C-139 Basin BMP Evaluation of Above Ground Impoundments (AGI): Hydraulic Assessment of an AGI

Final Report

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Executive Summary

A tracer study using the compound lithium chloride (LiCl) was performed at a permitted above-ground impoundment (AGI1) at C&B Farms in the C-139 Basin from September 10-14, 2012. Monitoring of lithium concentrations over time at the two adjacent outflow weirs enabled the characterization of the hydraulic efficiency of the AGI. The inflow (mean of 3427 m^3/hr [15,092 gpm]) and water depth (mean of 0.52 m) conditions that prevailed during the study indicated that AGI1 exhibited low hydraulic efficiency (short circuiting and high dispersion), with a tank-in-series number of 1.4. Measured hydraulic retention time was 1.10 days, with a tracer recovery of 105%. Internal sampling of both lithium and total phosphorus confirmed the poor hydraulic conditions indicated by the tracer response curve.

Introduction and Background

Numerous tracer projects conducted within wetlands indicate that flow patterns can depart widely from ideal plug-flow characteristics and that hydraulic short-circuits and dead zones may exist (Dierberg et al. 2005; Kadlec and Wallace 2009). Hydraulic short-circuits may result in a portion of the influent water reaching the outflow of the system well before the calculated hydraulic residence time (HRT), thereby reducing the phosphorus (P) removal efficiency of the system. These non-ideal flow patterns typically remain intact until the water is redistributed by structural means, such as relocation of inflow pumps or discharge weirs. The addition of levees, earthen berms, or vegetated strips that partition the treatment cell into semi-discrete areas are additional structural alterations that can be deployed.

In fiscal years 2009 and 2010, the South Florida Water Management District (District) funded two demonstration projects to improve the performance of above-ground impoundments (AGIs) to reduce P in discharges. One project evaluated the performance of an AGI built in accordance with Environmental Resource Permitting (ERP) criteria (basic AGI), and another evaluated the performance of an AGI where structural modifications, above and beyond ERP criteria, were implemented to improve P removal (modified AGI). As part of the basic AGI evaluation, completion of a tracer study was proposed. However, the test could not be conducted because of drought conditions. In fiscal year 2012, the District contracted DB Environmental, Inc. (DBE) to evaluate how features affect transport and removal in the basin AGI, thus justifying modifications to improve performance. This report describes the methodology and results of the hydraulic investigation performed by DB Environmental, Inc. (DBE) during September 2012.

Objective

The overall objective of this project was to assess the hydraulic efficiency and P removal performance of the basic AGI (designated AGI1) under a specified hydraulic loading and depth regime. This effort was conducted during the 2012 wet season, when there was sufficient water on the farm to generate continuous surface inflow to the basic AGI.

Location and Description of the AGI1

AGI1 is located within C&B Farms near Clewiston, FL, in Hendry County. The farm totals 1677 acres, and is located at the far southeast corner of the C-139 Basin and immediately west of STA-5 (Figure 1). An aerial photo of the farm and the AGIs are shown in Figure 2. The cultivated areas of the farm are characterized by Myakka and Immokalee fine sand soils, while the AGIs contain predominantly Myakka and Basinger fine sands (Shukla et al. 2011). A variety of vegetables and herbs are grown on the farm.

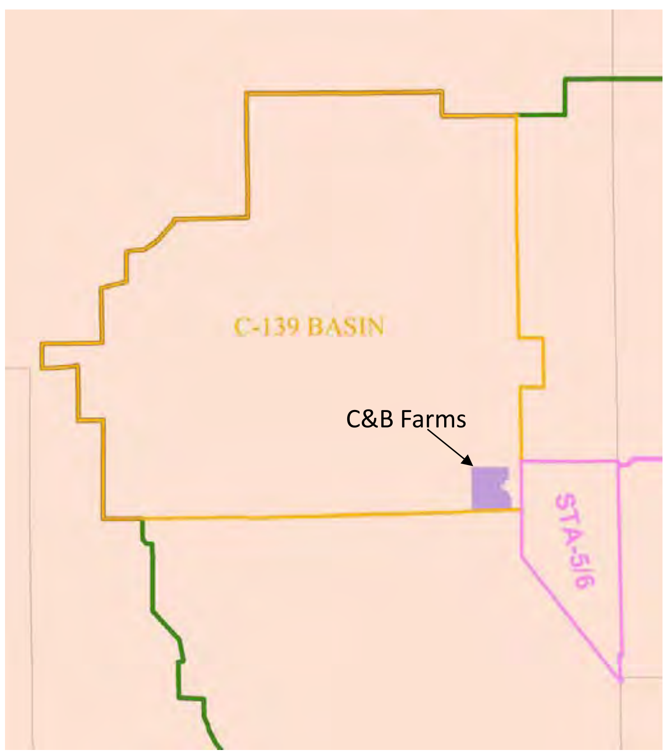

Figure 1. Location of C & B Farms in the C-139 Basin and its relation to STA-5/6 (Shukla et al. 2011)

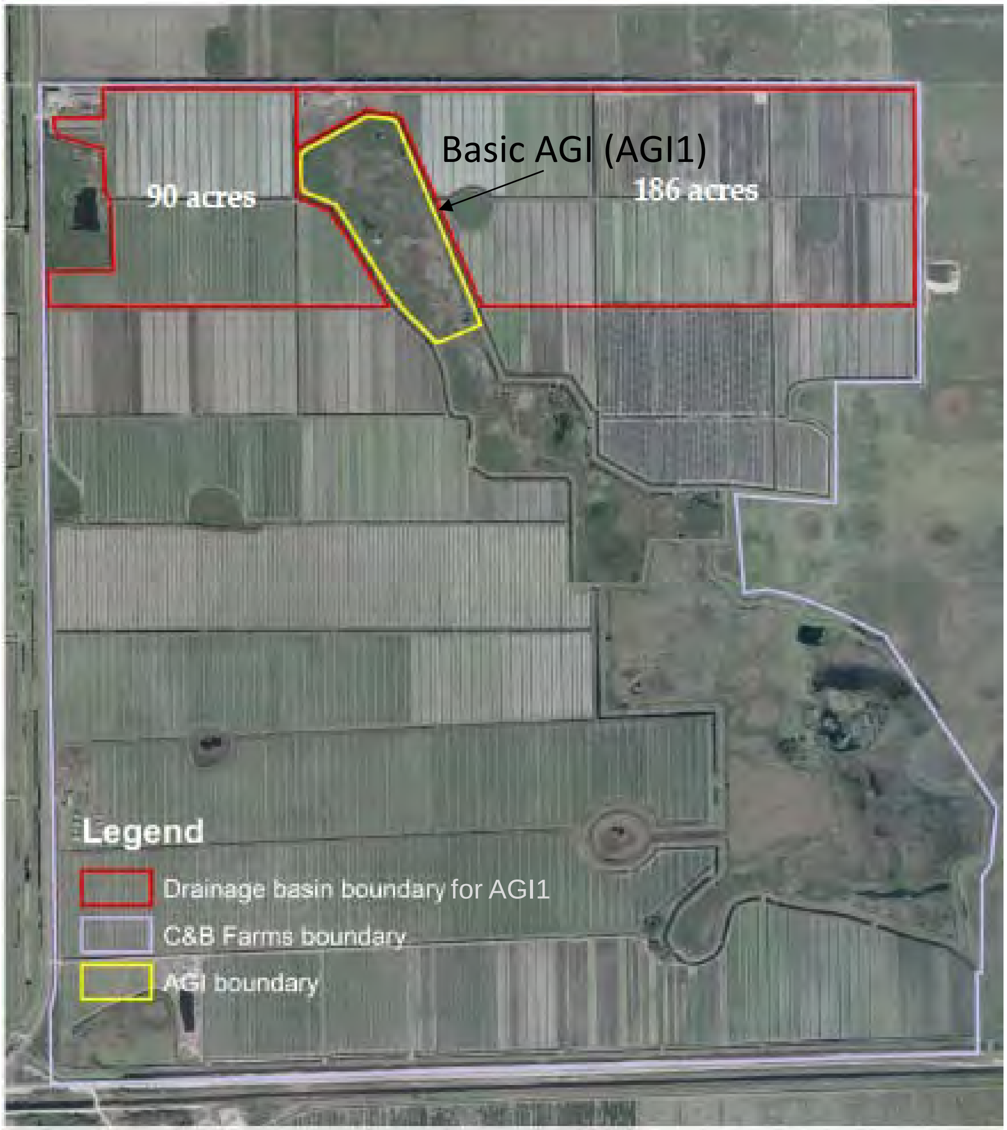

Figure 2. Aerial photo of AGI1. Modified from Shukla et al. (2011).

The cultivated areas within the farm are irrigated with a combination of drip and seepage irrigation. Both groundwater and surface water are utilized for irrigation. The farm drainage system takes advantage of the same conveyance canal system to route drainage water towards three connected AGIs. The drainage water is pumped into the AGIs by surface water pumps commonly called 'throw-out pumps' that are distributed around the AGIs' perimeter. The farm is divided into drainage basins to more efficiently drain the farm when necessary. By adjusting the flashboards in the risers located in the canals, water is routed to the nearest pump during drainage events. The pumps and the AGIs were designed and sized according to the area of their corresponding drainage basins and the potential runoff (Shukla et al. 2011).

The AGI (AGI1) studied in this project is the first of the three AGIs. AGI1 is 36.7-acres and designed to receive drainage from approximately 267 acres of the farm (Shukla et al. 2011). Drainage water is pumped into the AGI via three diesel-operated surface-water axial flow pumps (Figure 3). Note that for the purpose of this tracer study, only Pump Nos. 1 and 2 were operational, since these pumps are used more frequently than Pump 3, as documented in the 2009-2010 demonstration project (Shukla et al. 2011). The discharge structure of AGI1 (Figure 3) is located at the southern extreme of it and consists of two sharp crested weirs set at 19.5' NGVD29 (18.12' NAVD88). A 'borrow ditch' is located around almost the entire interior perimeter of the AGI. This 'borrow ditch' was created during construction when material excavated from inside the AGI was used to provide the necessary soil to construct the AGI embankment. The remaining interior of the AGI is characterized by flat, nearly level ground with the exception of four depressions, three of which are jurisdictional wetlands (Shukla et al. 2011).

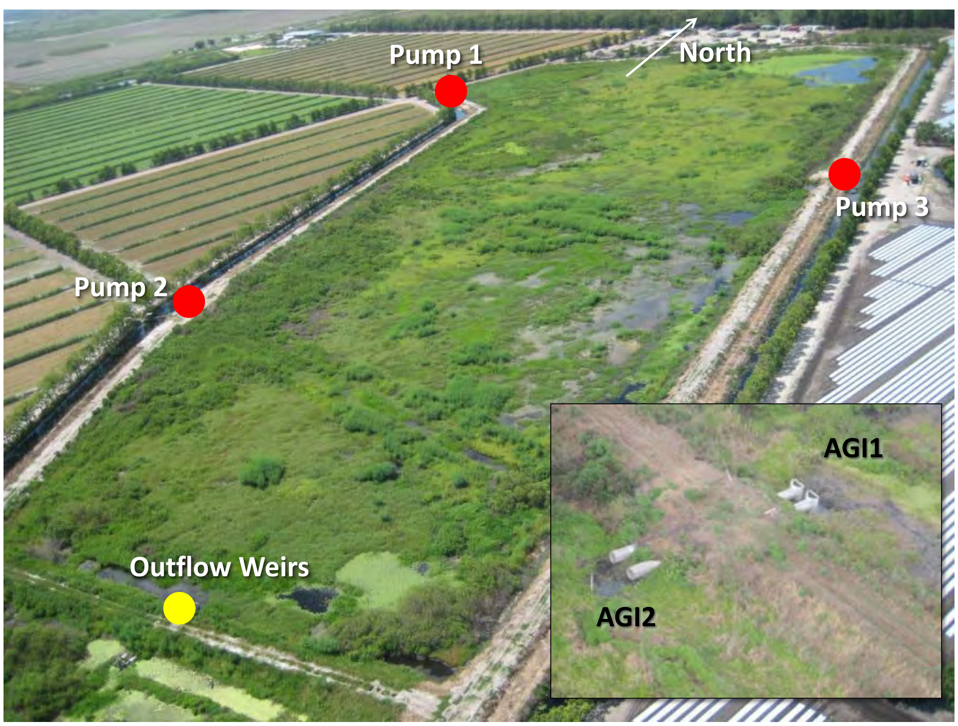

Figure 3. Aerial photo of AGI1 showing the three inflow pump stations and the outflow weirs. The inset is a photo of the outflow weirs. The pulse tracer (lithium chloride) injection and hydraulic loading characterization during the study were performed only at Pump Nos. 1 and 2. Tracer and total phosphorus concentrations were monitored in the surface waters at the inflow pumps, outflow weirs and at internal stations (Figure 5).

Site Visits Prior to Tracer Injection

Several site visits were conducted on the farm prior to injecting the tracer and subsequent monitoring. During the initial visit on May 9, 2012 (Figure 4), Forrest Dierberg, the DBE project manager, and four other DBE employees evaluated the logistical and technical aspects of conducting the surveys, the tracer test and subsequent hydraulic analyses. The tracer injection sites were selected, and the internal station locations (Figure 5) and equipment needs were assessed. Information from the initial site visit was incorporated into the Project Work Plan (Appendix A).

Figure 4. Representatives from the District, C&B Farms, and DBE who participated in the initial site visit on May 9, 2012.

