

## THE APPLICATION OF ALUM RESIDUAL AS A PHOSPHORUS ABATEMENT TOOL WITHIN THE LAKE APOPKA RESTORATION AREA

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### ABSTRACT

Lake Apopka, the fourth largest lake in Florida, is considered one of the most severely polluted lakes in the state. As part of the Lake Apopka restoration program, approximately 13,000 acres of muck (organic soil) farmland within the North Shore Restoration Area (NSRA) are being restored to marsh habitat to reduce external phosphorus (P) loading to Lake Apopka. In addition, the first 650 acres of the Lake Apopka Marsh Flow-Way (MFW), designed to filter particulate nutrients from Lake Apopka, has been constructed. The treatment wetland will be 3,400 acres when completed.

High phosphorus flux from the soil is expected to occur during initial reflooding of the highly organic soils of the NSRA and MFW. Although chemical treatment has been successful in lake restoration programs, large-scale soil amendment application in wetlands for phosphorus immobilization has not been done. If successful, the initial efficiency of wetland treatment of polluted waters will be greatly improved.

The St. Johns River Water Management District evaluated various chemical compounds and other materials for their ability to reduce P flux from the sediments and thus reducing water column P concentration. A variety of materials were tested in laboratory and small plot experiments. Based on these results a field scale experiment (three two-acre plots) was used to evaluate the effectiveness of calcium hydroxide ( $\text{Ca}(\text{OH})_2$ ), gypsum ( $\text{CaSO}_4$ ), and alum residual from a potable water treatment plant (WTR) to reduce soil P flux. The amendments were surface-applied to hydrologically isolated cells. After soil treatment, the enclosures were shallowly flooded and maintained at a water depth of approximately 25 cm. WTR strongly reduced TP levels in the floodwater compared to the control cell. Gypsum and lime were not as effective in reducing TP concentrations in the water column. WTR was selected as the most cost-effective soil amendment for large-scale application. WTR was subjected to extensive tests including P adsorption capacity, Toxicity Characteristic Leaching Procedure (TCLP), Synthetic Precipitation Leaching Procedure (SPLP), chemical characterization, and biological assays prior to use.

Approximately 52,610 wet tons of WTR were hauled (100 miles one-way) from Melbourne FL to the application site just north of Orlando, FL between March and May



of 1999. Another 13,500 tons were hauled in 2002. Approximately 2,000 acres were amended at a rate of 6.5 wet tons per acre between March and June of 1999. During the summer of 2000 650 acres in the Marsh Flow-Way were amended at a rate of 10 wet tons per acre. Approximately 57,000 tons are currently stockpiled on site. The total cost for hauling and spreading alum residual up to this point has been \$ 1.7 million. Initial reflooding began on a small area of the NSRA in 2002. The 650 acres of the MFW will be flooded in early 2003.

## **KEYWORDS**

water treatment residual, alum residual, beneficial use, land application, phosphorus, pollution abatement, non-point source pollution, Lake Apopka, phosphorus adsorption capacity, treatment wetland

## **INTRODUCTION**

Lake Apopka, the fourth largest lake in Florida, is considered one of the most severely polluted lakes in the state (EPA 1979). As part of the Lake Apopka restoration program, approximately 13,000 acres of muck farmland has been purchased by the St. Johns River Water Management District (SJRWMD) and is being restored to marsh habitat within the North Shore Restoration Area (NSRA) to reduce phosphorus importation to Lake Apopka. The marshes were drained in the 1940s and farmed until 1998.

In addition, the Lake Apopka Marsh Flow-Way (MFW), a 3,400-acre surface flow treatment wetland, is being constructed on some of the farmland to filter particulate nutrients from Lake Apopka. At this time, Phase I of the Flow-Way, including four cells with a total wetland area of 650 acres, has been completed. Reflooding is anticipated in early 2003.

During initial marsh restoration flooding, high soil phosphorus flux is expected to occur, and water column phosphorus concentrations may remain high for long periods.

