Irrigation Pond Characterization and Analysis: Impact of Weather and Management[1]

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Abstract

Weather and management practices were monitored to assess the impact on water quality at four stormwater retention ponds used for irrigation. Two retention ponds were located at Bayville Golf Club (BGC) in Virginia Beach, VA, and two were located at Knotts Creek Nursery (KCN) in Suffolk, VA. Total dissolved N concentrations were examined at increasing depths and over time at the pond inflows and middles. Multiple fertilizer products with variable analyses were applied more frequently at BGC, but N concentrations were consistently higher at KCN. In 2002, a drought year, water temperatures fluctuated little over the season or with depth, regardless of location. N concentration ranges were 1.0–3.5 mg·liter^{-1} (ppm) at BGC and 2.5–6.0 at KCN. Nitrogen concentrations fluctuated as water depth increased. In 2003 rainfall was above average. Water temperatures fluctuated more over the season than in 2002 and with increasing depth. N concentration ranges were 0.75–4.2 mg·liter^{-1} (ppm) at BGC and 0.5–6.0 at KCN; and were consistent as water depth increased. Both water temperatures and N concentrations fluctuated dramatically at the inflow locations compared to the middles of the ponds.

Index words: best management practice (BMP), golf course, nursery, nutrient runoff, retention basin, stormwater runoff, water pollution, wet pond.

Significance to the Nursery Industry

As regulations become increasingly stringent on runoff from commercial entities such as nurseries and golf courses, retention ponds or basins are more frequently used to collect runoff from rain and irrigation events for reuse for irrigation. Runoff, though, can carry pollutants; especially nitrogen (N), that can accumulate in these ponds. Therefore, it is important to characterize the concentrations of N that accumulate, how N is dispersed throughout a pond, and if the environment and nutrient management practices influence these processes. This knowledge can then be used to make recommendations for adjusting fertilizer products, application rates and frequency, and application methods (i.e. top dress versus incorporated). This information can provide insight related to locating irrigation pump intakes, buffer zones, and in-pond phytoremediation systems to reduce nutrient pollutant levels. This information can also be used to improve property best management practices, create a positive impact on water quality and visually enhance the aesthetic appearance and extend the life expectancy and functionality of the retention ponds.

Introduction

The protection and preservation of water resources is a key management requirement in the green industry in the United States (13), and in the states surrounding the Chesapeake Bay, in particular. Nitrogen (N) and phosphorus (P) polluted runoff threaten water quality (2, 3). Regulations are increasingly stringent on stormwater runoff from commercial entities such as nurseries and golf courses. As a result, best management practices like vegetated drainage ditches and buffers, constructed wetlands, and retention ponds are used to filter nutrient polluted runoff (1, 5, 6, 8, 12). Retention ponds are commonly used at nurseries and golf courses because the collected water can be used for irrigating high value nursery crops and intensively managed golf greens. Runoff from these production and recreation areas can carry nutrients, pesticides, sediments, and other pollutants that accumulate in these ponds (7, 16, 4), with N being a primary pollutant. While research has been conducted on the N removed from these ponds through natural processes, the amount is generally low; about 31% on average (14). And though some N is also removed when the water is used for irrigation, a significant amount remains in solution. Therefore, it is important to understand the concentrations of N that accumulate, how N is dispersed, and how the environment and nutrient management practices influence these processes. This knowledge can then be used to make recommendations for adjusting fertilizer products, application rates and frequency of application, and application methods (i.e. top dress versus incorporated). This information can provide insight related to locating irrigation pump intakes, buffer zones, and in-pond phytoremediation systems to reduce nutrient pollutant levels. This information can also be used to improve overall property best management practices, create a positive impact on water quality and visually enhance the aesthetic appearance and extend the life expectancy and functionality of the retention ponds.

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This paper presents physical descriptions of four stormwater and irrigation retention ponds; two located at Bayville Golf Club (BGC), an intensely maintained private golf club in Virginia Beach, VA, and two located at Knotts Creek Nursery (KCN), a commercial nursery specializing in container grown perennials, in Suffolk; both in the Chesapeake Bay area of Southeastern Virginia, USA. Data is presented on environmental conditions, including rainfall and ambient temperatures, nutrient management practices, including nutrient applications and irrigation, and N distribution in the ponds. The data was collected over two growing seasons, one dry year and one wet year.

Materials and Methods

Permission was secured from Bayville Golf Club (BGC) in Virginia Beach, VA and Knotts Creek Nursery (KCN) in Suffolk, VA to utilize two retention ponds on each property. The properties are 64 km (40 mi) apart. BGC is in USDA cold hardiness zone 8, and KCN is in zone 7. Each pond was surveyed to generate a topographic map and section view. Storage capacity of the retention ponds was calculated from the survey information. Water sampling was conducted every two weeks from July through October of 2002 and from May through October of 2003. A PVC pole was driven into the floor of the pond at the inflow and another at the middle point of each pond, and a floating marker buoy was attached so samples could be collected at the same point each time. Water samples were collected with a 1.5 liter (0.4 gal) water sampler (single line trigger mechanism, Forestry Suppliers, Jackson, MS) at depths in 25 cm (9.8 in) increments. The deepest sample also gave an indication of the water level on each sampling date. Samples were frozen immediately and batch processed and analyzed at the end of each season.

Total nitrogen (N) was determined using copper catalyst EPA Method 351.2. Water temperature was recorded at the same time water samples were collected and at the same depths (Oakton pH/CON10 pH/Conductivity/C hand-held waterproof meter, Oakton Instruments, Vernon Hills, IL). Ambient temperature and rainfall were recorded continuously over the period of the study at each location (HOBO Weather data logger, Onset Computer Corporation, Cape Cod, MA). Information on management of the area surrounding the ponds was collected from records of the superintendent at BGC and the owner at KCN.