A total of five follow-up trips (August 3, 7, 10, 23, and 30) were made to the site for calibrating Pump Nos. 1 and 2 (Figure 6) at various supply canal depths, and for surveying ground elevations and control structures in AGI1. An additional pre-injection trip was made on September 6 for setting up and conducting a trial tracer injection, and for further pump calibration. Canal water was used as a substitute for the lithium chloride (LiCl) tracer during this trial. Also on September 6, stations were located and marked along the internal transect (Figure 7), the pressure transducer was deployed (Figure 8), and autosamplers were tested.

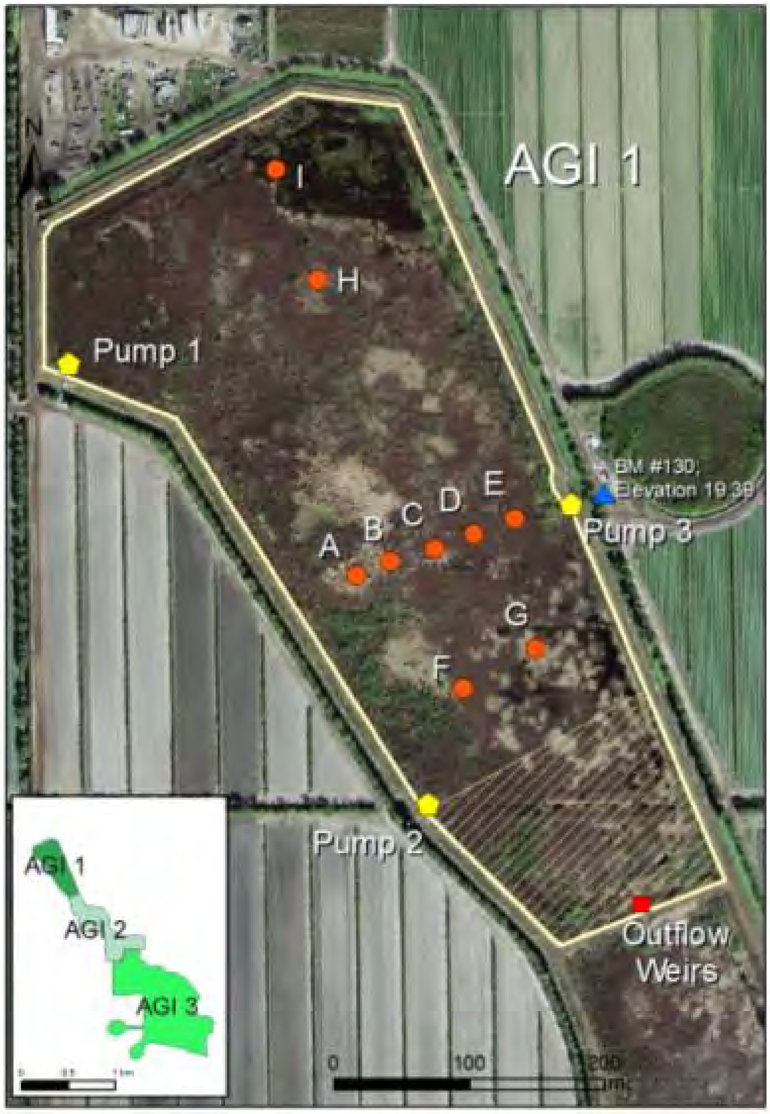

Figure 5. Locations of Pump Nos. 1 - 3, the outflow weir, and the internal stations (A-I) in AGI1. The pulse tracer (LiCl) injection and hydraulic loading characterization during the study were performed only at Pump Nos. 1 and 2. The cross-hatched area in the southern part of AGI1 represents the area assumed to receive discharge from Pump No. 2. The Benchmark #130, elevation 19.39 NGVD29, was used as the datum for survey points collected in AGI1 by DB Environmental, Inc.

Figure 6. Flow calibration at Pump 2 on August 3, 2012. The inset shows the flow sensor inserted into the pipe of Pump 1 and the meter indicating flow in gallons per minute.

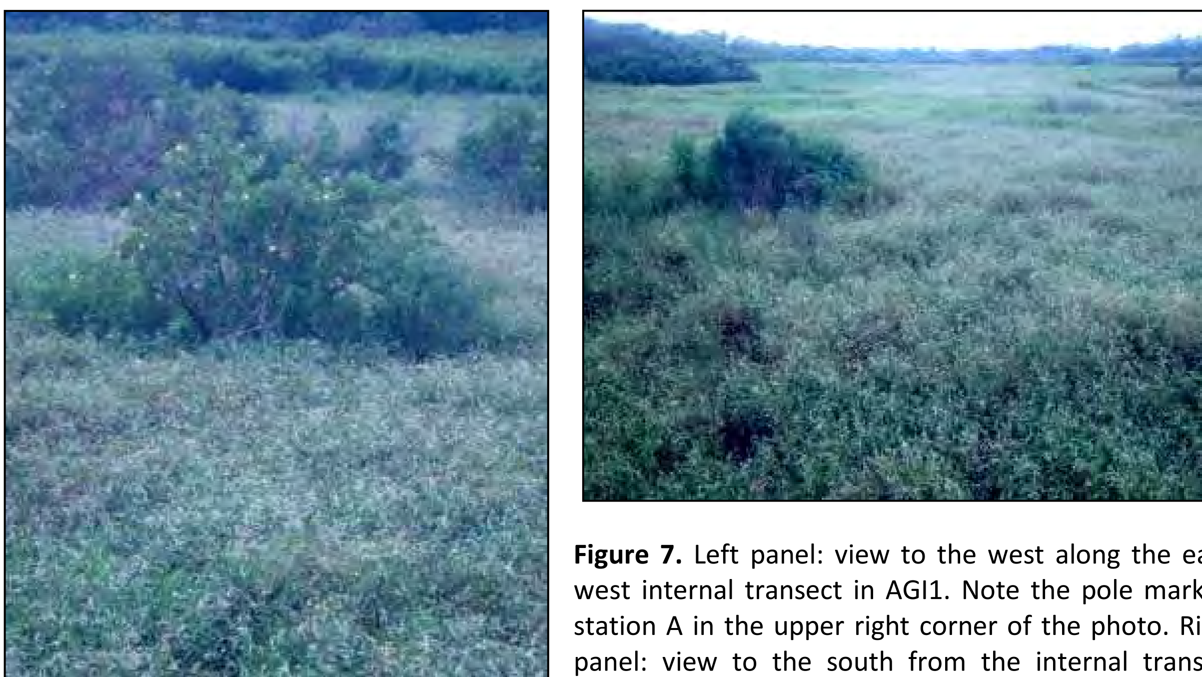

Figure 7. Left panel: view to the west along the east-west internal transect in AGI1. Note the pole marking station A in the upper right corner of the photo. Right panel: view to the south from the internal transect towards the southern berm of AGI1.

Figure 8. Deployment of the pressure transducer near the outflow weirs of AGI1 on September 6, 2012.

Methods

Topographic Survey in AGI1

DBE performed a limited survey of AGI1 to confirm a subset of the ground elevations reported in the more extensive survey by Shukla et al. (2011), and to help determine stage elevations and outflow weir discharges during the tracer and P monitoring period. All survey work was referenced to Benchmark #130, located near Pump 3 on the outside east perimeter of AGI1 (Figure 5).

Pump Inflow Calibration

Pump Nos. 1 and 2 were calibrated on August 3, 7 and 30, and September 6, when the supply canal water depths ranged from 1.29 - 1.77 m (4.23 – 5.81 ft). An insertion style paddle wheel flow sensor (George Fisher, Signet 2540 flow sensor and Signet 8550 flow transmitter) was placed into a 2-in diameter female fitting on top of the flange of the 24-in diameter pipe (Figure 6). A compression coupling between the sensor head and the female fitting prevented leakage of water from inside the pipe around the sensor insert. We varied the pump tachometer speed between 1000 and 1700 revolutions per minute (rpm) for Pump Nos. 1 and 2. For each flow measurement made at a specified pump speed, DBE independently verified the pump tachometer reading with a CEN-TECH™ Model 66632 photo optical tachometer. Lastly, to verify that the flow sensor was reading the volumetric flow accurately, DBE replaced it with a separate flow sensor of the same make and model during one of the pump settings. The agreement between the two sensors was between 95 and 99%.

Tracer Injection

One drum (55 gallons) of 52.4% LiCl (107,600 mg Li/L) was injected into AGI1 between 12:00 and 12:15 pm on September 10, 2012. Since the inflows from Pumps 1 and 2 were maintained at approximately equal flow rates (6655 and 6748 gpm, respectively) during the tracer injection period, DBE delivered one-half (27.5 gallons) of the contents of the one drum to each of the two inflow pump pipes. The delivery system consisted of diluting 27.5 gallons of LiCl in 192.5 gallons of canal water (Figure 9) prior to injecting it into the pipe of each pump by means of single-cylinder centrifugal pumps (Honda 4-stroke WX10 25cc pump with 37 gal/min maximum discharge capacity and an Echo WP-1000 2-stroke 21.2 cc pump with 27.7 gal/min maximum discharge capacity). The injection port of each pipe was the same as those used for the flow calibration.

The total mass of Li injected was 22.41 kg (49.40 lb). If this mass of Li was to be instantaneously mixed throughout the nominal wetland volume (76,000 m^3), then a Li concentration of 0.295 mg/L would be achieved.

Figure 9. Infrastructure for delivering the LiCl tracer to the pipe in Pump No. 1. The blue tub contained 220 gallons of diluted (1:8) concentrated LiCl solution. The 5-gal orange buckets contained supply canal water used for rinsing the blue tub of residual LiCl after nearly all of it was pumped to the inflow pipe.

Flow and Stage Data

Inflow rates from Pump Nos. 1 and 2 were periodically recorded by manually reading the rpm of the tachometers on each pump whenever DBE personnel were visiting the site during the tracer and P monitoring period (September 10-14). The tachometer readings were converted to volumetric flow rates via regression equations derived from previous calibration exercises (see Results section).

DBE also measured the volumetric outflow rate from the impoundment. The Kindsvater-Carter rectangular weir equation (IS0 1980) (Eq 1) for the twin 43-in long sharp-crested weir yielded discharge volumes depending on the water height above the weir crest, which was determined by the difference between the stage elevation of the standing water in the impoundment and the elevations of the two weirs (19.57 ft and 19.67 ft NGVD29 for east and west weirs, respectively), previously surveyed. A more detailed explanation of the Kindsvater-Carter equation can be found at http://www.lmnoeng.com/.

$$Q = C_e \frac{2}{3}\sqrt{2g}(b+K_b)(h+K_h)^{3/2} \qquad (1)$$

Where Q = discharge [L^3/T]; C_e = discharge coefficient; g = acceleration of gravity [L/T^2]; b = notch width [L]; h = head [L]; K_b and K_h account for effects of viscosity and surface tension [L].

The water depths within the impoundment during the monitoring period were continuously logged at one-hour Intervals by an Onset HOBO pressure transducer (range 0-4 m). The transducer was calibrated against the elevation of the nearby staff gauge (Figure 8). Rainfall data recorded at the C&B Farms weather station was minimal (0.06 inch) during the four-day monitoring period.

Tracer and Phosphorus Monitoring

DBE periodically measured the Li and total P (TP) concentrations at the inflow points to AGI1 at or near the discharges from Pump Nos. 1 and 2 (Table 1). For TP, the stream of water discharged from the pump pipe was sampled prior to being mixed with surface water of the mixing zone below (Figure 10). This prevented the inclusion of resuspended solids that might have occurred if the sample had been collected from the mixing zone immediately below the pipe outfall.

Table 1. Schedule of grab samples collected at inflow Pump Nos. 1 and 2 for lithium and TP analyses, and at the outflow weir for TP analysis only.

Date	Time
9/10/2012	10:15-12:05
9/10/2012	15:45-16:25
9/11/2012	09:00-09:10
9/11/2012	16:30-17:30
9/12/2012	08:45-09:30
9/12/2012	13:45-14:00
9/14/2012	10:05-10:15

Figure 10. Sampling the discharge from the inflow pump for total phosphorus analysis.

At the AGI's outfall, the LiCl tracer was collected by two ISCO Model 6712 automatic samplers (Figure 11), which provided a measure of redundancy in case of failure by one of the samplers. The twin automatic samplers also provided a means of collecting field duplicate samples. Sampling intervals were every 0.5 hr for the first 4 hours after tracer injection, then every hour for the next 47 hours, and finally every two hours for the last 46 hours. Grab samples for TP analysis at the outflow weirs occurred according to the schedule shown in Table 1.

Figure 11. Twin ISCO portable samplers powered by batteries and solar panels were deployed at the outflow weirs (shown in the background).

DBE also collected surface water samples at internal stations within the impoundment using an airboat for Li and TP analyses (Figure 5) at elapsed times of 3, 21, 45, and 95 hours after injection of the tracer (12:00-12:15 on September 10, 2012).

Laboratory Methods

Li was analyzed on filtered, field-preserved (pH < 2 with nitric acid) samples by EPA 7430 (USEPA 1992). Analysis of the Li samples was completed well before the six-month holding time had expired. After preserving the unfiltered TP samples with sulfuric acid to pH < 2, the sample bottles were placed on ice in the field and then refrigerated at 4°C until analyzed within the 28-day holding time according to SM 4500-P F after digestion (APHA 1992). DBE is certified under NELAP (National Environmental Laboratory Accreditation Program) for both Li and TP analyses.

Quality Assurance

A rigorous quality assurance program was followed in the field and laboratory, starting with equipment blanks. Equipment blanks for Li and TP were collected at the site from both ISCO automatic samplers prior to deployment to be certain that there was no contamination associated with the internal tubing of the samplers. TP and Li concentrations in the blanks from both automatic samplers were below the method detection limits (MDLs) of 0.003 and 0.010 mg/L, respectively.

