ENVIRONMENTAL EFFECTS OF FIREWORKS ON BODIES OF WATER

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ABSTRACT

The effects of fireworks decomposition products (FWDP) on the environment are unknown. The infrequence of fireworks displays at most locations, coupled with the wide dispersion of constituents, make detection of FWDP difficult. The present study was conducted to evaluate the impact of repeated fireworks displays (2,000 shows over a decade) on a small lake (WSL) located at EPCOT Center in Lake Buena Vista, Florida. Water chemistry data for WSL were collected from 1982 until the present, and sediments were characterized early in 1992. Heavy fireworks loading has not caused eutrophication or otherwise affected aesthetic characteristics of WSL, but it has added detectable amounts of barium, strontium and antimony to the water and sediments. The mass of antimony and barium in the surface sediments of WSL was found to be approximately 100X greater than that in the water column, demonstrating that these elements accumulate principally as insoluble compounds. Gradual increases in water column concentrations of antimony and barium over the past decade have paralleled the cumulative number of fireworks displays at the site. While current water column concentrations of these metals in WSL are higher than those of nearby lakes, these levels are not thought to be harmful to aquatic biota. Site-specific characteristics that will influence impacts of FW-borne constituents include size of the water body, hydraulic residence time, water and sediment physico-chemical characteristics, and cumulative fireworks loading over time. Data from this study suggest that environmental impacts from FWDP typically will be negligible in locations that conduct fireworks displays infrequently. Antimony may prove to be a good chemical "marker" for detecting fireworks activity at infrequently loaded sites, since for WSL, a close balance was found between the amount of antimony loaded from fireworks and the mass residing in the sediment and water column.

APPENDIX J

INTRODUCTION

Fireworks (FW) displays impose a variety of stresses upon local environments. These are manifested as the noise, explosive fiery, smoke and fallout debris that occur over communities during holidays and other festive occasions. Most of these effects are predictable, expected and short-lived.

The acute and chronic environmental impacts resulting from fireworks decomposition products (FWDP), however, are unknown. FWDP include a wide range of inorganic metals and organic polymer residues. The starting pyrotechnic composition consisting of oxidizers, fuels and binders, once reacted, produce a variety of metal oxides and particulate organics that fall to earth. Many of these metals (e.g., sodium, potassium, barium, strontium, magnesium and aluminum) comprise the cation in the various oxidizing agents, which typically are provided as nitrate and/or chlorate salts (1). Additionally, some metals (e.g., barium and strontium) are incorporated in FW to produce color effects. In most locations, the infrequence of FW displays and the wide spatial dispersion of constituents make it difficult to detect FWDP, or to evaluate their environmental impacts.

A small lake in central Florida has been the site of almost 2,000 fireworks displays in the past decade. This lake provides an ideal site for quantifying the long term accumulation of FWDPs, and of evaluating their environmental impacts. In the present study, we present findings on the accumulation of selected FWDP in the sediment and water column of this lotic system.

METHODS

Site Description

The study site is World Showcase Lagoon (WSL), a man-made lake located in EPCOT Center, Lake Buena Vista, FL, USA. The WSL is approximately 17.5 hectares in area, with an average depth of 3.5m. The lake volume is approximately 612,500 m^3. The hydraulic residence time for WSL is long: the only water inputs to this system are from rainfall and a small groundwater pump located at a nearby attraction. WSL receives no direct stormwater inputs, but considerable boat traffic and nearby maintenance activities (e.g., painting) may contribute contaminants to the system. Fireworks are thought to be a prominent contributor of particulate constituents to WSL. During FW displays, pyrotechnic devices are launched above WSL from the shoreline, as well as from barges anchored in the center of the lake. WSL is not utilized for recreation (no direct human contact occurs), nor is the lake used as a source of drinking water.

Field and Laboratory Techniques

Since 1982, quarterly water column measurements at two sites in WSL have been conducted for nutrients, metals and other general limnological parameters (e.g., alkalinity, conductivity, total organic carbon [TOC], pH and chloride). In January 1992, mid-depth water samples were collected from six sites in WSL. These samples were analyzed by ion chromatography for fluoride, chloride, nitrate, sulfate, alkalinity, sodium, potassium, magnesium and calcium.