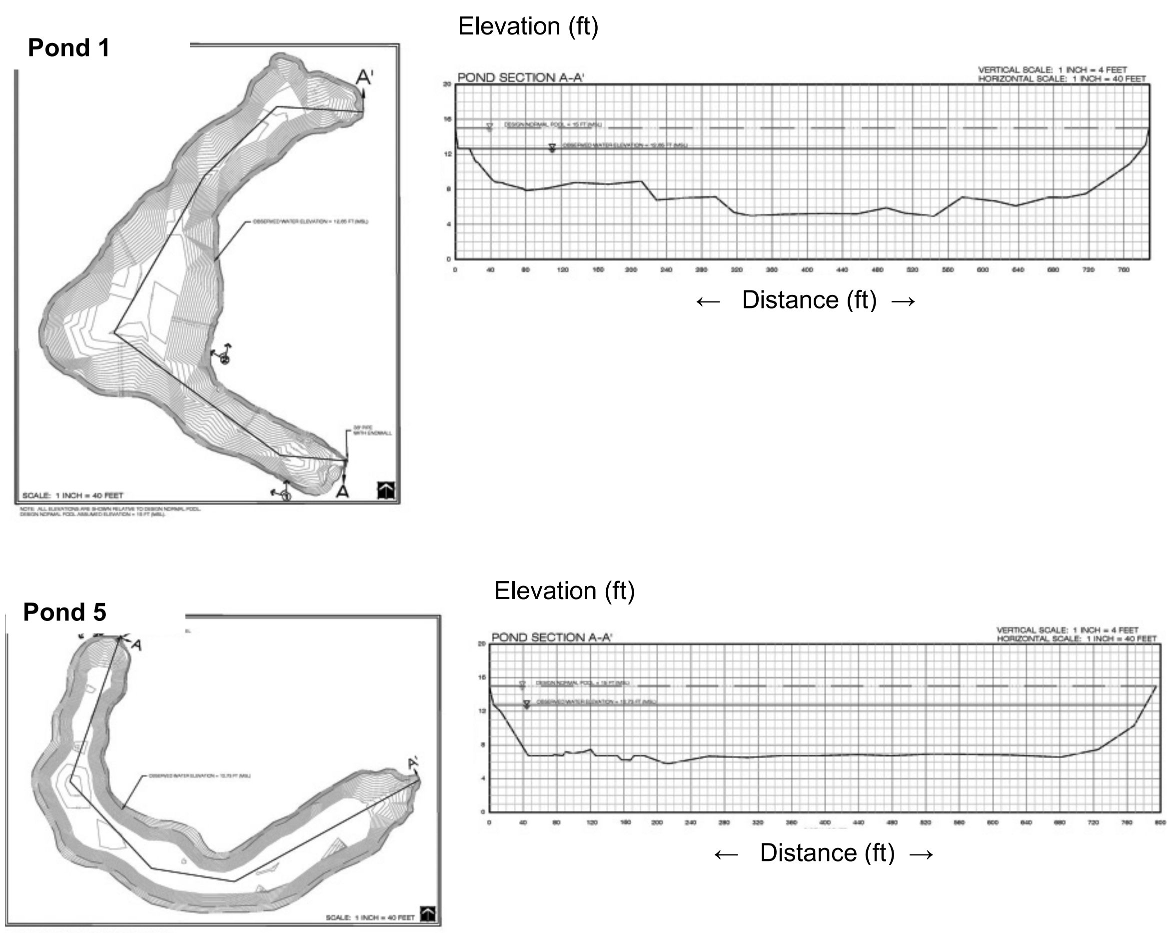

Fig. 1. Bayville Golf Club, Virginia Beach, VA, USA. Pond 1: maximum depth 3 m (9 ft), surface area at normal pool 0.73 ha (1.80 A), volume at normal pool 12.72 million liters (3.36 million gal). Pond 5: maximum depth 3 m (9 ft), surface area at normal pool 0.69 ha (1.71 A), volume at normal pool 12.45 million liters (3.29 million gal), surrounded entirely by a mixed herbaceous naturalized buffer that is mowed once a year in February.

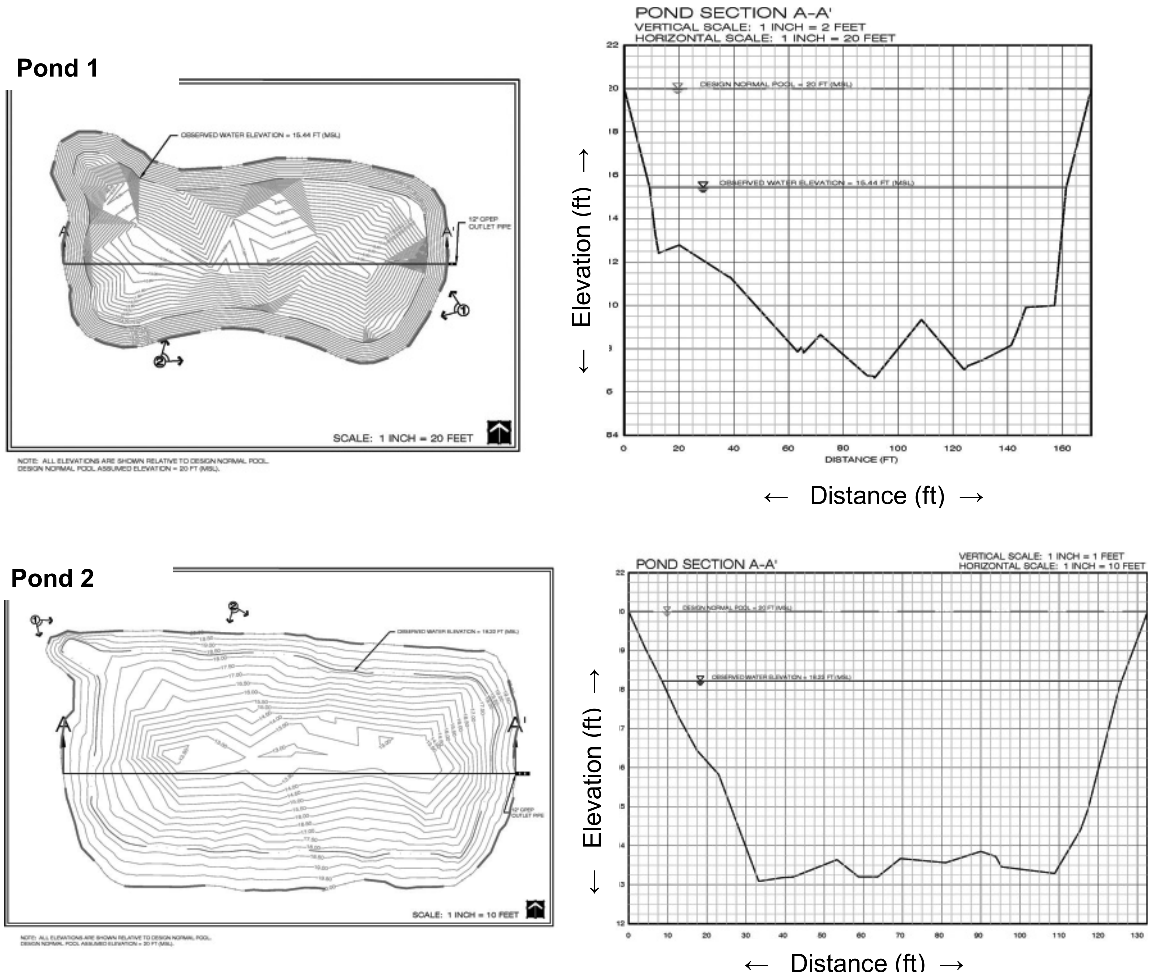

Fig. 2. **Knotts Creek Nursery, Suffolk, VA, USA. Pond 1: maximum depth 4 m (12 ft), surface area at normal pool 0.13 ha (.32 A), volume at normal pool 2.65 million liters (0.70 million gal). Pond 2: maximum depth 2 m (6 ft), surface area at normal pool 0.09 ha (0.22 A), volume at normal pool 0.87 million liters (0.23 million gal).**

