RECIRCULATING – REDUCING AND ALKALINITY PRODUCING SYSTEM (RERAPS) FOR THE TREATMENT OF ACIDIC COAL PILE RUNOFF [1]

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Abstract. The treatment of acidic coal pile runoff (CPR) using an alternative constructed wetland design was evaluated. This alternative design, which provided improved wetland performance, was based on the partial re-circulation of treated water into a detention basin located immediately upstream from a Reducing and Alkalinity Producing System (RAPS). This modification created a semi-passive RAPS-based system we refer to as a Recirculating RAPS (ReRAPS).

Previous work suggested that this wetland, utilizing the ReRAPS modification, could dampen the effects of intermittent, or "shock", loading usually associated with CPR and still achieve desired effluent contaminant concentrations. The purpose of this study was to confirm the previous results through more frequent chemical and hydrological monitoring. The ReRAPS was monitored during 41 days of CPR treatment, which included four storm events during January through March 2001. The CPR contained an average iron concentration of 12.8 mg/L, 24.8 mg/L of aluminum, 2.9 mg/L of manganese, and 178.0 mg/L of acidity. The detention pond removed 82% of the total iron, 59% of the aluminum, and 35% of the acidity loading prior to the RAPS component. Manganese behaved conservatively in the detention pond. Average concentrations at the wetland discharge for total iron, aluminum and manganese were less than 0.20 mg/L. The 2001 wetland monitoring has confirmed that the ReRAPS modification enhances the basic RAPS wetland design by moderating the pH of contaminated water and reducing the contaminant loading prior to the RAPS component.

Additional Key Words: RAPS, successive alkalinity producing system, SAPS, recirculating RAPS, ReRAPS, sulfate reduction

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Introduction

In the last two decades several approaches have been developed to treat acid mine drainage (AMD). Many of these designs have been used to successfully treat AMD, including the Reducing and Alkalinity Producing System (RAPS). The RAPS is an especially attractive approach due to low operation and maintenance costs. While RAPS-based wetlands have been developed and continue to treat AMD, research is continuing in efforts to improve or optimize the design for the treatment of acidic coal pile runoff (CPR). Unlike AMD, CPR flow to wetlands is intermittent resulting in "shock" loading of contaminants on the critical RAPS component. Of specific interest is a semi-passive design modification that would moderate the intensity of the CPR loading prior to the RAPS component.

In a previous paper (Garrett et al. 2001), we described an alternative wetland design using RAPS technology that specifically addressed the challenges associated with intermittent contaminant loading. The modification involved the partial re-circulation of treated water into a detention basin located immediately upstream from the RAPS component resulting in what we refer to as a semi-passive Recirculating Reducing and Alkalinity Producing System (ReRAPS). Pumping allows for the recirculation of alkalinity back to a detention pond and presents the opportunity to add alkalinity and suspended organic matter to the runoff prior to the RAPS. Acidity removing reactions in the detention pond will then occur in a predictable order that is consistent with the solubility products of the solids. Figure 1 compares the "environment of removal" for the primary contaminants in a passive RAPS-based wetland and in a ReRAPS wetland. In this semi-passive system the environment of deposition for both Al and Fe could precede the RAPS, therefore minimizing the potential for RAPS plugging due to metal precipitates. This may be especially beneficial for the pretreatment of Mn, which is difficult to oxidize in the presence of Fe(II) (Sikora et al. 2000). We expect that the recirculation of alkalinity and organic matter would reduce limestone consumption and increase the long-term production of organic alkalinity for severely acidic runoff. It is a logical progression to investigate the potential development of contaminant removal and alkalinity generating processes within a recirculating wetland.

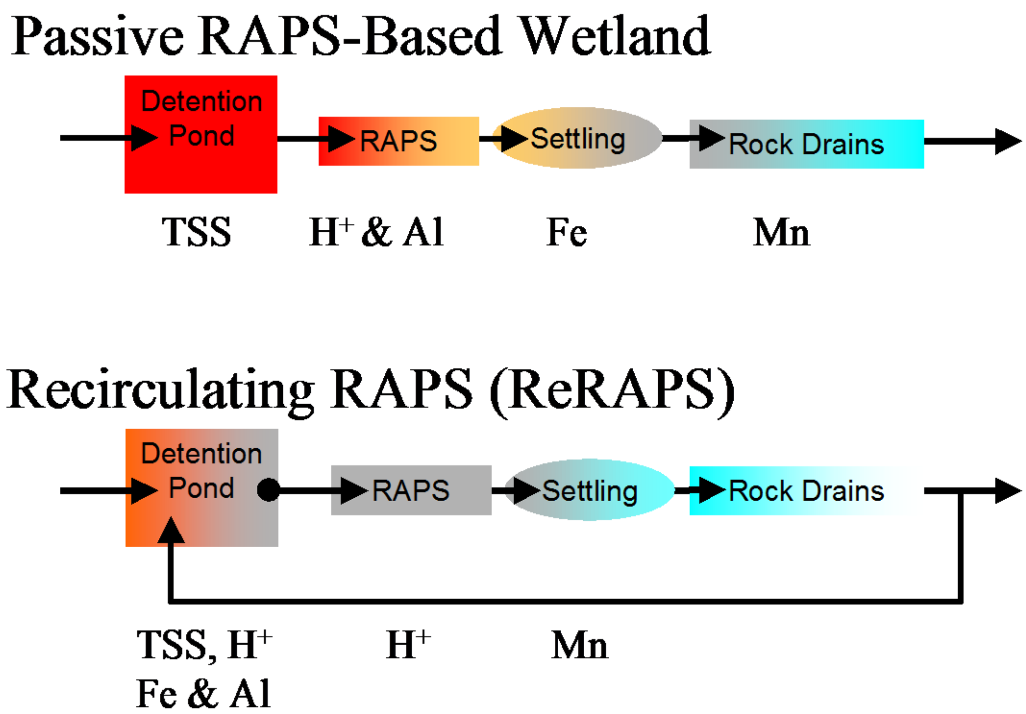


Figure 1. Primary environment of pollutant deposition or consumption in a passive RAPS-based wetland and in a semipassive ReRAPS wetland.