Field-filtered blanks were also collected during each internal sampling event, and never exceeded the Li or TP MDLs. Since duplicate autosamplers were deployed at the outflow weirs, DBE analyzed the Li concentrations in 60 pairs of field replicate samples, and found a mean relative standard deviation (rsd) of only 4.8%.

Table 2 provides the frequency of analysis and acceptance criteria for the laboratory analyses of the Li and TP concentrations. A secondary Li standard obtained from a different vendor (Spectrum or RTC) than the primary standard source (GFS) was included each day that analyses were performed. All laboratory duplicates, blanks, matrix spikes, and check standards associated with the tracer study were within the acceptance criteria presented in Table 2.

Table 2. List of Quality Assurance Checks performed, and their respective frequency and acceptance criteria.

			Acceptance Criteria	
Quality Assurance Checks	**Analysis Frequency**		**Lithium**	**TP**
Method Detection Limit (MDL)	na		0.010 mg/L	0.003 mg/L
Method Blank	Initially, and 1 per analytical batch[1]		<MDL or < 10X LSC††[2]	<MDL or < 10X LSC††
Certified Reference Material[3]/ Independent Check Standard	Initially	%R	L†: 75-125 M-H†: 80-120	L†: 75-125 M-H†: 85-115
Continuing Check Standard	Initially, and 1 per analytical batch[1]	%R	90-110[2]	90-110
Lab Duplicate	1 per analytical batch[1]	%RSD	L†: 0-30 M-H†: 0-10	L†: 0-40 M-H†: 0-20
Matrix Spike	1 per analytical batch[1]	%R	85-115[4]	L†: 70-130 M-H†: 80-120
Coefficient of Determination	Initially	r^2	≥0.99	≥0.99

[1] An analytical batch typically refers to 20 discrete samples.
[2] Performed every 10 samples for this analysis.
[3] Acceptable ranges provided in the manufacturer's sheet are followed.
[4] A Matrix Spike Duplicate is also required according to the method.
† L: Low concentrations ranging from 0-20% of the linear curve, or ≤20 times the MDL; M-H: Moderate to high concentrations ranging from >20-100% of the linear curve, or >20 times the MDL.
†† <10X LSC refers to when a method blank result can be accepted if the method blank result is less than 10 times the lowest sample concentration (LSC) in the analytical batch.
%R= percent recovery; **%RSD**= percent relative standard deviation

Computations for determining hydraulic parameters

Calculations for determining selected hydraulic parameters for AGI1, according to the tracer data collected at the outflow, were performed as follows.

The nominal hydraulic retention time HRT (τ) is the volume of water in the treatment impoundment (V) divided by the volumetric inflow rate of water (Q):

$$\tau = V/Q \qquad (2)$$

The tracer mean residence time (τ_a) is defined as the average time (days) that a tracer particle spends in the impoundment, and is the first moment of the residence time distribution (RTD) function (Equation 3). The RTD represents the time various fractions of water spent in the impoundment. It is the contact time distribution for the system and defines the key parameters that characterize the actual detention time (Kadlec 1994). Levenspiel (1989) uses the RTD in the analysis of reactor behavior.

The mean residence time (Equation 3) was calculated by dividing the first moment of the tracer flow distribution (M_1; Equation 5), by the outflow tracer mass (M_0; Equation 4), both of which are based on mean flow rates and outflow tracer concentrations (Kadlec 1994):

$$\tau_a = M_1/M_0 \qquad (3)$$

$$M_0 = \int_0^{t_f} Q_e(t)C(t)dt \qquad (4)$$

$$M_1 = \int_0^{t_f} tQ_e(t)C(t)dt \qquad (5)$$

where C(t) = outflow tracer concentration (g/m^3); Q_e = flow rate (m^3/day); t = elapsed time (days); and t_f = total time span of the outflow pulse (days).

To find the RTD, the concentration response curve (experimental C(t) vs. t) was converted to an E_t curve by changing the concentration scale so that the area under the response curve is unity (Levenspiel 1989). This was accomplished by multiplying the concentration readings by the volumetric flow rate divided by the mass (M) of injected tracer:

$$E_t = C(Q_e/M) \qquad (6)$$

where E_t = RTD function in reciprocal time units.

The RTD function is normalized when it is expressed in terms of a dimensionless time scale by multiplying the Y-axis (i.e., the E_t function) units by τ (the nominal HRT):

$$E_\Theta = \tau E_t \qquad (7)$$

where E_Θ= normalized RTD function, and dividing the time units of the X-axis by τ:

$$\Theta = t/\tau \qquad (8)$$

where Θ = dimensionless time scale and represents the number of mean HRTs.

These manipulations change the X and Y axes so that the area under the curve is still equal to one, but the Y and X axes are normalized to τ (Levenspiel 1972). The purpose of creating the normalized RTD function, E_Θ, is to be able to compare the flow performance among impoundments of different sizes and containing different plant communities and densities.

Whereas τ_a represents the centroid of the distribution and is the first moment of the RTD, the variance (σ^2) is the square of the spread of the distribution, or a measure of the dispersive processes, and is expressed in units of $(\text{time})^2$:

$$\sigma^2 = \frac{\int_0^{t_f} t^2 Q_e(t)C(t)dt}{\int_0^{t_f} Q_e(t)C(t)dt} - \tau_a^2 \qquad (9)$$

The variance, which is the second moment of the RTD, is particularly useful for matching experimental curves to one of a family of theoretical curves (Levenspiel 1972).

The variance can be rendered unit-less by dividing it by the square of the tracer detention time:

$$\sigma_\Theta^2 = \frac{\sigma^2}{\tau_a^2} \qquad (10)$$

where σ_Θ^2 is the dimensionless variance of the tracer pulse.

A common one-parameter model used to characterize non-ideal flows is the tank-in-series (TIS) model (Levenspiel 1972). The TIS model views flow through a series of equal-size ideal stirred tanks, and the parameter in this model is the number of tanks (N) in the chain. The number of constantly stirred tanks in the series that best matches the tracer response curve is given by N, which is inversely related to the dimensionless variance:

$$\sigma_\Theta^2 = \frac{1}{N} \qquad (11)$$

Results

Topographic Survey in AGI1

The reported ground elevations for five previously surveyed stations by Shukla et al. in March 2009 were slightly lower than the elevations of those same stations surveyed by DBE in August 2012 (Table 3). These differences are likely due to sedimentation during the intervening 2.5 years between surveys.

Table 3. Ground elevations in AGI1 for the same locations surveyed by Shukla et al. in March 2009 and DB Environmental (DBE) in August 2012. All data are in feet referenced to NGVD29.

	Ground Elevation		
Shukla Station No.	**Shukla (2009)**	**DBE (2012)**	**Difference**
7	18.85	19.01	0.16
10	18.84	18.94	0.10
17	18.82	19.00	0.18
19	18.86	19.02	0.16
22	18.77	18.80	0.03

DBE was able to calculate the mean water depth (Table 4) at various discharge rates over the two weirs by calculating the difference in the mean bottom contour elevations in the impoundment reported by Shukla et al. and the height of water cascading over the weirs at selected flow discharges (based on Equation 1). This allowed DBE to determine the volume of water contained within the impoundment for various weir discharge rates, which assumes the stage in the impoundment is controlled by the outflow weirs.

Table 4. The height above the west and east weirs, water elevation (relative to BM 130 referenced to NGVD29), and average cell depth for given flow rates at the weirs. All units are in feet except flow rates, which are in gallons per minute (gpm).

Flow (gpm)			Height Above Weirs		Water	AVG. Cell
West	East	Total	West	East	Elevation	Depth
5090	6000	11090	0.95	1.05	20.62	1.62
5513	6500	12013	1.00	1.1	20.67	1.67
6036	7000	13036	1.06	1.16	20.73	1.73
6487	7500	13987	1.11	1.21	20.78	1.78
6949	8000	14949	1.16	1.26	20.83	1.82
7423	8500	15923	1.21	1.31	20.88	1.87
7910	9000	16910	1.26	1.36	20.93	1.92
8409	9500	17909	1.31	1.41	20.98	1.97
8920	10000	18920	1.36	1.46	21.03	2.02
9337	10500	19837	1.40	1.50	21.07	2.06
9870	11000	20870	1.45	1.55	21.12	2.10
10304	11500	21804	1.49	1.59	21.16	2.14
10746	12000	22746	1.53	1.63	21.20	2.18
11195	12500	23695	1.57	1.67	21.24	2.22
11767	13000	24767	1.62	1.72	21.29	2.27
12232	13500	25732	1.66	1.76	21.33	2.31
12706	14000	26706	1.70	1.80	21.37	2.35
13186	14500	27686	1.74	1.84	21.41	2.38
13551	15000	28551	1.77	1.87	21.44	2.41

Pump Inflow Calibration

The results of the regression analyses of pump speed (rpm) versus discharge rate (gpm) as a function of stage are shown in Figure 12. The 0.74-0.78 m (2.43-2.56 ft) stages corresponded to water depths in the supply canal of 1.72-1.77 m (5.64-5.81 ft) whereas the 0.20 m (0.66 ft) to 0.45 m (1.48 ft) stages were equal to 1.13-1.47 m (3.71-4.82 ft) water depths. Note that the linear relationship does not exist for pumping rates < 1200 rpm for Pump 1 and < 1000 rpm for Pump 2 because the pipes do not flow full below those rates. Therefore, DBE operated the pumps near or above those cut-off rates during the study period. The raw data for each of the flow measurements are shown in Table B-1, along with the percent agreement between the pump and optical tachometers.

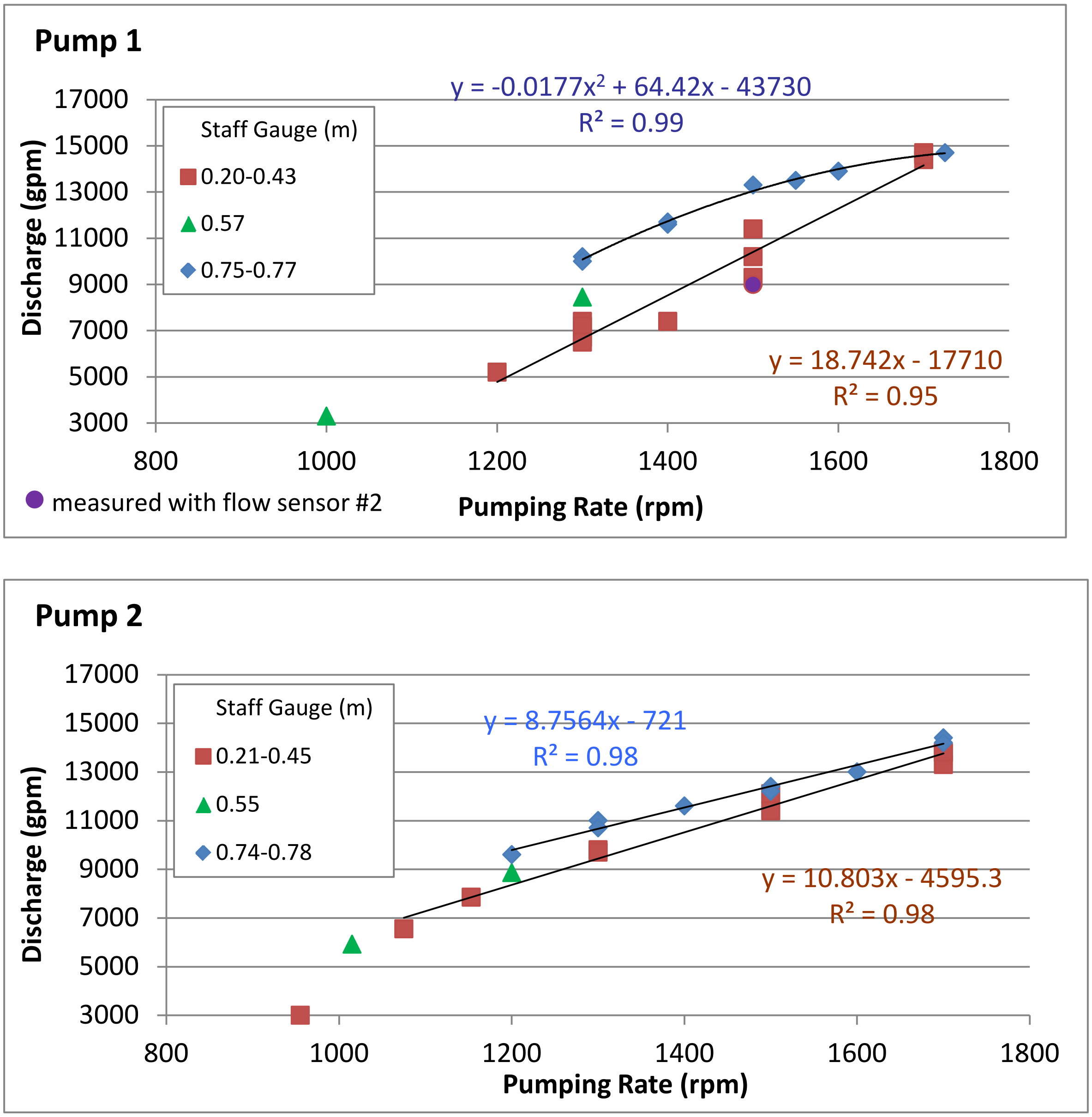

Figure 12. Pump regression equations predicting discharge volume (gallons per minute (gpm)) as a function of pump revolutions per minute (rpm) and stage for Pump Nos. 1 and 2 at AGI1. The two regression lines shown for each pump represent the relationship between pumping rate and discharge for water elevations of 0.74-0.78 m (2.43-2.56 ft) (upper line) and 0.20-0.57 m (0.66-1.87 ft) (lower line) in the supply canal.