Sediment samples also were collected from six sites in WSL during January 1992. These sediment cores (collected to a 20 cm depth) were partitioned into 4 depth increments: 0-2 cm; 2-5 cm; 5-10 cm; and 10-20 cm. Aliquots from each sediment layer were subjected to microwave digestion with acid, and the digestates were analyzed by ICP/MS (Inductively Coupled Plasma Mass Spectrometry). This instrument provided quantitative information for several metals, including chromium, manganese, iron, nickel, copper, zinc, antimony, barium and strontium.

The mass per unit area (in the top 20 cm of sediment) for selected metals in WSL was calculated as the product of sediment concentration and bulk density (dry mass per volume). This average value was then multiplied by the bottom area of the lake to provide an estimate of total mass of a particular metal in the WSL sediments.

An estimate of FWDP loading to WSL was calculated as follows. The mass (gross weight) of pyrotechnic devices exploded over WSL since 1982 was provided by entertainment personnel at EPCOT Center. A rough estimate of the composition of these FW was obtained from the pyrotechnic literature. Total mass loading to WSL by a particular constituent was estimated as the product of total FW mass and the average FW constituent concentration.

RESULTS AND DISCUSSION

Water Column and Sediment Characteristics

Water quality characteristics of WSL were summarized for three periods: during 1982 and 1983, prior to the extensive use of fireworks at the site; during 1987 and 1988, after the display of approximately 1,000 fireworks shows; and, January 1992, after display of nearly 2,000 shows (Tables 1 & 2). It should be noted that in 1989, WSL was connected to another lake system via a narrow canal. Hence, subsequent changes in water quality may have been due to mixing or dilution, rather than to activities occurring within or around the lake.

Of the non-metal constituents, total kjeldahl nitrogen (ammonium + organic forms) and alkalinity were the only water column parameters that changed substantially during the first five year period (Table 1). Alkalinity continued to increase during the subsequent five years, and slight increases in nitrate-N and chloride were also observed during this period. The major anion and cation analytes measured in 1992 in WSL all occur at concentrations typical of freshwater systems (Table 2). The nitrogen, phosphorus and total organic carbon concentrations show that WSL can be classified as an oligo-mesotrophic lake (2). The trophic status of WSL did not change during the 10 year study, and no marked changes in biota (aquatic macrophytes, fish or phytoplankton populations) were observed.

While most chemical and biological characteristics in WSL showed little temporal variation (Table 1), water column antimony (Sb) and barium (Ba) concentrations in WSL increased linearly from 1982 until 1989 (Fig. 1). The increase in concentrations of these elements in the water column undoubtedly was due to FW activity, since both of these elements are common constituents in pyrotechnic devices. Concentrations of other metals (copper, zinc, cadmium, manganese and selenium) remained unchanged in WSL during the study. The decline in water column concentrations of Ba and Sb in 1989 (Fig. 1) probably was due to the dilution of WSL waters with that of the adjacent lake.

Metals concentrations in WSL sediments were highest in the top sediment layer (0-2 cm), and declined with depth (Fig. 2). For most metals, WSL surface sediment concentrations (Table 3) were typical of natural or "non-impacted" sediments (3). However, an unusual feature of WSL sediments is that Sb, Ba and strontium (Sr) were found in moderate to high concentrations. Little information on "typical" sediment concentrations for these metals could be found, but it is known that they usually occur at concentrations much lower than those of zinc, manganese and lead. Strontium, like Ba and Sb, is a common firework constituent (1) with few other commercial uses. Aluminum and magnesium also are used in pyrotechnic devices, but these were not analyzed for in the present study due to their high native concentrations in Florida soils and sediments.

While surface sediments displayed highest metals concentrations (e.g., Fig. 2), this sediment layer also was the least consolidated, with the lowest amount of dry mass per unit volume. The bulk density of 0-2 cm, 2-5 cm, 5-10 cm, and 10-20 cm sediment layers averaged 0.15, 0.68, 1.21, and 1.71 g/cm^3, respectively. Consequently, differences in total mass of metals among the sediment depth layers was not as pronounced as would be suggested by concentration differences. For example, the mean mass of Sb per unit area at 0-2 cm, 2-5 cm, 5-10 cm, and 10-20 cm sediment depths in WSL was 8.3, 13.0, 27.6, and 4.9 g/m^2, respectively.

