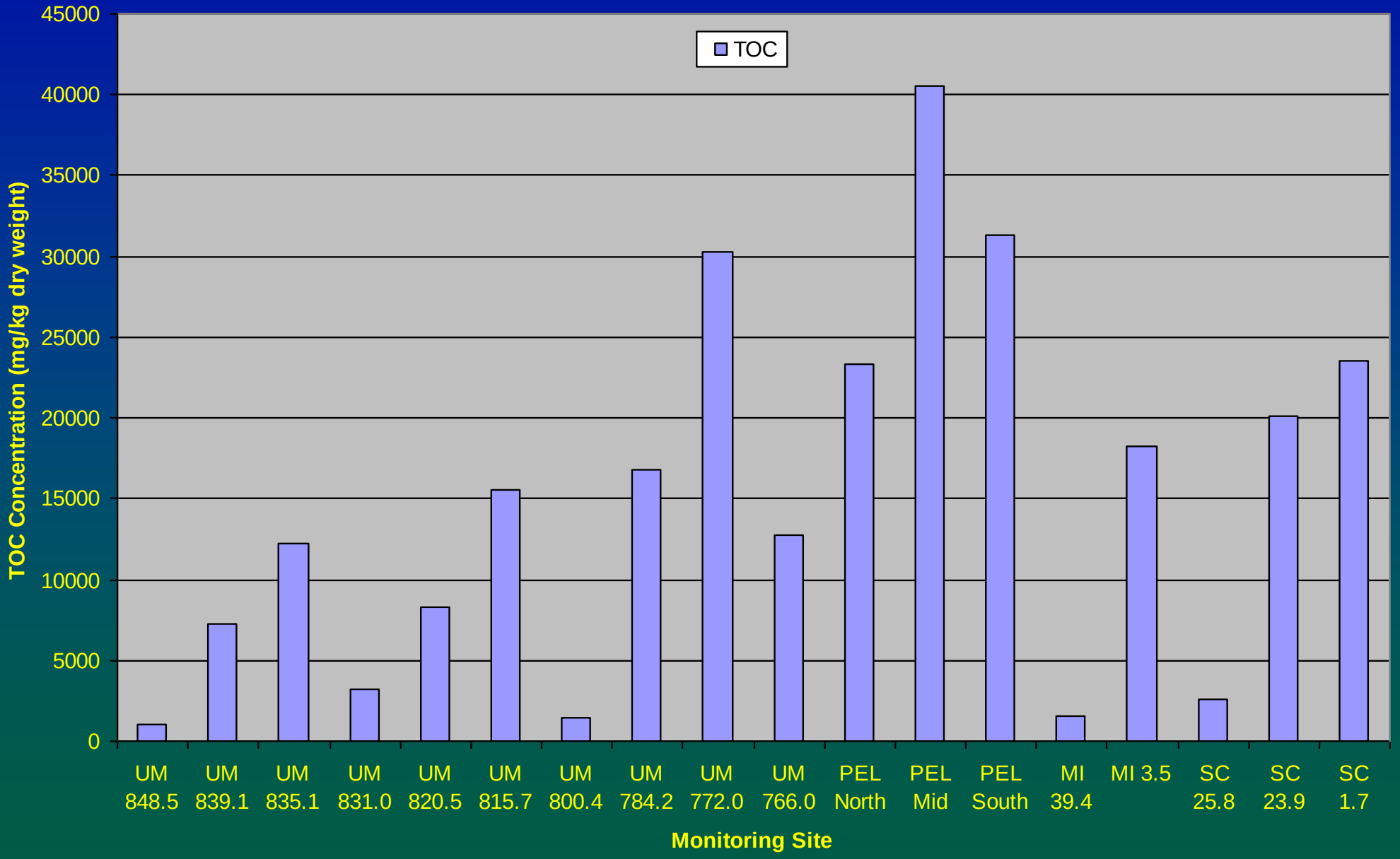
Cross Channel Particle Size Variation at a Mississippi River Sediment Monitoring Site (UM 839.1)



Conclusions: Sediment Grain Size Analysis

- Riverine lakes (Pig's Eye Lake, Spring Lake, Lake Pepin, Lake St. Croix) and the Lower Minnesota River (Ft. Snelling) are depositional areas, with high percentages (>50%) of silt and clay
- Mainstem river sites exhibit considerable grain size variation, from gravel (UM 848.5, UM 831.0, UM 800.4, UM 766.0, SC 25.9) to gravel/sand (MI 39.4) to sand/silt (UM 839.1, UM 835.1, SC 23.9)
- Substantial cross-channel variation in sediment grain size composition is evident at a number of main-channel monitoring sites, likely due to differences in flow velocity across the channel and the impact of commercial navigation traffic

TOC Concentrations in Mississippi, Minnesota, and St. Croix River Sediments: 1998-2001 Survey



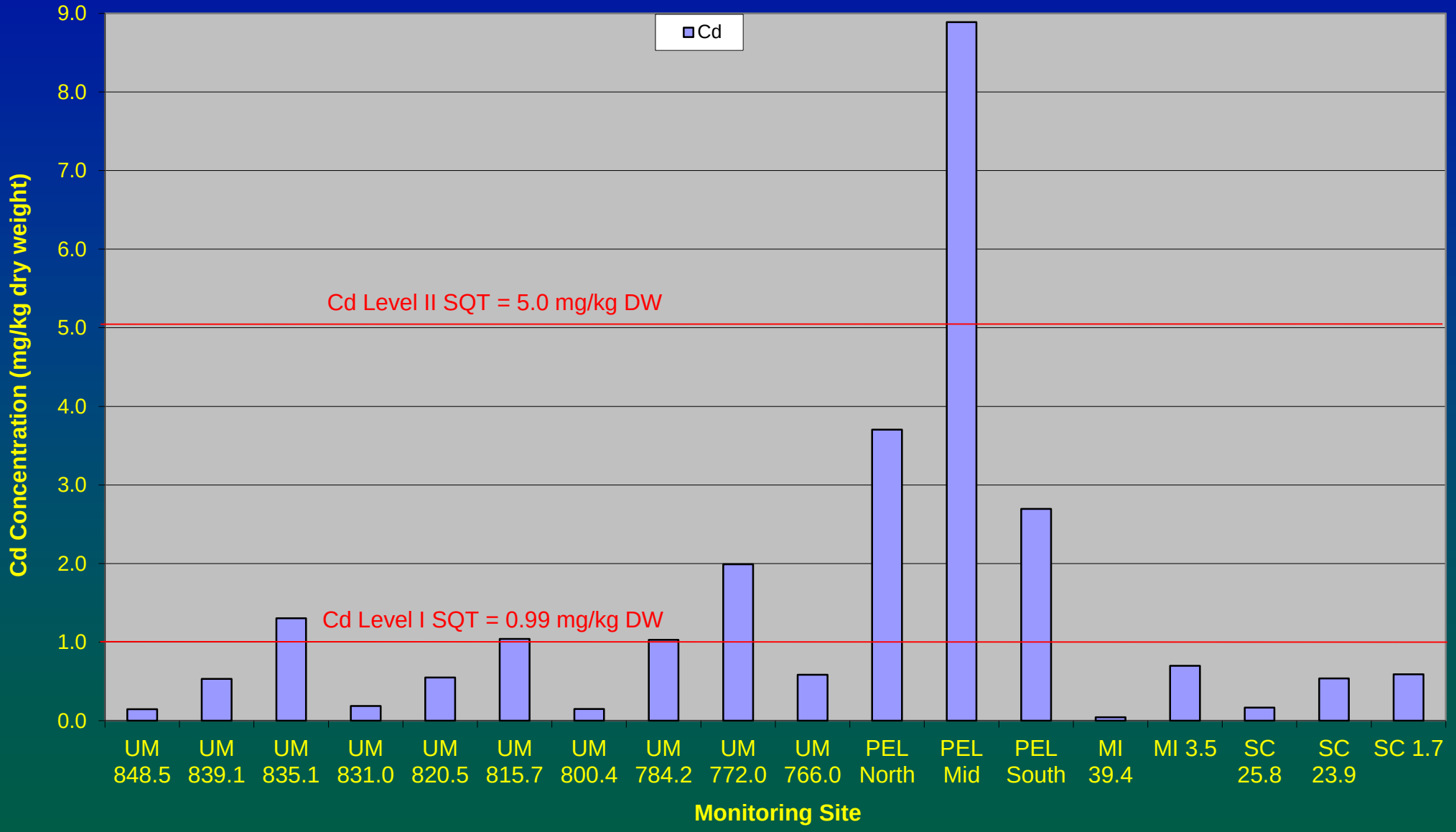
Sources of Trace Metals in the Environment

- Cadmium (Cd): Batteries, pigments, coating and electroplating, plastics
- Copper (Cu): Electronics, household products (plumbing, roofing, cookware), biomedical products, pesticides
- Lead (Pb): Batteries, ceramic glazes and glass, ammunition, fishing tackle, electronics (solder), gasoline (until 1973), paint (until 1978)
- Mercury (Hg): Coal-fired power plants (40%), industrial processes (steel and metal production), municipal waste incineration, medical applications (dentistry and vaccines), batteries, light bulbs (fluorescent and CFL), thermometers