Previous studies found large pools of labile (available) phosphorus in the organic soils in the MFW (Ann 1996, 2001). The condition of the MFW soils is very similar to that of the soils throughout the NSRA. During the MFW Demonstration Project, the soluble reactive phosphorus (SRP) pool in the soil after initial flooding was approximately 3 g P/m<sup>2</sup> (Coveney et al. 2002). Optimization of the MFW for P removal will require the reduction of this P flux from previously farmed soils and newly formed soils. This, and the need to minimize the discharge of phosphorus from the NSRA to Lake Apopka led SJRWMD to evaluate a variety of materials for their ability to reduce phosphorus flux from organic soils. These tests resulted in a large-scale application to enhance the restoration of the Lake Apopka Ecosystem.

Chemical treatment has been used successfully to treat P flux from lake sediments. Large-scale soil amendment for phosphorus immobilization in wetlands is unproven. The



purpose of this paper is to report a large-scale field application of alum residual as a soil amendment for phosphorus immobilization, describe chemical characteristics of the amendment, and to provide a synopsis of the work leading to this application.

## **SOIL AMENDMENT LABORATORY AND FIELD STUDIES**

The field scale application effort was the culmination of a series of field and laboratory studies designed to identify the best material to cost-effectively reduce phosphorus flux from the organic Lake Apopka muck soils. Laboratory evaluations to test P sequestration and P flux reduction were followed by field tests that focused on water column and soil nutrient levels.

### ***Materials Tested***

A number of materials have the potential to sequester soluble phosphorus. Tested materials included pure chemicals, industrial byproducts, and byproducts of potable water treatment processes:

- Lime  $\text{Ca}(\text{OH})_2$
- Calcium carbonate  $\text{CaCO}_3$
- Dolomite  $\text{CaMg}(\text{CO}_3)_2$  (a naturally occurring rock material)
- Alum  $\text{Al}_2(\text{SO}_4)_3$
- Ferric Chloride  $\text{FeCl}_3$
- Alum residual from the Melbourne FL potable water plant (WTR)
- Gypsum – a waste product from the production of sheetrock

### ***Laboratory Experiments***

The University of Florida Wetland Soils Laboratory conducted three batch experiments (Reddy et al. 1996, Ann et al 2000a, Ann et al 2000b) under contract to SJRWMD.

These experiments were designed to:

- Determine the effect of various chemical amendments on P flux between the soil and floodwater.
- Study P distribution in chemically-amended soils.
- Evaluate P solubility in chemically-amended soils.

Floodwater SRP concentration in the unamended soil increased from 0.15 mg P/L to about 1.0 mg P/L. At rates of 102 g  $\text{CaCO}_3$ /kg of soil, about 70 percent of the water soluble P was removed from solution. Soils treated with 36 g/kg  $\text{Ca}(\text{OH})_2$  (calcium hydroxide) decreased the water soluble P by 95 percent. Soils treated with  $\text{CaMg}(\text{CO}_3)_2$  (dolomite) actually released P during the experiment. Removal of more than 80 percent of water soluble P required  $\text{Al}_2(\text{SO}_4)_3$  (alum) and  $\text{FeCl}_3$  (ferric chloride) rates higher than 14.4 and 7.1 g/kg, respectively. Based on P flux calculations and the floodwater concentrations during the entire incubation period, the effectiveness of chemical amendments were as follows:  $\text{FeCl}_3 > \text{Alum} > \text{Ca}(\text{OH})_2 > \text{Ca}(\text{CO}_3)_2 > \text{Dolomite}$  (Reddy et al. 1996).



### ***Mesocosm Experiment***

To expand the scope of the laboratory work, SJRWMD and the University of Florida (Reddy et al. 1998) conducted a field experiment. The experiments were conducted in relatively shallow organic soils in the northwestern corner of the agricultural area. The organic soil layer (1- 2 feet in depth ) was underlain with a marl horizon.