Hydraulic and Hydrologic Conditions

Due to a malfunction of one of the pumps providing water from outside the farm to the supply canal from where Pump Nos. 1 and 2 draw water, the water level in the supply canal dropped to such low levels in the morning (September 10) prior to the injection that Pump Nos. 1 and 2 were temporarily turned off until repairs could be made to the outside perimeter pump. As a result, it wasn't until 21 hours after tracer injection when a more-or-less a steady-state stage level was achieved (Figure 13). During the study, the stage ranged from 20.41 to 20.83 ft NGVD29 (Figure 13). This equates to water depths of 0.44 to 0.55 m (1.44 to 1.80 ft) (Figure 13). The average water depth was 0.52 m (1.71 ft) based on the previous survey performed by Shukla et al. (2011) (but adjusted for an average sedimentation of 0.13 ft) and the predicted water surface height above the weirs at given volumetric outflow discharge rates.

DBE calculated the average discharge from AGI1 as being 21% less than the average inflows (64,300 vs 81,540 m^3/day) during the four-day study monitoring period. The water balance would have been closer if evapotranspiration (10% of the outflow according to Shukla et al. 2012) had been included. Possible deflection of the outflow weirs, and uncertainties in the measurements and calculations of the discharges from the inflow pumps and outflow weirs, could also have contributed to the disparity in the average inflow and outflow.

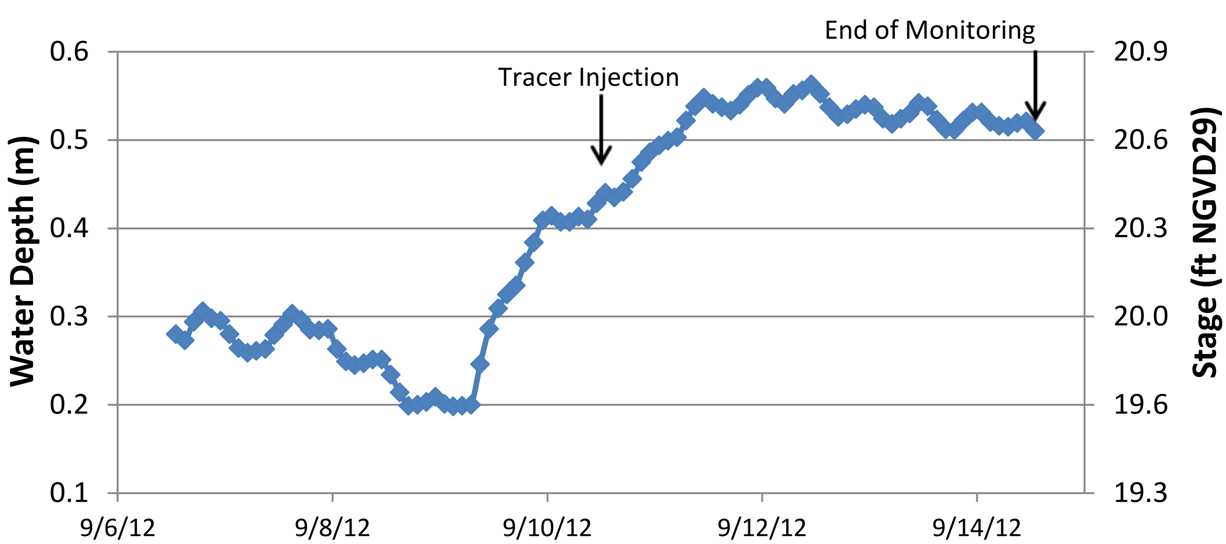

Figure 13. Stage elevations and water depths in AGI1 before and during (September 10 – 14, 2012) the tracer study.

Outflow Tracer Concentrations

The tracer response profile indicates that background Li concentrations at the outflow weirs for the first 3 hr after tracer injection (12:00 to 12:15 on September 10, 2011) were below the MDL of 0.010 mg/L (Figure 14). Thereafter, the tracer concentration increased dramatically, reaching a peak concentration of 0.440 mg/L after an elapsed time of 9 hr from tracer injection. From this peak concentration, Li concentrations decreased just as dramatically as they had increased until 13 hr post-injection, from where the decrease was more gradual until reaching a minimum of 0.013 mg/L after 31 hours. From this concentration "trough", the Li concentrations increased to 0.115 and 0.125 mg/L in double secondary peaks at 40 and 50 hours, respectively. After 89 hours, Li concentrations decreased to near background levels of 0.011 mg/L. A complete listing of Li concentration data for the outflow is provided in the Appendix C (Table C-1).

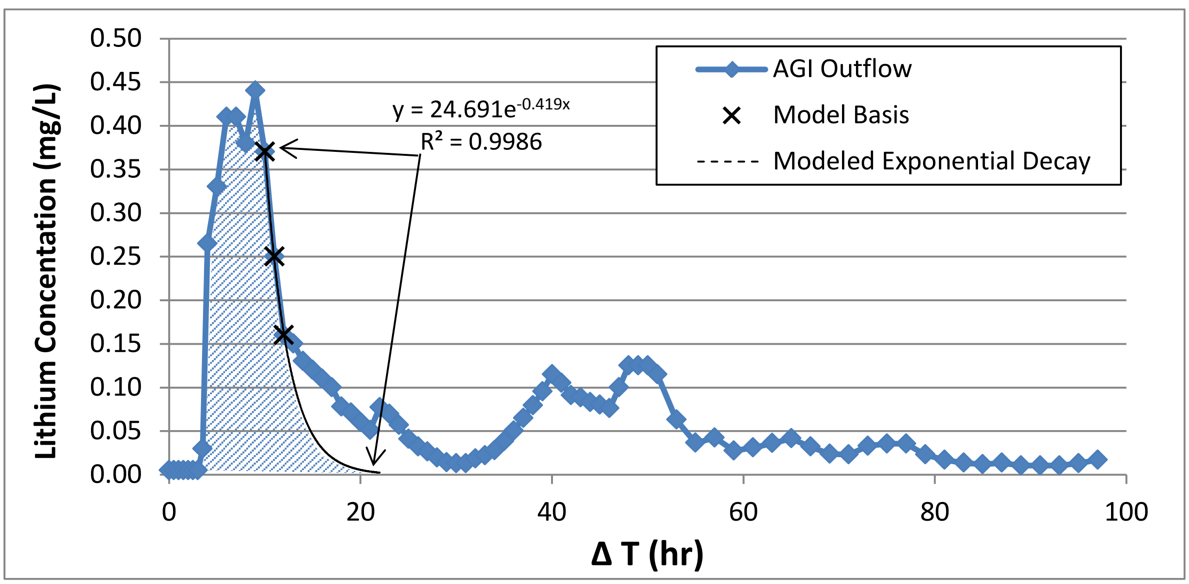

Figure 14. Concentration of lithium tracer measured at the outflow weirs for elapsed times after tracer injection (T = 0) at 12:05 on September 10, 2012. Values represent means of duplicate autosamplers, except between 17:05 on September 10 and 09:05 on September 11, when samples were collected from only one autosampler. The dashed line is the extrapolated exponential decay of the descending limb of the first peak in the hydrograph, which is assumed to be contributed from only Pump No. 2

Previous tracer investigations by DBE have shown that recirculation of the tracer, whereby the tracer exiting the wetland of interest re-enters the wetland at a later date by means of a closed hydraulic loop, can occur. In order to verify if this was occurring, DBE collected water samples from the outflows of the discharge pipes from Pump Nos. 1 and 2 on September 12 and 14 (two and four days into the four-day monitoring period) and analyzed their Li concentrations. The concentrations were below the MDL of 0.010 mg/L, indicating tracer recirculation did not occur during the study.

Nominal Hydraulic Retention Time (HRT)

The nominal HRT is calculated by dividing the volume standing water confined within the cell over the inflow (Equation 2). Since the stage, and thus the water depth, varied within the impoundment (Figure 13), the average nominal HRT was determined by time-weighting the depths over the four-day monitoring period. For the impoundment in its entirety, the nominal HRT was 0.94 day.

However, due to the relative locations of the two inflow pumps that received the tracer, DBE also calculated a nominal HRT for Pump No. 2, which was situated down-gradient from Pump No. 1 and much closer to the outflow weirs (Figure 3). For this exercise, the area of the impoundment was subdivided by assuming that the portion of the impoundment exposed to tracer from just Pump No. 2 was equal to that shown in Figure 5, and only the measured inflows from Pump No. 2 were considered. Using these data and assumptions, a nominal HRT of 0.28 day, or 6.8 hours was found.

Tracer Mass Balance

An estimated 105% of the injected mass was recovered at the outflow weirs. In the previous section on Nominal HRT, DBE attempted to separate the tracer flow paths associated with Pump No. 2 from the more distally located Pump No. 1. A mass of 11.4 kg of Li, which is 102% of the 11.2 kg of Li injected into the pipe from Pump No. 2, was found when integrating the hatched area shown in Figure 14, which was assumed to have been contributed by only flow discharged from Pump No. 2. This provides a line of evidence supporting the assumptions made and the short HRT of 6.8 hours calculated above for the water contributed only by Pump No. 2.

Tracer Detention Time

The measured HRT for Pump Nos. 1 and 2 according to Equation 3 was 1.10 days, or 17% longer than the nominal HRT (0.94 day) based on water depth and flow conditions during the monitoring period

(Equation 2). Both HRTs indicate a short the time, on average, a parcel of water spends within the impoundment, and thus minimal time for P treatment. Although the water discharged from Pump No. 2 flow more in a plug flow fashion, it spends considerably less time within the impoundment than did water from Pump No. 1, which in itself resides nearly twice as long in the impoundment than the "average" water parcels contributed by both pumps. The lengthier HRT from Pump No. 1 discharge resulted in a more dispersive pattern than the nearly plug flow observed for the discharge from Pump No. 2 (Figure 14).

Internal Tracer Profiles

The LiCl injected into the discharge pipes of Pump Nos. 1 and 2 was swept downstream from the mixing zone below the pipe outfalls within 3 hours of the injection since neither pump mixing zones showed detectable Li concentrations (Figure 15). There was, however, an elevated Li concentration of 4.3 mg/L at station F three hours post-injection, which is upstream of the discharge point from Pump No. 2 (Figure 5). This value was confirmed by measuring the Li concentration from water collected for TP analysis (which was contained in a separate bottle than water for Li analysis) at that same station, and found the concentration to be 4.1 mg/L. All the other upstream stations had Li concentrations that were below the MDL. We believe that part of the LiCl plume from Pump No. 2 migrated upstream before ultimately being swept downstream and over the discharge weirs. Note that the Li concentration at station F was below the MDL for the remaining three times when water from the station was analyzed (Figure 15), indicating a very low residence time for this section of the impoundment. The Li contribution from Pump No. 1 to the monitored internal stations becomes obvious in the 21-hr sampling (Figure 15). Not only most of the stations along the mid-transect of the impoundment exhibit elevated Li concentrations, but the 21-hr post-injection interval is the only time when Li concentrations above the MDL occurred at the two most northern stations (H and I). Twenty-four hours later (ΔT = 45 hr after injection), Li in the surface water from all of the five stations along the mid-transect except the furthest east station (E) was less concentrated than 24 hr prior. Lower Li concentrations found for the more easterly stations (E and G) indicated less of the pump discharge was routed along the eastern levee of the impoundment. Nearly all the tracer had left the impoundment some 95 hours after the LiCl injection, which was close to the end of the tracer monitoring period (Figure 15), and supports our finding that the tracer mass injected four days prior had all exited the impoundment.

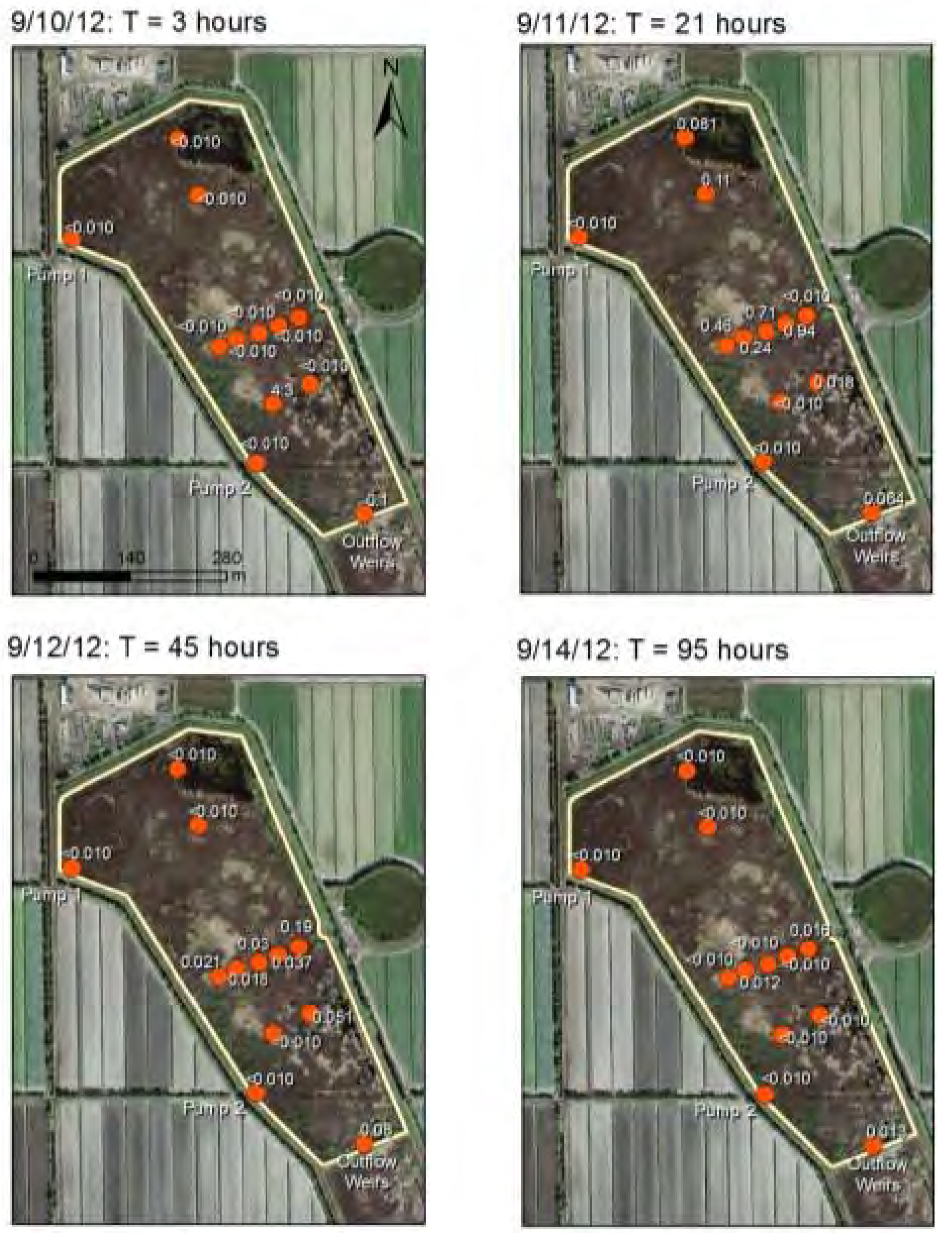

Figure 15. Spatial distribution of lithium (Li) concentrations (mg/L) in the surface waters of AGI1 after 3, 21, 45 and 95 hours after Li tracer injection. A value of <0.010 mg/L indicates the concentration was below the method detection limit of 0.010 mg/L.