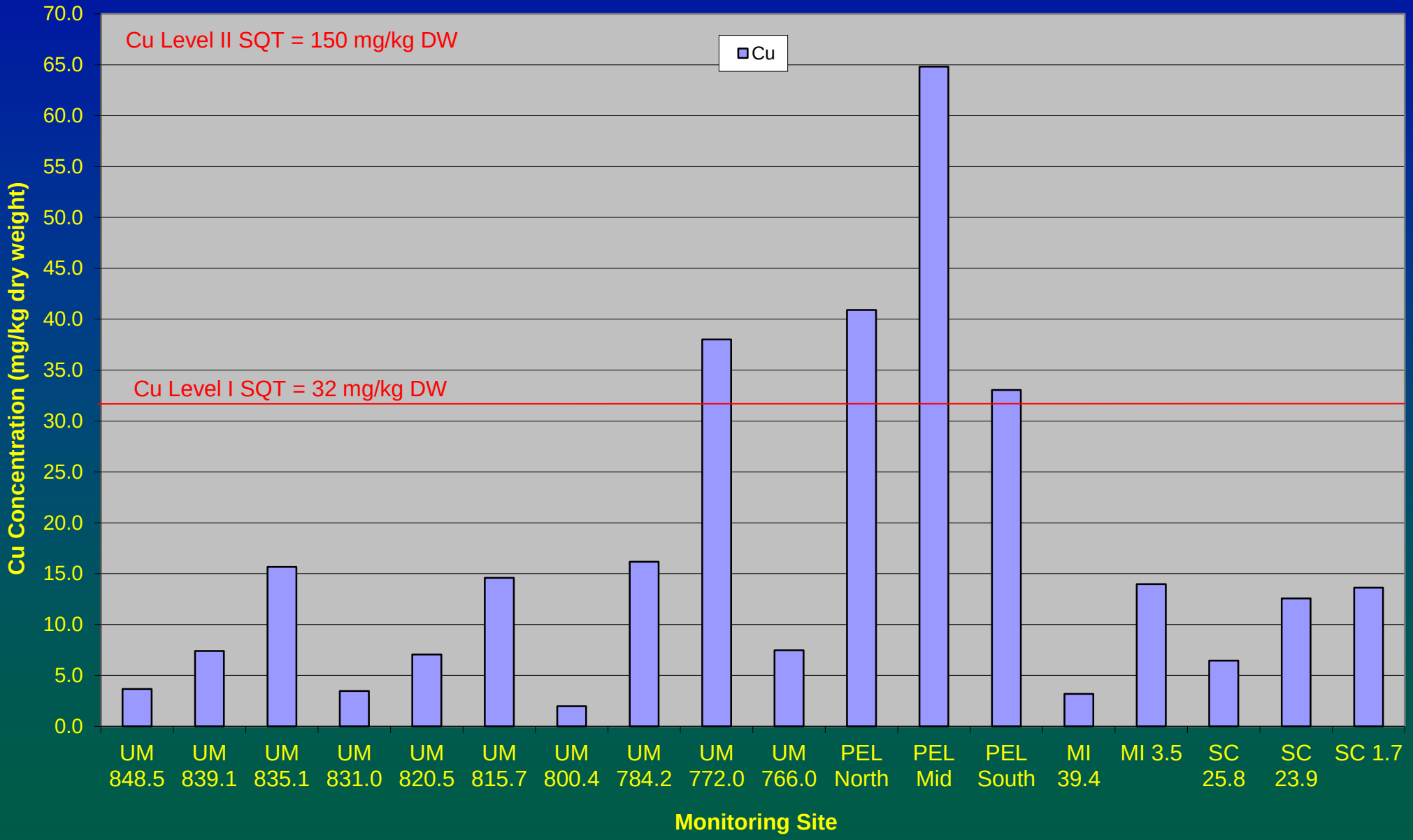
Sediment Quality Targets (SQTs)
Established by the Minnesota Pollution Control Agency

- Level I Sediment Quality Targets (SQTs) identify contaminant concentrations below which harmful effects on sediment-dwelling organisms (benthic macroinvertebrates) are unlikely to be observed
- Level II Sediment Quality Targets (SQTs) identify contaminant concentrations above which harmful effects on sediment-dwelling organisms (benthic macroinvertebrates) are likely to be observed

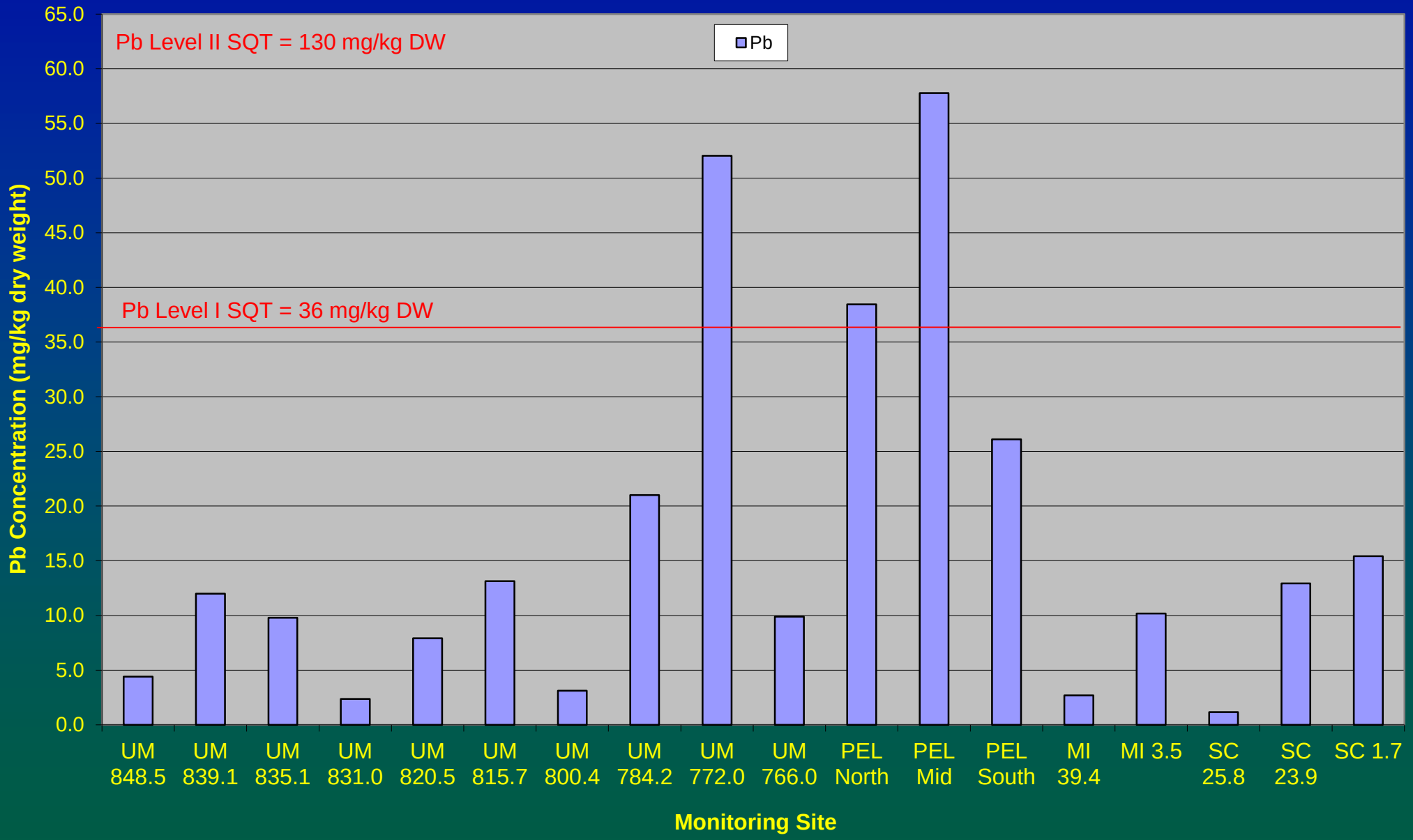
Cd Concentrations in Mississippi, Minnesota, and St. Croix River Sediments: 1998-2001 Survey