Five treatments (control, alum, alum residual (WTR), calcium carbonate residual from a water softening process, and calcium hydroxide) were replicated three times in 15 isolated enclosures (10m x 10m each). The amendments were surface-applied and not incorporated into the soil column. Three weeks following the soil treatment and flooding, pore water equilibrators were installed to a depth of about 30 cm to obtain dissolved nutrient concentrations in the soil-water column of each enclosure.

The water depth was maintained at approximately 50 cm. Water column pH, dissolved oxygen (halfway down water column and sediment surface), turbidity, alkalinity, total suspended solids, total P, total dissolved P, soluble reactive P, dissolved calcium, total silicon, total aluminum and dissolved aluminum were measured weekly or more frequently during the experimental period.

Water column P concentrations were lowest in mesocosms treated with WTR and alum. Concentrations of P in calcium carbonate-treated mesocosms were not greatly different from those of the untreated mesocosms. None of the amendments influenced the development of P gradients in the soil column. The low water column P concentrations in enclosures with alum and WTR suggested that these applications created a chemical barrier to P flux at the soil surface.

Plant growth and animal activity in marshes disturb and mix surface soils, which over time will reduce the benefits of the application. Key conclusions of these experiments were that the first flush of P will be best treated with alum or WTR and application rates should be the highest that are economically feasible in order to maintain reduced P water column concentrations while long-term biological mechanisms of P storage develop.

### ***Field Scale Experiment***

Based on the results of laboratory and mesocosm experiments, a field experiment was conducted in 1998 at another site in the NSRA with deep organic soils. The area had recently been farmed with sweet corn and harvested. Four two-acre plots were isolated hydrologically with soil berms. Treatments included alum residual, calcium hydroxide (lime as  $\text{Ca}(\text{OH})_2$ ), gypsum, and a control.

Soil cores were taken within each cell prior to the soil amendment application. The samples were evaluated for soil pH, water content, ash free dry weight, TOC, P and N species and metals. A 5-cubic yard manure spreader applied approximately 10-wet



tons/acre of alum residual. Gypsum was applied at a rate of 4.5-wet tons per acre. Approximately 2-dry tons per acre of lime was applied as slurry (33 % solid).

After soil treatment, the enclosures were shallowly flooded to a depth of approximately 25 cm with water from the irrigation canal system. Water was periodically let into the enclosures to maintain the depth and to compensate for evapotranspiration and seepage. Samples for nutrient analyses were taken in each treatment area and the inflow for 16 weeks.

Total phosphorus (TP) in enclosure water either came in during initial flooding or with make-up water, or came from phosphorus released from the soils. However, nutrient-rich water from irrigation ditches was let into all the enclosures more-or-less equally. Therefore, the difference between TP levels in a treated enclosure and levels in the control enclosure was attributed to the soil treatment.

For both the lime and gypsum treatments, the differences in TP levels among treatment and control enclosures varied around zero throughout the experiment (Figure 1). In contrast, TP levels in the alum residual treatment cell remained significantly lower (0.6 to 0.9 mg/L less) than TP levels in the control enclosures throughout the experiment. These results indicated that the alum residual material prevented wholly, or in part, the net release of TP from the soil during the experiment.

Based on the results of laboratory and field experiments, a thorough review of the scientific literature on the use and potential hazards of the material, and a cost analysis, alum residual was selected for large-scale application.