The total mass of Sb, Ba and Sr in the WSL sediments (top 20 cm) was estimated to be 9,400, 84,000 and 18,500 kg, respectively. The spatial variability in concentrations of these metals in WSL sediments was high (due either to uneven depostion or to variations in native metals concentrations), so the above mass values should be considered rough approximations. Additionally, we have not yet quantified "natural" levels of these elements in nearby soils and lake sediments, so the percentage of these metals in WSL contributed by FW is unknown.

Antimony was selected for a mass balance calculation because it has a very low crustal abundance of 0.2 mg/kg (4). For purposes of this comparison, we therefore have assumed that all Sb in WSL was derived from fireworks. The total mass of Sb dissolved in the water column was estimated (using 1988 "maximum" concentration values) to be 200 kg. WSL therefore contains 9,600kg Sb, only 2.1% of which is in a dissolved form. The total mass loading of Sb to the WSL from pyrotechnic devices was estimated to be 11,800 kg, a value in fairly close agreement to the calculated mass of Sb in the water column and sediments. That most of the Sb is detectable in WSL is not surprising, since this element is not used as a nutrient by either plants or animals, and is not likely to be transported from the system.

A similar mass balance conducted for Ba was less precise: 84,500 kg of Ba was found in the WSL system (0.6% of which is in the water column), but only 19,000 kg of Ba was calculated to have been loaded from FW displays. The poor agreement between the calculated mass of Ba loaded from FW and the mass observed in WSL is likely due to an underestimate in the amount of Ba utilized in the pyrotechnic devices, or to high native Ba levels in the WSL sediments.

Environmental Impacts of Fireworks Decomposition Products

Fireworks activity does not appear to contribute substantially to the eutrophication of water bodies. FW contain almost no phosphorus (1), which frequently is the "growth-limiting" nutrient for aquatic plants. FW do contribute nitrogen, an element that can stimulate unwanted plant (micro- or macroscopic) growth. However, the biochemical N cycle in aquatic systems is dynamic, and there are several pathways through which N is lost to the atmosphere in gaseous forms (5). In WSL, a small lake with very heavy fireworks loading, no visible decline in the aesthetic quality (e.g., appearance of nuisance algae) of the system has occurred.

This study demonstrates that a principal environmental impact of FW activity is the deposition of selected metals. In WSL, a site that has received heavy FW loading for a decade, the FW-derived metals Ba, Sr and Sb were found both in the water column and sediments. These metals are deposited in largely insoluble forms, since in WSL, 97.9% of the Sb and 99.4% of the Ba occur in the sediments. Fireworks contain other metals (e.g., aluminum, magnesium and copper) that also are deposited in dryfall, but high "background" or native concentrations of these elements may render the small mass of metals contributed by FW difficult to detect. Antimony may prove to be a good chemical "marker" for detecting fireworks activity at infrequently loaded sites, since for WSL, a close balance was found between the amount of antimony loaded from fireworks and the mass residing in the sediment and water column.

The environmental consequences of FW metal deposition are difficult to discern. For any aquatic system over which FW are displayed, environmental impacts of FWDP will depend on the area and depth of the water body, hydraulic residence time, water and sediment physico-chemical characteristics, and total fireworks loading. For most sites that conduct FW displays infrequently, environmental impacts of FWDP probably are negligible. In contrast, a "worst-case" scenario would be where heavy, routine fireworks loading is conducted over a small, relatively stagnant body of water that is utilized as a drinking water source. It would be prudent to conduct periodic monitoring for metals at such locations, because both Sb and Ba at low levels are under consideration for various surface water and drinking water priority lists (6).