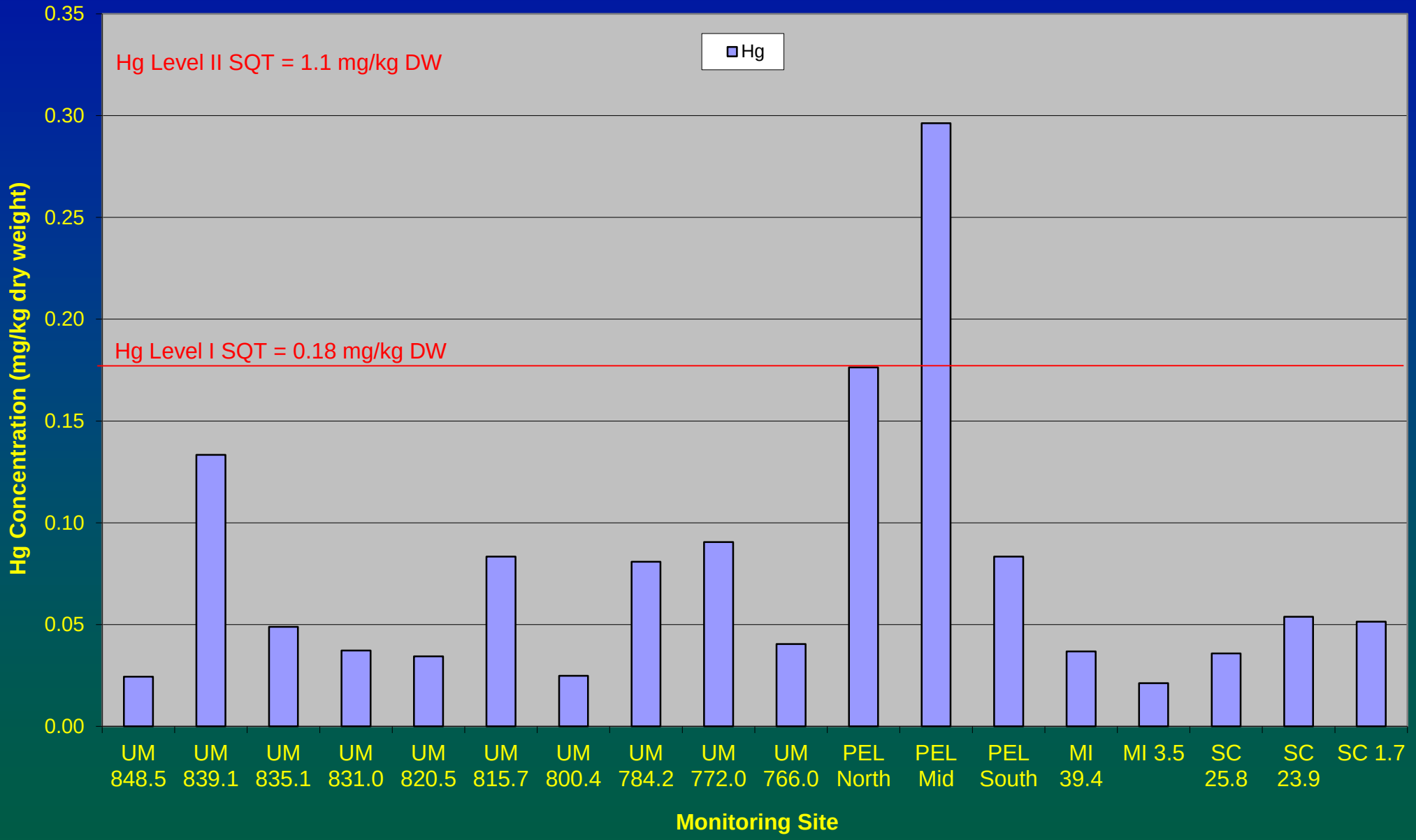
Cu Concentrations in Mississippi, Minnesota, and St. Croix River Sediments: 1998-2001 Survey



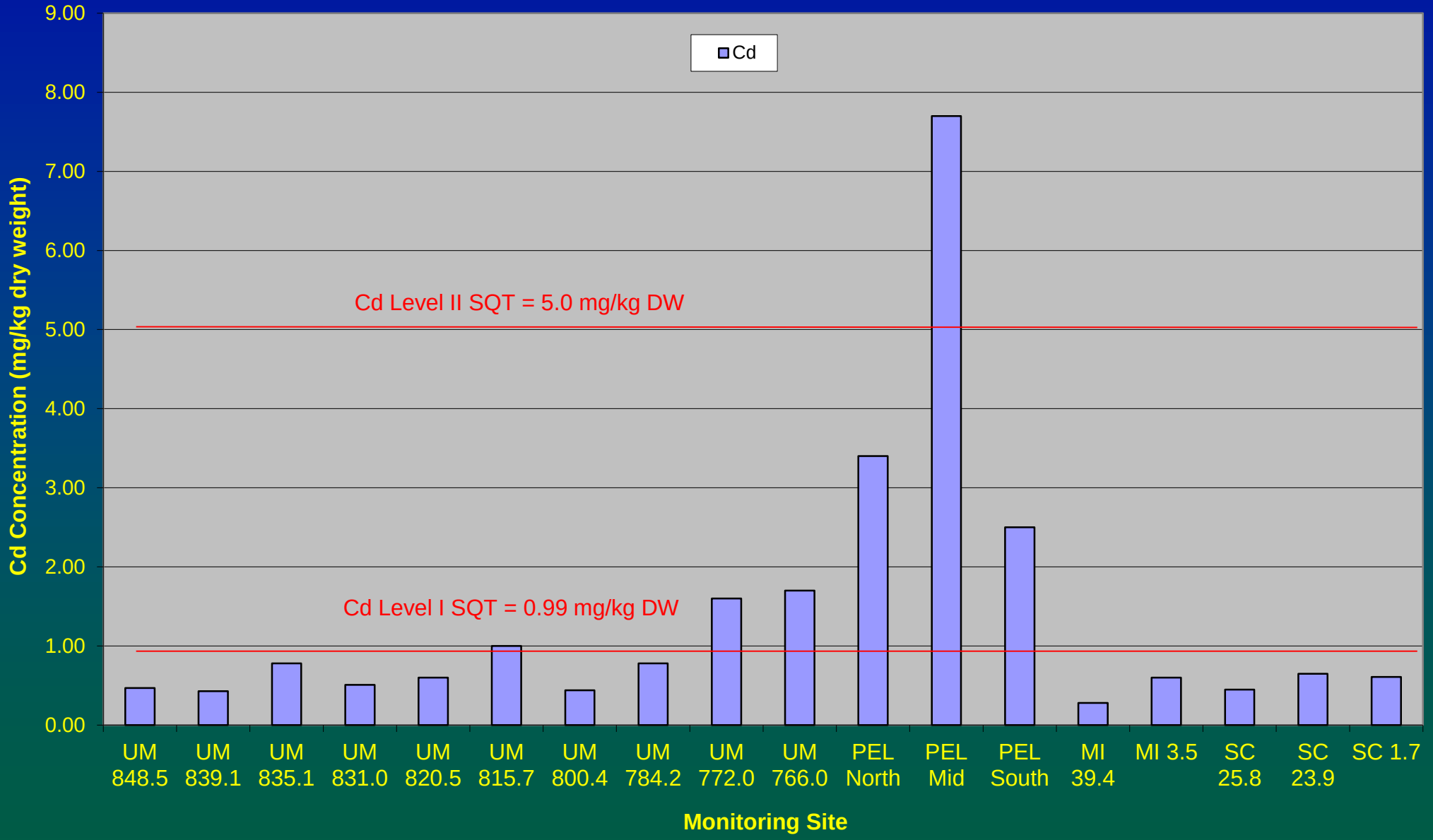
Pb Concentrations in Mississippi, Minnesota, and St. Croix River Sediments: 1998-2001 Survey



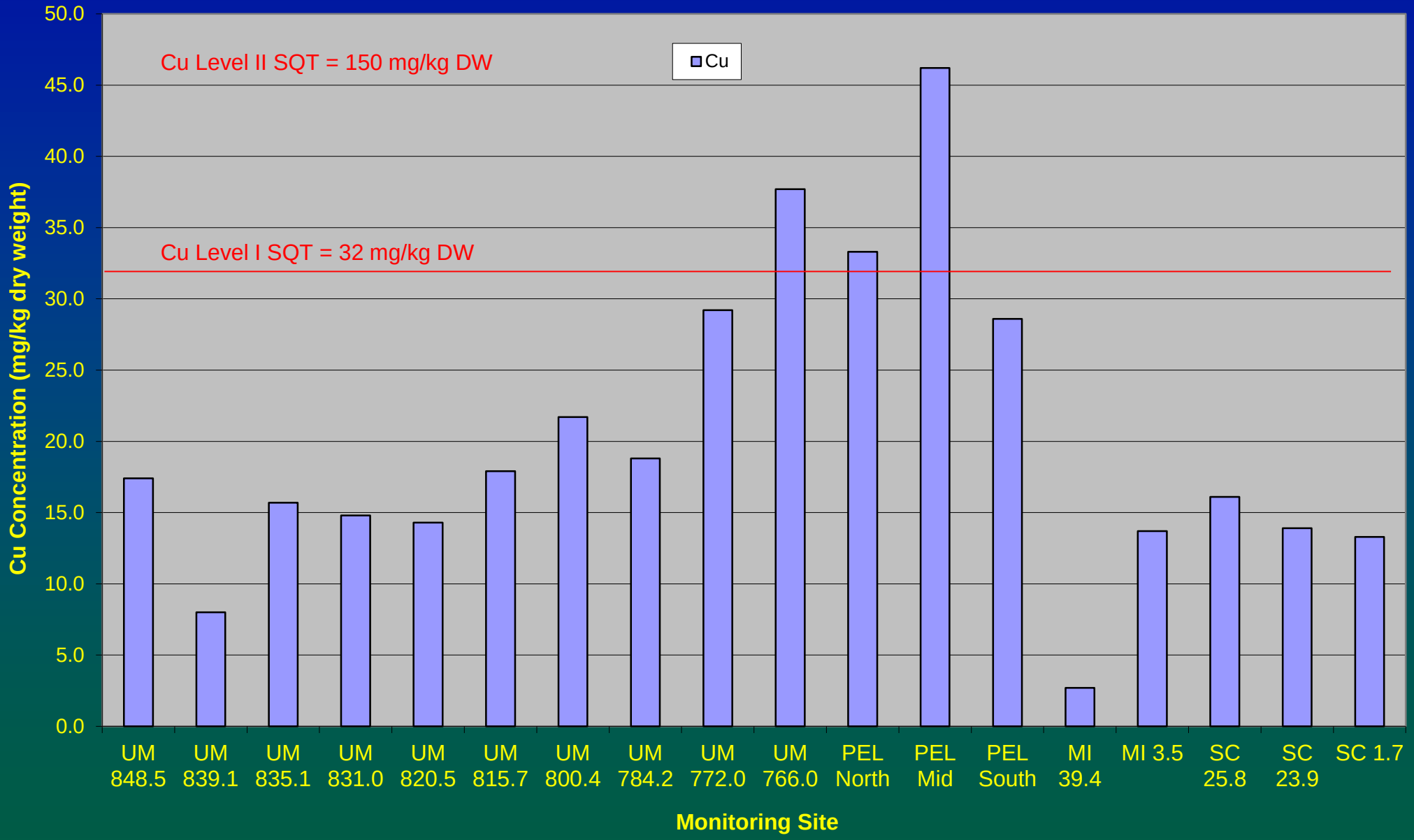
Hg Concentrations in Mississippi, Minnesota, and St. Croix River Sediments: 1998-2001 Survey