In this paper, we will confirm that the Plant Gorgas ReRAPS wetland can significantly reduce the Al and Fe loading to the RAPS component. We also propose that the early pretreatment of Fe prior to the RAPS allow for earlier treatment of Mn by shifting the environment of Mn deposition further upstream into the settling basin. We will confirm that the reuse of alkalinity reduces limestone consumption in a ReRAPS treatment wetland thereby increasing the operational life of the system. Finally, we will explore the level of contaminant removal in the Plant Gorgas ReRAPS relative to the U.S.EPA National Recommended Water Quality Criteria For Non Priority Pollutants (EPA 1999).

The previous study conducted in January 2000 by Garrett et al. (2001) found that 95, 85, and 75 percent of the Fe, Al, and Mn, respectively, were pretreated prior to the RAPS component. Limestone consumption rates were also lower due to the recirculation of generated alkalinity. This study seeks to confirm the previous results. During this study, the ReRAPS was intensively monitored during 41 days of CPR treatment. The treatment period included 4 storm events, which produced measurable amounts of CPR during January through March 2001. This ReRAPS treatment occurred while the wetland was in its fourth year of operation.

Experiment Design and Methods

Monitoring was performed during 2001 for 41 days from 29 January through 11 March to evaluate the treatment of coal pile runoff resulting from four runoff producing rain events. A schematic of the Plant Gorgas ReRAPS wetland is presented in Figure 2. Hydrologic and water quality monitoring was performed at Nodes N1, N2, N4, N5, N7, N10 and N12/13 during the treatment period. These nodes represent the inlets and outlets of the major components.

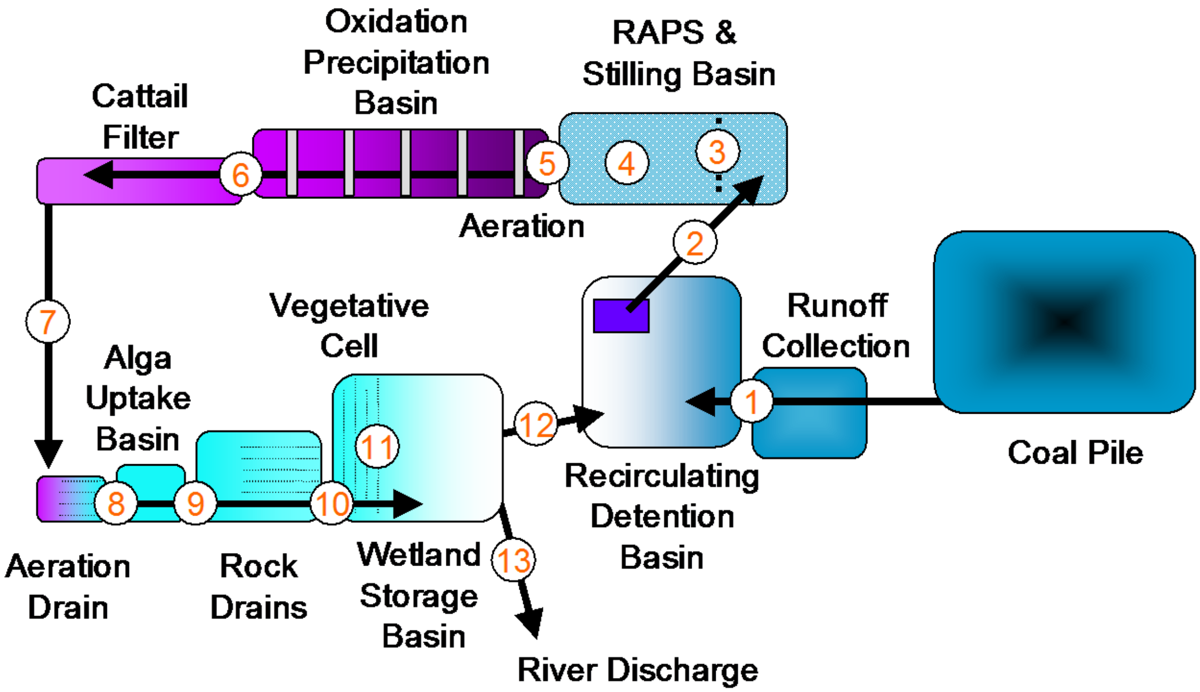


Figure 2. Schematic of the Plant Gorgas Wetland configuration. The wetland nodes N1 through N13 are labeled numerically.

Bubble flow/level meters with microprocessors were used to continuously record water levels. Detention pond levels were continuously monitored just prior to the rain events and throughout each of the treatment periods. Typically a 1.4cm (0.6in) rain or greater is required to produce CPR at N1. Figure 3 presents the detention pond storage, rain depths and CPR flow for the 41-day treatment period. The pump operation timing cycle was measured by using a continuous recording conductivity monitor at N2. An 8-inch pipe weir was continuously monitored at N12 to determine the recycle flow. The detention pond pump flow rates and recycle flow rates are presented in Figure 4. Manually measured flows were also performed at each of the primary nodes throughout the treatment period and were used as data control for the continuous flow monitoring equipment when applicable.

Throughout the treatment period treated water was preferentially recirculated through N12. During a portion of the second storm event, N12 was temporarily shut off due to unrelated operational requirements for draining water away from the coal pile (Figure 4). Nevertheless, CPR treatment in the detention pond benefited from the presence of existing "pretreated" water in the detention pond during this time period. During this study any excess "treated" water which was not recirculated through N12 was discharged through N13 to the receiving river.