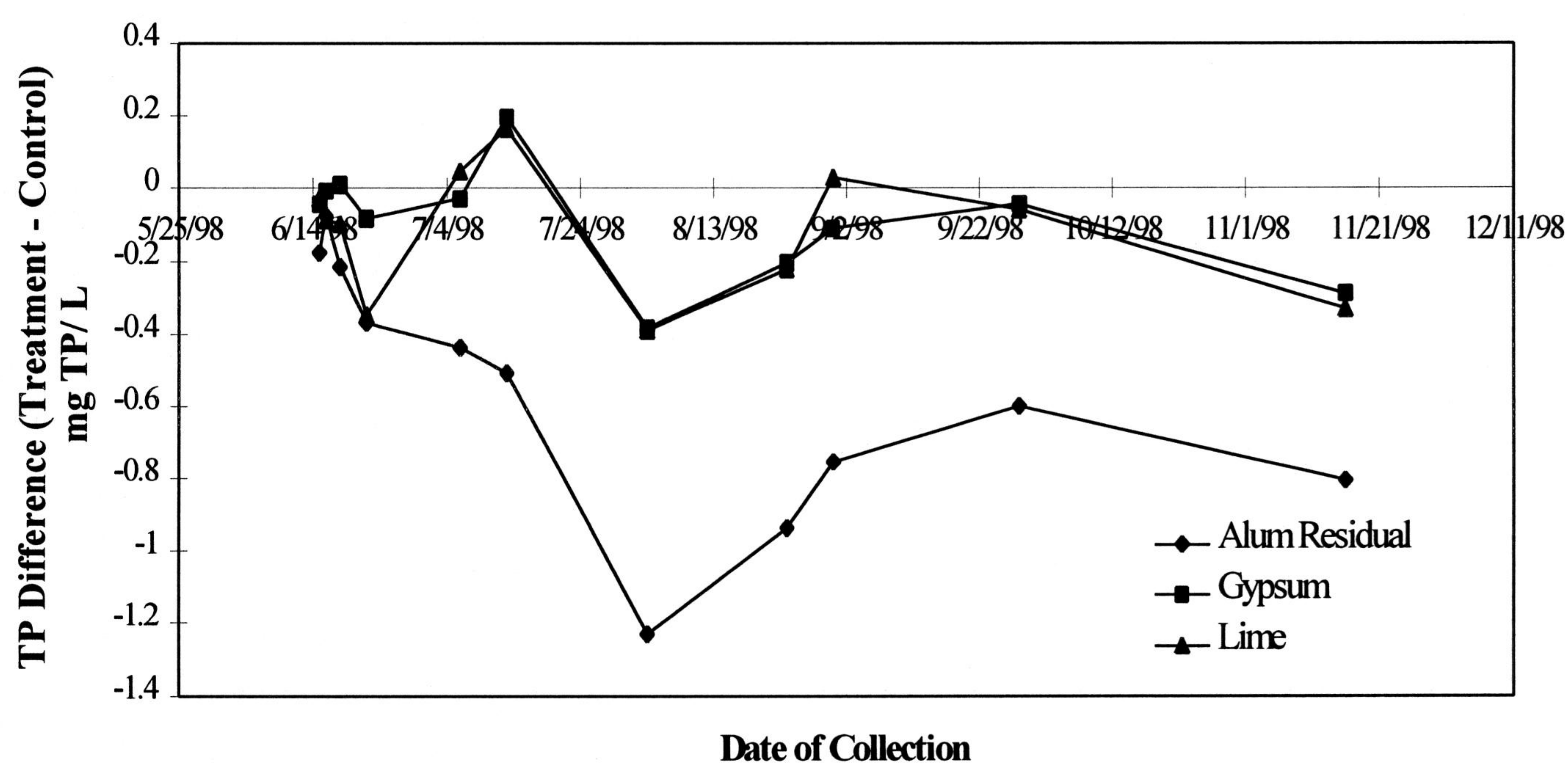


Figure 1. Effect of soil treatment on floodwater TP. All values in mg/L



## **WATER TREATMENT RESIDUAL (WTR) CHARACTERISTICS**

### ***WTR Production and Storage***

Alum water treatment residual from the Lake Washington Water Treatment Plant in Melbourne, FL was selected as the soil amendment for the NSRA and the Lake Apopka Marsh Flow-Way. The plant, about 100 miles from the application site, was the nearest source of the material. Available literature on the material was reviewed (Hoge 2001). Other more distant sites were identified as potential sources, but these residuals did not sequester phosphorus as effectively as the Melbourne source material and so were not further pursued.