Data on FWDP presented herein suggest a number of topics that merit further study. These include: evaluating factors that influence speciation and mobility of fireworks metals in aquatic systems; evaluating techniques for reducing concentrations of selected analytes within FW shells; and, investigating the efficacy of binding FW-borne metals in lake sediments by chemical immobilization. In order to ensure that environmental impacts are understood and minimized, more detailed studies on the chemistry of FW-borne metals likely will be conducted in WSL during the coming decade.

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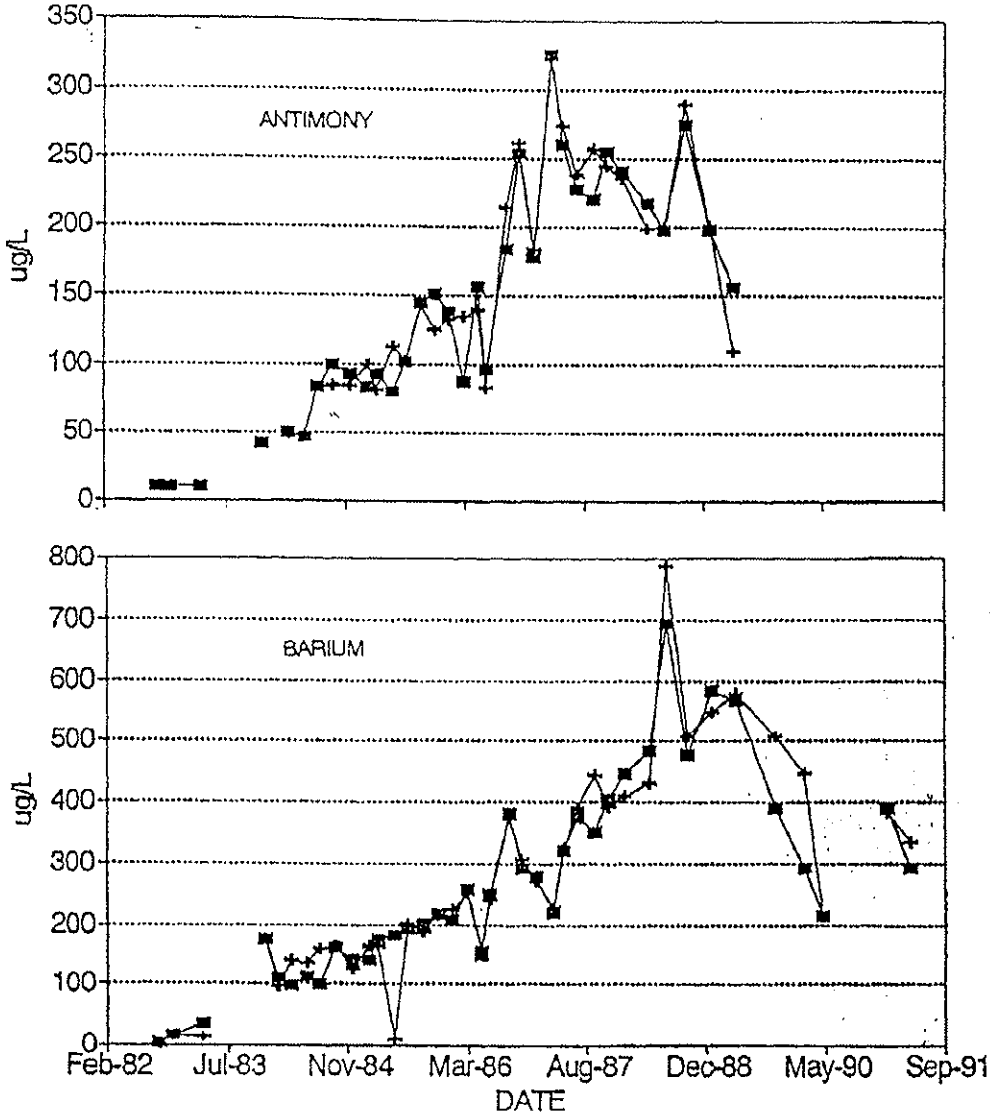

Figure 1. World Showcase Lagoon (WSL) water column antimony and barium concentrations from 1982 through 1991. The two symbols on each graph depict values from separate surface water sampling stations.