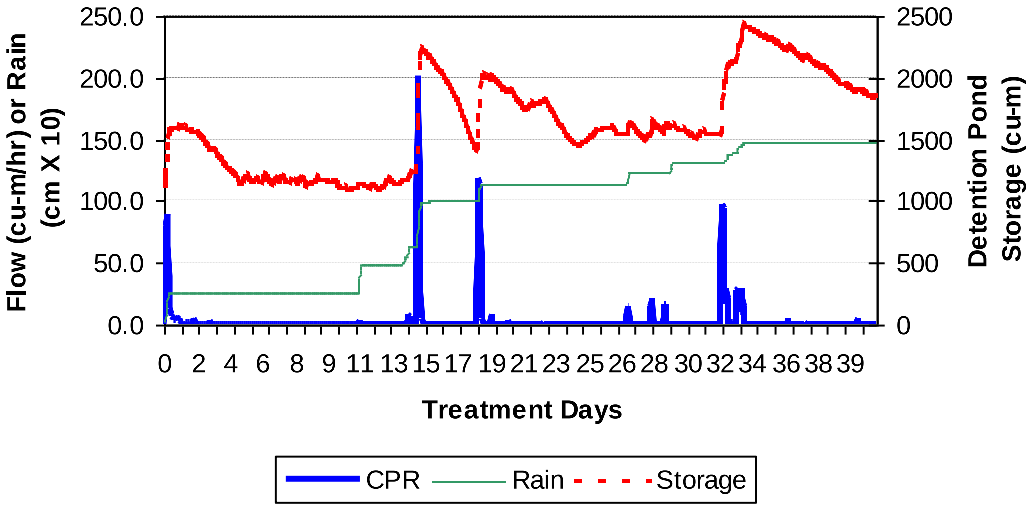


Figure 3. Calculated coal pile runoff (N1, cu-m/hr), measured detention pond storage (cu-m), and measured cumulative rain depths times 10 (cm) during the 41-day ReRAPS treatment of CPR.

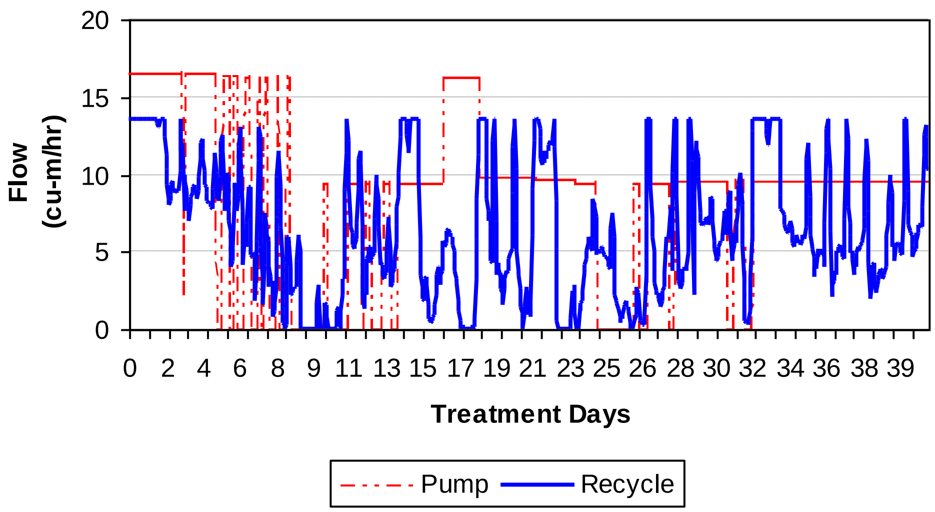


Figure 4. Measured pump (N2) and recycle (N12) flows (cu-m/hr) during the 41-day ReRAPS treatment of CPR.

Sampling Frequency

Automatic sequential sampling devices were used to collect total metals and anions at N1, N2, N4 and N5 to improve loading estimates. The chemistry of the water passing through nodes N12 and N13 is similar. Manual field measurements for flow, pH, ORP, conductivity and ferrous iron were performed 1 to 2 times per day throughout the 41 day CPR treatment at each of the primary nodes. Samples for total alkalinity and acidity were also collected during these site visits.

Sample Analyses

Chemical analyses and field measurements were performed according to U.S. EPA (EPA 1983; EPA 1994) methods or Standard Methods (American Public Health Association. et al. 1989). Total cations (Al, Fe, Mn) were analyzed using the Atomic Emission Inductively Coupled Plasma Method (ICAP, EPA Method 200.7). Alkalinity (EPA Method 310.1) and acidity (Std. Methods 2310, hot peroxide) measurements were performed within 24 hours of sampling. Field measurements included pH, water temperature, and ferrous iron (Hach Colorimetric Method).

Statistical Analyses and Performance Calculations

Daily characterization of the CPR (N1) and the treatment nodes within the ReRAPS (N2, N4, N5, N7, N10 and N12/13) were developed from an hourly matrix of actual and interpolated values for the entire monitoring period. An hourly flow and water chemistry database was developed for all of the nodes. Interpolated flow and chemistry values were used for hourly periods where measurements were not obtained. The daily average flow and flow weighted water chemistry concentrations for each of the nodes were calculated from this data matrix. The statistical analyses were performed using the daily flow weighted averages.

Previously measured contaminant values from the various wetland nodes have shown that the data were not normally distributed and exhibited unequal variances between nodes. Commonly used transformations of the data have failed to produce the normal distributions required for parametric testing of differences. The highly erratic loading of contaminants render this type of data as highly variable in the initial wetland components. The homogeneity of variance for the levels of contaminants between components is not satisfied due to the subsequent moderating effects of mixing and contaminant reductions. Therefore, the Wilcoxon Signed Rank non-parametric test was used to determine differences between the inlets and outlet concentrations for each of the major components. The Wilcoxon Signed Rank test is appropriate for determining if differences exist because many of the daily flow weighted averages among the nodes were related to each other over time (Gilbert 1987).