Results and Discussion

Pond descriptions. Pond contour maps and cross sections are in Fig. 1 (BGC) and Fig. 2 (KCN). BGC is a 108 hectare (266.7 A) private 18 hole golf course located on the Lynnhaven River at the Chesapeake Bay. The property has seven runoff collection ponds that are used for irrigation and aesthetic purposes. Pond 1 is adjacent to hole 1 and Pond 5 to hole 5 on the course. Each hole is a greens complex usually comprised of the greens (hybrid bermudagrass), bermudagrass roughs and bunkers, and mixed cool season grass (mainly fescues) naturalized buffer areas with some shrub vegetation (*Baccharis halimifolia*, groundsel-bush; *Myrica cerifera*, wax myrtle; and *Salix nigra*, black willow). Pond 1 is surrounded predominantly by a mixed cool season grass naturalized buffer that is mowed once a year in February, with limited shrub vegetation (< 10%). Normal pool (normal water level) is defined as the lowest crest level of an overflow for a pond that has a fixed overflow (15). Pond 1 has a maximum depth of 3 m (9 ft), a surface area at normal pool of 0.73 ha (1.80 A), and a volume at normal pool or 12.72 million liters (3.36 million gal). Pond 5 is also surrounded by a mixed cool season grass naturalized buffer, that is mowed once a year in February, but it has more shrub vegetation (~ 60%). Pond 5 has a maximum depth of 3 m (9 ft), a surface area at normal pool of 0.69 ha (1.71 A), and a volume at normal pool of 12.45 million liters (3.29 million gal).

KCN is a three ha (7 A) commercial production nursery specializing in container grown perennials. It is located between Bennett's Creek and Knotts Creek which flow into the Nansemond River, then into the James River, and finally into the Chesapeake Bay. The production areas are comprised of non porous geotextile fabric covered ground with overhead irrigation. The production areas drain into vegetation-free collection swales which then drain into the ponds. Approximately two ha (5 A) of production area drain into Pond 1 and one ha (2 A) into Pond 2. Both ponds are used for irrigation. Pond 1 is completely surrounded by a mature mixed hardwood tree buffer which shades most of the water. Pond 1 has a maximum depth of 4 m (12 ft), a surface area at normal pool of 0.13 ha (0.32 A), and a volume at normal pool of 2.65 million liters (0.70 million gal). Pond 2 is surrounded entirely by a mixed herbaceous naturalized buffer that is mowed once a year in February. Pond 2 has a maximum depth of 2 m (6 ft), a surface area at normal pool of 0.09 ha (0.22 A), and a volume at normal pool of 0.87 million liters (0.23 million gal).

Management practices. BGC is an intensively maintained golf course for the purposes of playability and aesthetics. BCG has been acknowledged by the City of Virginia Beach, the Golf Course Superintendent's Association of America, and the Chesapeake Bay Foundation for environmentally conscientious management practices, especially as they impact water quality. Fertilizer products are diverse and applications are very specific to targeted areas (Table 1). The naturalized buffer areas are mowed once a year with the clippings left in place. Irrigation is on an as needed basis to keep the turf as dry as possible to prevent disease pressure. Irrigation occurs May through September at 10–15 mm (0.4–0.6 in) of water per week based on wind, dew point, and evapotranspiration rates, when there is no natural rainfall.

At KCN an eight to nine month slow release fertilizer (21-4-7 Scotts Fertilizer, Marysville, OH) is incorporated into the potting substrate at the time of planting. Container grown plants then receive one application of quick release liquid fertilizer (8-4-6 Crop Production Services, Ivor, VA) through the overhead irrigation system to 'quick start' them until the slow release nutrients become available. Irrigation occurs April through October at a rate of approximately 205 mm (8.2 in) per week when there is no natural rainfall. The rate is reduced from November through March to 127 mm (5 in) on an as needed basis. Because the potting substrate is very porous [2:1 aged pinebark:Biocomp 5S (peanut hulls/sphagnum/composted pinebark, Biocomp Corp., Edenton, NC)] irrigation is applied daily (36 mm; 1.4 in) in a split application with half in the morning and half in the afternoon.

Rainfall. Average yearly rainfall for Virginia Beach is 1143 mm (45.7 in) and for Suffolk is 1219 mm (48.8 in) (10, 11). Data and sample collection was done July through October in 2002 and May through October in 2003. Historical average rainfall for those four months of 2002 was 445 mm (17.5 in) for Virginia Beach and 635 mm (25.0 in) for Suffolk; and for those six months of 2003 was 485 mm (19.0 in) for Virginia Beach and 686 mm (27.0 in) for Suffolk. Actual rainfall totals for the two locations were: for 2002, 422 mm (16.6 in) at BGC in Virginia Beach, and 249 mm (9.8 in) at KCN in Suffolk; for 2003, 813 mm (32.0 in) at BGC and 864 mm (34.0 in) at KCN. Rainfall in 2002 was below average for both locations, with severe drought conditions experienced at the KCN location. Rainfall in 2003 was considerably above average at both locations. For the purpose of this paper a rain event is considered any event producing 20 mm (0.8 in) or more of rainfall within 24 hours. Four such events occurred at BGC and only two at KCN in 2002, while 11 events occurred at BGC and 12 at KCN in 2003 (Table 1).

Pond depth. Average pond depths were: BGC Pond 1 at 2.2 m (7.2 ft), Pond 5 at 2.5 m (8.2 ft), KCN Pond 1 at 3.4 m (11.2 ft), and Pond 2 at 2.0 m (6.6 ft). In 2002, the ponds at BGC were approximately 0.08 m (0.3 ft) below normal pool level. The ponds at KCN were approximately 0.2 m (0.7 ft) and 0.06 m (0.2 ft) below normal pool level in Pond 1 and Pond 2, respectively. In 2003, the ponds at both locations remained at normal pool level. During the drought year, the shallow state of the ponds caused the water to stagnate, and the water temperatures and N concentrations fluctuated very little over the season and with increasing depth. In 2003, frequent inflows of runoff caused the water temperatures and N concentrations to fluctuate widely over the season and with increasing depth.

Temperature. In 2002 for the months of July through October, BGC had an average daily maximum temperature of 32C (90F) and an average daily minimum temperature of 15C (59F). KCN had an average daily maximum temperature of 31C (88F) and an average daily minimum temperature of 13C (55F). In 2003 for the months of May through October: BGC had an average daily maximum temperature of 30C (86F) and an average daily minimum temperature of 10C (50F). KCN had an average daily maximum temperature of 29C (84F) and an average daily minimum temperature of 8C (46F).

Water levels were low in 2002; therefore only the temperature data for the four pond middle locations is reported in Fig. 3. At BGC water temperatures were warmest on the July 5 date in both ponds. There was also a distinctive trend of the water temperatures cooling at increasing depths on that date. On the later sampling dates, the water temperatures were generally around 25C (77F), and they remained consistent as depth increased. At KCN the July 12 water temperatures in Pond 1 followed the same trend as the July 5 readings at BGC; with the range of temperatures in Pond 1 over the sampling dates wider than at BGC. KCN Pond 2 had less fluctuation of temperatures over sampling dates than Pond 1, but not as concise as at BGC. Water temperatures cooled slightly as water depth increased in both ponds.