Dispersion and Tanks-in-Series

The normalized second moment of the RTD (Equation 9) measures the spread of the response curve and is termed the variance, which describes the tracer dispersion (i.e., degree of mixing). The dispersion, σ^2, is expressed in $(\text{time})^2$, and describes the time interval over which the tracer mass passes through the outflow structure. Under an ideal plug-flow condition, for example, the σ^2 would be quite low, with essentially all of the injected mass arriving instantaneously at the outflow. However, the measured σ^2 was high at 0.84 days^2 (482 hr^2) in AGI1.

A commonly-used hydraulic parameter that provides a measure of dispersion is the tanks-in-series (TIS) number (Equation 10). The higher the TIS number, the closer the hydraulic condition approaches plug flow. Plug flow is considered an ideal and efficient distribution of water parcels throughout the cell, and is commonly associated with more effective P removal. Although we have measured TIS numbers in stormwater treatment area (STA) cells as low as 1.1 (Cell 4 of STA-1W), other STA cells have exhibited TIS numbers as high as 14.6 for the combined cells of the Taylor Creek STA (Table 5). When placed in the context of the previous hydraulic tracer characterizations performed by DBE in STA cells, the TIS number (1.4) for AGI1 ranks as one of the lowest. This condition is a close approximation to a completely stirred tank reactor (CSTR), which is considered to be an inefficient distribution of water parcels since much of the inflow is discharged from the impoundment much earlier than one HRT (θ = 1 in Figure 16) because of the short distance between Pump No. 2 and the outflow weirs. Moreover, the travel time of the discharge from Pump No. 1 took approximately 2 HRTs to exit the impoundment, indicating a high degree of dispersion and hydraulic inefficiency (e.g., dead zones) within AGI1.

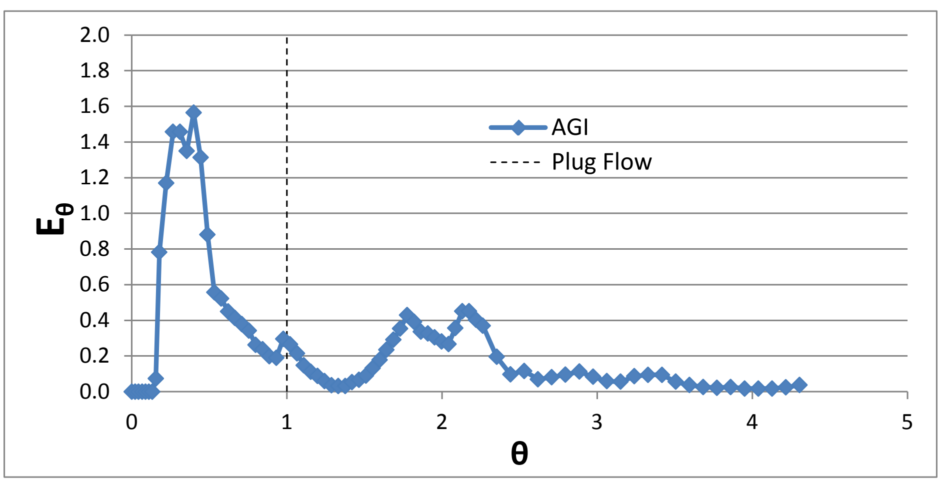

Figure 16. Tracer response curve at the outflow of AGI1 where θ (dimensionless) is the time after tracer injection normalized to the nominal retention time (0.94 day) and E_θ (also dimensionless) is the tracer concentration normalized to the mass of tracer injected (22.41 kg Li). A θ of 1 is equal to one nominal HRT.

Table 5. Tanks-in-series (TIS) numbers for selected STA cells compared to the basic impoundment (AGI1). All TIS numbers are from hydraulic tracer investigations performed by DB Environmental, Inc.

STA	Cell	Sample Year	TIS Number
STA-1W	4	1999	1.3
STA-1W	4	2001	1.1
STA-1W	1	2001	3.4
STA-1W	2	2001	2.8
STA-1W	5b	2004	10.6
STA-2	3	2005	5.5
STA-3/4	PSTA	2009	5.8
Taylor Creek STA	1 and 2	2010	14.6
Taylor Creek STA	1	2010	6.1
Aboveground Impoundment	1	2012	1.4

Total P Internal Concentrations and Overall Impoundment Retention

The internal TP concentrations were high (358-529 µg/L) and relatively spatially and temporally consistent during the study period (Figure 17). This indicates the impoundment is not providing much P treatment, likely due, in part, to the poor hydraulics as shown by the low TIS number of 1.4. Under the flow conditions (3427 m^3/day) imposed during this four-day tracer study, the average concentration of TP leaving the AGI was 8% higher than the average TP concentration entering the AGI (Table 6: 382 vs. 417 µg/L). The flow rates maintained in this study, which were 16% higher than the maximum daily flow rate reported over the one-year period conducted by Shukla et al. (2011), may have contributed to the high P export from the impoundment. Notwithstanding those high flow rates, the impoundment still has a history of poor retention (i.e., 20 %) even under average yearly flow conditions (Shukla et al. 2011).

Table 6. Inflow (Pump Nos. 1 and 2) and outflow (Weirs West and East) total phosphorus concentrations (µg/L) during the 4-day tracer study in the Basic impoundment (AGI1)

Date/Time	Pump No. 1	Pump No. 2	Weir West	Weir East
9/10/2012 10:15-12:05	353	464	447	458
9/10/2012 15:45-16:25	340	451	447	398
9/11/2012 09:00-09:10	341	368	399	516
9/11/2012 16:30-17:30	370	417	372	375
9/12/2012 08:45-09:30	349	378	384	467
9/12/2012 13:45-14:00	365	376	369	396
9/14/2012 10:05-10:15	398	383	373	472
Mean	**359**	**405**	**399**	**440**

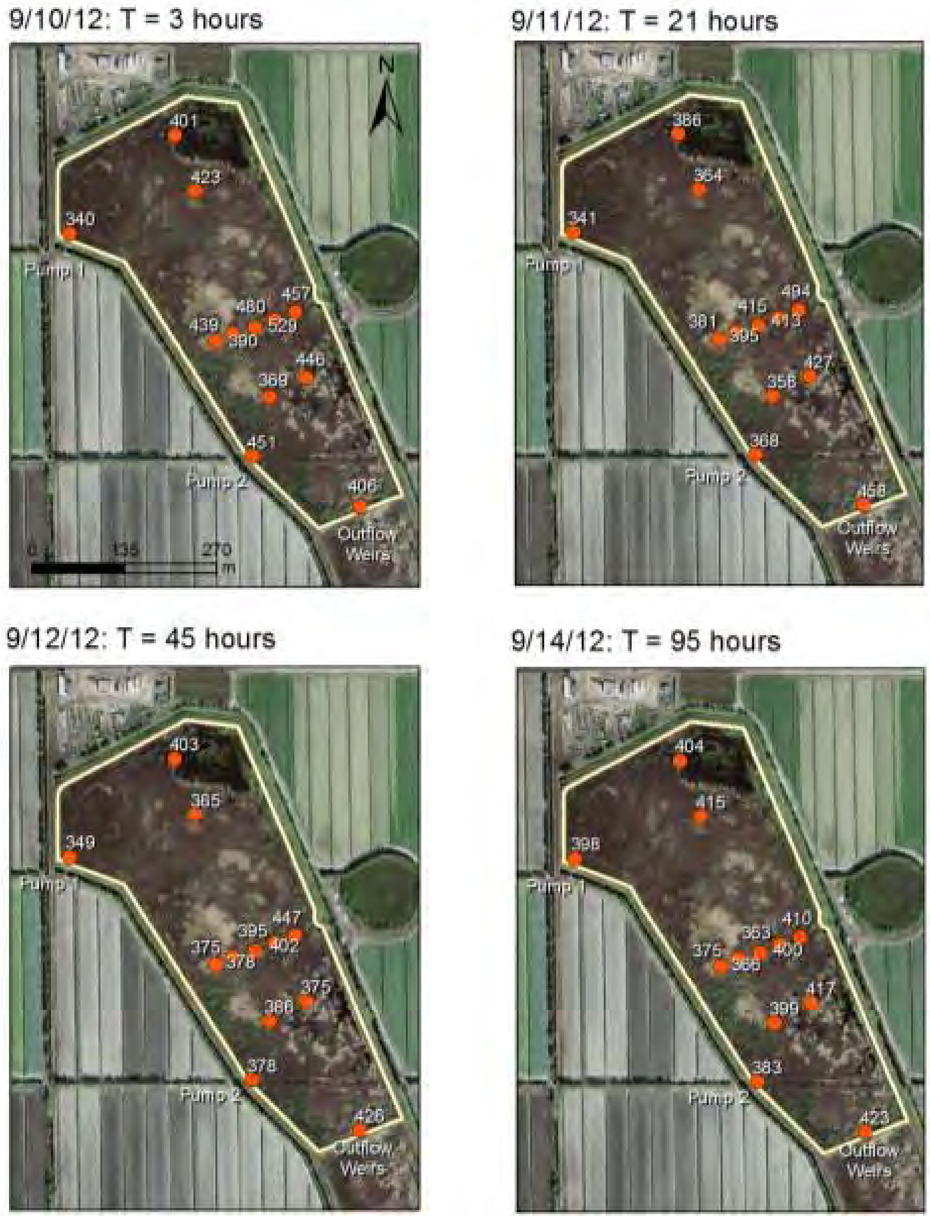

Figure 17. Spatial distribution of total phosphorus concentrations (µg/L) in the surface waters of the basic impoundment (AGI1) 3, 21, 45 and 95 hours after lithium tracer injection.

Conclusions and Recommendations

The hydraulic assessment of AGI1, using LiCl as tracer, indicated opportunities to improve the hydraulic efficiency of the impoundment as discussed below:

a) Hydraulic Retention Time (HRT): The measured HRT (1.10 days) was 17% longer that the nominal HRT (0.94 days) based on water depth and flow conditions. However, due to the relative location of the inflow pumps, water discharged from Pump No. 2 spends considerably less time (0.28 days) within the impoundment than did water from Pump No. 1. Thus, minimizing the time for phosphorus treatment.

b) Tank in Series Number (TIS) - Dispersion: The TIS number for AGI1 (1.4) approximates a complete stirred tank reactor instead of plug flow. This is considered to be an inefficient distribution of water parcels since much of the inflow is discharged from the impoundment much earlier because of the short distance between Pump No. 2 and the outflow structure.

As it is typical with tracer studies, data were collected at continued pumping conditions. The amount of water pumped into AGI1 prior to and during the tracer study was equivalent to a 5.3-day storm averaging 2.5 inches per day of rainfall falling in the drainage basin. Thus, the results represent what would have occurred if, for example, runoff from a storm of duration and intensity similar to that recorded by Shukla et al. (2009) over March 12 to April 3, 2010 entered into the reservoir while the water level at the outfall weir was already at the control elevation. However, the HRT and TIS should increase under the intermittent pumping conditions that are typical of this type of operation.

The following modifications could be implemented in order to improve the P removal performance of AGI1:

- Relocating Pump No. 2 to the northern end of the impoundment (close to Pump No. 1). This would extend the travel time of the water discharged from this pump, thereby allowing more time for treatment; or
- Although the impoundment is only 36.7 acres, splitting the impoundment into two compartments/cells may result in improved P retention; or
- Constructing short levees (about one-third the width of the impoundment) or a densely vegetated strip (using, for example, giant bulrush) perpendicular to the western and eastern levees about one-third to one-half down the length of AGI1 (Figure 18). This may increase the travel time by forcing the water to circulate in a zigzag manner throughout the impoundment until reaching the discharge structure.

Figure 18. Short levees at three locations within AGI1

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Appendices

Acknowledgements

This study would not have been possible without the cooperation of Mr. Chuck Obern, President of C&B Farms, who allowed access to the farm and supplied the needed inflow water during the monitoring period. Funding was provided by the South Florida Water Management District under project management by Ms. Ximena Pernett.