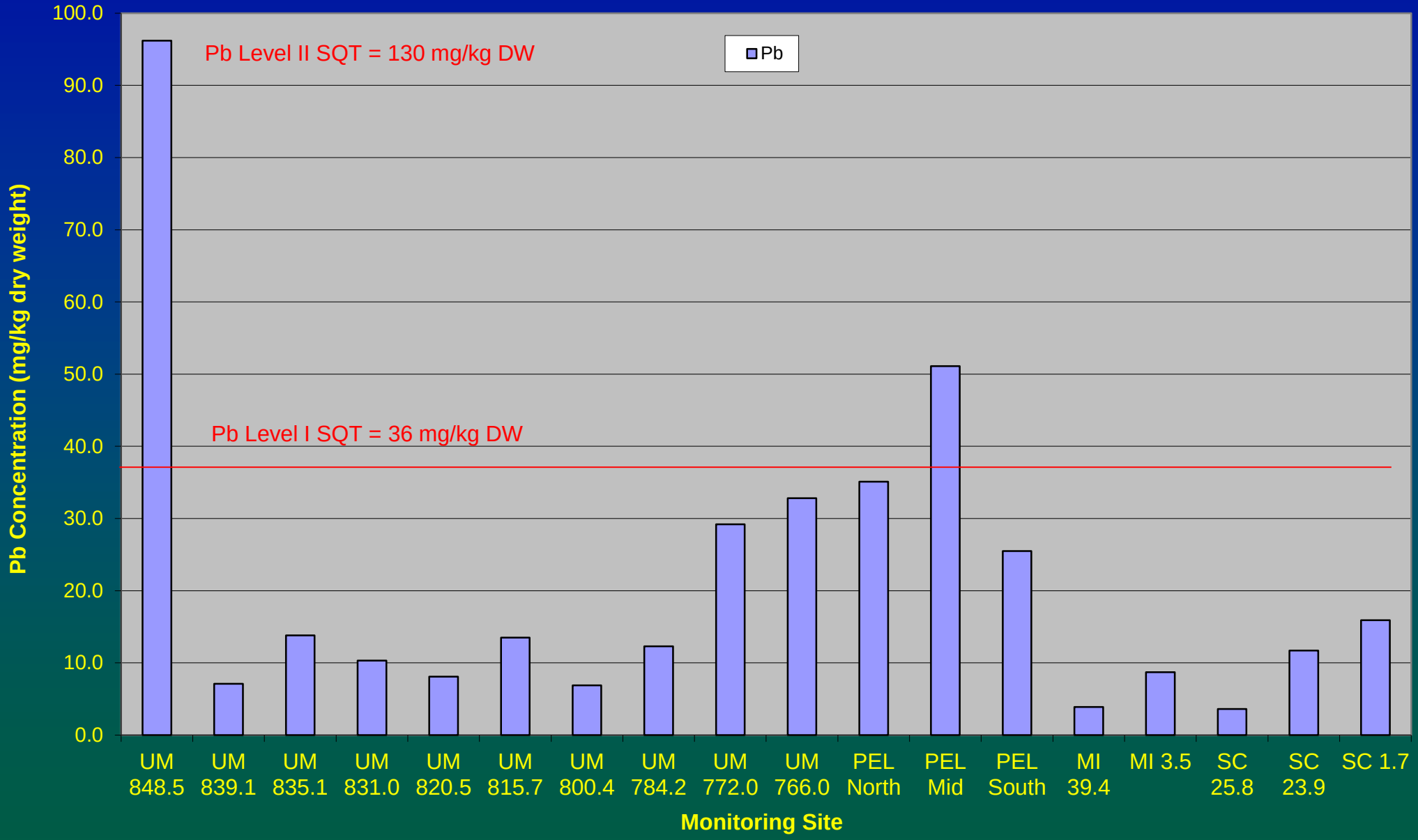
Cd Concentrations in Mississippi, Minnesota, and St. Croix River Fine-Grained Sediments (<0.18 mm): 1998-2001 Survey



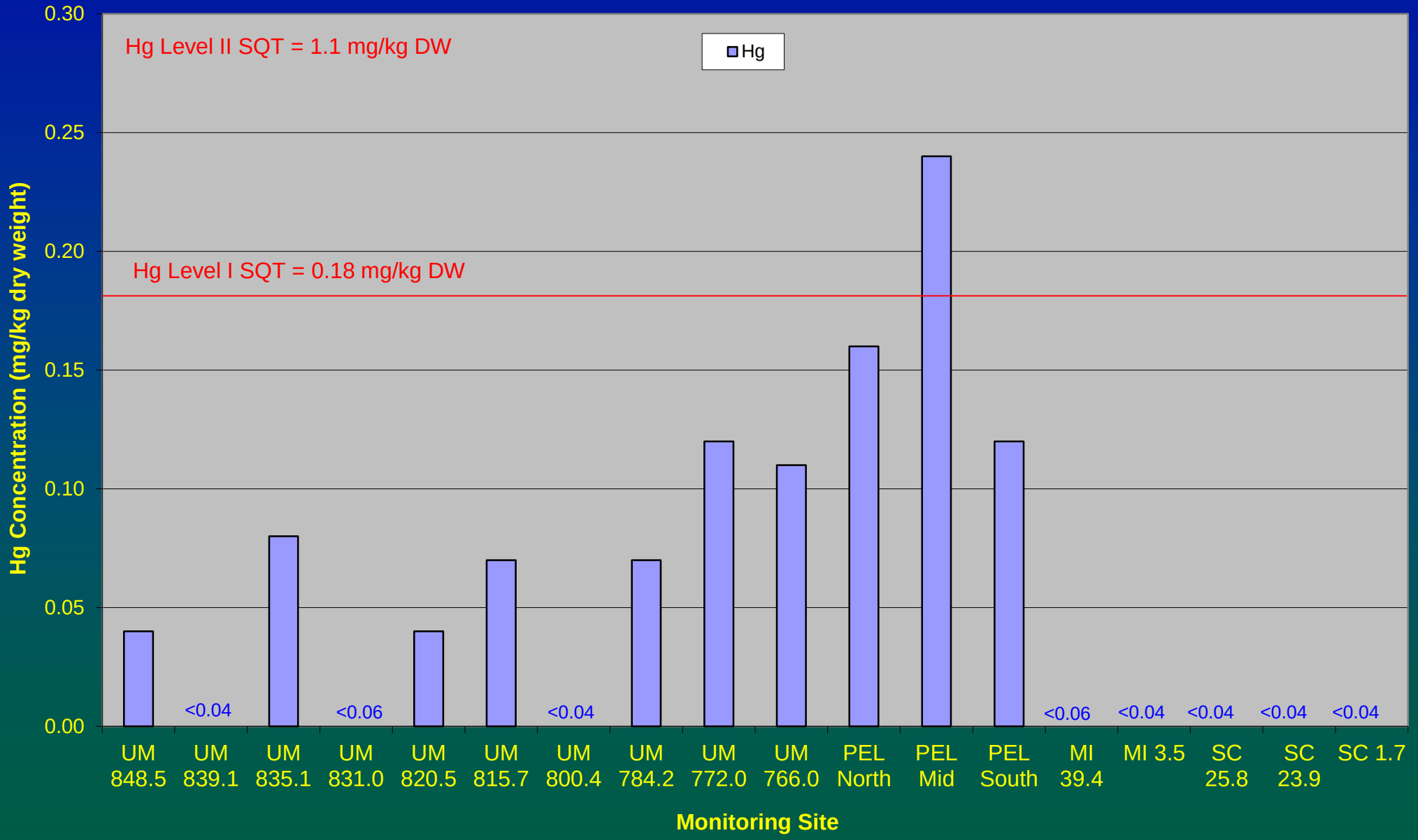
Cu Concentrations in Mississippi, Minnesota, and St. Croix River Fine-Grained Sediments (<0.18 mm): 1998-2001 Survey



Pb Concentrations in Mississippi, Minnesota, and St. Croix River Fine-Grained Sediments (<0.18 mm): 1998-2001 Survey



Hg Concentrations in Mississippi, Minnesota, and St. Croix River Fine-Grained Sediments (<0.18 mm): 1998-2001 Survey