Rainfall was above average during the growing season in 2003, so inflow and middle of the pond water temperature data is reported for all four ponds at more sampling depths and dates (Fig. 4). At BGC water temperatures ranged between 16 and 29C (61 and 84F) at the inflow and middles of both ponds. Generally, water temperatures cooled slightly as depth increased in both locations in both ponds on most sampling dates. Of particular note though, are the drastic temperature decreases as pond depth increases on May 1 at the middle of both ponds, on June 26 at the inflows and middles of both ponds, and July 24 at the middle of Pond 1. Stratification is common in ponds during the summer, especially in deeper ponds when temperatures are high and winds are low. No significant rain events were associated with these dates. At KCN water temperatures ranged between 16 and 25C (61 and 77 F) at the inflow and middle of Pond 1, and between 16 and 29C (61 and 84F) at the inflow and middle of Pond 2. The trend of drastically decreasing water temperatures with increasing depth occurs more frequently in the KCN ponds; sometimes as much as 12C (54F) in 2.8 m (9.1 ft). This trend occurs mainly on sampling dates earlier in the season, although it was observed on the August dates at the middle of both ponds, though not as strong. The KCN ponds are smaller and well protected by buffers; which restricts wind, possibly accounting for the stratification occurring earlier in the season and more frequently than at BGC.

Nitrogen concentration and distribution. Total dissolved Nitrogen (N) concentrations at 102 cm (40 in) deep were examined at the middles of all ponds both years (Fig. 5). This depth was selected because use of phytoremediation systems to address N in deeper water is not practical. Replicate samples were taken for backup and not analyzed for sampling error. At BGC, N concentrations remained below 4.0 mg·liter^{-1} (ppm) in both ponds for both years. In 2002,

Table 1. Fertilizer applications and rain events for Ponds 1 and 5 at Bayville Golf Club (BGC) and Ponds 1 and 2 at Knotts Creek Nursery (KCN) for 2002 and 2003.

2002						
BGC Pond 1, greens 2601 m^2, bermudagrass 8.5 ha, bunkers 0.4 ha, cool season grasses 1.2 ha BGC Pond 5, greens 1858 m^2, bermudagrass 6 ha, bunkers 0.4 ha, cool season grasses 0.4 ha						
Day of year	**Date**	**Fertilizer (formulation, manufacturer)**	**Area fertilized**	**Pond 1 (kg)**	**Pond 5 (kg)**	**Rain event (mm)**
121	May 1	0-0-28, Lesco	greens	47	34	
122	May 2	19-19-19, Home Field	bunker edges	45	45	
143	May 23	30-4-10, Home Field	bermudagrass rough	953	680	
161	June 10	4-2-0 organic, Harmony	bermudagrass rough	9525	6804	
189	July 8	6-2-12 organic, Harmony	greens	44	31	
198	July 18	20-20-20, Prolific	greens	4	3	
205	July 24					41
206	July 25	20-20-20, Prolific	greens	4	3	
220	Aug 8	20-20-20, Prolific	greens	4	3	
224	Aug 12	20-20-20, Prolific	greens	4	3	
244	Sept 1					20
259	Sept 16					128
262	Sept 19	14-28-10, Anderson's	greens	51	37	
273	Sept 30	19-19-19, Home Field	cool season grasses	14	5	
275	Oct 2	5-0-30, Home Field	bermudagrass rough	953	680	
284	Oct 11					91
297	Oct 24	5-0-30, Home Field	bermudagrass rough	953	680	
KCN Pond 1, collects runoff from 2 ha of production area KCN Pond 2, collects runoff from 1.2 ha of production area						
Day of year	**Date**	**Fertilizer (formulation, manufacturer)**	**Area fertilized**	**Pond 1 (kg)**	**Pond 5 (kg)**	**Rain event (mm)**
74	Mar 15	21-4-7, Scotts	container pads	2835	1701	
		8-4-6, Crop Prod. Srvcs.	container pads	1284	642	
195	July14					57
240	Aug 28					58
2003						
BGC Pond 1, greens 2601 m^2, bermudagrass 8.5 ha, bunkers 0.4 ha cool season grasses 1.2 ha BGC Pond 5, greens 1858 m^2, bermudagrass 6 ha, bunkers 0.4 ha, cool season grasses 0.4 ha						
Day of year	**Date**	**Fertilizer (formulation, manufacturer)**	**Area fertilized**	**Pond 1 (kg)**	**Pond 5 (kg)**	**Rain event (mm)**
118	Apr 28	30-4-10, Home Field	bermudagrass rough	667	476	
142	May 22					24
143	May 23					26
154	June 3	30-4-10, Home Field	bermudagrass rough	1048	748	
165	June 14					25
170	June 19					49
181	June 30	6-2-12 organic, Harmony	greens	33	24	
189	July 8	6-2-12 organic, Harmony	greens	44	31	
195	July 14					58
200	July 19					28
209	Jul 28	30-4-10, Home Field	bermudagrass rough	1048	748	
222	Aug 10	20-20-20, Prolific	greens	4	3	
226	Aug 14	20-20-20, Prolific	greens	4	3	
229	Aug 17					62
239	Aug 27	20-20-20, Prolific	greens	4	3	
254	Sept 11	0-0-50, Home Field	bermudagrass rough	953	680	
255	Sept 12					27
256	Sept 13					25
261	Sept 18					57
275	Oct 2	0-0-50, Home Field	bermudagrass rough	953	680	
		20-20-20, Prolific	greens	4	3	
279	Oct 6	20-20-20, Prolific	greens	4	3	
282	Oct 9	20-20-20, Prolific	greens	4	3	

Table 1. Continued...

Table 1. Continued...

KCN Pond 1, collects runoff from 2 ha of production area KCN Pond 2, collects runoff from 1.2 ha of production area						
Day of year	**Date**	**Fertilizer (formulation, manufacturer)**	**Area fertilized**	**Pond 1 (kg)**	**Pond 5 (kg)**	**Rain event (mm)**
74	Mar 15	21-4-7, Scotts	container pads	3118	1871	
		8-4-6, Crop Prod. Srvcs.	container pads	1284	642	
142	May 22					33
143	May 23					26
166	June 15					37
200	July 19					26
211	July 30					24
216	Aug 4					39
220	Aug 8					20
247	Sept 4					102
255	Sept 12					52
261	Sept 18					105
267	Sept 24					23

N concentrations were slightly higher earlier in the growing season and declined to below 2.0 mg·liter^{-1} (ppm) by the end of the season. In 2003, N concentrations were higher earlier in the season, declined to below 2.0 mg·liter^{-1} (ppm) midseason, and had a significant peak, with a 3 mg·liter^{-1} (ppm) increase, day 259 (September 16), before returning to below 2.0 mg·liter^{-1} (ppm). At KCN in 2002, N concentrations initially increased in Pond 1 and decreased in Pond 2 to remain between 4.0 and 5.0 mg·liter^{-1} (ppm) the rest of the season. In 2003, N concentrations were lower, and consistently between 1.8 and 3.0 mg·liter^{-1} (ppm) until the peak, again with a 3 mg·liter^{-1} (ppm) increase, at day 259 similar to the pond at BGC. That peak is attributed to hurricane Isabel and over 100 mm (4 in) of rainfall.