C-139 Basin BMP Evaluation of AGI

Purchase Order # 4500066799

June 21, 2012

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

PREPARED BY: DB Environmental, Inc.
365 Gus Hipp Blvd.
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Introduction and Background

Numerous tracer projects conducted within wetlands indicate that flow patterns can depart widely from ideal plug-flow characteristics and that hydraulic short-circuits and dead zones may exist (Dierberg et al. 2005; Kadlec and Wallace 2009). Hydraulic short-circuits may result in a portion of the influent water reaching the outflow of the system well before the calculated hydraulic residence time (HRT), thereby reducing the phosphorus (P) removal efficiency of the system. These non-ideal flow patterns typically remain intact until the water is redistributed by structural means, such as relocation of inflow pumps or discharge weirs. The addition of levees, earthen berms, or vegetated strips that partitions the treatment cell into semi-discrete areas are additional structural alterations that can be deployed.

In fiscal years 2009 and 2010, the District funded two demonstration projects to improve the performance of above ground impoundments (AGIs) to reduce P in discharges. One project evaluated the performance of an AGI built in accordance with Environmental Resource Permitting (ERP) criteria (basic AGI), and another evaluated the performance of an AGI where structural modifications, above and beyond ERP criteria, were implemented to improve P removal (modified AGI). As part of the basic AGI evaluation, completion of a tracer study was proposed. The test could not be conducted because of drought conditions. Data collected under this PO will be evaluated to assess how features affect transport and removal in the basic AGI, thus justifying modifications to improve performance. The tracer test will be initiated during the 2012 rainy season when there is sufficient runoff from the vegetable fields to generate continuous surface inflow to the basic AGI.

In addition, a hydrologic assessment of the modified AGI will be conducted under this PO. Based on the results, the feasibility of conducting a dye tracer evaluation in the modified AGI at a future date will be evaluated.

Objectives

The overall objective of this project is to assess the hydraulic efficiency of the basic AGI (designated AGI1) under a "typical" hydraulic loading and depth regime, and to assess the hydrologic characteristics of the modified AGI (designated AGI3).

Location and Description of the Basic and Modified AGIs

Both AGIs are located within C&B Farms near Clewiston, FL. The farm totals 1677 acres, and is located at the far southeast corner of the C-139 Basin and immediately west of STA-5. (Figure 1). An aerial photo of the farm and the AGIs are shown in Figure 2. The cultivated areas of the farm are characterized by Myakka and Immokalee fine sand soils, while the AGIs contain predominantly Myakka fine sand and Basinger fine sand (Shukla et al. 2011).

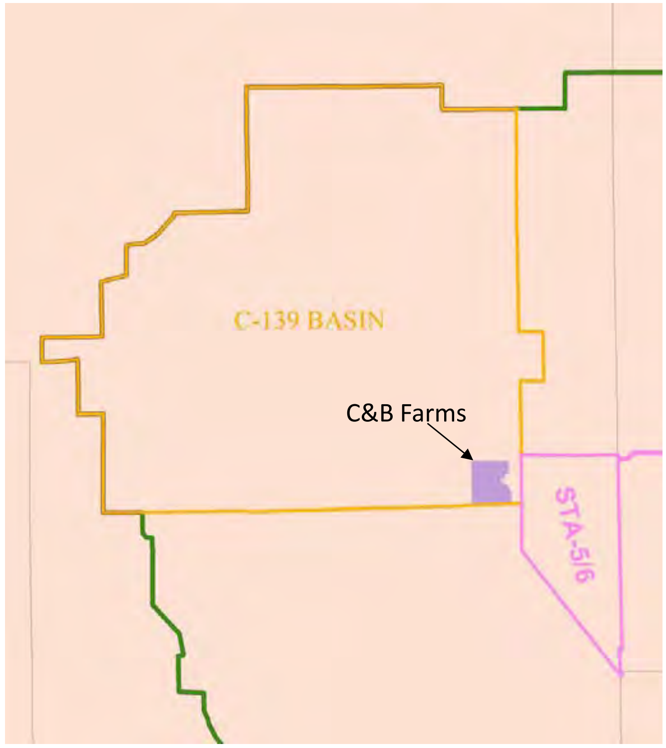

Figure 1. Location of C & B Farms in the C-139 Basin and its relation to STA-5/6 (Shukla et al., 2011)

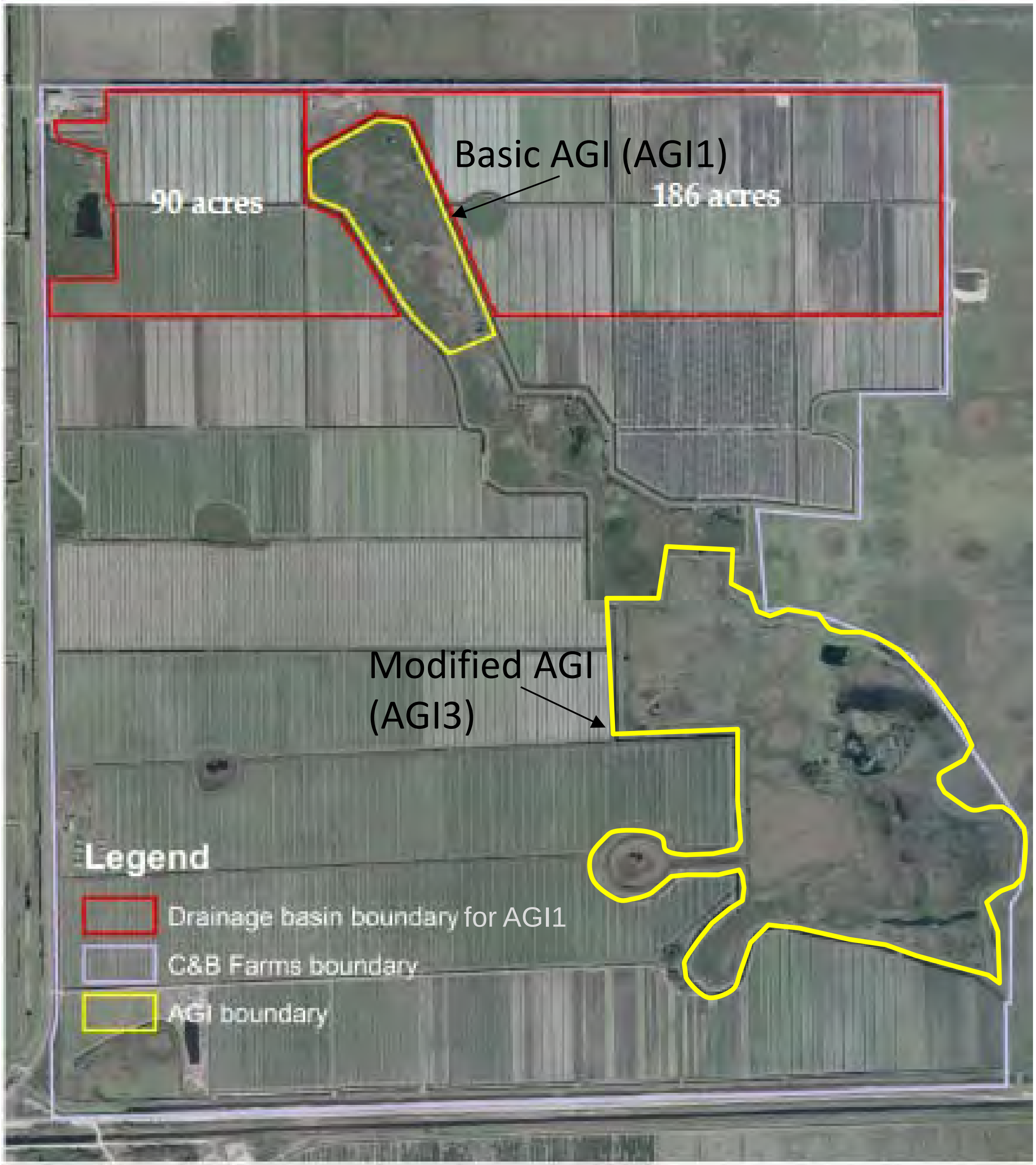

Figure 2. Aerial photo of the basic AGI (AGI1) and modified AGI (AGI3) boundaries. Modified from Shukla et al. (2011).

The cultivated areas within the farm are irrigated with a combination of drip and seepage irrigation. For both types of irrigation, the source water comes from both groundwater and surface water. The farm drainage system takes advantage of the same conveyance canal system to route drainage water towards the AGIs. The drainage water is pumped into the

AGIs by surface water pumps commonly called 'throw-out pumps' that are distributed around the AGIs' perimeter. The farm is divided into drainage basins to more efficiently drain the farm when necessary. In other words, by adjusting the flashboards in the risers located in the canals, water is routed to the nearest pump during drainage events. The pumps and the AGIs were designed and sized according to the area of their corresponding drainage basins and the potential runoff (Shukla et al., 2011).

The Basic AGI is 36.7 acres and was designed to receive drainage from ~ 267 acres of the farm (Shukla et al., 2011). Drainage water is pumped into the AGI via three diesel-operated surface-water axial flow pumps (Figure 3). Maximum flow rate for each pump is approximately 5,000 gallons per minute (GPM). The discharge structure of the AGI (Figure 3) is located at the southern extreme of the AGI and consists of two sharp crested weirs set at 19.5′ NGVD29 (18.12′ NAVD88). A 'borrow ditch' is located around almost the entire interior perimeter of the AGI. This 'borrow ditch' was created during AGI construction when material inside the AGI was excavated to provide the necessary soil to construct the AGI embankment. The remaining interior of the AGI is characterized by flat, nearly level ground with the exception of four depressions, three of which are jurisdictional wetlands (Shukla et al., 2011).

The nominal average water depth in AGI1, as controlled by the elevation of the discharge weirs, is 1.9 ft. The mean flow rate during the tracer study is expected to be 7.0 (3.5 at pumps 1 and 2) cubic feet per second (cfs), which will provide a nominal HRT in the impoundment of 5.1 days. Note that for the purpose of this tracer study, only pumps 1 and 2 will be used as these pumps are operated more frequently than pump 3 as documented in the 2009-2010 demonstration project (Shukla et al., 2011).

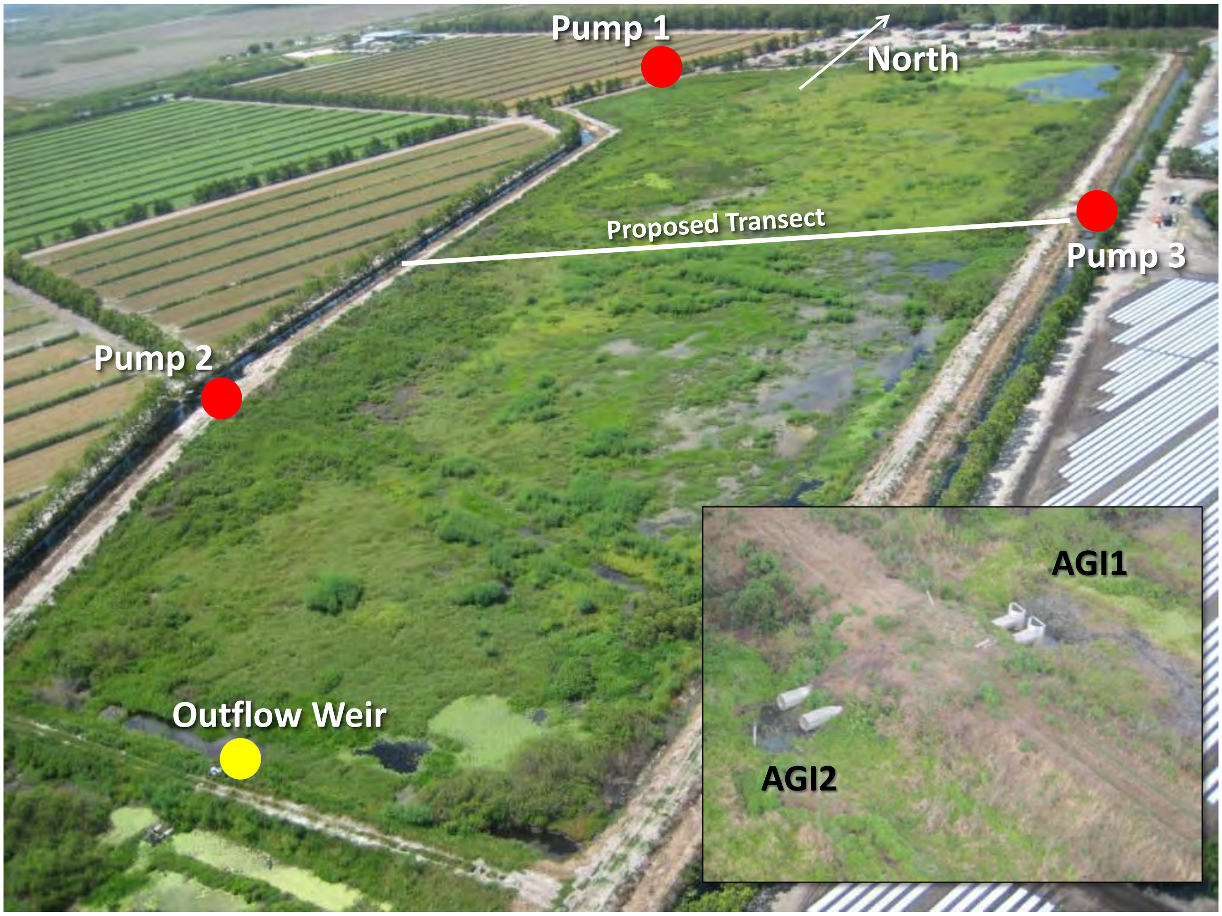

Figure 3. Aerial photo of AGI1 showing the three inflow pump stations, the outflow weirs, and the proposed internal sampling transect. Inset is of the outflow weirs. Tracer injection will occur only at Pumps 1 and 2, and monitored at the outflow weirs and along the proposed transect (if feasible).