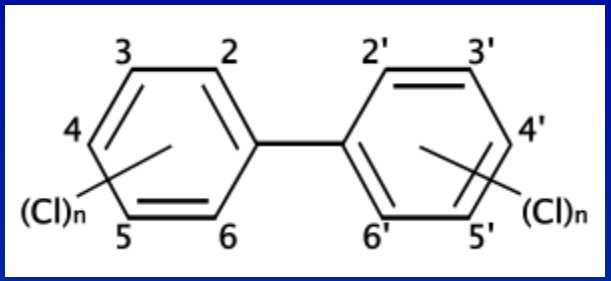
Conclusions: Trace Metals Analysis - Bulk Sediment

- Bulk Sediment: 24 exceedances of Level I SQTs:
  1 at UM 835.1 (Cd)
  1 at UM 815.7 (Cd)
  1 at UM 784.2 (Cd)
  6 at UM 772.0 in Lake Pepin (Cd, Cr, Cu, Ni, Pb, Zn)
  5 at PEL North (Cd, Cu, Hg, Pb, Zn)
  7 at PEL Mid (Cd, Cr, Cu, Hg, Ni, Pb, Zn)
  3 at PEL South (Cd, Cu, Ni)
- Bulk Sediment: 2 exceedances of Level II SQTs:
  1 at UM 772.0 in Lake Pepin (Ni)
  1 at PEL Mid (Cd)

Conclusions: Trace Metals Analysis - Fine-grained Sediment and Pore Water

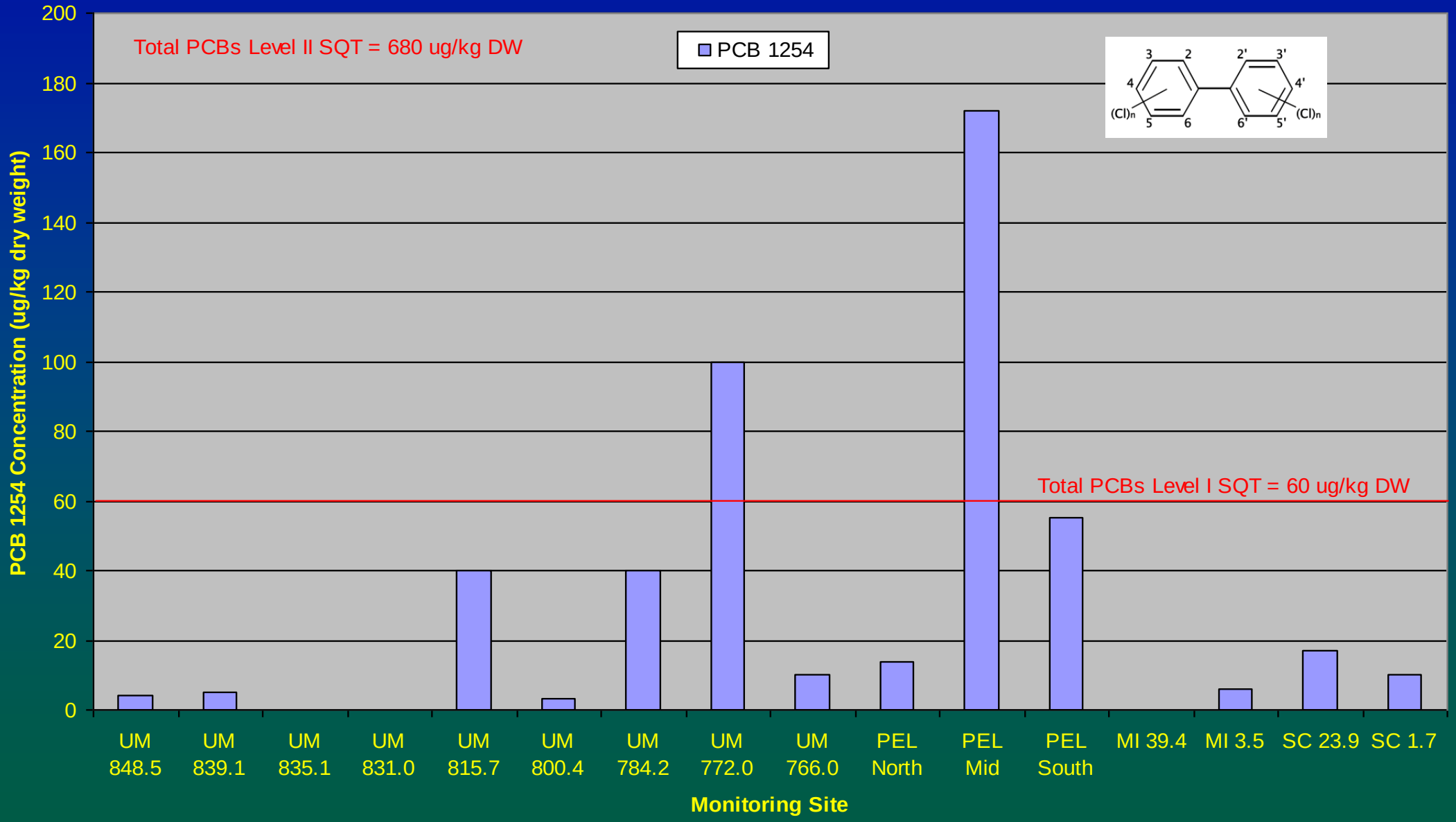
- Fine-grained Sediment: 18 exceedances of Level I SQTs:
  1 at UM 848.5 (Pb)
  1 at UM 815.7 (Cd)
  2 at UM 766.0 in Lake Pepin (Cd, Cu)
  3 at UM 772.0 in Lake Pepin (Cd, Ni, Zn)
  3 at PEL North (Cd, Cu, Zn)
  7 at PEL Mid (Cd, Cr, Cu, Hg, Ni, Pb, Zn)
  1 at PEL South (Cd)
- Fine-grained Sediment: 1 exceedance of Level II SQT:
  1 at PEL Mid (Cd)
- Pore Water: No exceedances of chronic and/or maximum WQ standards

Sources of PCB in the Environment

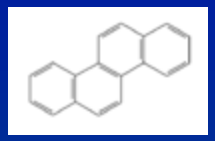


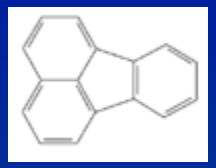
- General chemical formula: $C_{12}H_{10-x}Cl_x$
- 7 Aroclors and 209 Congeners
- Very stable compounds; bioaccumulative; carcinogenic
- Uses: Transformers and capacitors; hydraulic fluids; lubricating and cutting oils; pesticides; paints; carbonless copy paper; adhesives; sealants; plastics
- Domestic production banned in 1977
- Large quantities have been landfilled

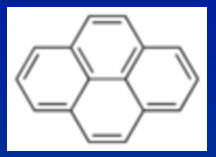
PCB 1254 Concentrations in Mississippi, Minnesota, and St. Croix River Sediments: 1998-2001 Survey