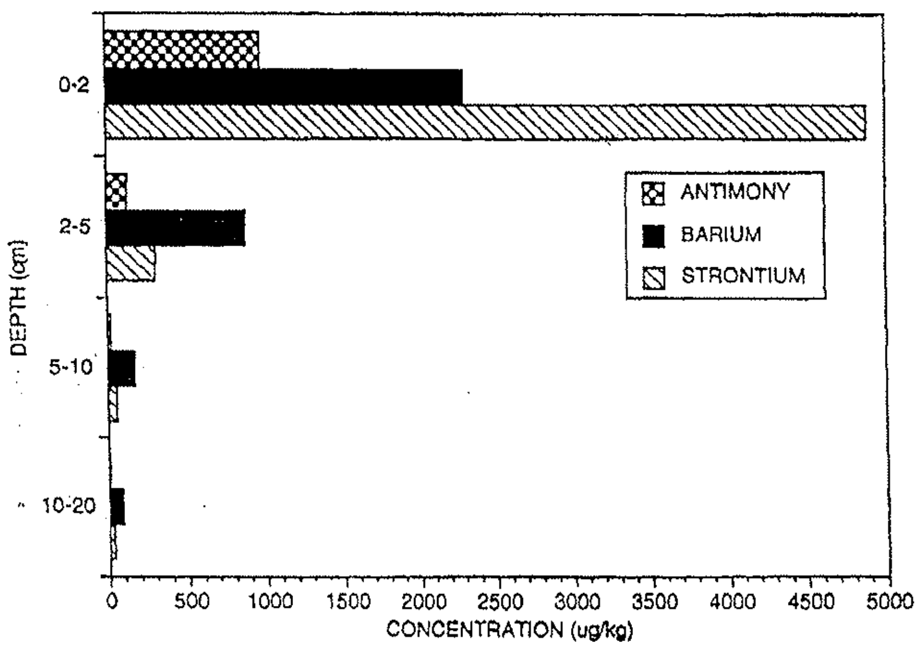

Figure 2. Concentrations of strontium, barium and antimony with sediment depth in WSL. These values are from one core sample collected on the east side of WSL.

Table 1. Mean water quality characteristics for WSL at a mid-lake sampling station before (1982-1983) and after (1987-1988) five years of heavy fireworks loading.

analyte	1982-1983	1987-1988
Total Kjeldahl N (mg/L)	0.22	0.40
Ammonium-N (mg/L)	0.05	0.04
Nitrate-N (mg/L)	0.06	0.05
Total phosphorus (mg/L)	0.03	0.02
Total organic C (mg/L)	3.3	3.8
Chloride (mg/L)	6.0	6.2
Conductivity (umhos/cm)	174	162
Alkalinity (mg/L)	29.4	57.0

Table 2. Mean anion and cation concentrations (mg/L) for WSL at mid-lake sampling stations in January 1992. Median reference values (with ranges) are from a study of 165 Florida lakes (7). Other data references are cited below.

analyte	WSL	Reference Values
Fluoride	0.14	0.26[1]
Chloride	8.7	14 (2 - 2300)
Ammonium-N	0.02	NA
Nitrate-N	0.10	NA
Sulfate-S	11.1	11 (3.4 - 186)
Alkalinity	72.0	10 (0 - 204)
Sodium	4.2	7.6 (1 - 1200)
Potassium	2.6	1.3 (0 - 51)
Magnesium	5.0	4.1[2]
Calcium	24.4	1.5[2]

1 Reference #2
2 Reference #4

NA - not available

Table 3. Mean metal concentrations for surface (0-2 cm) sediments from WSL, January 1992. Values reflect the mean of six sampling sites.

Metal	WSL Sediment (mg/kg)	Natural or Non-Impacted Sediments[1] (mg/kg)
Iron	189	< 17,000
Barium	23.2	NA
Copper	8.9	< 25
Antimony	7.6	NA
Strontium	4.8	NA
Zinc	1.97	< 90
Manganese	0.77	< 300
Lead	0.70	< 90
Chromium	1.47	< 25
Nickel	0.67	< 20

1 Reference #3

NA - not available