# URBAN CREATED WETLANDS AS AN ALTERNATIVE TO URBAN PONDS: AN ANALYSIS OF ENVIRONMENTAL AND ECONOMIC BENEFITS


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# CHAPTER I

# URBAN CREATED WETLANDS AS AN ALTERNATIVE TO URBAN PONDS: AN ANALYSIS OF ENVIRONMENTAL BENEFITS

*Abstract:* Urban stormwater can be responsible for degrading the water quality and wildlife utilization of urban water bodies. Stormwater ponds can remove suspended sediment and nutrients from stormwater runoff, but typically have water quality problems similar to the water bodies they are designed to protect. These problems include nutrient enrichment, turbidity and low dissolved oxygen and can result in increased maintenance costs, deterioration of aesthetic value, and decreased wildlife usage. An obvious need exists for more effective design and management strategies for urban stormwater ponds. This study examines the environmental benefits of constructing urban wetlands instead of urban ponds as a management alternative to indefinite aeration, repeated herbicide and pesticide treatments, turbidity treatments, and basin and shoreline sediment maintenance. Four urban stormwater ponds receiving varying levels of maintenance, and two created wetlands in central Oklahoma were monitored seasonally for representative water quality parameters and avian usage. Baseline data collected included soil physiochemical analysis and hydrology. Avian usage was significantly higher in created wetlands than urban ponds. Water quality in urban created wetlands was comparable if not better than urban ponds monitored in this study. Dissolved oxygen levels were significantly higher in created wetlands than in ponds regardless of the presence of aeration fountains. Turbidity levels were highest in an urban pond with steep shoreline slope and noticeable erosion. Mean chlorophyll *a* concentrations as an estimate of plankton biomass were significantly higher in urban ponds versus created wetlands, even in ponds utilizing algae control practices. High levels of nutrients in stormwater runoff entering the sites during a storm event in summer 1997, in addition to high landscape development intensity suggests all sites have significant amounts of stormwater pollution stress. The higher avian usage and equal or better water quality in created wetlands versus urban ponds, even with intense maintenance, illustrates some of the potential benefits of constructing urban wetlands instead of ponds.

*Key Words:* Stormwater runoff, created wetlands, stormwater ponds, eutrophication, wetland monitoring, water quality, stormwater pollution.

## INTRODUCTION

Ponds are constructed in urban areas for aesthetic reasons as well as stormwater management. Ponds are typically integrated into golf courses, business parks, and residential communities to either fulfill stormwater permit requirements or for aesthetic appeal. Recent surveys by the National Association of Home Builders, U.S. Department of Housing and Urban Development, and the U.S. Commerce Department indicate that real estate in proximity to natural or manmade water courses can increase property values (Mahan 1997, U.S. EPA 1995). Improved water quality has been shown to consistently increase property values (Mahan 1997). Conversely, poor water quality and safety issues (e.g., steep slopes of an urban pond) can decrease property values (U.S. EPA 1995).

Water quality problems typically encountered in urban ponds include eutrophication, low dissolved oxygen (DO), and turbidity which can result in increased maintenance costs, deterioration of aesthetic value, and decreased wildlife usage (Horner et al. 1994, Mason 1996, McComas 1993, Pitt 1995, Wren et al. 1997). These water quality problems can be attributed to several pollutants carried in stormwater runoff, e.g., as solids, oxygen-demanding substances, nutrients, pesticides, metals, pathogens such as fecal coliform bacteria, petroleum hydrocarbons, and synthetic organics (Horner et al. 1994). Over-enrichment of ponds with nitrogen and phosphorus from fertilizers in stormwater runoff can result in algal blooms which can lower DO, decrease submerged aquatic vegetation by increasing turbidity, and result in changes in plankton and fish community composition (Horner et al. 1994, Mason 1996, Nix 1994). Urban ponds constructed for stormwater retention typically intercept stormwater, hold it, and discharge it to natural waterways. In these situations, the poor water quality of the stormwater pond can also adversely affect natural water courses by discharging warm water as well as pollutants (Schueler and Galli 1995).

Another maintenance concern with urban ponds is shoreline erosion and basin sedimentation. Steep slopes and lack of proper vegetation on slopes result in erosion of the shoreline and increased sedimentation in the basin. Increased turbidity may result which can lead to a decline in submerged aquatic vegetation by preventing the penetration of sunlight, thus hindering photosynthesis. Erosion and sedimentation can lead to a decreased life span and the aesthetic value of the basin (McComas 1993). In addition, the steep banks typical of stormwater ponds can increase the risk of accidental drowning (U.S. EPA 1995).

Eutrophication and low DO are typically managed by the application of herbicides and aeration of the water with fountains. If mosquitoes are a nuisance, pesticides may also be used. Turbidity is controlled by the addition of calcium carbonate or calcium hydroxide or the installation of filtration devices. Eroded shorelines eventually require the installation of rip-rap or detaining walls or re-grading of the slope. Basin sedimentation requires occasional dredging and removal of the sediments. These maintenance practices are usually only temporary fixes and can be expensive (McComas 1993, Probert 1989).

A need esists for more cost-effective design and management strategies for urban ponds to ensure higher water quality of pond discharges to natural water courses and more aesthetically pleasing natural areas within urban areas. Augmentation of the littoral zone of urban ponds with wetland vegetation was explored in this study as an alternative to current management practices. It has been demonstrated that created wetlands can be useful in assimilating stormwater pollution, decreasing erosion and sedimentation rates, and providing wildlife habitat (Barten 1987, Brown 1985, Crites et al. 1997, Daukas et al. 1989, Ferlow 1993, Knight 1993, 1997, Mitsch 1993, Roesner 1988, Wood 1995, Wotzka and Oberts 1988). Stormwater treatment wetlands can provide strong visual values in urban areas if they are aesthetically pleasing and attract wildlife (Knight 1997, Leccese 1997, White and Meyers 1997). This paper compares the environmental benefits of urban created wetlands and urban ponds.