Sources of PAH Compounds in the Environment

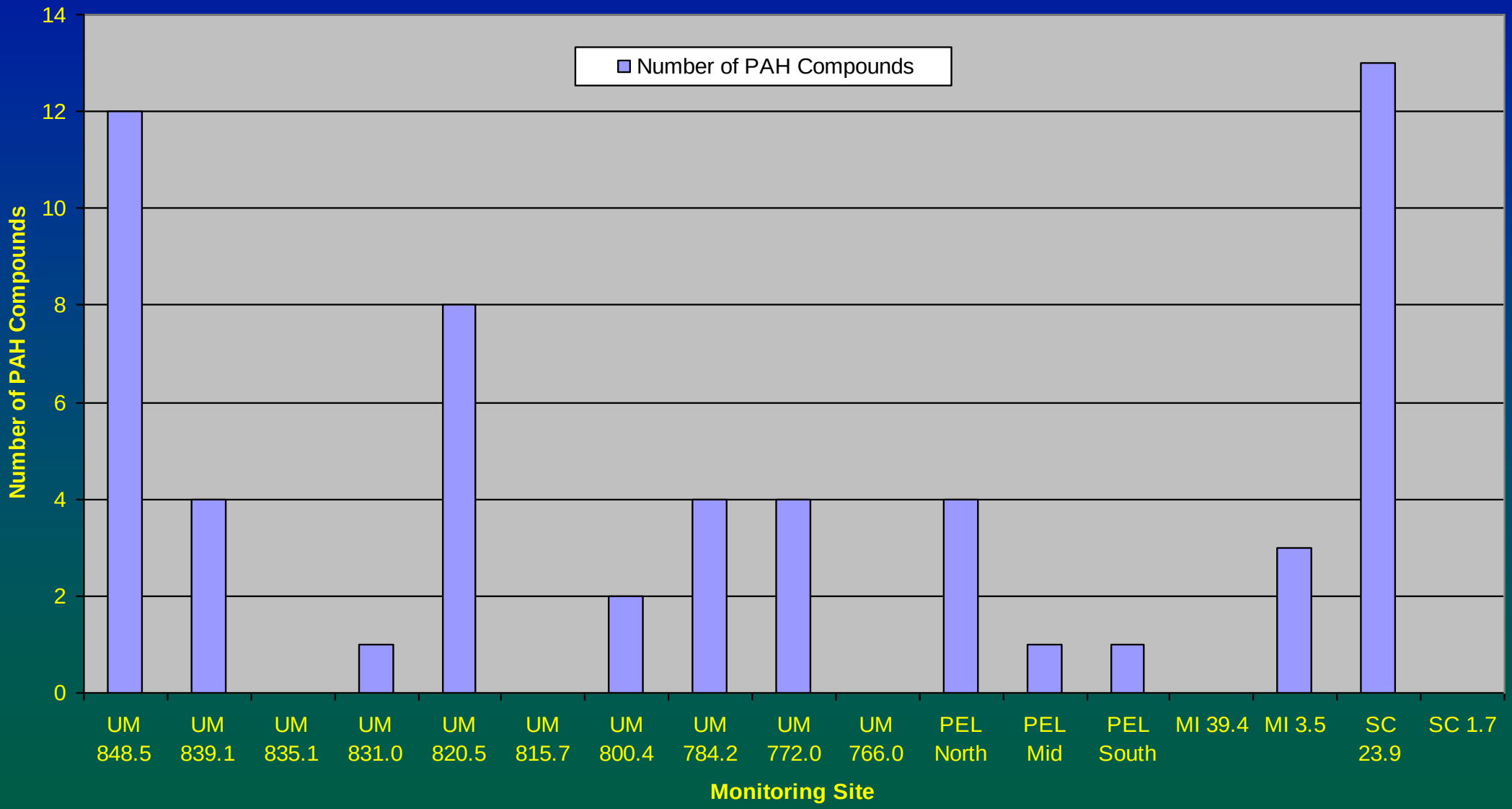
Chrysene 

Fluoranthene 

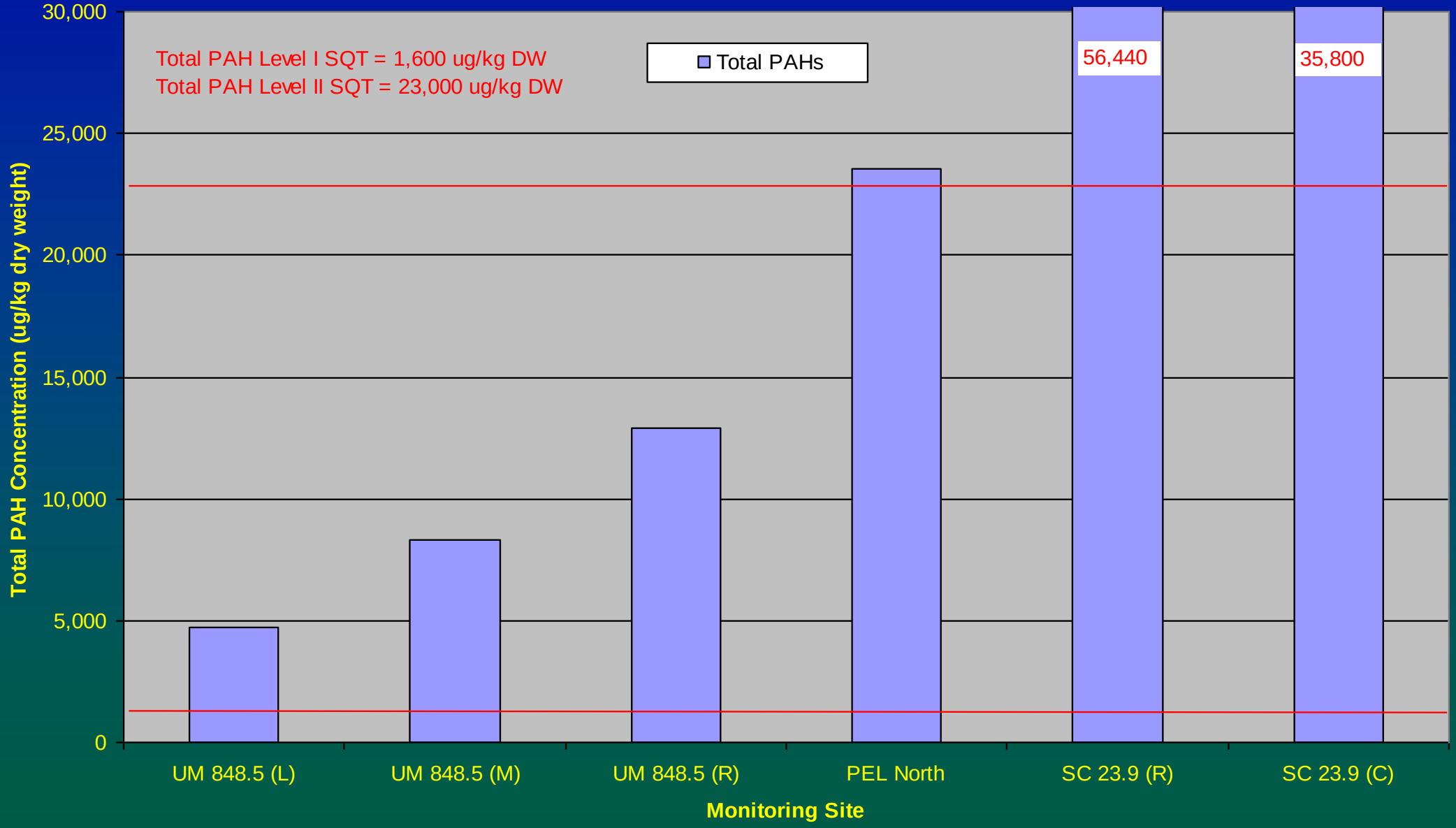
Pyrene 

- Chemical compounds with fused aromatic rings (3-7)
- Formed by incomplete combustion of fossil fuels
- Sources: Wood; coal; oil; gasoline; diesel; tar; fat; tobacco
- One of the most widespread organic pollutants
- Both point sources (oil spills) and non-point sources (atmospheric deposition)
- Some PAHs are known or suspected carcinogens; toxicity is structurally-dependent (based on the isomer)

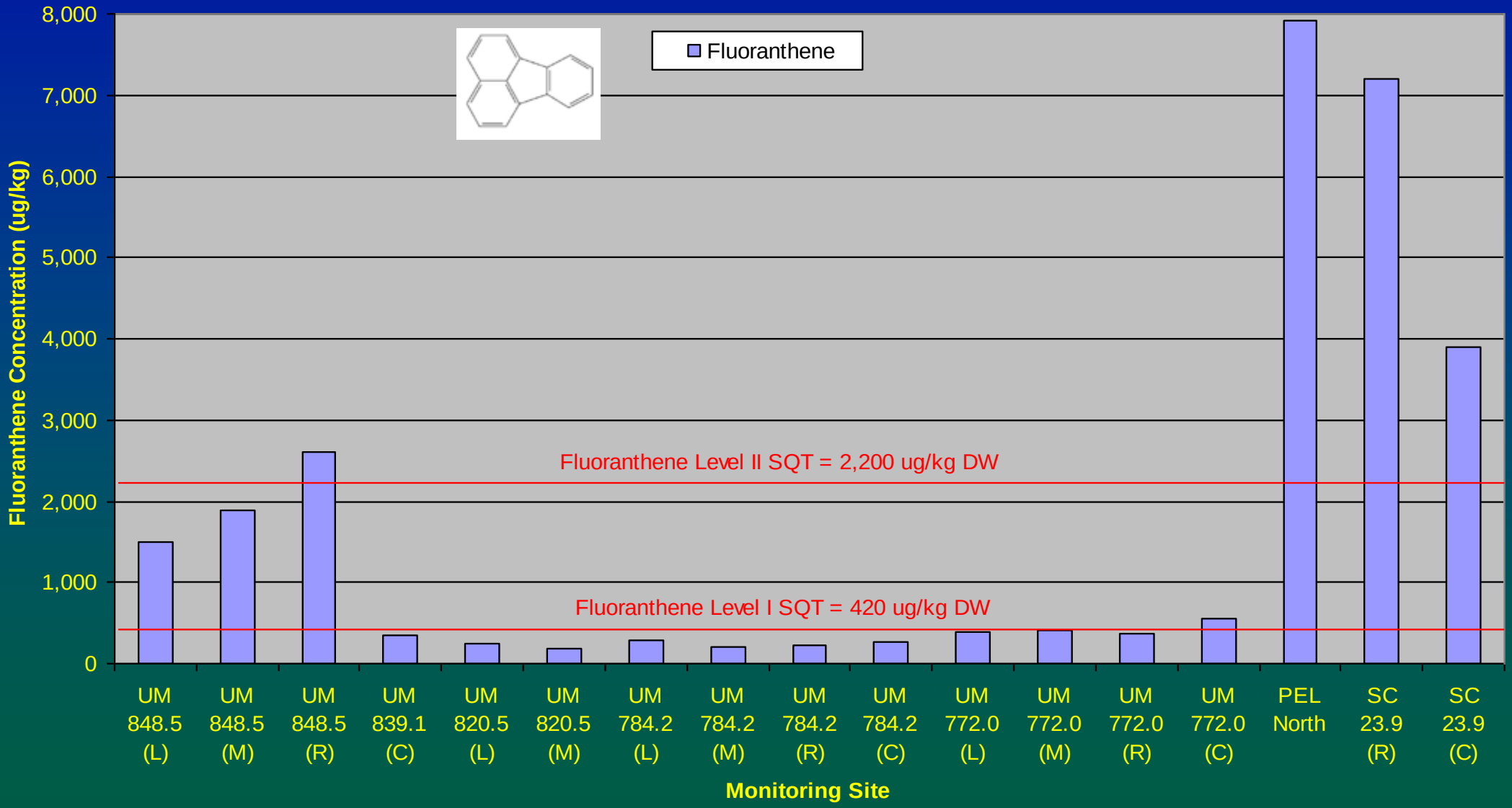
Number of PAH Compounds Detected in Mississippi, Minnesota, and St. Croix River Sediments: 1998-2001 Survey



