TECHNICAL PUBLICATION
ERA #424

Preliminary Analysis of Stormwater Treatment Area 5 (STA-5) Performance: Calcium, Alkalinity and $CaCO_3$ Saturation

By:

Binhe Gu, Jana M. Newman and Michael J. Chimney
Everglades Division
Watershed Management Department

May 2005

South Florida Water Management District
3301 Gun Club Road
West Palm Beach, FL 33406

Preliminary Analysis of Stormwater Treatment Area 5 (STA-5) Performance: Calcium, Alkalinity and $CaCO_3$ Saturation

Binhe Gu, Jana M. Newman and Michael J. Chimney
Everglades Division
Watershed Management Department
May 2005

Introduction

Stormwater Treatment Area 5 (STA-5) is a large constructed wetland with an effective treatment area of 4,110 acres arranged in two parallel flow-ways. The north flow-way (Cells 1A and 1B) and the south flow-way (Cells 2A and 2B) consist of 2,055 treatment area, respectively (Figure 1). The main purpose of STA-5 is to remove P from the stormwater runoff. However, since it became operational, outflow total P concentration has been well above the design target of 50 μg/L and had lower total P removal efficiency than the Everglades Nutrient Removal Project (ENRP) which had similar surface area, plant community and hydraulic loading rate (Table 1).

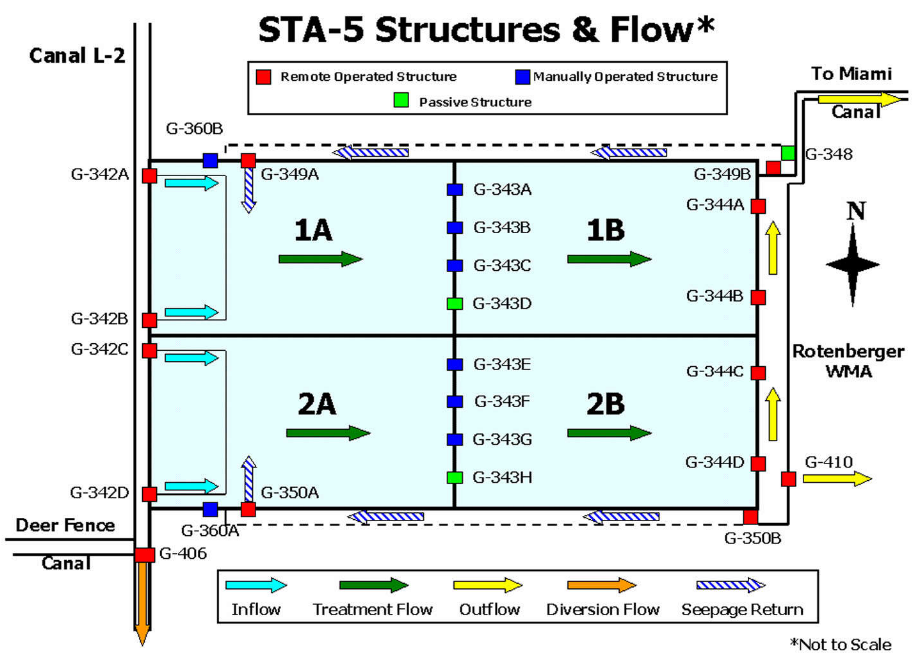

Figure 1. Schematic diagram of STA-5.

One speculation recently raised about the poor performance of STA-5 is a connection with the low inflow Ca concentration and alkalinity. Low Ca concentration and poor buffering capacity of water can inhibit plant growth and probably reduce nutrient removal efficiency in constructed wetlands. This analysis addresses the following questions: (1) are Ca concentration and alkalinity indeed low in STA-5? and (2) how comparable is the P removal performance in other wetlands with similar Ca concentration to STA-5?

Table 1. A comparison of selected morphological, hydraulic and water quality variables for ENRP and STA-5. Data period is from 10/99-2/05.

	ENRP	STA-5
Morphology & Hydrology		
Effective treatment area (acres)	3819	4110
Hydraulic loading rate (m/yr)	10.3	10.1
TP load and removal		
Inflow TP (μg/L)	125	177
Outflow TP (μg/L)	35	111
TP loading (g m^2-yr)	1.53	2.15
TP removal (g m^2-yr)	1.11	1.34
% removal	72%	37%
Vegetation coverage		
SAV	41%	35%
Cattail	36%	30%
Others	23%	35%

Methods

Hydrologic and water quality data are taken from the District DBHydro data base. Daily or biweekly data are reduced to monthly means before overall means are calculated.