The Lake Washington Water Treatment Plant used aluminum sulfate, (alum  $[(\text{Al}_2(\text{SO}_4)_3(14\text{H}_2\text{O}))]$ ) as the primary coagulant in a potable water treatment chain. Other materials added during the treatment process that were also part of the WTR included powdered, activated carbon (PAC), quicklime (CaO), and acrylamide and sodium acrylate copolymers. All additives used meet current potable water quality assurance and safety standards. To dewater the floc material, a belt filter press was used to compress the material between two belts of decreasing diameter rolls, which left the material at approximately 20 percent total solids.

To produce approximately 9.5 MGD of treated drinking water at the Lake Washington plant during July 1997, the plant used 14,250 pounds of alum ( $\text{AlSO}_4$ ), 2,850 pounds of PAC, 3,000 pounds of quick lime (CaO), and minor quantities of copolymer materials daily (City of Melbourne 1997). The process produced approximately 10,000 cubic yards of WTR annually. Stockpiling of WTR adjacent to the plant began in 1988. Between 85,000 and 100,000 cubic yards of total stockpiled material was available at that site in 1998 .

### ***Physical Characteristics***

The Melbourne alum residual physically resembled a black greasy loam soil. The material was slippery and could become brick-like upon drying. It did not have an odor and crumbled easily while moist. When dried and pulverized, it became a fine powdery dust, with the potential for handling problems. The bulk density varied between 1200 – 1500 lbs./cubic yard. Sand particles could be felt and seen upon close inspection.

### ***Pesticide Scan***

A full pesticide scan of samples from all ages of material was negative (below limits of detection) for both registered and unregistered pesticides.

### ***Biological Analysis***

The Florida Department of Environmental Protection conducted acute toxicity tests on biological assays of the Melbourne Water Treatment Plant residual using *Ceriodaphnia dubia* (daphnia) and *Cyprinella leedsii* (banner fin shiners) in March 1999. The “pass



test" is a mortality less than 50% in a 96-hour test. *Daphnia* are used because of their sensitivity to pesticides, metals, and disturbances of the ionic composition of their environment. No mortality was observed in 100 percent elutriate or dilutions.

### ***Chemical Characteristics***

A thorough sampling of the stockpiled residuals at the Lake Washington Water Treatment Plant was first conducted in June 1997 (Table 2). The samples ranged in age from fresh material to material covered with small pine trees and dense vegetation (approximately 10 years of age). Chemical tests included elemental analysis, Toxicity Characteristic Leaching Procedure (TCLP) Synthetic Precipitation Leaching Procedure (SPLP), a comprehensive pesticide scan, and biological assays for toxicity.

Based on sediment guidelines for the State of Florida, only arsenic was present in levels that presented a potential environmental hazard. The arsenic concentration of the WTR was slightly higher but not significantly different from the arsenic content of the surface sediments of the former farm fields on the north shore of Lake Apopka. The proposed application did not significantly change the soil concentration in the top 6 cm. Soil sampling results showed no significant difference between applied and unapplied sites within the NSRA. The average concentration (n=12) of WTR was 5.9 mg As/kg. The average (n=50) soil arsenic concentration on the treatment sites was 2.6 mg As/kg. Therefore, the contribution of arsenic by the WTR was calculated to be approximately 0.8% of the existing burden within the top 6 cm of soil even at the highest application rate of 10 wet tons/acre. A statewide survey by Chen et al. (2002) showed that the highest arsenic concentrations are found in wetland soils, such as saprists (0.25-11.7 mg As/kg). The organic soils on the north shore of Lake Apopka are primarily saprists, which are predominantly decomposed organic soils.

Leaching test methods are used to determine if a material should be classified as hazardous waste. The Toxicity Characteristic Leaching Procedure (TCLP) analysis revealed very low, if any, potential for heavy metal leaching (Table 3). Therefore, this material is not considered a hazardous material according to 40 CFR 268.41.

A Synthetic Precipitation Leaching Procedure (SPLP) was conducted by the Florida Department of Environmental Protection (FDEP) (Table 4). The SPLP was developed to simulate leaching under acid rain conditions. The extraction fluid has a pH of 4.20 to evaluate the potential for leaching metals into ground and surface waters (EPA 6010 mod.).