Site Visit and Work Plan

Subtask 1.1: District-Contractor Site Visit

On May 9, 2012, the District project managers (Ms. Ximena Pernett and Ms. Carmela Bedregal) and five DB Environmental (DBE) personnel (Forrest Dierberg, Scott Jackson, Patrick Owens, Terry Auter, and Doug Hatton) met with the grower of C&B Farms, Mr. Chuck Obern, to conduct a site visit. During this visit, the logistical and technical aspects of conducting the tracer test in AGI1 and subsequent hydraulic analyses were discussed. Tracer injection sites were identified, and sampling locations and equipment needs were reviewed. In addition to the focus on the tracer injection and monitoring in AGI1, DBE also explored additional survey needs in AGI3 in anticipation of a second tracer study to be implemented in that impoundment in 2013. Information obtained from the site visit was used to develop the following Work Plan.

Subtask 1.2: Work Plan and Study Prep

Overview

The tracer injected into AGI1 will be characterized by adding a batch "slug" of chemical tracer, evenly distributed into each of the two inflow pipes downstream from pumps #1 and #2 (Figure 3). Approximately three hydraulic retention times (HRTs) or one month, whichever is shorter, is estimated to be a sufficient time to capture the majority of the tracer at the outflow and to allow for the development of an acceptable tracer response curve. A third pump (Pump #3) should be kept off-line during the injection and for the monitoring period thereafter. Monitoring efforts (outflow sampling) will begin just prior to release of the tracer. In addition to routine outflow tracer sampling performed using duplicate (redundant) automatic samplers, the feasibility of obtaining grab samples for tracer analyses collected along one internal transect within the AGI will be examined during a second site visit prior to tracer injection. A transect location has been proposed (Figure 3), and if found to be amenable to sampling by airboat, then this internal transect will help identify dominant flow paths, and to document any hydraulic short circuiting.

Significant "up front" work at AGI1 will need to be completed prior to the tracer injection. This includes inspection of the proposed internal transect and make-shift boat ramp, modification of the flange cover on the inflow pipes, and confirmation of the pump discharge volumes.

Additional survey work will occur in AGI3 as part of this PO. Contrary to AGI1 where a complete hydrologic study and bottom contour survey have been performed (Shukla et al. 2011), less hydrologic and survey information have been gathered for AGI3. Additional survey data are needed in AGI3 in preparation for a planned tracer study in that AGI during 2013 wet season.

Pump Calibration and Tracer Test in AGI1

Pump Calibration

Pumps #1 and #2 were calibrated in 2009 (Figure 4), and pump equations predicting discharge volume as a function of pump revolutions per minute (RPM) and canal stage were provided (Shukla et al. 2011). DBE intends to confirm those equations by performing a pump test to Pump #1 and #2 at the expected ranges of pumping during the tracer study.

Figure 4. Inflow pump calibration being performed by the field personnel during the AGI1 investigation performed by Shukla et al. (2011).

For the calibration exercise to be successful, the pipe from the pump needs to be flowing full during during the tracer study. This can be confirmed by farm personnel by setting the pumps to rates less than the expected pumping range during the tracer study, and then looking inside the pipe by detaching the existing flange cover. Knowing whether the pipe is flowing full prior to our next field trip will allow DBE to bring the appropriate flow sensor (i.e., George Fisher Signet Model 2540 paddlewheel) for the calibration. Cutting a 2-inch diameter hole in the existing 22-inch flange cover, and then welding a female threaded coupling into the opening so as to accept a 2-inch male adaptor, would greatly assist in the calibration process, as well as in the delivery of the tracer (see below).

Tracer Selection

Initial analyses indicate that lithium chloride (LiCl) is the tracer of choice for this hydraulic assessment. The selection of tracer type, and appropriate injection volume, are dictated by several factors, including the background or native concentration of the tracer compound in the inflow water, stability of the chemical in the wetland, the analytical detection limit, and the tracer cost. Because of the uncertainty in providing consistent hydraulic loading rates (HLRs) throughout the duration of the tracer study (which may lead to longer HRTs), and of the large biomass of emergent vegetation, DBE has chosen LiCl to be the tracer that would yield the highest percentage of recovery during the study (Dierberg and DeBusk 2005) at the most reasonable cost.

During the 9 May 2012 site visit, water samples were collected for lithium (Li) analysis to provide a measure of the background concentration. The results indicated concentrations < 10 μg/L, which are low enough to warrant LiCl as a suitable tracer.

For purposes of this Work Plan, DBE performed calculations to estimate the quantities of LiCl required. Based on analytical detection limits, LiCl should be injected with sufficient mass to achieve a continuously stirred tank reactor (CSTR) concentration of 192 μg/L. Using this concentration and the volume of the wetland (86,700 m^3) at an average water depth of 0.58 m where water is being discharged over the weir, the required tracer volume for a 40.9% LiCl stock solution is 55 gallons.

Tracer Injection

The tracer injection methodology is one of the more critical steps in achieving a successful tracer study outcome. Since the aim is to conduct the study under equal inflow volumes from Pumps #1 and #2, then equal amounts of LiCl to Pumps #1 and #2 need to be injected. Pump #3, which provided only 14% of the total water volume to AGI1 in the July 2009 to July 2010 period (Shukla et al. 2011), should not be operating during the tracer injection and the tracer monitoring period thereafter.

Prior to injection of the tracer, it will be important for the stage in AGI1 to be full and discharge occurring over the weirs. This will insure that the hydraulics present during the tracer study represent flow-through conditions, and not a situation where much of the inflow volume goes towards "filling up" the AGI. The idea is to test the hydraulics and P removal of the AGI under flow-through conditions, and not under conditions when the wetland is an isolated detention basin with no outflow. Delivering constant volumetric inflows and outflow during the tracer study to achieve relatively steady-state storage conditions are also important as steady flows will greatly facilitate a meaningful interpretation of the data.

To initiate the tracer test for Task 2 of the study, an equal volume of tracer chemical will be injected into each of Pumps #1 and #2 over an equivalent and relatively short time period (15-30 min). The tracer, LiCl, will be gravity-fed through an opening into each of the two inflow pipes leading from Pumps #1 and #2 to AGI1. As described above under Pump Calibration section, the injection process will be facilitated by a 2-inch diameter port welded to the top of the flange cover.

The specific gravity of the stock LiCl solution (1.25 g/cm^3) is higher than that of water, so it is possible that settling and "pooling" of the tracer can occur at the injection point, particularly under quiescent conditions. Because DBE anticipates relatively high velocities at each inflow pipe at the 3.5 cfs flow, and dilution of the LiCl with site water prior to injection, DBE is confident that sufficient mixing and dilution will occur during the tracer injection

To prevent interruptions during tracer injection or loss of data during the monitoring period, duplicates of all mechanical equipment will be kept onsite during the study. This will include, but not be limited to, autosamplers, batteries, and gas and electric pumps.

Inflow and Outflow Tracer Monitoring

DBE will initiate the collection of samples for tracer analyses at the outflow weirs just prior to tracer injection at the inflow pipes. Grab samples will be collected using time-proportional autosamplers. Samples will be collected for a maximum of three HRTs or one month (whichever is shorter), which is estimated to be a sufficient time to capture the majority of the tracer at the structure and to allow for the development of an acceptable tracer response curve. Three times the nominal HRT through this system at a combined pumping rate of 7.0 cfs has been calculated to be approximately 15.3 days. The sampling frequency at the outflow structure will be every two hours for the first HRT of collection, every four hours for the next HRT, and every eight hours for the remainder of the study.

During heavy flow events, the discharge weirs in AGI1 can become flooded from water backing up from AGI2 into AGI1 (Shukla et al. 2011). This leads to invalidation of the weir equations for determining discharge volume. To assist in accurately measuring the discharge rate at the weir structure, the water stage downstream in AGI2 should be kept below the weir elevation in AGI1 of 18.1 ft (NAVD88).

Internal Monitoring

During the tracer test, DBE will perform internal monitoring on days 1, 2, 3 and 5 following tracer injection by collecting grab samples at the same 3-4 stations along the transect depicted in Figure 3. This assumes that the proposed transect location can accommodate an airboat and has an access point. Tracer and TP concentrations will be analyzed during every internal monitoring event.

Phosphorus Monitoring

Because TP concentrations are not expected to change as much as the tracer concentrations under steady-state flow conditions within the wetland, DBE intends to composite the samples collected at the outflow weirs within daily intervals for TP analysis. Grab samples will be collected from each of the two inflow pipes whenever DBE personnel are at the site (daily for the first three days, then every 2-3 days thereafter). For stations along the internal transect, TP analysis will occur for each of the proposed sampling events (i.e., days 1, 2, 3, and 5 following tracer injection).

Additional Site Visit Prior to Tracer Study

At least one additional site visit by DBE personnel needs to occur before performing the tracer injection. The following objectives will be undertaken during the visit:

1. Examine the proposed internal transect location for access by airboat and inspect the newly constructed boat ramp;
2. Calibrate flows within the inflow pipes of Pumps #1 and #2;
3. Determine whether flows within inflow pipes from Pumps #1 and #2 are full during the range of expected flow regimes during the tracer test by running pumps at lower than expected rates for the tracer study;
4. Test the newly welded or threaded fitting to the port on top of each inflow pipe for leakage and compatibility to fittings at the terminal end of the LiCl delivery pipe and flow meters;
5. Simulate a tracer injection using only site water for estimating appropriate delivery rates and durations;
6. Test GPS WiFi signal on survey equipment.

Surveying in AGI3

Surveys exist for elevations of the outside levees of AGI1 and AGI3 (March 2009; RHT Engineering), the internal berms and culverts in AGI3 (January 22, 2009; RHT Engineering), benchmark locations and elevations for the farm (March 2008; RHT Engineering), and bottom topography of AGI3 (L.F. Rooks & Assoc. for Schreuder, Inc.; August 28, 1997). DBE intends to contact each of the surveyors and request the electronic files of each of the above surveys. These surveys can be overlayed onto the most recent available aerial photos taken of C&B Farm. This "composite" figure of the ground and structural elevations embedded within recent aerial photographs will assist in identifying potential short circuits, dead zones, and locations to "ground truth" (i.e., re-survey) within AGI3. For example, DBE anticipates that deeper borrow channels exist along the inside of the levees in AGI3, a result of the construction of the levee system that occurred after the bottom contour survey in 1997. Approximately two dozen locations adjacent to the inside and outside levees in AGI3 will be surveyed. In addition, DBE will confirm structure elevations such as weirs and pipes, and ground truth (within 4-inch accuracy) a dozen ground elevations provided in the 1997 survey since depositional and erosional forces in the intervening 15 years may have altered the bottom topography. DBE will use BM 126 and BM 129 for the benchmarks in surveying AGI3.

Basically, there are three alternative locations where tracer can be injected into AGI3:

1. Injecting the tracer at the outflow weir from Cell 6A. This would be the easiest, but would exclude Cell 6A from the tracer flow path.
2. Injecting the tracer into the levee canal in Cell 6A (Figure 5), which receives flow from the outer perimeter canal and is the header cell that routes water to the remaining cells (6B-6F). This is the next easiest alternative. In order to determine the feasibility of this alternative, a finer-scale survey to define the cross-sectional profile at several points along the canal would need to be done in order to select where (i.e., narrowest width and deepest) along the canal is best for the injection.

3. Injecting the tracer at each of the 8 inflow pumps. This is the least desirable alternative. However, if that ultimately becomes the best choice, then calibration of each of those pumps will be necessary.

Which of these three alternatives is eventually chosen as the point of tracer injection in 2013 will depend on the survey data, and on discussions between District Project managers, the grower, and DBE personnel.

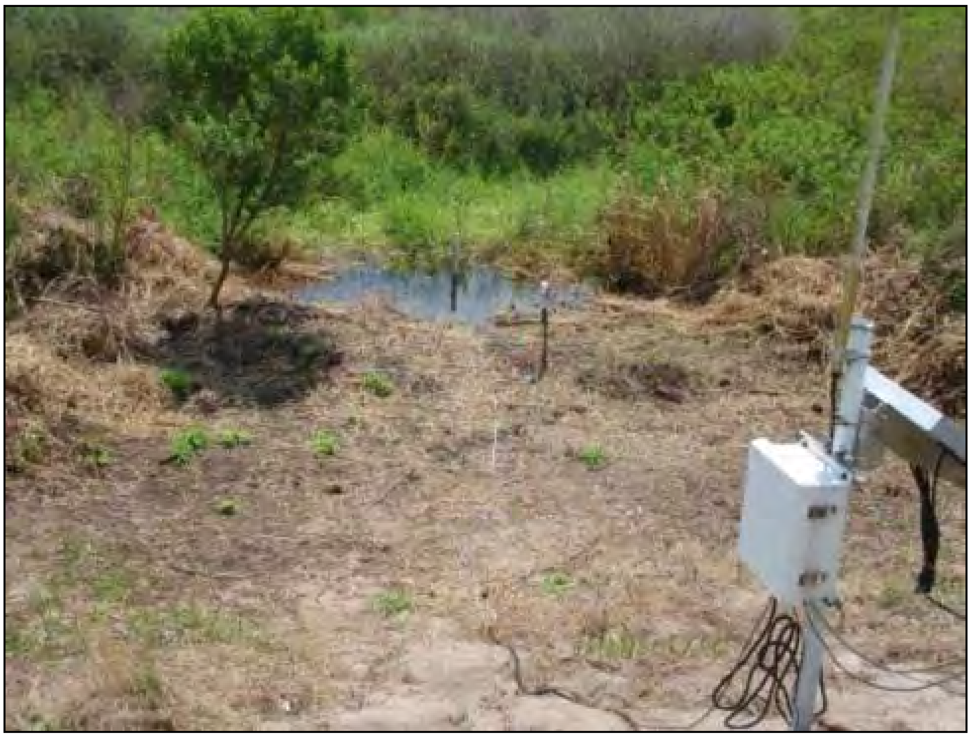

Figure 5. Proposed area in Cell 6A of AGI3 for injection of the tracer during the 2013 wet season.