The $CaCO_3$ Saturation Index (APHA, 1998) was calculated as:

$$SI = pH - pH_s \tag{1}$$

where SI is the $CaCO_3$ Saturation Index, pH is the measured pH and pH_s is the pH of the water if it were in equilibrium with $CaCO_3$ at the existing Ca and bicarbonate (HCO_3^-) concentrations. pH_s was determined using the following analytical solution:

$$pH_s = pK_2 - pK_s + p[Ca_t] + p[Alk_t] + 5pf_m \tag{2}$$

$$pK_2 = 107.8871 + 0.03252849T - 5151.79/T - 38.92561\log_{10} T + 563713.9/T^2 \tag{3}$$

$$pK_s = 171.9065 + 0.077993T - 2839.319/T - 71.595\log_{10} T \tag{4}$$

$$pf_m = A\left[\frac{\sqrt{I}}{1+\sqrt{I}} - 0.3I\right] \tag{5}$$

$$A = 1.82\times10^6 (ET)^{-1.5} \tag{6}$$

$$E = \frac{60954}{T+116} - 68.937 \tag{7}$$

$$I = 0.5\sum_{i=1}^{i}[X_i]Z_i^2 \qquad (8)$$

where p denotes the $-\log_{10}$ of that variable, K_2 is the second dissociation constant for carbonic acid at the measured water temperature, K_s is the solubility product constant for $CaCO_3$ at the measured water temperature, Ca_t is the total Ca concentration (g-moles L^{-1}), Alk_t is total alkalinity as $CaCO_3$ (g-moles L^{-1}), f_m is the activity coefficient for monovalent species at the measured water temperature, T = water temperature (°K [°C +273.2]), E is the dielectric constant, I is the total ionic strength, X_i is the concentration of constituent i (Ca, Cl, K, Mg, Na, SO_4 and alkalinity as $CaCO_3$; g-moles L^{-1}) and Z_i is the charge on constituent i. A positive $CaCO_3$ SI denotes water supersaturated with $CaCO_3$, negative values indicate undersaturated conditions and a value of zero represents equilibrium conditions.

Analysis

(1) Calcium concentration and alkalinity in STA-5

The Ca concentration from available data in STA-5 fluctuated between 40 to 82 mg/L at inflow and between 30 to 88 mg/L at outflow (Figure 2). The average Ca concentration was 68 mg/L and 53 mg/L for inflow and outflow, respectively (Table 2). The inflow Ca concentration from ENRP was 84 mg/L. These concentrations are relatively high (Wetzel 2001). STA-5 removed over 20% of inflow calcium while ENRP removed only 5% of inflow calcium. Mechanisms for calcium removal are likely due to plant uptake and $CaCO_3$ precipitation.

This level of calcium in STA-5 did not appear to inhibit plant growth based on high plant coverage in STA-5 (Table 1). In fact, high plant coverage has been reported in wetlands and shallow lakes with much lower Ca concentrations than STA-5 (Bachmann et al. 2001; Knight et al. 2003).

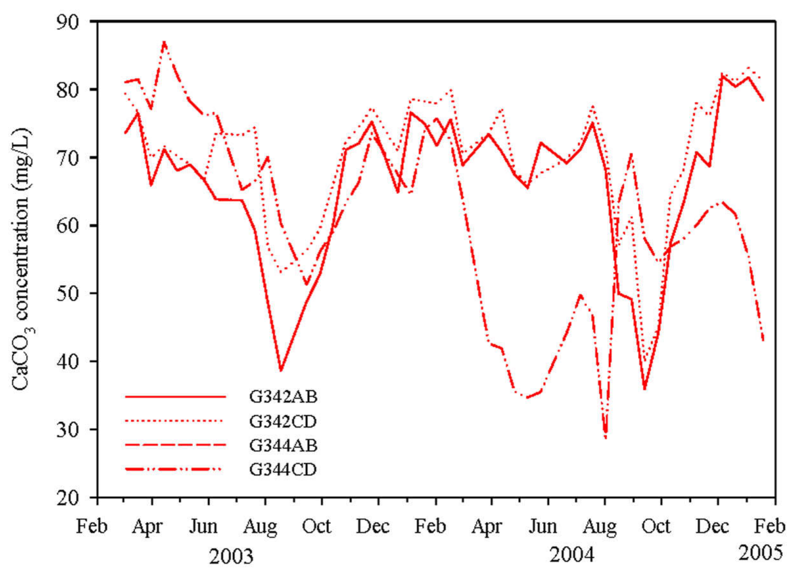

Figure 2. Seasonal variations in calcium concentration from inflow (G342AB and G342CD) and outflow (G344AB and G344CD) in STA-5.

