COMPARATIVE TOXICITY OF IMPOUNDED SEDIMENTS IN NEW ENGLAND

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ABSTRACT

Information presented in this report is the final documentation of an examination of the comparative toxicity of impounded sediments from a limited survey level sampling of hydropower and other dam facilities in New England. To assess the potential for accumulated contaminants, a Microtox solid phase bioassay was used to test hydropower project sediments. Eleven of the forty seven tested sites showed high to severe relative toxicity. Eighteen sites showed an intermediate relative toxicity. These results imply that some reservoirs might be impacting fish and wildlife.

PREFACE

Questions, comments, and suggestions related to this report are encouraged. Written inquiries should refer to the Comparative Toxicity of Impoundment Sediments in New England report and can be directed to the following address:

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INTRODUCTION

The incidence of retention of contaminants upstream of impoundment facilities has been a growing concern. The damming of streams often leads to the interruption of sediment transport. Waterborne contaminants, traveling downstream, may also collect within impoundment sediments. In order to gain a better understanding of this issue, of accumulated toxins, this project sought quantitative data on the relative toxicity of dam sediments. We examined the comparative toxicity of impounded sediments from a limited survey level sampling of dam facilities in New England.

The majority of the tested sites are hydropower facilities. This focus is due to the ensuing concern that hydropower facilities create, by far, some of the largest impacts on riparian habitats throughout New England. Concern focuses on the continued detrimental effects of dams upon water quality, river flows, fish migration, sediment loading, erosion, wetlands, and resident wildlife. The potential for the accumulation of toxic sediments is especially important in the review of hydropower dam alterations or removal as viable alternatives in dam relicensing proceedings of the Federal Energy Regulatory Commission (FERC).

The hydro relicensing process and relicensing procedures on new projects could assess the incidence of concentrated toxic materials within accumulated sediments and responsibility for any accumulation. The possibility that contaminants exist at toxic levels in dam impoundment sediments may effect proposals of dam repair, alteration or removal as part of these proceedings. Conversely, disturbance causing the reintroduction of potentially toxic sediments into the water column may adversely affect water quality and impact downstream riparian ecosystems.

Sediment samples are useful in assessing chemical and physical properties of an aquatic environment. Toxic sediments can serve as a source and a pathway for further contamination. Numerous aquatic organisms ingest sediments which allows for the continued transport and possible bio-accumulation of sediment bound contaminants (Audet et al 1994).

The use of bioassay techniques to determine relative toxicity is an useful method to determine possible contamination of sediments (EPA 1983). This is important given that testing for unknown toxins is problematic due to the vast numbers of potential chemicals in the environment (Baudo et al 1994). Bioassays utilizing bioluminescent bacteria to indicate relative toxicity levels have attracted increasing attention. The bioassessment of sediments in Halifax Harbor (Tay et al 1992) supports the validity of the solid-phase bioassay over a range of sediments.

In this screening level study, a marine bacterium was utilized as part of a solid-phase bioassay to test for toxicity of collected sediments. We sampled from a broad survey of hydropower sites across New England. Impoundments sediments were tested for relative toxicity. We hoped to determine whether there was a problem in the first place. We also determined possible need for additional investigation.

STUDY OBJECTIVES

The primary objectives of the cooperative study were to conduct a broad spectrum survey of impoundment sediments and determine their relative toxicity; determine possible relationships between substrate and relative toxicity; and determine the possible need for additional exploration of this issue

MATERIALS AND METHODS

Study Area:

Samples were gathered from 47 sites throughout New England (FIGURE 1). Our primary dam sites were chosen from hydropower facilities that are scheduled to comply with upcoming Federal Energy Regulatory Commission relicensing processes or have proposed to have a new hydro facility. Fish and wildlife concerns at these sites include anadromous fish habitat and passage, endangered and threatened species, contaminants, stream flow, wetlands, and other water quality issues. The secondary sites were chosen due to their proximity to primary sites and similar relicensing schedules or environmental concerns.

Collection of Samples:

Our protocol for sampling included the use of a small Ponar dredge sampler, and chemically clean, clear glass jars with teflon-lined caps for sample containment. A non-metal boat was used to minimize sources of contamination. Sampling equipment was decontaminated immediately prior to use and between each sampling location. The decontamination protocol of sampling apparatus was conducted as per Coeur d'Alene standard operating procedures (Burch 1993). Samples consisted of a composite composed of at least three grabs from the top 10-30 centimeters of substrate. A stainless-steel bucket and scoop were used to hold and mix sediments prior to containment. Sample jars were labeled with location information and packed in ice-filled coolers to preserve sample integrity during transport to the laboratory facility.