Total dissolved Nitrogen (N) concentrations were examined at 51 cm (20 in) deep at the inflows of all ponds both years (Fig. 6). The relationships between N concentrations in the two ponds at both BGC and KCN are difficult to examine for 2002 because the severe drought conditions limited the number of samples collected. N concentrations followed very similar patterns in both ponds at BGC each year. Almost no fluctuation was observed in 2002 due to the lack of runoff, and N concentrations remained below 2.0 mg·liter^{-1} (ppm). While more fluctuation was observed in 2003, N concentrations remained below 3.0 mg·liter^{-1} (ppm) with the exception of the peak caused by hurricane Isabel at day 259. At KCN, no samples were collected from the inflow for Pond 2 in 2002. N concentrations in Pond 1 increased from 3.5 to 5.0 mg·liter^{-1} (ppm) where they remained consistent the rest of the season. In 2003, the N concentration fluctuated more, but remained below 3.0 mg·liter–1 (ppm) with the exception of the peak from hurricane Isabel. While the fluctuation patterns at BGC and KCN for 2003 were similar to those observed at the 102 cm (40 in) depth, they were more dramatic. This was attributed to a dilution effect as the runoff mixed into the pond water volume. Major storm events can cause several

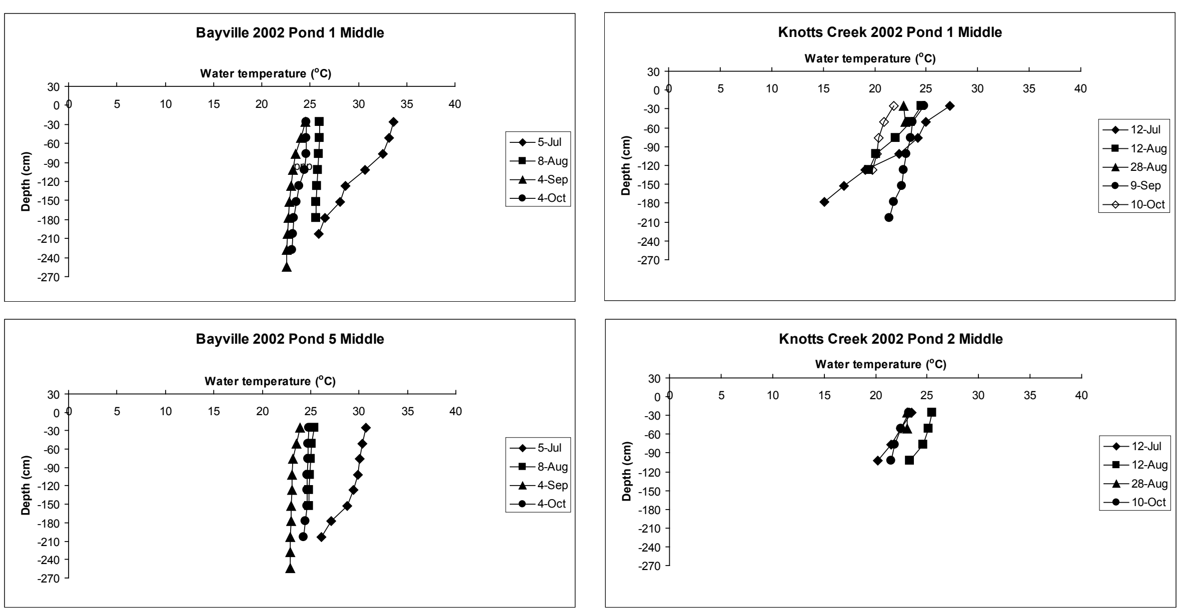

Fig. 3. Water temperature (C) at increasing depths at the middle of the pond at BGC Ponds 1 and 5 and at KCN Ponds 1 and 2 for 2002.

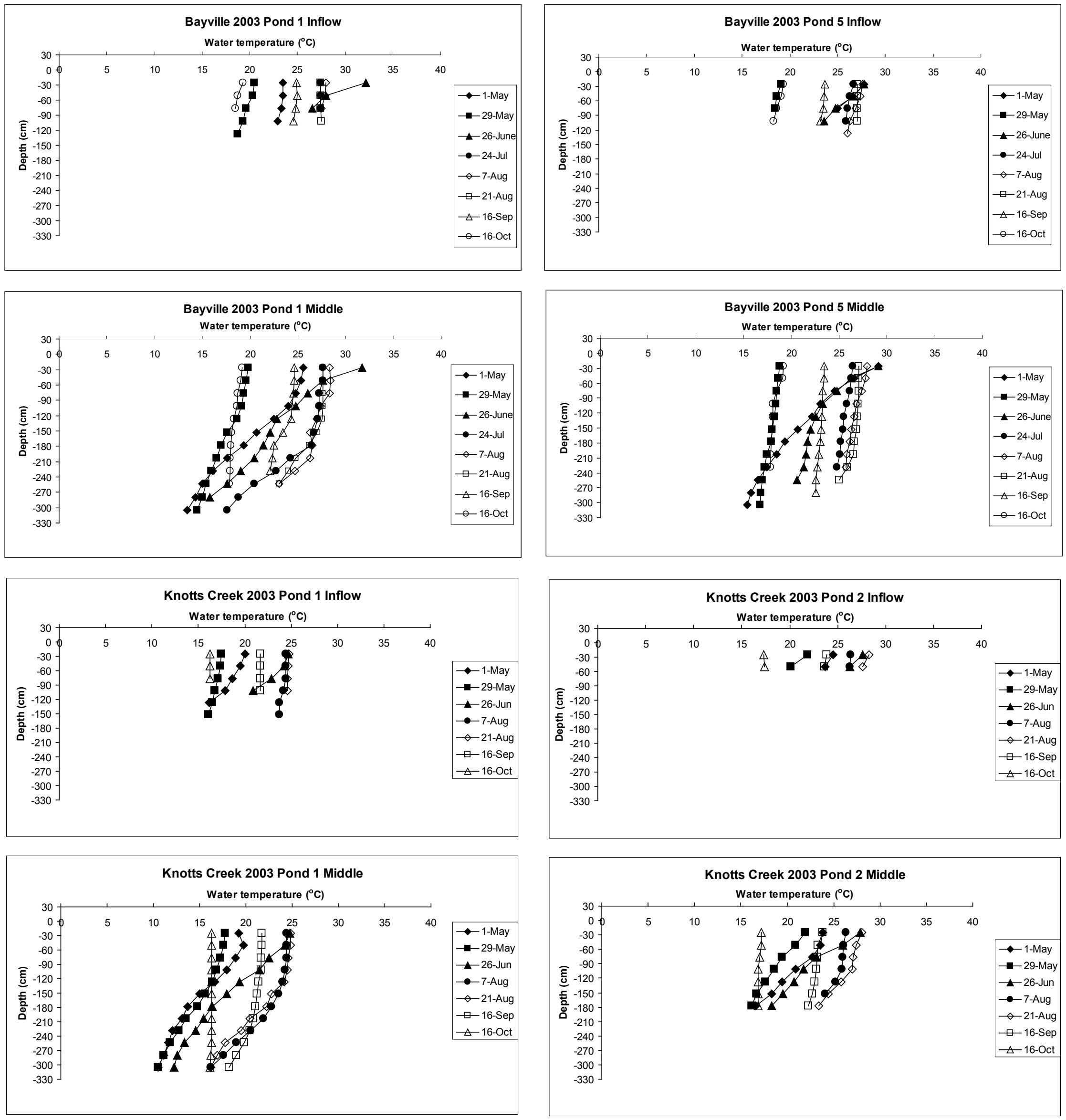

Fig. 4. Water temperature (C) at increasing depths at inflow and middle of pond at BGC Ponds 1 and 5 and at KCN Ponds 1 and 2 for 2003.

possible scenarios. With heavy rain; more N can leach from containers or runoff, causing higher concentrations in the pond. More stormwater runoff going into the pond can dilute the N already in the pond. Finally, the ponds can overflow allowing N to move into natural waterways.