An analysis was also performed to determine if there were differences in the contaminant concentrations between each of the four CPR events. The non-parametric Kruskal-Wallis test was used to determine differences between data pooled by CPR event (Gilbert 1987). SPSS (SPSS 1999) was used to analyze the pooled data.

The overall 41-day, average, flow-weighted values for acidity from the primary nodes were used along with the daily average flows, and area measurements to determine the contaminant removal efficiencies, removal rates and alkalinity production rates.

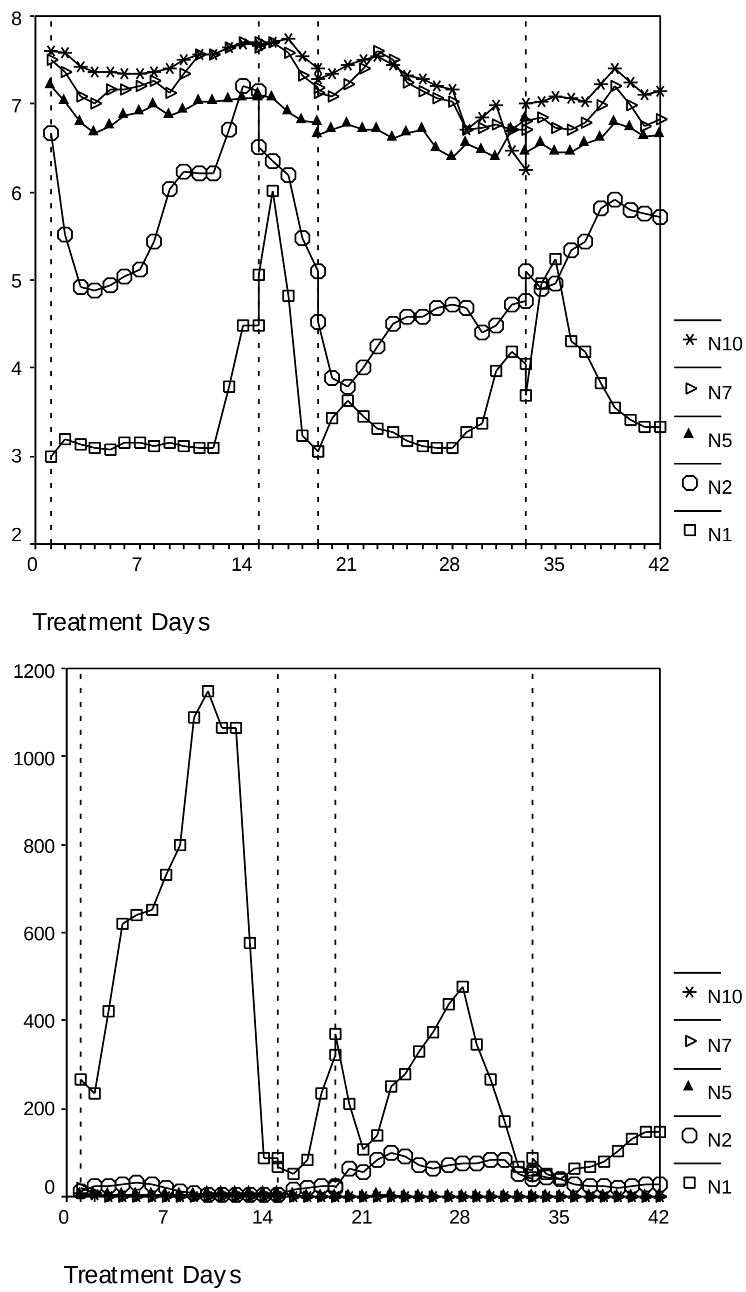
Results

The concentrations of contaminants were significantly reduced as water was routed through the wetland. Figures 5a through 5e present the daily flow-weighted average concentrations at each of the primary nodes during the 41-day treatment period. The mean contaminant levels along with the results of the Wilcoxon Signed Rank analyses of the paired data are presented in Table 1.

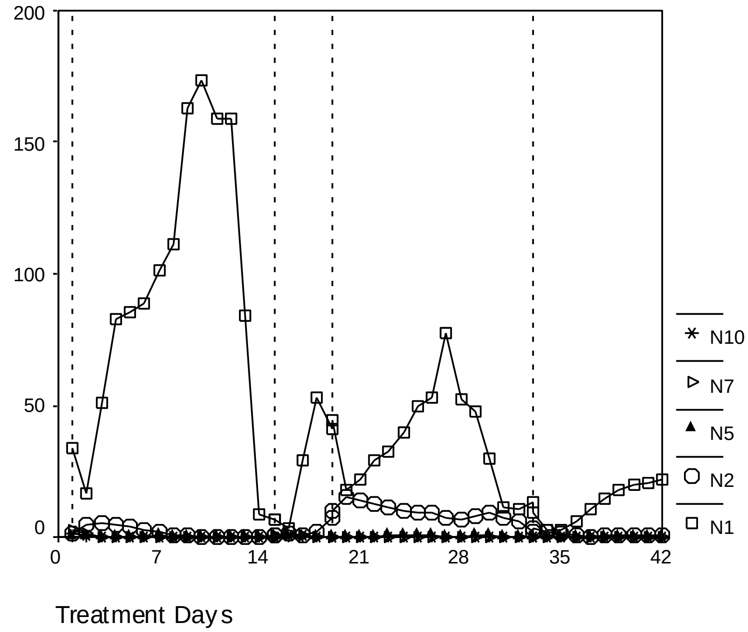
As expected, the influent concentrations in the CPR (N1) were extremely variable. Contaminants typically accumulate in the stagnant water at the base of the 11-acre coal pile between intermittent rain events. Following the events, the contaminants are flushed through N1 into the detention pond. The mass and chemical composition of the CPR is affected by many factors including frequency of rain events, extent of pyrite oxidation in the stored coal, and moisture content of the coal. It is important to note that the variable concentrations in the CPR (N1) were dampened in the initial, upstream component (detention pond, N1-N2) of the wetland.