A Global Positioning System (GPS) unit was used to ascertain exact dam site and sampling locations. Protocol for GPS generation of longitudes and latitudes was conducted as per Trimble Navigation (1991).

Sediment Analysis:

Sediment samples were tested for their relative toxicity. A Microbics' Microtox bioassay utilized bioluminescent bacteria, *Photobacterium phosphoreum*, to directly test serially diluted sediment concentrations and measure their relative toxicity. A photometer measured the amount of light generated by these bacteria in contact with various sediment concentrations. A control or blank sample for each group of assays established a standard level of bioluminescent activity for each series of bioassays. Measurable decreases in the activity of the bacteria (emitted light) correlated to an inhibited response to test samples (Microbics 1994a).

Our protocol for Microtox analysis followed the solid-phase bioassay technique as proscribed by the manufacturer Microbics Corporation (1994a). Sample and control solutions were maintained at the recommended temperature of 15 degrees Celsius, where the reagent is most sensitive to the widest range of contaminants. The recommended twenty minute exposure time for the solid-phase test was employed. Samples were first screened at concentrations of 19.736% to quickly determine the median effect concentrations or EC_{50} (fifty percent of bioluminescent bacteria populations inhibited, measured in percent of sample). In the event of relative toxicity levels causing invalid gammas, the accepted measure of bioluminescence lost in response to sediment (Ribo and Kaiser 1987, Microbics 1994a), we retested the sample with an appropriately adjusted concentration for an EC_{50}. The narrow range of values generated by our blank samples seems to indicate minimal influence from glassware and testing procedures.

The levels of relative toxicity were delineated by EC_{50} and toxicity units or TU (as defined by the EPA, TU are derived by dividing 100 by the EC_{50} value). High levels of TU or very low EC_{50} would indicate the potential for a contaminant problem to exist within the tested sediments. The range of TU values have been categorized into four classifications; TU numbering between 0 and 10 represent a low relative toxicity, TU between 10 and 25 represent an intermediate relative toxicity, TU between 25 and 50 represent a high relative toxicity and TU above 50 a reflect severe relative toxicity, an environmental quality concern that should be addressed in greater detail. This standard compares favorable with contaminants known to effect toxic conditions (Rowlen et al 1983, Matthews and Hastings 1987).

Impoundment substrate types were delineated by ranking them along an arbitrary scale from zero through four. The number attributed to the type of sediment corresponds directly with the relative size of the sediment particles; zero was reserved to describe sites not sampled, one for silt, two for silty sand, three for sand, and four for sandy gravel.

RESULTS AND DISCUSSIONS

Our analysis indicate that eleven of the forty seven tested sediments exhibited high to severe relative toxicity. Eighteen sites showed an intermediate relative toxicity. The remaining eighteen tested sites do not readily indicate a toxicological problem. These results (Table 2) imply that some reservoirs might be impacting fish and wildlife.

The results from some dams that exhibited high to severe toxicity have a potential link to known sources of upstream contamination. The impoundment basin at Moore Dam is downstream of the resource threats that include landfills and NPDES sites. Hadley Falls dam sediments could reflect a historic legacy of pollution that may include pesticides, treated sewage and waste from former coal gasification plants. Stevenson, Rocky River and Bulls Bridge dam sediments may be influenced by contaminants from a RCRA site, a paper mill and a former coal gasification plant. The Pine Valley and McLane dam sediments may be impacted by RCRA sites, landfills and superfund sites.

Other results are more obscure. The Sooboomook dam and the Waterbury reservoir showed unexpectedly higher levels of toxicity. As we can only speculate on what could be contributing to this result, we advocate additional testing. This phenomenon should be examined in greater detail to determine whether it is the result of an anomaly or if unknown sources of pollution are impacting these areas.

Studies have supported the use of bioluminescent bacteria as a biological indicator of toxicity in sediments (Tung et al 1990, Tay et al 1992). The Microtox test system has a proven correlation with other test species including *daphnia spp*. and fathead minnows (Bulich et al 1980, Baudo et al 1990, Tay et al 1992). The Microtox bioassay is sensitive enough to test water soluble and insoluble, and organic and inorganic contaminants (Tay et al 1992). The degree of precision available with the Microtox test is somewhat variable which is typical of a bioassay. The average coefficient of variation is approximately thirteen percent (Microbics 1994b). For a survey level study the Microtox test provides a useful analysis.