In a series of batch experiments using the Melbourne WTR material of four different ages (one week, one month, one year, and greater than five years), SJRWMD attempted to determine the maximum sorption capacity using the Freundlich isotherm. However, even in solutions containing up to 500 mg P/L, the P was completely removed from the solution by the WTR. The experiment was repeated using increased levels of phosphorus (up to 3000 mg P/L). As in the first test, the asymptotic relationship between equilibrium P concentrations and amount of P adsorbed was never attained and the results did not



conform to classical adsorption isotherms. The explanation for this discrepancy could be a chemical fixation process, such as a chemical precipitation or chemisorption. Therefore, the maximum "fixation capacity" was estimated to be greater than 60 mg/g (DB Environmental Laboratories, Inc. 1998, 1999).

The equilibrium phosphorus concentration (EPC), the phosphorus concentration at which adsorption and desorption are equal, was also defined (DB Environmental Laboratories, Inc. 1999). This value can be used to predict phosphorus movement at the sediment-water interface. The typical range of EPC values for optimal agricultural production is 50 to 200  $\mu\text{g/L}$  EPC<sub>o</sub>. The EPC for the WTR was near zero, indicating "little to no desorption capacity" (DB Environmental Laboratories, Inc 1998, 1999). Although the WTR contained 600 to 1000 mg TP/kg the high bonding energies of the material essentially prohibited desorption of P.

Based on the results above, an application rate of 10 wet tons residual/acre could capture 33.60 g P/m<sup>2</sup> assuming an adsorption capacity of 60 mg P/g dry residual. Coveney et al. (2002) found that the average total pool of soluble P released after flooding in the Marsh Flow-Way Demonstration Project was approximately 3.0 g P/m<sup>2</sup>.



**Table 2. Analysis of eight Lake Washington alum residual samples taken June 1997.  
(All values in mg/kg on a dry weight basis unless otherwise noted).**

	1	2	3	4	5	6	7	8	Avg.
% solids	21.5	21.5	23.4	26.2	21.6	27.0	42.0	33.6	22.9
pH	5.91	5.63	5.57	5.59	5.96	6.13	5.73	4.68	5.65
Bulk den. (lbs/ft <sup>3</sup> )	44.91	47.36	44.61	50.27	52.49	46.92	46.22	44.43	47.15
Al	82,000	99,000	90,000	69,000	87,000	95,000	70,000	83,000	84,375
Sb	0.52	0.59	0.43U	0.42	4.2	0.43U	0.21U	0.67	1.28
As	6.0	6.5	5.6	2.7	6.4	4.3	3.7	3.2	4.8
Ba	16	19	13	24	12	34	23	8.7	19
Be	0.37	0.29	0.28	0.29	0.42	1.2	1.2	0.23	0.54
Cd	0.089U	0.10U	0.076U	0.074U	0.081U	0.075U	0.038U	0.049U	
Ca	2,000	2,200	1,500	2,200	1,400	3,000	2,100	390	1,849
Cr	8.8	4.2	3.9	71	5.2	48	52	99	37
Cu	7.5	6.8	5.8	10	6.9	13	14	5.5	8.7
Fe	1,600	1,600	1,600	3,300	1,600	4,600	4,400	3,700	2,800
Mg	330	280	220	340	190	510	400	33	288
Mn	33	45	39	41	24	35	22	12	31
Ni	13	10	9.4	6.8	12	8.5	8.1	2.9	8.8
K	95	91	84	120	81	8.5	8.1	2.9	8.8
Se	1.3	0.89	1.0	1.6	1.8	1.6	1.1	1.4	1.3
Ag	0.13U	0.15U	0.11U	0.11U	0.12U	0.11U	0.054U	0.90	
Na	180	140	180	150	240	54U	53	35U	
Tl	2.2U	2.5U	1.8U	1.9	2.0U	1.8	0.91U	1.2U	
Sn	6.3	33	6.3	7.5	5.7	2.0	1.2	51	14
V	27	28	26	35	27	44	52	40	35
Zn	19	16	13	11	12	21	21	3.3	15
Hg	0.055	0.054	0.055	0.049	0.029	0.036	0.042	0.061	0.048

U - The compound was analyzed for but not detected

V - Indicates that the analyte was detected in both the sample and the associated blank.