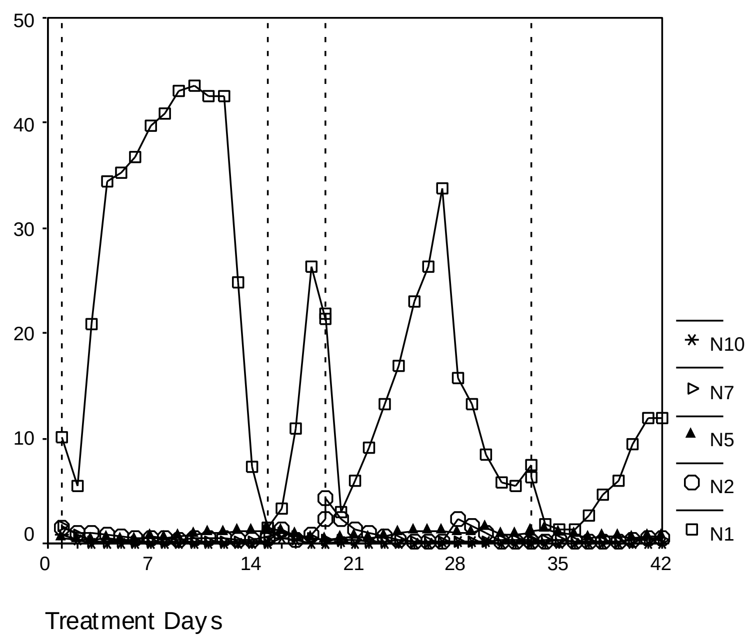
Significant increases in pH ($p<0.001$) and significant decreases in acidity ($p<0.01$) were seen following each component in the ReRAPS. Total Al was significantly reduced within each of the components except for the settling basin where minimal Al levels were observed. Significant reductions of Fe and Mn were observed in all of the treatment components except in the RAPS, where conservative behavior was expected to occur. It should be noted that concentrations of acidity, Al, Fe, and Mn at the wetland storage basin outlet (N12/13) were slightly greater ($p<0.01$) than the drains/basin outlet (N10). This final component is likely receiving a small amount of acidic seepage and did not realize any net removal of contaminants. Therefore this component should only be considered as a storage basin for “mostly” treated water and is not included in any of the removal calculations for the ReRAPS.

Results presented in Table 1 show that significant contaminant concentration reductions were achieved in the detention pond when compared to the CPR (N1). The average levels of Fe and Mn at the detention pond outlet (N2) were significantly lower ($p<0.001$) than the permitted discharge requirements of 3 and 2 mg/L, respectively. The average pH consistently exceeded ($p<0.001$) the lower regulatory limit of 6 at the RAPS discharge (N5).



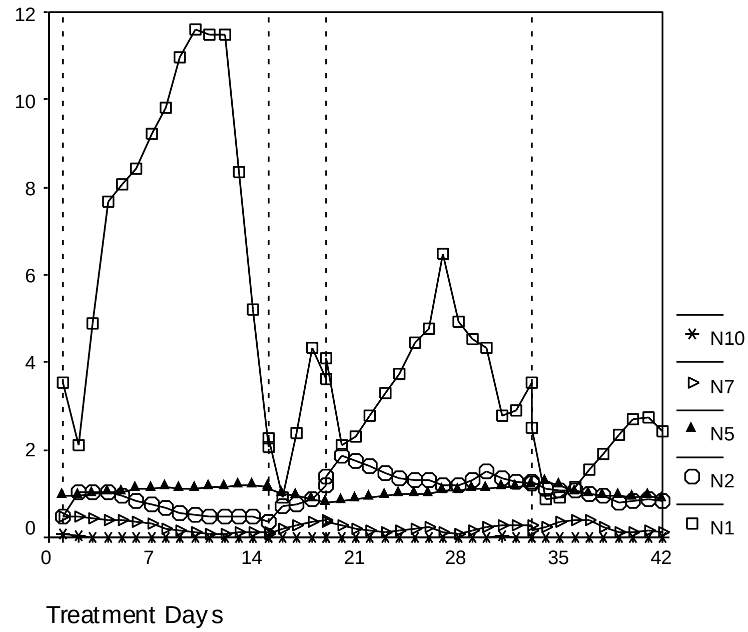
Figures 5a-5b. Daily average flow-weighted pH and acidity in the ReRAPS wetland throughout the 41-day treatment of 4 CPR events from January 29 through March 11, 2000. The storm events that occurred on treatment days 1, 15, 19, and 33 are referenced using a dashed vertical line.





Figures 5c–5d. Daily average flow-weighted aluminum and iron in the ReRAPS wetland throughout the 41-day treatment of 4 CPR events from January 29 through March 11, 2000. The storm events that occurred on treatment days 1, 15, 19, and 33 are referenced using a dashed vertical line.

Figure 5e. Daily average flow-weighted manganese in the ReRAPS wetland throughout the 41-



day treatment of 4 CPR events from January 29 through March 11, 2000. The storm events that occurred on treatment days 1, 15, 19, and 33 are referenced using a dashed vertical line.

Table 1. The average flow-weighted contaminant concentrations at the inlet and outlet of each ReRAPS wetland component along with the Wilcoxon Signed Ranked tests for differences in the daily averages.