Analysis showing intermediate relative toxicity from a substrate of moderate particle size such as sand may only exhibit a fraction of potential contaminants. The smaller surface area of moderately sized particles are associated with a lesser ability to bind to contaminants (Baudo 1990, Bulich 1992). Fine sediments exposed to the same water quality conditions may show a higher level of toxicity that might otherwise be undetected. The example of the intermediate toxicity of the Riley dam sediment supports the

TABLE 1: COMPARATIVE TOXICITY OF IMPOUNDED SEDIMENTS IN NEW ENGLAND

Project Number	Project Name	EC_{50}	Toxicity Units	Sediment Type	Relative Toxicity
2077C	MOORE 2	6.22	16.08	1	intermed
2931A	GAMBO	5.14	19.47	1	intermed
2576D	BULLS BRIDGE	3.06	32.65	1	**high**
2558B	BELDENS	0.67	148.27	1	**severe**
2660A	FOREST CITY	28.34	3.53	2	low
2942A	DUNDEE	11.88	8.42	2	low
2634A	RAGGED LAKE, W.BR. STO	11.31	8.84	2	low
2666A	MEDWAY	8.95	11.16	2	intermed
2634A	CAUCOMGOMOC, W.BR. STO	7.55	13.25	2	intermed
2801A	GLENDALE	6.57	15.22	2	intermed
2612A	FLAGSTAFF	6.08	16.45	2	intermed
2634A	CANADA FALLS LAKE, W.BR.	4.53	22.09	2	intermed
2090A	WATERBURY 22-2	4.33	23.08	2	intermed
2090A	WATERBURY 22	3.38	29.62	2	high
2576A	STEVENSON	3.05	32.80	2	high
2634A	SEBOOMOOK, W.BR. STO	1.40	71.30	2	severe
2576C	ROCKY RIVER	1.05	95.68	2	severe
2077C	MOORE	0.80	124.54	2	severe
7725A	BARTON VILLAGE	-	-	3	*
8714A	MERRIMACK VILLAGE	242.77	0.41	3	low
2631A	WORONCO	169.56	0.59	3	low
2365A	ANSON	124.11	0.81	3	low
1893C	GARVINS FALLS	58.84	1.70	3	low
#	RUSSELL	44.78	2.23	3	low
1893A	AMOSKEAG	26.45	3.78	3	low
2375B	JAY	16.56	6.04	3	low
2674A	VERGENNES 9 & 9	9.25	10.81	3	intermed
2928A	MERRIMACK	7.54	13.26	3	intermed
2375A	LIVERMORE MILL	6.89	14.51	3	intermed
2375C	RILEY MILL	6.87	14.55	3	intermed
2194A	BAR MILLS	5.85	17.09	3	intermed
2077A	MCINDOES	5.26	19.00	3	intermed
2077B	COMERFORD	4.80	20.83	3	intermed
11055A	WILTON	4.80	20.84	3	intermed
9282A	PINE VALLEY	3.31	30.26	3	high
8924A	MCLANE	2.78	35.92	3	high
2142A	HARRIS (INDIAN POND)	2.59	38.56	3	high
2004A	HADLEY FALLS	1.49	66.93	3	severe
2932A	MALLISON FALLS	-	-	4	*
3090A	VAIL STATION	-	-	4	*
2721A	HOWLAND	230.18	0.43	4	low
1893B	HOOKSETT	40.61	2.46	4	low
2618A	WEST BRANCH ST. CROIX	25.81	3.88	4	low
2558A	HUNTINGTON FALLS	21.11	4.74	4	low
2941A	LITTLE FALLS	16.93	5.91	4	low
2312A	GREAT WORKS	7.82	12.78	4	intermed
2897A	SACCARAPPA (WEST BROOK)	6.02	16.61	4	intermed

* No accurate TEST result due to low levels of contaminants.
# This site in Russell MA has no current FERC number.

need for further testing to clarify our test results. Although the Riley dam site reflected an intermediate toxicity, the intermediate sized substrate may inhibit a higher contaminant loading rate for the sediment.