Using the highest N concentrations observed in the ponds [3 mg·liter^{-1} (ppm)], water hyacinth N uptake capacity, pond volume, and the average incoming light and radiation use efficiencies, it is possible to calculate the amount of biomass and area of pond coverage necessary to remediate a given amount of N. The amount of biomass and coverage needed to remediate the highest N concentrations observed in the ponds at BGC was 20%, and at KCN was 6% or less of the total surface area. Ideally, the hyacinths would be contained at the pond inflows to intercept and filter the most concentrated polluted runoff before it is diluted by the pond water volume or before it the nutrients sink below the hyacinth root zone and become inaccessible. The hyacinth biomass would need to be thinned periodically to prevent plant competition and maintain an efficient remediation rate.

Total dissolved N concentrations were also examined at increasing water depths on specific sampling dates over the growing season. Three trends were observed. First, N concentrations stayed the same as depth increased. Second, N concentrations increased as depth increased, and third N concentrations decreased as depth increased. All three trends were seen in each pond. Only the N concentrations for the middles of the ponds were graphed for 2002 (Fig. 7). At BGC in Pond 1, N concentrations are between 1.5 and 3.5 mg·liter^{-1} (ppm), while in Pond 5 they are between 0.75 and 2.75 mg·liter^{-1} (ppm). On the July 5 sampling date for Pond 1, N concentrations initially decrease with increasing depth, then dramatically increase at depths greater than 152 cm (60 in). For the same date for Pond 5, N concentrations increase slightly with increasing depth, then dramatically at depths greater than 152 cm (60 in), the same as in Pond 1. As there

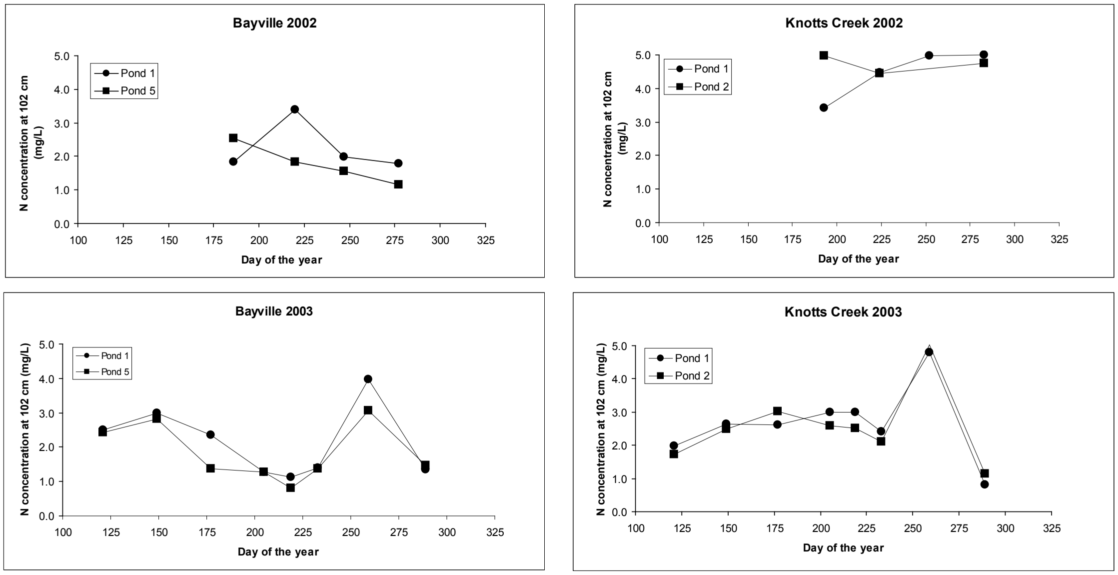

Fig. 5. Total dissolved Nitrogen concentrations (mg·liter^{-1}) 102 cm (40 in) depth at middle sampling locations in BGC Ponds 1 and 5 and in KCN Ponds 1 and 2 for 2002 and 2003.

was no rain event prior to sampling on this date, the high N concentrations are attributed to suspended solids close to the pond floor that were possibly exacerbated by the sampling process. At the October 4 date in Pond 1, N concentrations decreased with increasing depth from 3.2 to 1.7 mg·liter^{-1} (ppm). In Pond 5, they were consistently between 1.0 and 1.5 mg·liter^{-1} (ppm) and were the lowest of all the dates. N concentrations were fairly consistent as depth increased for the middle season sampling dates for both ponds.

At KCN in 2002, N concentrations in Pond 1 were between 2.5 and 6.0 mg·liter^{-1} (ppm) and in Pond 2 between 3.5 and 5.0 mg·liter^{-1} (ppm), with the exception of the unusually high concentrations, 10.0 mg·liter^{-1} (ppm), observed on August 28 in both ponds just after a major rain event of 58 mm (2 in). The July 12 and August 12 N concentrations follow the increasing N with increasing depth trend in both ponds. The October 10 concentrations are consistent as depth increases in both ponds.

With more rainfall in 2003, a more comprehensive picture of N concentrations relative to pond depth emerges. For BGC in both ponds at both locations the N concentrations were between 1 and 4 mg·liter^{-1} (ppm) overall (Fig. 8). The concentrations for the early season (May) dates were generally between 2 and 3 mg·liter^{-1} (ppm), while the concentrations on the later season dates (August through October) were generally between 1 and 2 mg·liter^{-1} (ppm). September was