	Detention Pond (Inlet (N1) – Outlet (N2))	**RAPS (N2-N5)**	**Settling Basin (N5-N7)**	**Drains & Basins (N7-N10)**
pH (su)	4.0-5.2***	5.2-6.8***	6.8-7.2***	7.2-7.4***
Acidity (mg/L)	178.0-38.4***	38.4-2.1***	2.1-1.4**	1.4-0.5***
Total Al (mg/L)	24.85-4.48***	4.48-0.21***	0.21-0.27ns	0.27-0.14***
Total Fe (mg/L)	12.81-0.77***	0.77-0.71ns	0.71-0.34***	0.34-0.11***
Total Mn (mg/L)	2.88-1.05***	1.05-0.94ns	0.94-0.28***	0.28-0.01***

Wilcoxon Signed Rank Paired Test for differences in node concentration

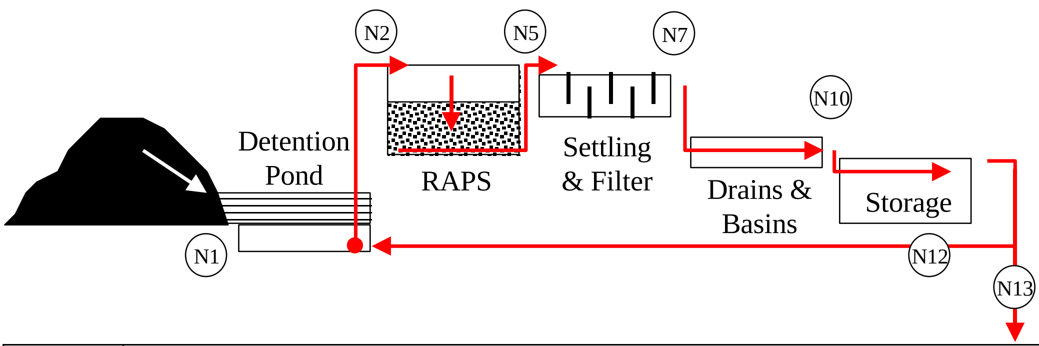
ns = Not significant, $p>0.05$, one tailed

* = Significant concentration change, $p < 0.05$, one tailed

** = Significant concentration change, $p < 0.01$, one tailed

*** = Significant concentration change, $p < 0.001$, one tailed

While the reduction of contaminant concentrations clearly occurred in the wetland (most markedly in the detention pond) it is not clear how much of the reduction was due to actual removal and how much was an artifact of dilution by recycled, treated water. Evaluating the reductions in the total loading (kg/event) of contaminants at N2 when compared to N1 would confirm the occurrence of removal processes within the detention pond. A schematic of the ReRAPS along with a tabular presentation of the concentrations, overall mass loading, percent removals, and removal rates for the contaminants are presented in Figure 6. About one-third of the CPR acidity, 59 percent of the total Al, and 82 percent of the total Fe was consumed in the detention pond. These values are consistent with the previous study (Garrett et al. 2001). In contrast to the previous study, no "net" Mn removal was observed in the detention pond.



	Overall Average Flow Weighted Outlet Concentrations, mg/L					
	CPR	**Detention**	**RAPS**	**Settling**	**Drains**	**Storage**
Al	24.85	4.48	0.21	0.27	0.14	0.18
Fe	12.81	0.77	0.71	0.34	0.11	0.16
Mn	2.88	1.05	1.01	0.28	0.01	0.06
Acidity	178.0	38.4	2.12	1.37	0.5	0.8

	Average CPR Load (kg/d)	**Average Event Removals, Cumulative Percent***				No net removal due to slight seepage
		Detention	**RAPS**	**Settling**	**Drains**	
Al	1.8	59.2	97.6	95.9	97.8	
Fe	1.0	82.0	80.2	90.4	97.2	
Mn	0.2	-0.7	-1.3	71.4	99.1	
Acidity	13.2	35.2	97.0	98.1	99.4	

	Removal Rates, g/day-m^2				No net removal due to slight seepage
	Detention	**RAPS**	**Settling**	**Drains**	
Al	0.80	1.18	-0.03	0.03	
Fe	0.81	-0.03	0.08	0.06	
Mn	0.01	0.00	0.17	0.07	
Acidity	4.47	11.71	0.17	0.18	

* The average event removal is based on the total mass removal of contaminant (T-Al, T-Fe, T-Mn, and acidity) entering the system at the base of the coal pile (N1) during each CPR treatment period.

Figure 6. Cross sectional schematic of the ReRAPS along with tabular concentrations, loadings, percent removals, and removal rates for each of the main components (N1, N2, N5, N7, N10, N12/13) where applicable

The average rates of Al and Fe removal in the detention pond were similar (0.8 g/d-m^2). However, the removal rates between runoff events varied greatly. A Kruskal-Wallis Test was used to analyze for concentration differences between event periods. This analysis revealed that highly significant ($p<0.001$) differences existed between the events for all of the hourly primary contaminant concentrations. The Al and Fe detention pond removals ranged from 0.6-1.4 and 0.2-1.9 g/d-m^2, respectively. The average Mn removal in the detention pond was low (0.019 g/d-m^2) but also varied. It should be noted that the highest rate of Al, Fe and Mn removal occurred during the second runoff event where removal rates were 1.4, 1.9 and 0.1 g/d-m^2, respectively. During this short treatment period, pH values were at their highest level and averaged 5.9.

The average net alkalinity produced at the RAPS effluent (N5) for each of the CPR events ranged from 26.2 to 46.8 mg/L. The average RAPS alkalinity generation rates for each of the CPR events ranged from 14 to 35.9 g/d-m^2 .The concentrations of Ca^{2+} and SO_4^{-2} at nodes N2 and N4 indicate possible supersaturation with respect to gypsum ($CaSO_4$). Therefore, the types of alkalinity generation with respect to Ca^{2+} and SO_4^{-2} differentials are not reported.

Discussion

The hydrological and chemical monitoring performed during this study were generally consistent with the findings of a previous study (Garrett et al. 2001). In this study, sampling was much more intensive; approximately 2,300 samples (8 samples/day for 41 days at 7 nodes) were analyzed versus 98 samples (1 sample/day for 14 days @ 7 nodes) during the previous study.