Mississippi, Minnesota, and St. Croix River Monitoring Sites with Sediment Total PAH Concentrations Exceeding Level I and II SQTs: 1998-2001 Survey



Fluoranthene Concentrations in Mississippi, Minnesota, and St. Croix River Sediments: 1998-2001 Survey



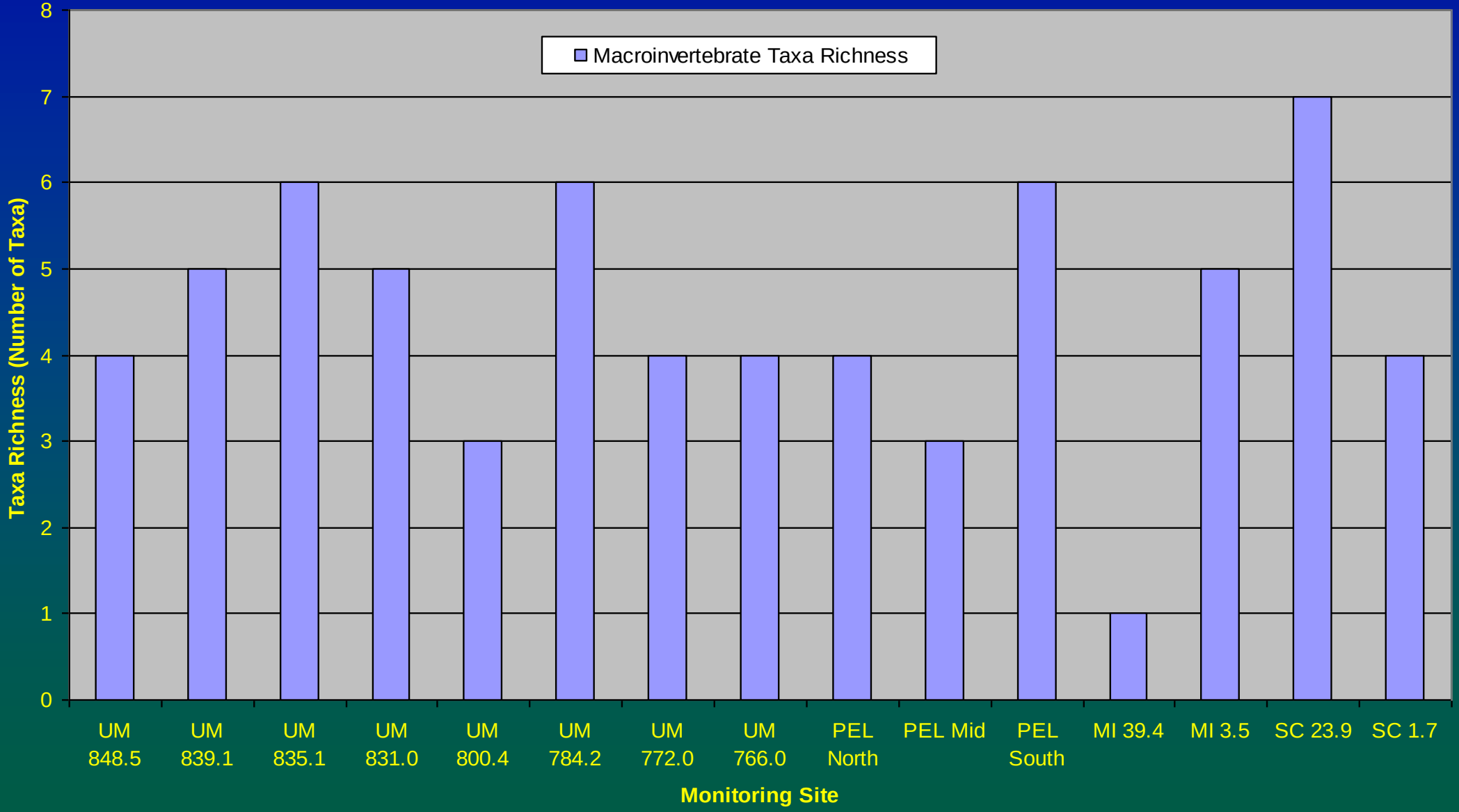
Conclusions: PAH Analysis

- Monitoring sites with the highest numbers of sediment PAH compounds include UM 848.5 (12), UM 820.5 (8), and SC 23.9 (13), reflecting storm water, industrial, and recreational impacts, respectively
- Total PAH concentrations were highest at UM 848.5, PEL North, and SC 23.9
- Total PAH Level I SQT exceedances occurred at 3 sites (UM 848.5; PEL North; SC 23.9)
- Total PAH Level II SQT exceedances occurred at 2 sites (PEL North; SC 23.9)
- Multiple exceedances of Level I SQTs for individual PAH compounds occurred at UM 848.5 (9), UM 839.1 (2), UM 820.5 (2), PEL North (3), and SC 23.9 (8)
- Multiple exceedances of Level II SQTs for individual PAH compounds occurred at UM 848.5 (5), PEL North (3), and SC 23.9 (8)

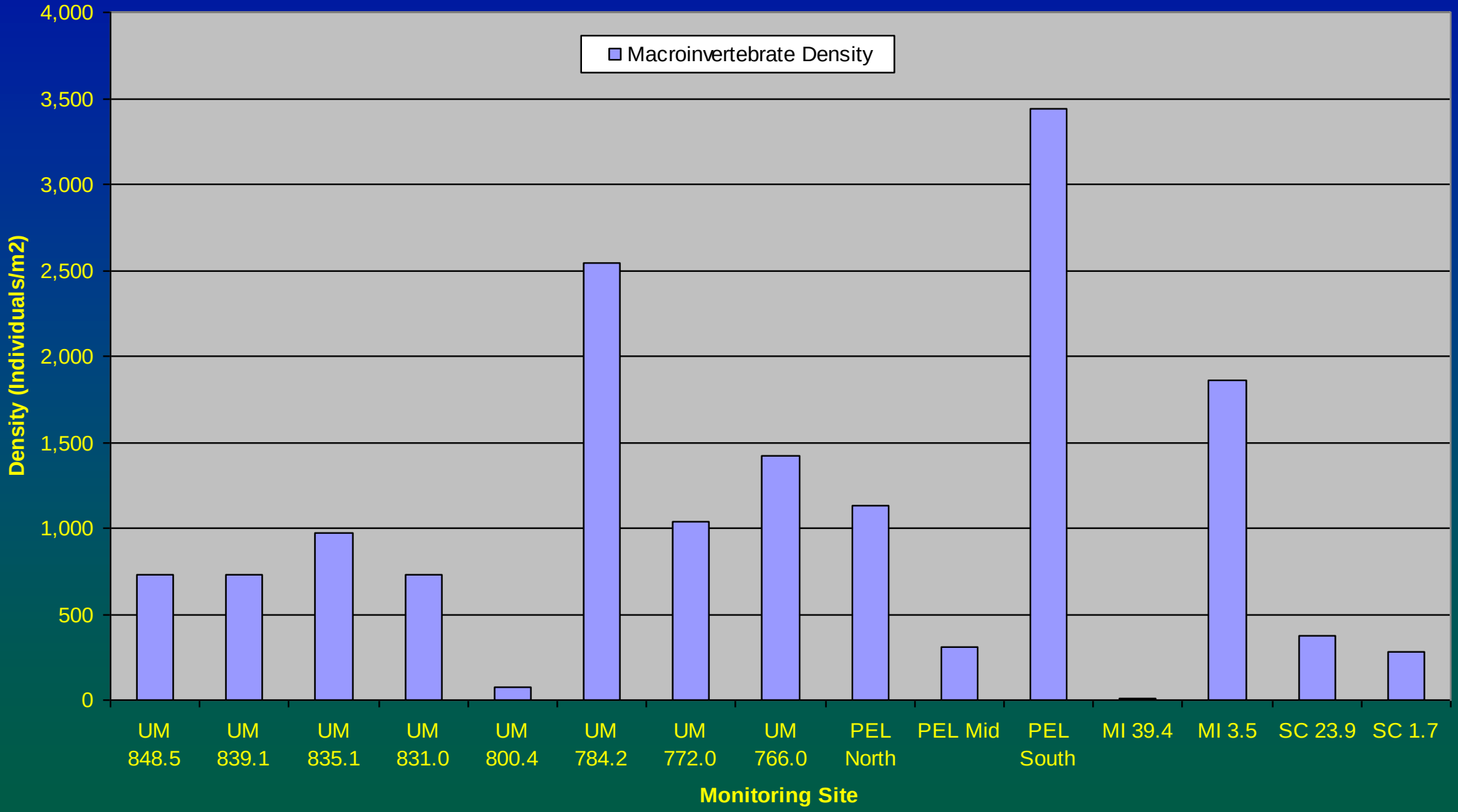
Benthic Macroinvertebrates

- Benthic = Bottom-dwelling; Macro = Visible to naked eye; Invertebrate = Animal without backbone
- Examples: Aquatic Insects (Mayflies, Stoneflies, Caddisflies, Midges; Black Flies); Oligochaetes; Clams; Snails
- Important part of the aquatic food chain (especially food for fish)
- Spend significant portions of their life cyles in the water, making them excellent indicators of water quality
- Wide range of sensitivity to stressors such as organic pollutants and contaminants
- Mayflies, stoneflies, and caddisflies are generally pollution-intolerant
- Midges and aquatic worms are generally pollution-tolerant