Inflow alkalinity in both ENRP and STA-5 was over 200 mg $CaCO_3$/L (Table 2), indicating strong buffering capacity in both wetlands. High buffering capacity implies that STA-5 is capable of neutralizing the acid produced during microbial metabolism, allowing it to a stable pH environment for flora and fauna. This is evidenced by consistent pH in both inflow and outflow despite a net consumption of dissolved oxygen (DO) in STA-5 (Table 2 and Table 3).

Table 2. A comparison of pH, calcium and alkalinity for ENRP and STA-5. Data period is from 1/03-2/05.

Variables	ENRP	STA-5
Inflow pH	7.6	7.5
Outflow pH	7.4	7.4
Inflow Ca (mg/L)	84	68
Outflow Ca (mg/L)	80	53
Inflow alkalinity (mg $CaCO_3$/L)	248	204
Outflow alkalinity (mg $CaCO_3$/L)	248	161

Table 3. Average values of selected water quality variables from each culvert in STA-5. Data period for water quality and flow is from 10/99-2/05.

North Flow-Way	TP	Ca	Alkalinity	pH	DO	Flow
	µg/L	mg/L	mg $CaCO_3$/L	SU	mg/L	cfs
G342A	173	65.3	187	7.5	4.6	42.6
G342B	141	68.0	195	7.5	4.6	47.4
Average	**157**	**66.7**	**191**	**7.5**	**4.6**	**45.0**
G343B	94	57.7	172	7.3	2.4	
G343C	103	58.9	173	7.4	2.9	
Average	**99**	**58.3**	**173**	**7.4**	**2.7**	
G344A	69	44.3	139	7.6	2.8	52.6
G344B	87	45.3	138	7.7	2.7	45.1
Average	**78**	**44.8**	**139**	**7.6**	**2.8**	**48.9**
South Flow-way						
G342C	173	69.2	200	7.5	4.6	38.2
G342D	184	71.9	205	7.5	5.0	35.3
Average	**179**	**70.6**	**203**	**7.5**	**4.8**	**36.8**
G343F	114	65.8	196	7.2	2.3	
G343G	110	67.5	201	7.2	2.3	
Average	**112**	**66.7**	**199**	**7.2**	**2.3**	
G344C	147	60.7	204	7.3	3.1	27.1
G344D	120	60.8	200	7.4	3.3	22.9
Average	**134**	**60.8**	**202**	**7.4**	**3.2**	**25.0**

Internally, Ca and alkalinity decreased along each flow way with the north flow-way removing more calcium and total P than the south flow-way (Table 3). Dissolved oxygen also declined as the water moved through the wetland. However, pH showed its resilience to the decreases in Ca, alkalinity and DO concentration.

To evaluate if Ca concentration was sufficiently high to facilitate SRP removal by coprecipitation in STA-5, we calculated $CaCO_3$ saturation index (SI). Precise calculation of SI requires data for pH, Ca, alkalinity and all the other major ions. Unfortunately, these data are only available from a single sampling event at the STA-5 inflow culvert (G342). Using these data, a SI value of 0.05 was produced, indicating that the inflow water to STA-5 was slightly supersaturated with $CaCO_3$. Using data for an upstream site (G136) resulted in an average SI of 0.45. The two dates on which of SI indicated $CaCO_3$ undersaturation resulted from low inflow pH, Ca and alkalinity (Figure 3). Nevertheless, this average is comparable to the average SI values of 0.13 and 0.14 from G250 and G251 of the ENRP (Gu et al. submitted), indicating that Ca concentration was sufficiently high to facilitate SRP removal by coprecipitation.