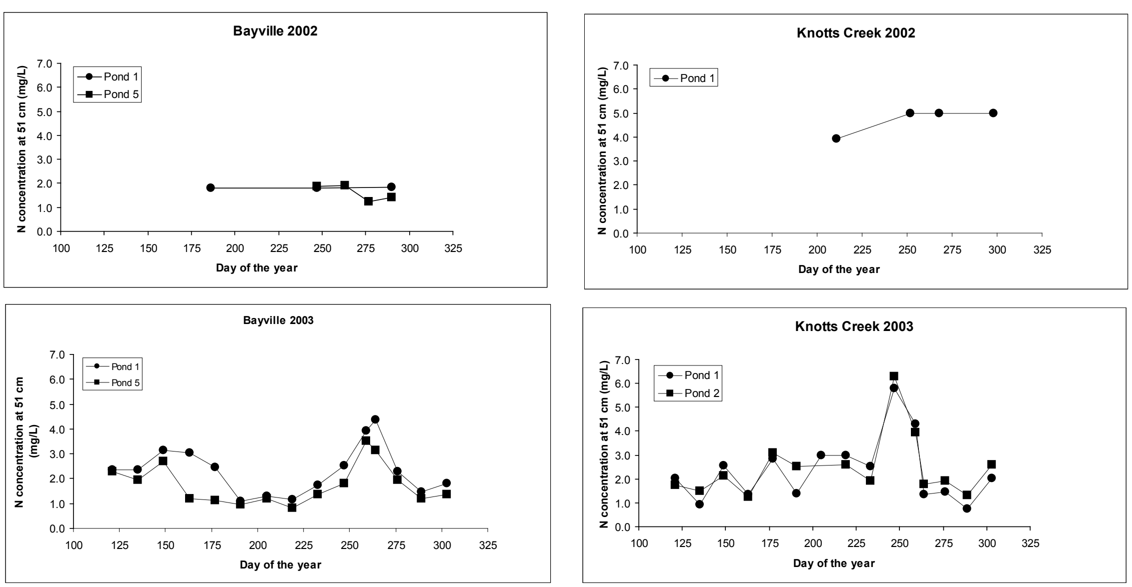

Fig. 6. Nitrogen concentration (mg·L^{-1}) patterns at 51 cm (20 in) depth at inflow sampling location in BGC Ponds 1 and 5 and in KCN Ponds 1 and 2 for 2002 and 2003.

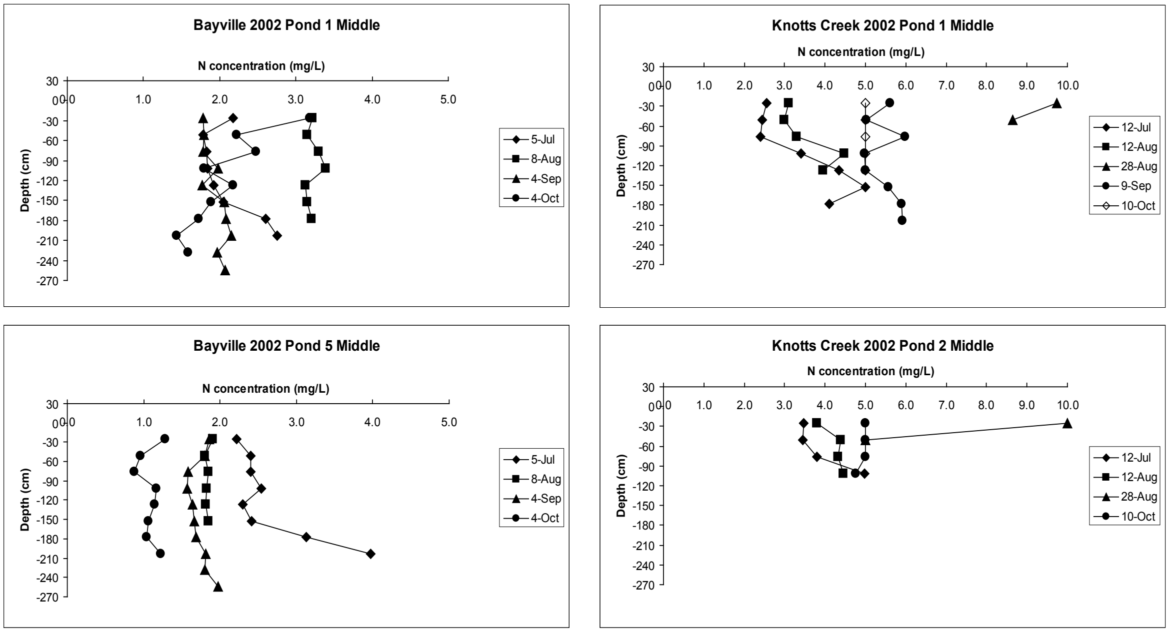

Fig. 7. Total dissolved nitrogen concentration (mg·liter^{-1}) patterns at increasing depths at the middle sampling location on selected sampling dates in BGC Ponds 1 and 5 and in KCN Ponds 1 and 2 for 2002.

the exception, with N concentrations between 3 and 4.5 mg·liter^{-1} (ppm) which is attributed to hurricane Isabel. At the inflows of both ponds, May 1 concentrations initially increased with increasing depth, and then decreased. The May 10 concentrations were consistent with increasing depth in both ponds. The later season (August through October) concentrations were consistent at increasing depth in Pond 1, but seemed to increase slightly at increasing depths in Pond 5. At the middle of each pond, 1 May concentrations increased with depth in Pond 1. N concentrations increased initially and then were consistent with increasing depth in Pond 2. The May 29 N concentrations were consistent with increasing depth in both ponds. The July 24 concentrations were also consistent as depth increased in both ponds with the exception of the dramatic increase that occurred at the deepest levels in Pond 1, which is attributed to suspended sediment. Early August concentrations were consistent as depth increased in both ponds. N concentrations on August

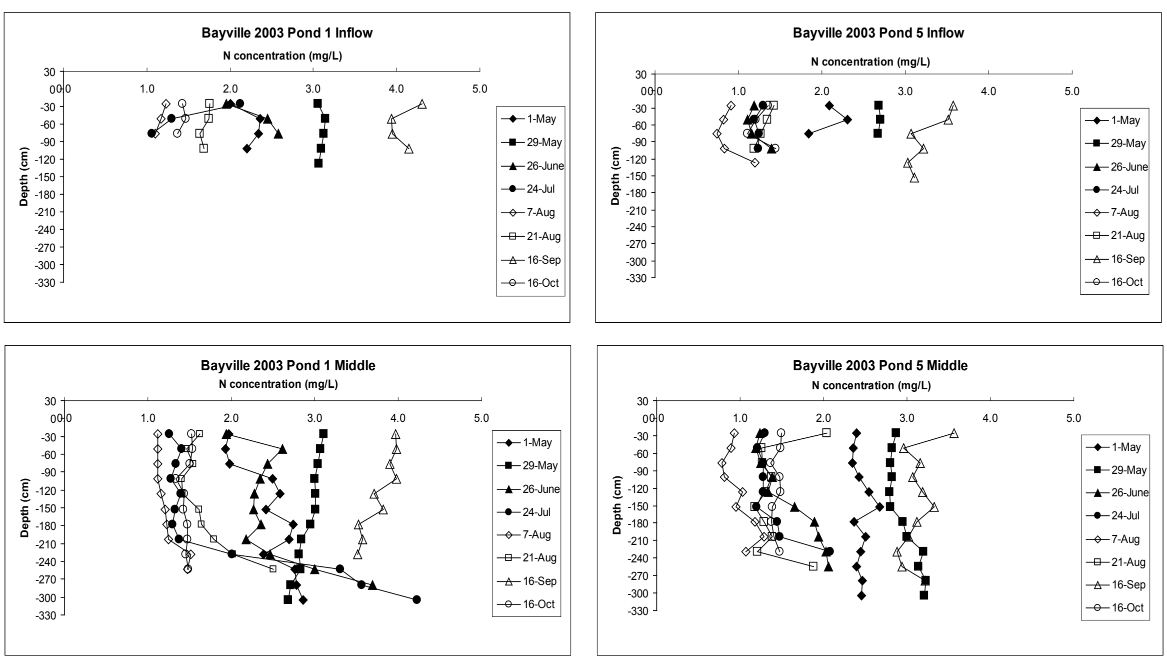

Fig. 8. Total dissolved nitrogen concentrations (mg·liter^{-1}) at increasing depths at the inflow and middle sampling locations on selected sampling dates in BGC Ponds 1 and 5 for 2003.