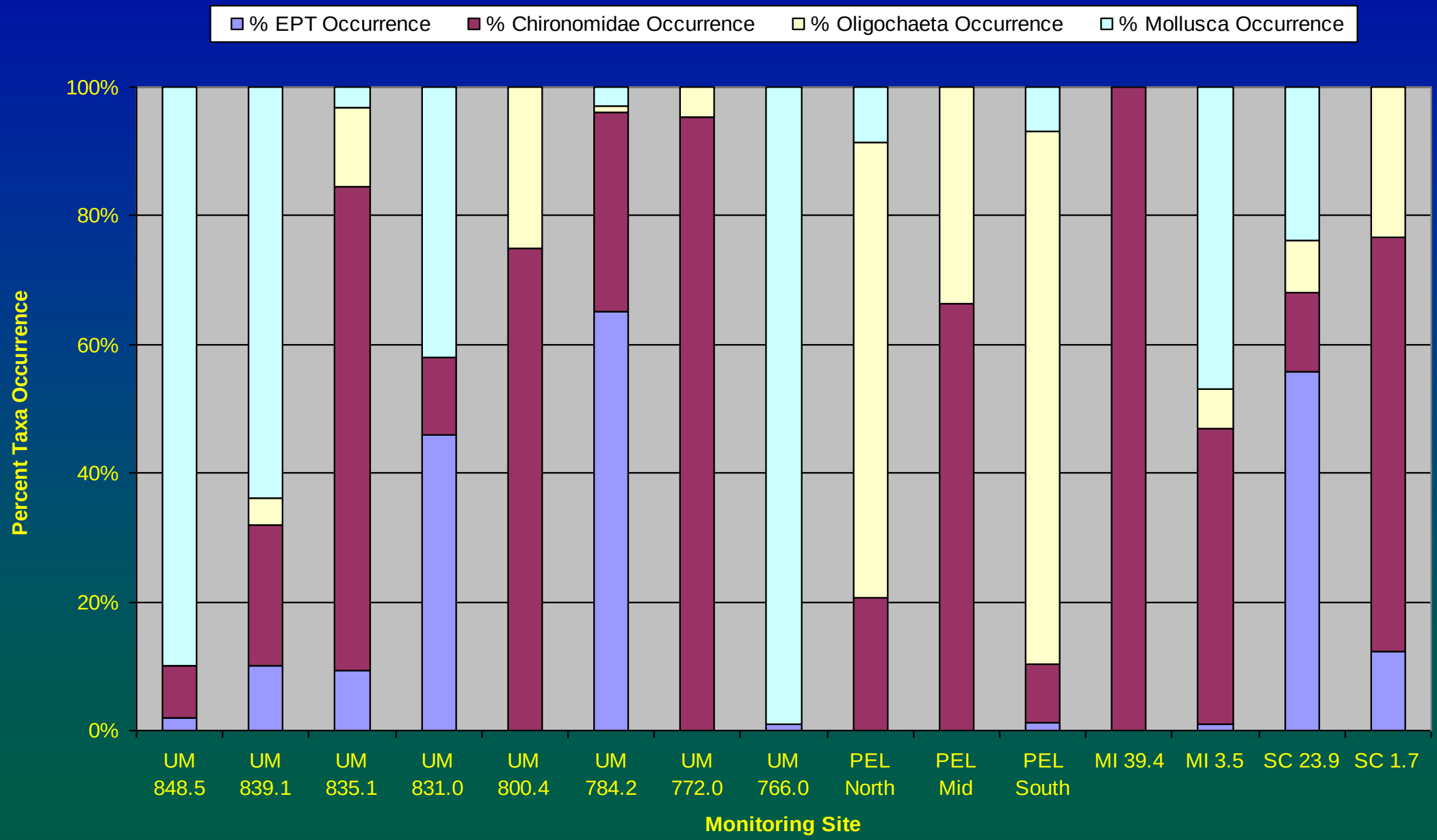
Macroinvertebrate Taxa Richness at MCES Sediment Monitoring Sites: 1998-2001 Survey



Macroinvertebrate Density at MCES Sediment Monitoring Sites: 1998-2001 Survey



Percent Occurrence of Major Macroinvertebrate Taxa at MCES Sediment Monitoring Sites: 1998-2001 Survey



Conclusions: Benthic Macroinvertebrate Analysis

- Taxa richness (diversity) is generally low at all sites (only 1-7 taxa), primarily due to habitat type, but sediment contaminants may reduce diversity at some locations
- Highest densities are found in Lake Pepin, PEL North and South, and MI 3.5, possibly due to the greater presence of fine-grained sediments
- Change in dominant taxa across Lake Pepin: mayflies (64%) at UM 784.2; midges (83%) at UM 772.0; zebra mussels (99%) at UM 766.0
- Contaminant-related impacts at UM 772.0 (reduced taxa richness and density; dominated by midges)
- Contaminant-related impacts at PEL Mid (reduced taxa richness and density; dominated by midges)

Results: Sediment Toxicity-Testing

- Bed Sediment Toxicity-Testing:
  Significant reductions in Hyalella azteca survival at MI 39.4 and PEL Mid
  Significant reductions in Chironomus tentans survival at UM 772.0, UM 839.1, and SC 23.9
  No significant reductions in Chironomus tentans weight
- Sediment Pore Water Toxicity-Testing
  No significant reduction in Ceriodaphnia dubia survival

Chemical and Biological Impacts of Mississippi, Minnesota, and St. Croix River Bed Sediments: 1998-2001 Survey Sediment Impact Matrix

Assessment Tool	Monitoring Site																	
	UM 848.5	UM 839.1	UM 835.1	UM 831.0	UM 820.5	UM 815.7	UM 800.4	UM 784.2	UM 772.0	UM 766.0	PEL North	PEL Mid	PEL South	MI 39.4	MI 3.5	SC 25.8	SC 23.9	SC 1.7
BS-TM-SQTI			Cd			Cd		Cd	Cd,Cr,Cu,Pb,Ni,Zn		Cd,Cu,Hg,Pb,Zn	Cd,Cr,Cu,Pb,Hg,Ni,Zn	Cd,Cu,Ni					
BS-TM-SQTII									**Ni**			**Cd**						
FGS-TM-SQTI	Pb					Cd			Cd,Ni,Zn	Cd,Cu	Cd,Cu,Zn	Cd,Cr,Cu,Pb,Hg,Ni,Zn	Cd					
FGS-TM-SQTII												**Cd**						
PW-TM-CS																		
PW-TM-MS																		
BS-PCB-SQTI									PCB			PCB						
BS-PCB-SQTII																		
BS-PAH-SQTI	T+9 I	2 I			2 I			1 I	1I		T+3I						T+8I	
BS-PAH-SQTII	**5I**										**T+3I**						**T+8I**	
BS-MAC-R									R			R						
BS-MAC-D									R			R						
BS-TT-HAS												**R**		**R**				
BS-TT-CTS		**R**							**R**								**R**	
BS-TT-CTG																		
PW-TT-CDS																		
Total Impacts	3	2	1		1	2		2	8	1	4	8	2	1			3	
Critical Impacts	1	1							2		1	3		1			2	

Conclusions: 1998-2001 Sediment Survey

The Sediment Quality Triad Approach Revealed:

- Sediment quality in the Mississippi, Minnesota, and St. Croix Rivers is generally good, with minimal impacts on aquatic life
- Level I SQTs for trace metals and/or PAHs are exceeded at all sites except UM 831.0, UM 800.4, MI 39.4, MI 3.5, and SC 1.7
- Macroinvertebrate richness is reduced at many sites, but likely due to habitat limitation and/or grain size effects
- Reductions in macroinvertebrate richness and density in Lake Pepin (UM 772.0) and PEL (Mid) may be contaminant-related
- Based upon Level II SQT exceedances and sediment toxicity, critical impacts were apparent near urbanized areas (UM 848.5 and UM 839.1), in Lake Pepin (UM 772.0) and PEL (North and Mid), in the Minnesota River (MI 39.4), and in the St. Croix River (SC 23.9)

Pig's Eye Dump

- Located in Mississippi River floodplain, east of St. Paul, MN
- Operated from 1956-1972 on 250-acre site, accepting 8.3 million cubic yards of municipal and industrial waste (east Metro Area)
- 1977-1985: 236,000 cubic yards of MWCC sewage sludge ash placed on top of old garbage (solid waste permit issued by MPCA)
- Placed on MPCA Superfund list in 1989
- Contaminants: Cd, Pb, Hg (batteries, paint, tires); PCBs and solvents (drums sampled in 1999); cyanide; DDT
- Contaminants transported to Pig's Eye Lake via Battle Creek, runoff, and groundwater
- Remedial action plan prepared by St. Paul and submitted to MPCA in 1999
- Phase I and II site remediation in 2002-2004 ($5.7 M): 90,000 cy of waste relocated; 440,000 cy of fill/cover placed; 400 drums removed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