**Table 3. TCLP analysis of eight alum residual samples taken June 1997 (all values in mg/L)**

	1	2	3	4	5	6	7	8
As	0.0032U	0.0032U	0.0032U	0.0032U	0.0032U	0.0032U	0.0032U	0.0032U
Ba	0.077V	0.087V	0.069V	0.12V	0.067V	0.11V	0.10V	0.056V
Cd	0.0007U	0.0007U	0.0007U	0.0007U	0.00070U	0.0007U	0.0007U	0.0007U
Cr	0.0018	0.0018	0.0018	0.0080	0.0018	0.0054	0.0050	0.0087
Pb	0.0030U	0.0030U	0.0030U	0.0030U	0.0030U	0.0030U	0.0030U	0.0030U
Se	0.0027V	0.0038V	0.0022V	0.0045V	0.0033V	0.0061V	0.0021V	0.0043V
Ag	0.0010U	0.0010U	0.0010U	0.0010U	0.0010U	0.0010U	0.0010U	0.0010U
Hg	0.00006	0.00006	0.00006	0.00006	0.000062	0.00006	0.00006	0.00006
	U	U	U	U	U	U	U	U

U - The compound was analyzed for but not detected

V - Indicates that the analyte was detected in both the sample and the associated blank. The TCLP blank contained barium at 0.0049 mg/L, selenium at 0.0046 mg/L, and mercury at 0.00014 mg/L.



**Table 4. SPLP analysis of six alum residual samples taken in March 19099 and conducted by FDEP (all values in µg/L unless otherwise noted).**

Parameter	1	2	3	4	5	6
Aluminum_308	4400	706A	855	859	865	779
Arsenic	2.5U	2.5U	5.0U	5.0U	5.0U	5.0U
Antimony	2.5U	2.5U	2.5U	2.5U	2.5U	2.5U
Barium	307	219A	235	260	227	203
Beryllium	0.050U	0.050U	0.050U	0.050U	0.050U	0.050U
Boron	271	140A	149	183	159	155
Cadmium	0.25U	0.25U	0.25U	0.25U	0.25U	0.25U
Calcium (mg/L)	30.9	32.8A	33.3	41.8	38.1	39.3
Chromium	8.7	2.0U	2.6I	7.8I	2.0U	2.0U
Cobalt	0.50U	0.50U	0.50U	0.51I	0.50U	0.050U
Copper	7.7	3.6I	3.7I	2.8I	4.0	1.9I
Iron_259	141	26I	31I	47	21I	34I
Lead	1.5I	1.5U	1.5U	1.5U	1.5U	1.5U
Magnesium (mg/L)	2.86	3.13A	3.02	2.91	3.40	2.86
Manganese	7.51	5.47A	5.72	5.92	5.08	6.51
Molybdenum	1.0I	0.70U	0.70U	0.86I	0.70U	0.70U
Nickel	6.9	1.6I	3.1I	5.6I	2.7I	1.5U
Potassium (mg/L)	1.04	0.757A	0.762	0.701	0.733	0.638
Selenium	2.0U	2.0U	2.0U	2.0U	4U	2.0U
Sodium (mg/L)	4.6	2.9A	2.9	3.0	3.0	2.5
Strontium	164	172A	169	195	201	182
Thallium	4.0U	4.0U	4.0U	4.0U	4.0U	4.0U
Tin	10U	10U	10U	10U	10U	10U
Titanium	1.8I	0.40U	0.51I	0.43I	0.40U	0.40U
Vanadium	4.2	3.3A	1.3I	1.7	1.7	2.1
Zinc	417	200A	195	193	219	158
Silver	0.050U	0.050U	0.050U	0.050U	0.050	0.050U

A – Value reported is the mean of two or more determinations

I – The reported value is between the laboratory method detection limit and the laboratory practical quantitation limit.