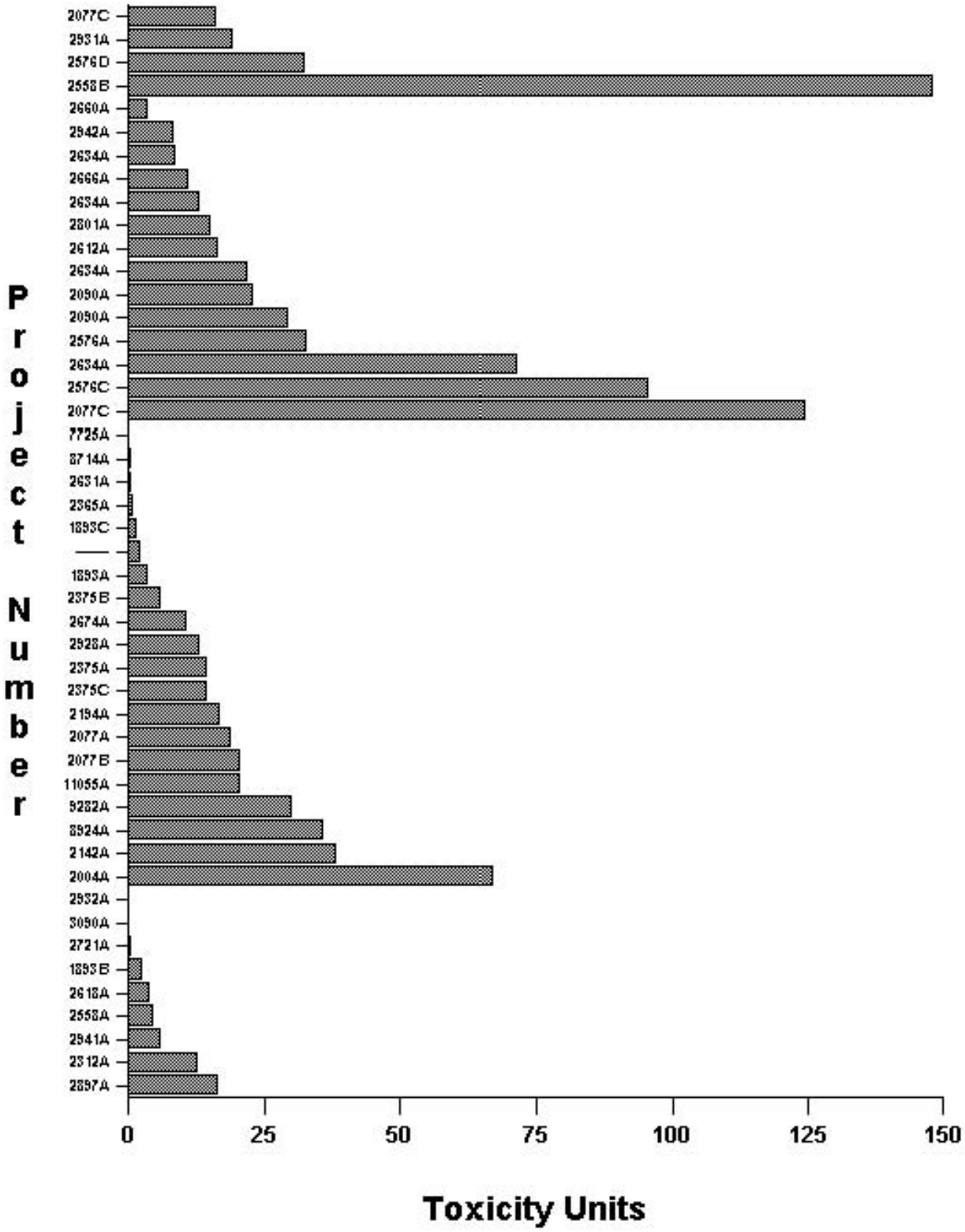
Another variable that could also be considered in future analysis in that amount of time that sediment and contaminants are in contact. Contact time between sediment particles and potential contaminants is directly related to the potential for sorption. For example, assuming equity in sediment particle size and distribution, a reservoir with a relative short retention time, faster flows etc could demonstrate much less contamination of sediments that would a reservoir with greater retention time and slower flows. Thus a measurement of intermediate relative toxicity of sediment in an environment with moderate contact times may not adequately indicate the potential for water quality problems. Intermediate toxicity values indicate they are not benign and there is still cause for concern.

There are mixed views concerning the extent of sediment particle size influencing Microtox analysis. Discussion with Mel Green of Microbics Corporation on September 13, 1994 brought forth the possibility of interference relative to samples' substrate type. Fine to very fine substrates have a much greater surface area than equivalent volume of coarse material. Fine particles may possibly bind contaminants and possibly the *P. Phosphoreum* bacteria, pulling them out of solution, to a much greater extent than coarser sediment with a lesser surface area. Both these activities may reduce the resultant EC_{50} (Bulich et al 1992). Other studies have indicated that sediments with high percentages of clay and other fine materials have not grossly affected assays (Tay et al 1992). Comparisons of *P. Phosphoreum* with other bioassays support the sensitivity of the Microtox solid-phase assay for the determination of relative toxicity (Tay et al 1992).