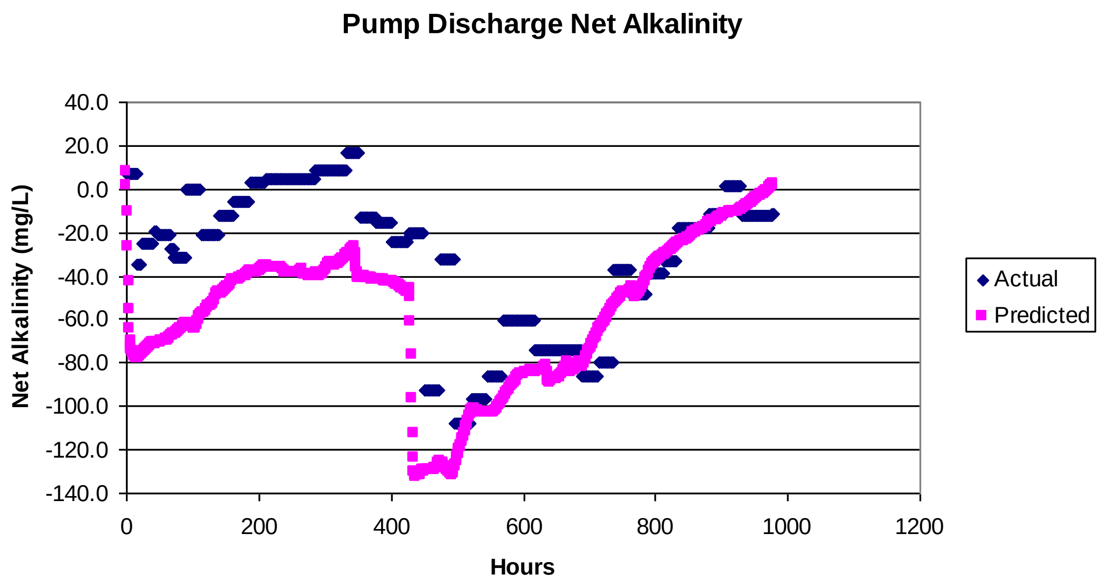
The removals of acidity, Fe, and Al observed in this study were generally consistent with the findings of the previous study. The 35 percent removal of acidity (Figure 6) in the detention pond confirms that the consumption of limestone could be reduced and the operational life of the RAPS could be increased by the same percentage. Contrary to the 2000 study, where it was suggested that some Mn removal might have taken place in the detention pond, very little Mn removal was observed and was therefore conserved in the recirculating detention pond. Because far more samples were obtained in this study, we now believe that previous observation of Mn removal was an artifact of too few samples to adequately describe the actual Mn behavior in that component. Nevertheless, additional efforts were made to better understand the fate of Mn and other contaminants in the system.

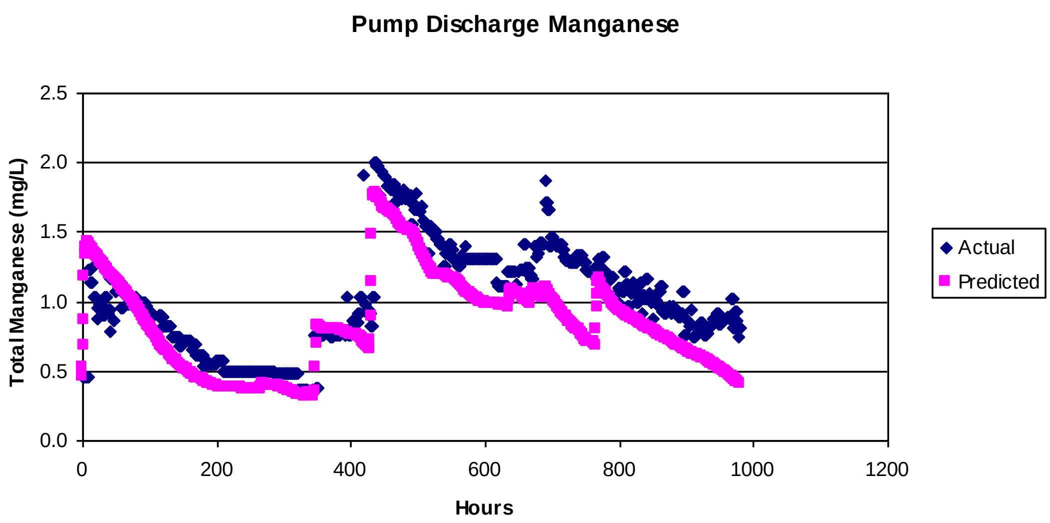
The average alkalinity generation (14.0-35.9 g/d-m^2) during the CPR treatment events compares favorably with the rate of 23 g/d-m^2 which was measured during the winter of 2000 (Garrett et al. 2001). These rates are also comparable to RAPS that receive partially treated AMD. Watzlaf et al. (2000) found that for a second RAPS in a SAPS, generation rates ranged from 14-35 g/d-m^2.

A mass balance was developed to describe the concentration of each contaminant in the detention pond. In this mass balance it was assumed that each parameter was conservative (i.e., not a reactant in any removal mechanism) and that the detention pond behaved as a "well-mixed" reactor. This mass balance was used to compare the theoretical effluent concentration to the measured concentration via a regression analysis. A close agreement between the "predicted" concentration and the actual concentration would indicate that the contaminant was conserved. Conversely, a poor correlation would suggest that the contaminant was not conserved. Relatively close agreements were found for Mn (r^2 = 0.73) and net alkalinity (r^2 = 0.48). The results of the regression analyses are compared to the measured values for these analytes and are given in Figures 7a and 7b. We wish to emphasize that the absence of Mn removal in the detention pond observed under these conditions does not suggest that Mn removal will not occur under different conditions (e.g., retention time, Fe concentration, higher pH). The relatively poor predictive behavior for the remaining contaminants further suggests that these are not conserved and removal mechanisms (e.g., precipitation and settling) were occurring.