U – Material was analyzed for but not detected; The value reported is the minimum detection limit.

## LARGE SCALE APPLICATION

Between March and May of 1999, 52,610 wet tons of WTR were hauled (100 miles one-way) from Melbourne. Another 13,500 tons were hauled in 2002. All trucks, which made 2 to 3 round trips per day, were weighed on State of Florida certified scales to obtain a net weight. The WTR hauled in 1999 was contaminated with construction debris and vegetation. After hauling from Melbourne it was passed through a shaker screen located near the application site loaded on small dump trucks and hauled to stockpiles located around the project area. The residual hauled in 2002 was free of contamination and stockpiled at one site on a concrete pad within the NSRA.



About 2,000 acres of the NSRA were amended at a rate of 6.5 wet tons per acre between March and June of 1999. Approximately 100 acres that could be hydrologically isolated were not treated so that they could serve as a control site for performance monitoring. About 650 acres in Phase I of the MFW were amended over a 13-week period during the summer of 2000 at a rate of 10 wet tons per acre. Due to low lake levels and pesticide residuals in the soil, initial reflooding was not begun until mid 2002. Approximately 60,000 tons of alum residual are currently stockpiled for application to other areas in the NSRA.

The total cost to date of hauling and spreading WTR is \$1.7 million. The cost per acre for loading, hauling, screening, unloading, and spreading ranged from \$190/acre at Duda Jem Farm (6.5 wet tons/ac) to \$384/ac on the Marsh Flow-Way (10 wet tons/ac). Much of the increase was due to the cost of spreading per acre (\$32/ac vs. \$131/ac). The MFW cost is a more accurate reflection of expected costs to do this work. The per acre cost for NSRA treatment did not cover all the contractor's activities due to the novel material and job characteristics. The MFW was bid after the NSRA work and correctly accounted for the all contractor expenses.

Following flooding in late August 2002, water quality and macroinvertebrate monitoring was initiated.

## **DISCUSSION**

Several lessons were learned during the large-scale application. The proper equipment and material management techniques were essential to effective and efficient spreading over the large area. There was a distinct learning period at the beginning of the large-scale application that slowed the work. This may be unavoidable when novel materials are used and the site requires intensive management in order to maintain appropriate access conditions.

In order to reach all areas of the fields, balloon-type tires were used on the spreaders. Wet conditions impeded the ability of typical farm machinery to operate. A clear field was also essential. Vegetation on the site (primarily weeds, but with some woody vegetation) was disked, chopped or removed to allow an even distribution of WTR.

Several alterations were made to the equipment to improve spreading efficiency. During application, the spreaders were only filled two-thirds full to reduce the strain on the spreader chain mechanism, which was subject to breaking under a full load. The spreaders were also completely emptied at the end of each day because the WTR cemented if allowed to remain in the spreaders overnight.

Calibration of each spreader was conducted each morning by running the spreader over a 9' x 6' tarp to test weight and coverage of the residual distribution. If the material weight was not within a 10 percent weight threshold, the spreader mechanism was adjusted. If the coverage of the distributed material was uneven, the auger was checked for



obstructions. During the day, calibrations were performed with small plastic containers and a small postage scale. Loads per field were tallied to double check proper application rates. Supervision of the spreading operation was continuous to ensure that even coverage was attained. The spreading rate became much more consistent as the operators gained experience with the material.

## CONCLUSION

The restoration of former agricultural lands is a complex and lengthy process. Water treatment residuals can be used to cost-effectively reduce the influence of impacted areas on the surrounding ecosystem and shorten the restoration timeline. For example, the use of alum residual to reduce the movement of phosphorus from the farmland to Lake Apopka cost approximately 0.059 cents per gram of phosphorus removed. In contrast, mechanical harvest of hydrilla from a large shallow lake was estimated to cost approximately 2 cents per gram of phosphorus removed in a South Florida scenario (Harvey and Havens, 1999). The decrease in phosphorus discharged to Lake Apopka from the soils will benefit the lake ecosystem and downstream waters.

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