Repeated analysis with increasing or decreasing concentrations of the same sediment samples did not greatly deviate from the initial test results. Figure 2 illustrates the range of toxicity units within each substrate type. The comparison of sites with similar substrate type showing a range of relative toxicities, not just acute toxicity. This would indicate that sediment particle size does not seem to have an overwhelming impact upon the veracity Microtox analysis and the measured values for TU and EC_{50}.

Future sampling and testing projects may take into account slightly different protocols for sampling and analysis. They could include a solid-phase bioassay, an analysis of the interstitial water, a determination of sediment particle size, and comparative use of a 'clean' reference sample. A solvent extraction test, to strip contaminants from sediment particles, may also be considered. Analysis utilizing Microtox and fathead minnow or *Daphnia spp* could reduce potential variability of Microtox tests.

Figure 2. Toxicity Units by Project Number and Substrate Type



CONCLUSIONS AND RECOMMENDATIONS

There is potential for toxic sediments to accumulate behind dams. This phenomenon should be accounted for in the FERC hydropower relicensing process. Dam operators should be cognizant of the potential accumulation of contaminated sediments and recognize their potential responsibility in event of the reintroduction of contaminants into the water column. Perhaps operating policies could reflect an effort to minimize sedimentation. The fashion by which reservoirs are drawn down could reflect a tendency to encourage a flowthrough situation. A flowthrough dynamic may be affected by draining an impoundment at the same rate as it is filled and at the correct depth to exhaust incoming streamflows. Capturing a density current and shunting it out directly through the dam outlet may reduce sedimentation rates, as well as, possible contamination accumulation rates. This could become important in the event of alterations or modifications.

The possibility of an environmental impact or degradation in the case of accumulating toxic sediments should be addressed by further study. Our experience has shown that there is a need for further examination of dam sediments and their toxicological potential. Hydropower sites that showed high to severe relative toxicity should be retested to confirm toxicity. Areas that showed intermediate toxicity should also be tested again although perhaps less rigorously. Although our results did not provide a clear understanding of the probability of toxicological effects in accumulating sediment and the relationship between the relative toxicity of sediments with substrate type, they did provide the necessary impetus for a more widespread and in-depth analysis that was not possible in our project.

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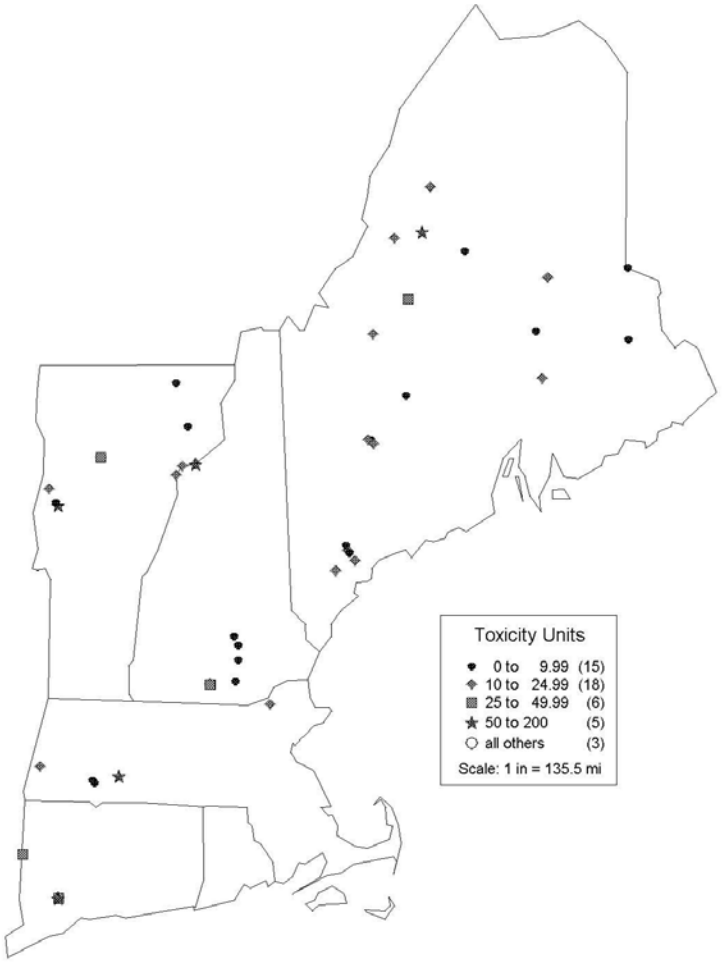
Figure 1. Spatial Distribution and Toxocity Units of Sediment Samples Collected From Hydropower Dams, 1994.



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