The removal rates for Fe and Mn in surface flow systems have been reported to range from 10 to 20 g/d-m^2 and 0.5 to 1 g/d-m^2, respectively (Hedin et al. 1994). Sikora et al. (2000) has recommended a design rate of 5 to 10 g/d-m^2 for Mn-removal in rock drains constructed of limestone aggregate. The lower Fe removal rate within the detention pond (0.81 g/d-m^2) is likely due to the low Fe concentrations and low pH in the pond (pH 4.0-5.2) relative to other AMD loading rates on which these rates were based (pH~6-7) (Hedin et al. 1994). The lower Mn removal rates in the settling pond (0.17 g/d-m^2) and the drains/basin area (0.07 g/d-m^2) are likely due to the low inlet Mn concentrations as well as lower pH. The lower removal rates experienced within the Plant Gorgas ReRAPS may represent the sizing factors that would be required to achieve an effluent, which approaches a non-toxic quality. There is no information on Al removal rates in surface flow wetland systems. The sizing factors for Fe and Al removal in surface flow wetland components, which receive mixtures of alkaline and acidic water, require further study.

The modification to this wetland (i.e., partial recirculation of treated water) improved Fe and Al removal *prior* the RAPS component is especially noteworthy. First, removal of Fe and Al in the detention pond lessens the amount of metal hydroxides that could precipitate in the RAPS





Figures 7a-7b. Predicted pond versus actual pump alkalinity and manganese during the 41-day treatment of CPR.

substrate thereby extending the operational lifetime of the component. Second, recognizing that Mn removal often occurs only after significant removal of Fe, the removal of Fe in the detention pond might move the locale of Mn removal further upstream in the treatment system.

The substantial reductions of Al, Fe and Mn concentrations indicates that the ReRAPS may be capable of producing an effluent with contaminant levels that are similar or below the "EPA National Recommended Water Quality Criteria For Non Priority Pollutants" for freshwater aquatic life (EPA 1999). The removal of contaminants to levels below those known to cause chronic toxicity to aquatic life may be applicable in industrial settings where constructed wetland technology might be applied to treat other types of acidic waste streams. The Criterion Continuous Concentrations (CCC's) recommended for total Fe and Al are 1.0 and 0.087 mg/L, respectively (EPA 1999). The ReRAPS treated Fe to below the recommended CCC at the detention pond outlet (N2) ($p<0.05$). The ReRAPS was not able to reduce the levels of Al to below the recommended CCC. However, the ReRAPS reduced Al to levels that are relatively close to the recommended CCC. The Al concentration (0.14 mg/L) at the Drains and Basins outlet (N10) may be non-toxic because the EPA recommended CCC is not adjusted for hardness. The EPA suggests the use of the Water-Effect Ratio (WER) test to determine site-specific toxicity in situations where moderate to high hardness levels and higher pH may mitigate for toxic effects to aquatic life (EPA 2001). At N10, the hardness (350 mg/L as $CaCO_3$, average) and the pH (7.3, average) are greater than the level from which the Al CCC is based on (EPA 1999). Typically the dissolved form of the metal is toxic. However, the total recoverable Al is appropriate for Al toxicity monitoring because the hydroxide particles are toxic to fish (EPA 1999; Henry et al. 1999). The total recoverable analytical procedure for metals may be measuring aluminum associated with the suspended clay particles from the ReRAPS liner and therefore could be a biased estimate of the suspended Al hydroxide. The major ion or salinity effect should also be evaluated if complete toxicity removal of acidic runoff is required (Goodfellow 2000).

Conclusions

This more intensive study of the ReRAPS has provided dependable contaminant removal rates and alkalinity generation rates for various components commonly used in most RAPS-based systems. Also, it should be emphasized that data presented in this study are based on treatments performed during some of the cooler months of the year. The RAPS water temperatures ranged from 9 to 15^{o}C). The wetland had been in operation for three full years prior to this study and therefore represents a conservative rate and an accurate assessment of the ReRAPS applicability during the winter in the southeastern U.S.

Further efforts are being made to better understand the factors that affect the ReRAPS performance. The amount of treated water that is recycled can be controlled so current efforts are focusing on understanding how the recycle and pumping rates affect the effective hydraulic retention time. For example, initial results suggest that the recycle ratio is key to controlling alkalinity generation in the RAPS and acidity consumption in the detention pond. Also, the fate of Ca^{+2} and SO_4^{-2} in the RAPS, which may be supersaturated with anhydrite ($CaSO_4$) also needs further study.

An analyses of the ReRAPS potential to treat various types of CPR and AMD reveals that the use of the ReRAPS may "only" be limited to applications where; (1) electrical pumping is an option; and enough area is available to meet the retention requirements for, (2) metal hydroxide precipitation in the detention pond; (3) alkalinity generation in the RAPS; and (4) Mn deposition in the rock drains. Retention ponds should be considered in situations where peak runoff flow require unrealistic recycle rates for detention pond removal of metals.

Wetlands for the treatment of acidic runoff are used as a cost effective low maintenance option to conventional chemical treatment systems. A limitation for the cost effectiveness could conservatively be considered a condition where the cost of electrical pump "duty" activity required to meet the retention or recycle flow requirements exceeds the cost of chemical addition. This analyses reveals that the RAPS pump duty cost would approximate one-third the cost of base chemical for acid neutralization (50% NaOH, $0.1/lb; and $0.07 kWh, 50ft head loss).

Care should be taken when designing RAPS-based systems required to achieve toxicity removal criteria because Al and Mn removal rates experienced within the Plant Gorgas ReRAPS are lower than the recommended rates typically required to meet the regulatory standards. Further study and toxicity testing are required to confirm this.

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