Unlike AGI3, DBE anticipates conducting only minor survey work in AGI1. This is because the survey data collected for AGI1 is more recent (March 2009) than the survey performed in AGI3 (1997), which means that the file formats from the AGI1 surveys are more compatible to the most up-to-date CAD/CAM programs that DBE will use for merging the various survey data previously collected. Also, the bottom topography of AGI1, as measured in 2009, is likely to have been subjected to less erosional and depositional processes than in AGI3, when the topographic survey was performed in August 1997. Lastly, there are less structures (i.e., internal berms and connecting culverts/weirs) in AGI1 than in AGI3, which combined with the nearly 5-fold smaller area of AGI1 than AGI3, simplify both the integration process of combining the disparate survey information as well as the interpretation of the images with respect to identifying short circuits and dead zones.

Data Analyses and Hydraulic Assessment

The DBE project team will submit to the District a Draft Final Report for Tasks 3 and 4 of the study. This report will include, but not be limited to, (a) an Executive Summary; (b) an Introduction, including all tasks performed; (c) a Methods section, including a description of the calibration, sampling, and surveying methodology and all data analyses performed, and all calculations related to the initial concentration of tracer injected; and (d) a Results section, including all raw data, hydraulic analyses, spatial/ temporal tracer and P concentration maps, survey points and elevations, and pump rating curves.

Assuming that flows can be maintained at a consistent rate over the three HRTs and can be accurately measured at the two inflow and outflow structures, the hydraulic analysis of the tracer data set will employ the residence time distribution (RTD) moment analysis. This analysis defines the key parameters used to characterize the hydraulic performance of a wetland cell. The absolute zeroth moment yields the total mass of tracer that has been recovered at the exit of the wetland cell. The normalized first moment yields the centroid of the area under the RTD, which is the actual HRT. Finally, the normalized second moment of the RTD measures the spread of the curve and is termed the variance, which is the dispersion (i.e., degree of mixing). For internal sampling events, DBE will provide all raw data, as well as spatial (GIS) and temporal depictions of internal tracer profiles. A tracer response curve of the tracer concentration profile at the discharge weirs vs. time will be included.

Upon receipt of District comment's on the Draft Final Report, DBE will revise and resubmit the document in final form.

Project Management

Dr. Forrest Dierberg will manage the project for DBE. DBE's field efforts will be managed by Mr. Scott Jackson, who will be assisted in tracer deployment and field sampling by Mr. Doug Hatton and Ms. Stacey Cote and Dawn Sierer. Ms. Janelle Potts, DBE's Laboratory Manager, will be responsible for ensuring that all project aspects meet the appropriate Quality Assurance and Quality Control criteria. Mr. Patrick Owens will supervise the surveying to be performed in AGI3 under this purchase order. Mr. Terry Auter will be charged with conducting the flow calibrations of the two inflow pumps (Nos. 1 and 2) to which the tracer is to be injected downstream in the pipes.

Project Schedule

The tracer injection will be initiated during the wet season, at a time when farm operational personnel are confident that steady state flows can be provided to the AGI over a period encompassing three wetland HRTs (approximately 15.2 days). Since the hydrologic assessment, including additional survey of AGI3, is not weather dependent, the survey work in AGI 3 will be done at the convenience of DBE personnel and access to the property. DBE will submit the Draft Final Report to the District within thirty (30) calendar days after completion of the tracer test and data analyses and no later than September 15, 2012, unless a timeline extension is agreed to by the District Project Manager to facilitate substantial improvement to the final work product.

References

Dierberg, F.E., and J.J. Juston, T.A. DeBusk, K. Pietro, and B. Gu. 2005. Relationship between hydraulic efficiency and phosphorus removal in a submerged aquatic vegetation-dominated treatment wetland. Ecol. Eng. 25:9-23.

Dierberg, F.E., and T.A. DeBusk. 2005. An evaluation of two tracers in surface-flow wetlands: rhodamine-WT and lithium. Wetlands 25:8-25.

Kadlec, R.H. and S.D. Wallace. 2009. Treatment Wetlands, 2nd Edition. CRC Press, Boca Raton, FL. 1016 pp.

Shukla, S., J.M. Knowles, and A. Shukla. 2011. Evaluation of Agricultural Impoundments for Reducing Farm-scale P Discharge in South Florida. Final Report Submitted to South Florida Water Management District, West Palm Beach, FL.

Table B-1. Raw data used for calibrating Pumps 1 and 2. The data were used to generate regression equations predicting discharge volume (gpm) to pump speed (rpm) and stage.

Pump 1								
Sample Date	**Reading No.**	**Staff Gauge (m)**	**Water Depth (m)**	**Tachometer Readings (rpm)**			**Discharge (gpm)**	
				pump	**optical**	**% agreement**		
8/3/2012	1	0.77	1.77	1500	1588	94	13300	
8/3/2012	2	0.76	1.76	1400	1415	99	11600	
8/3/2012	3	0.76	1.76	1300	1352	96	10200	
8/3/2012	4	0.76	1.76	1550	1614	96	13500	
8/3/2012	5	0.76	1.76	1400	1414	99	11700	
8/3/2012	6	0.76	1.76	1300	1352	96	10000	
8/3/2012	7	0.76	1.76	1600	1694	94	13900	
8/3/2012	8	0.75	1.75	1725	1800	96	14700	
8/7/2012	1	0.38	1.47	1700	1782	95	14700	
8/7/2012	2	0.38	1.47	1500	1521	99	11400	
8/7/2012	2	0.38	1.47	1500	1490	101	10200	
8/7/2012	3	0.38	1.47	1300	1310	99	6700	
8/7/2012	3	0.38	1.47	1300	1372	95	7400	
8/7/2012	4	0.35	1.44	1700	1775	96	14400	
8/7/2012	5	0.20	1.29	1700	1788	95	14600	
8/7/2012	6	0.20	1.29	1500	1520	99	9300	
8/7/2012	7	0.22	1.31	1300	1359	96	7200	
8/7/2012	8	0.20	1.29	1500	1549	97	9000	*
8/30/2012	1	0.57		1000	1060	94	3300	
8/30/2012	2	0.57	na	1300	1397	93	8450	
9/6/2012	1	0.43	na	1300	1342	97	6500	
9/6/2012	2	0.43	na	1400	1426	98	7400	
9/6/2012	3	0.43	na	1200	1223	98	5200	
* measured with flow sensor #2			Average			97		

Pump 2							
Sample Date	**Reading No.**	**Staff Gauge (m)**	**Water Depth (m)**	**Tachometer Readings (rpm)**			**Discharge (gpm)**
				pump	**optical**	**% agreement**	
8/3/2012	1	0.78	1.76	1500	1516	99	12400
8/3/2012	2	0.76	1.74	1400	1408	99	11600
8/3/2012	3	0.76	1.74	1300	1309	99	11000
8/3/2012	4	0.75	1.73	1200	1212	99	9600
8/3/2012	5	0.74	1.72	1600	1595	100	13000
8/3/2012	6	0.74	1.72	1700	1692	100	14400
8/3/2012	7	0.74	1.72	1500	1502	100	12200
8/3/2012	8	0.74	1.72	1700	1702	100	14200
8/3/2012	9	0.74	1.72	1300	1302	100	10700
8/7/2012	1	0.45	1.37	1700	1680	101	13300
8/7/2012	2	0.42	1.34	1500	1490	101	12100
8/7/2012	3	0.40	1.32	1300	1308	99	9800
8/7/2012	4	0.24	1.16	1700	1683	101	13800
8/7/2012	5	0.23	1.15	1500	1491	101	11400
8/7/2012	6	0.22	1.14	1300	1301	100	9700
8/7/2012	7	0.21	1.13	1700	1682	101	13800
8/30/2012	1	0.55		na	1015	na	5920
8/30/2012	2	0.55		na	1200	na	8860
9/6/2012	1	0.39		1200*	1075	na	6550
9/6/2012	2	0.39		1300*	1153	na	7850
9/6/2012	3	0.39		1100*	955	na	3000
na= pump was broken					Average	100	
* new installed tachometer							

Table C-1. Lithium concentration raw data from autosamplers located at outflow weir.

Date/Time	Station Name	Autosampler 1	Autosampler 2
9/10/12 12:05	Outflow -1	<0.010	<0.010
9/10/12 12:35	Outflow -2	<0.010	<0.010
9/10/12 13:05	Outflow -3	<0.010	<0.010
9/10/12 13:35	Outflow -4	<0.010	<0.010
9/10/12 14:05	Outflow -5	<0.010	<0.010
9/10/12 14:35	Outflow -6	<0.010	<0.010
9/10/12 15:05	Outflow -7	<0.010	<0.010
9/10/12 15:35	Outflow -8	0.029	0.030
9/10/12 16:05	Outflow -9	0.27	0.26
9/10/12 17:05	Outflow -10	0.33	ns
9/10/12 18:05	Outflow -11	0.41	ns
9/10/12 19:05	Outflow -12	0.41	ns
9/10/12 20:05	Outflow -13	0.38	ns
9/10/12 21:05	Outflow -14	0.44	ns
9/10/12 22:05	Outflow -15	0.37	ns
9/10/12 23:05	Outflow -16	0.25	ns
9/11/12 0:05	Outflow -17	0.16	ns
9/11/12 1:05	Outflow -18	0.15	ns
9/11/12 2:05	Outflow -19	0.13	ns
9/11/12 3:05	Outflow -20	0.12	ns
9/11/12 4:05	Outflow -21	0.11	ns
9/11/12 5:05	Outflow -22	0.100	ns
9/11/12 6:05	Outflow -23	0.078	ns
9/11/12 7:05	Outflow -24	0.071	ns
9/11/12 8:05	Outflow -25	0.060	ns
9/11/12 9:05	Outflow -26	0.051	ns
9/11/12 10:05	Outflow -27	0.063	0.091
9/11/12 11:05	Outflow -28	0.069	0.070
9/11/12 12:05	Outflow -29	0.056	0.058
9/11/12 13:05	Outflow -30	0.040	0.042
9/11/12 14:05	Outflow -31	0.032	0.032
9/11/12 15:05	Outflow -32	0.026	0.027
9/11/12 16:05	Outflow -33	0.020	0.019
9/11/12 17:05	Outflow -34	0.013	0.015
9/11/12 18:05	Outflow -35	0.012	0.014
9/11/12 19:05	Outflow -36	0.013	0.013
9/11/12 20:05	Outflow -37	0.019	0.018
9/11/12 21:05	Outflow -38	0.021	0.023
9/11/12 22:05	Outflow -39	0.028	0.028
9/11/12 23:05	Outflow -40	0.038	0.039
9/12/12 0:05	Outflow -41	0.050	0.051
9/12/12 1:05	Outflow -42	0.063	0.067
9/12/12 2:05	Outflow -43	0.078	0.081
9/12/12 3:05	Outflow -44	0.098	0.093
9/12/12 4:05	Outflow -45	0.12	0.11
9/12/12 5:05	Outflow -46	0.11	0.10
9/12/12 6:05	Outflow -47	0.092	0.090
9/12/12 7:05	Outflow -48	0.091	0.086

Date/Time	Station Name	Autosampler 1	Autosampler 2
9/12/12 8:05	Outflow -49	0.080	0.086
9/12/12 9:05	Outflow -50	0.080	
9/12/12 10:05	Outflow -51	0.076	
9/12/12 11:05	Outflow -52	0.10	0.10
9/12/12 12:05	Outflow -53	0.12	0.13
9/12/12 13:05	Outflow -54	0.12	0.13
9/12/12 14:05	Outflow -55	0.12	0.13
9/12/12 15:05	Outflow -56	0.11	0.12
9/12/12 17:05	Outflow -57	0.059	0.067
9/12/12 19:05	Outflow -58	0.038	0.035
9/12/12 21:05	Outflow -59	0.043	0.042
9/12/12 23:05	Outflow -60	0.028	0.027
9/13/12 1:05	Outflow -61	0.031	0.031
9/13/12 3:05	Outflow -62	0.036	0.036
9/13/12 5:05	Outflow -63	0.040	0.043
9/13/12 7:05	Outflow -64	0.035	0.029
9/13/12 9:05	Outflow -65	0.029	0.019
9/13/12 11:05	Outflow -66	0.022	0.024
9/13/12 13:05	Outflow -67	0.032	0.034
9/13/12 15:05	Outflow -68	0.034	0.037
9/13/12 17:05	Outflow -69	0.035	0.036
9/13/12 19:05	Outflow -70	0.022	0.024
9/13/12 21:05	Outflow -71	0.017	0.017
9/13/12 23:05	Outflow -72	0.014	0.013
9/14/12 1:05	Outflow -73	0.013	0.011
9/14/12 3:05	Outflow -74	0.015	0.012
9/14/12 5:05	Outflow -75	0.011	0.010
9/14/12 7:05	Outflow -76	0.011	0.010
9/14/12 9:05	Outflow -77	0.010	0.011
9/14/12 11:05	Outflow -78	0.012	0.014
9/14/12 13:05	Outflow -79	0.017	0.017