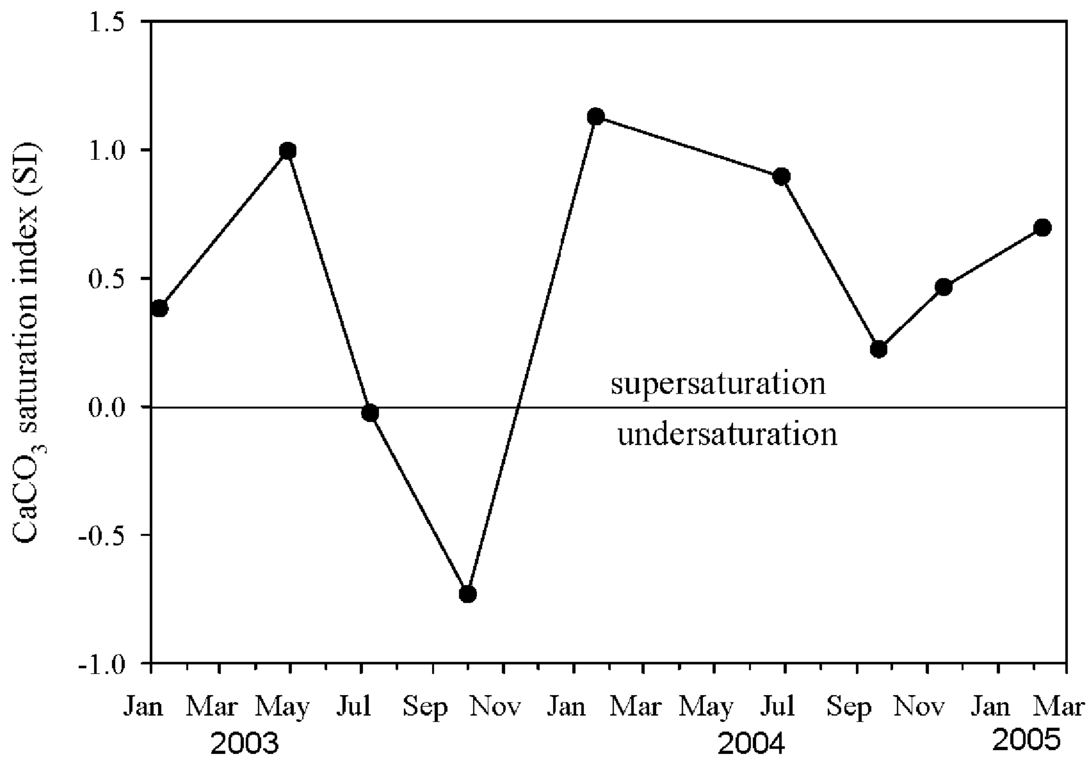

Figure 3. $CaCO_3$ saturation index calculated from data for G-136.

(2) P removal performance in other wetlands with similar Ca concentration to STA-5

The first example is Stormwater treatment Area 1 West (STA-1W) Cell 5B. This cell had similar Ca and alkalinity to STA-5 (Tables 2 and 4). Average inflow and outflow total P concentrations at Cell 5B were 136 and 65 μg/L between July 2000 and January 2004. Total P reduction in STA-1W Cell 5B was 52% compared to only 37% in STA-5.

This suggests that the poor performance in STA-5 cannot be attributed to calcium concentration and alkalinity.

Table 3. Selected water quality variables in STA-1W Cell 5 B. Data period is from 7/00-7/04.

Variable	DO	pH	Ca	Alkalinity	Total P
Unit	mg/L	SU	mg/L	mg/L	μg/L
Inflow (G305s)	3.2	7.5	76	231	136
Outflow (G306s)	3.1	7.8	60	188	65

Secondly, Knight et al (2003) recently analyzed total P removal performance in natural SAV systems including rivers and lakes in Florida. The natural systems had an average Ca concentration of less than 50 mg/L and however showed high efficiency of total P removal with an average settling rate constant (k) of 15 m/yr. Knight et al (2003) also reported an inflow Ca concentration of ~10 mg/L and a k value of 32 m/yr in Seminole Lake.

Conclusions

The above information suggests that total P removal in wetlands with similar or lower Ca concentration demonstrates better results than STA-5. We conclude that (1) Ca concentration is not low in STA-5 compared to other shallow lakes and wetlands in Florida and (2) the high outflow concentration and low removal efficiency for total P in STA-5 were not the results of low Ca and alkalinity. We suggest that factors, such as total P overloading (Table 1) and possible hydraulic short-circuiting, be the alternative explanations for the poor total P removal performance in STA-5.

References

APHA, 1998. Standard Methods for the Examination of Water and Wastewater, 20th Edition. American Public Health Association, American Water Works Association and Water Pollution Control Federation, Washington, DC, 1162 pp.

Bachmann RW, Horsburgh CA, Hoyer MV, Mataraza LK and Canfield DE (2002) Relations between trophic state indicators and plant biomass in Florida lakes. Hydrobiologia 470: 219-234.

Gu B, Chimney MJ, Newman J and Nungesser MK A limnological survey of a constructed wetland in south Florida. Submitted to Ecological Engineering.

Knight RL, Gu B, Clarke RA and Newman JM (2003) Long-term phosphorus removal in Florida aquatic systems dominated by submerged aquatic vegetation. Ecological Engineering 20: 45-63.

Wetzel RG (2001) Limnology: Lake and River Ecosystems, 3rd Edition. Academic Press, San Diego, CA, 1006 pp.