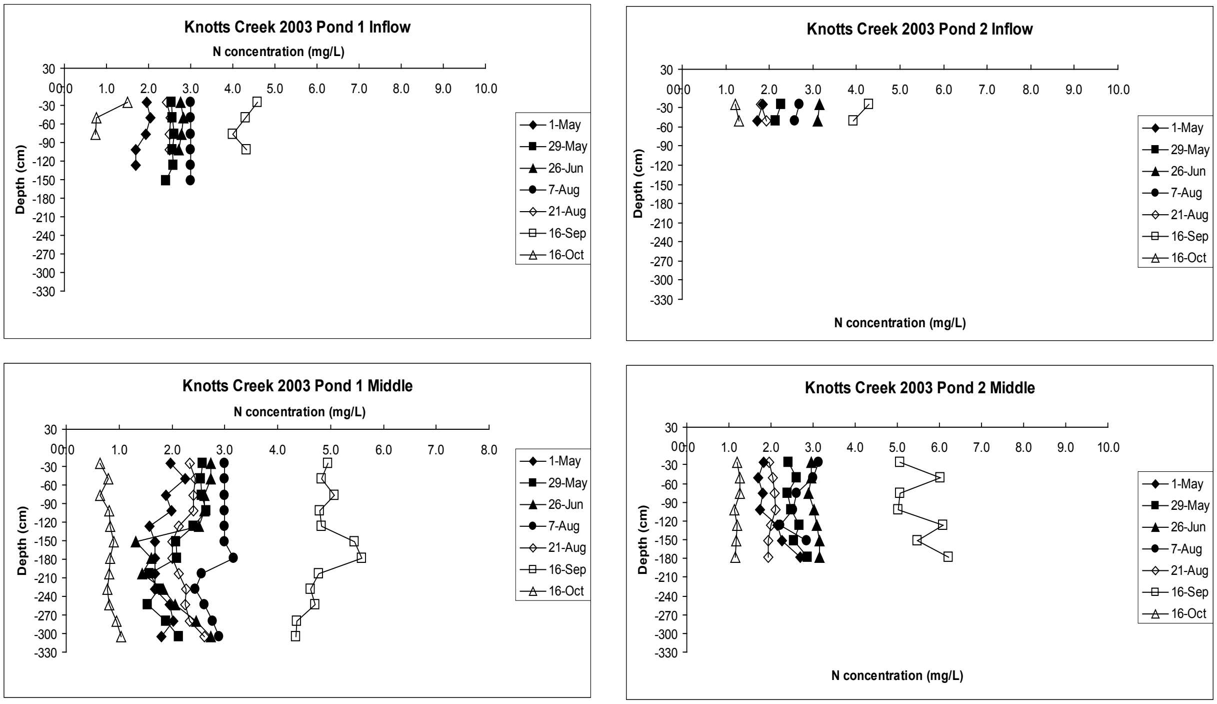

Fig. 9. Total dissolved nitrogen concentrations (mg·liter^{-1}) at descending depths at the inflow and middle sampling locations on selected sampling dates in KCN Ponds 1 and 2 for 2003.

21 showed an initial decrease followed by an increase as depths increased. October concentrations increased with increasing depth. For KCN in both ponds at both sampling locations, the N concentrations were between 0.5 and 3 mg·liter^{-1} (ppm) overall (Fig. 9). Again the exception was the high N concentrations (4–5 mg·liter^{-1} (ppm) at the inflows and 5–6 mg·liter^{-1} (ppm) at the middle of each pond) in September. KCN received almost twice as much rainfall as BGC during hurricane Isabel. N concentrations for May 1–August 21 generally remained between 2.0 and 3.0 mg·liter^{-1} (ppm) at the inflows and middles of both ponds. October concentrations were lowest, around 1.0 mg·liter^{-1} (ppm) at both locations in both ponds. There was a general overall trend at KCN for N concentrations to be consistent at increasing depths. Notable differences include: May 1 where a slight increase was observed at increasing depths in both ponds, and June 26 where an initial decrease followed by an increase was observed in Pond 1.

Obviously weather and management practices influenced amount and N concentration in the runoff collected by these ponds. Pond size, depth, and openness also influence water temperatures, stratification and N concentrations and distribution in the pond. During the four months data were collected in 2002, rainfall was well below average. Pond volumes were low. Water temperatures fluctuated little over the season or with depth. N concentrations were generally low and within a narrow range. There were greater fluctuations in N concentration as depth increased. All of these conditions were attributed to lack of water inflow into the ponds. During the six months data were collected in 2003, rainfall was above average leading to an entirely different situation. Pond volumes were usually at normal capacity. Water temperatures fluctuated more over the season and with increasing depth due to the influx of cooler water. N concentrations were observed across a wider range over the season. This can be attributed to the increased volume and frequency of nutrient polluted runoff inflow into the ponds. Overall, N concentration values were very similar as depth increased. Fluctuations in temperature and N concentrations were noticeably elevated at the pond inflows compared to the middles as expected. The ponds at BGC were larger and deeper with full sun and wind exposure whereas the ponds at KCN were smaller, with Pond 1, deeper and mostly protected and shaded and Pond 2, the smallest and shallowest. Open ponds are more subject to passive solar heating and wind which can impact water temperatures.

More types of fertilizers were used and with more frequency at BGC than at KCN which would seem to increase the potential for nutrient polluted runoff; however, they were applied to solidly vegetated areas, in multiple applications, over an extended time. While fewer types of fertilizers were used at KCN, container substrate is notoriously porous requiring frequent irrigation. Applications through an overhead irrigation system also cause fertilizer to fall on un-vegetated space between the containers. Both of these factors lead to higher N concentrations and runoff volumes (9). Irrigation was applied more frequently at KCN, and considering the above circumstances, it was not surprising to find considerably higher N concentrations in the ponds at KCN compared to BGC. Rain events significantly influenced nutrient runoff and subsequent amounts in ponds. This was very apparent with the unique event, hurricane Isabel in September 2003, which caused some interesting, but not unexpected effects. KCN received twice as much rainfall as BGC. Pond water temperatures decreased dramatically with the excessive and cooler inflow.

Targeting specific sites with or incorporating complete fertilizers, using incomplete or custom fertilizers, using slow release fertilizers, and applying granular formulations of fertilizers in split applications can all reduce the amount of N that runs off into collection ponds. Examining historical weather data, using soil tensiometers, evapotranspiration rates, cyclic irrigation and improved sprinkler heads can all improve irrigation efficiency which will reduce runoff and conserve water resources. Incorporating buffer areas around the ponds and installing phytoremediation systems at pond inflows will increase N remediation through plant uptake. Lower N levels in the pond reduces algae and other aquatic vegetation growth, which slows the natural eutrophication process and extends the life expectancy and functionality of the pond.

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