## STUDY AREA

The study sites included two created urban wetlands and four urban ponds constructed in central Oklahoma in 1995 (Figure 1.1). Rainfall and stormwater runoff are the primary sources of water driving the hydrology in all these ponds and wetlands. All six sites are located within the Arkansas-White-Red River Water Resources Region. Maintenance practices, size and location of each site are summarized in Table 1.1. The bottoms of Ponds A and B and Wetlands 1 and 2 are not lined, but Pond C and D are lined with Phillip/Gundle liner and were top dressed with approximately 25 cm of native soil. The surrounding land uses are primarily urban, including roadways, commercial, agricultural and residential. Climate conditions in central Oklahoma are represented by an average annual temperature of 15.6° C and mean annual precipitation of 84.7 cm (OCS 1997).

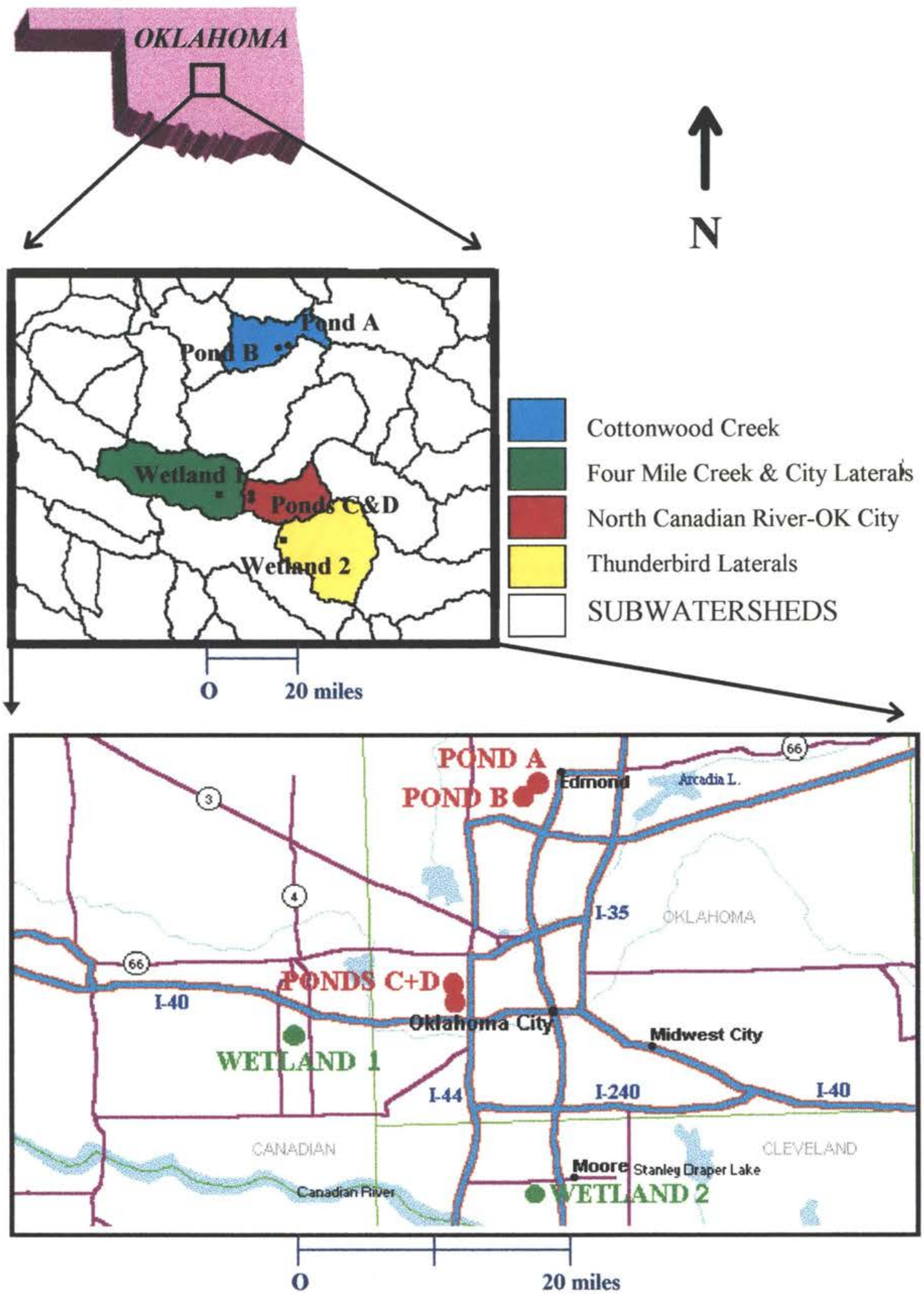


**Figure 1.1. Location of four urban ponds and two urban created wetlands in central Oklahoma.**

**Table 1.1. Site information for urban ponds and created wetlands.**

| Site | Area (ha) | Maximum Depth | Average Side Slope (degrees) | Surrounding Land Use | Maintenance Practices | |
|---|---|---|---|---|---|---|
| | | | | | fountain(s) | algae control |
| Pond A | 0.42 | 1.83 m | 50 | apartment complex | 3 | AquaShade |
| Pond B | 0.21 | 1.83 m | 40 | office park | 1 | Manual removal |
| Pond C | 0.30 | 1.98 m | 40 | golf course | 0 | AquaShade |
| Pond D | 0.30 | 1.83 m | 40 | golf course | 0 | none |
| Wetland 1 | 0.25 | 1.83 m | 30 | school/playground | 0 | none |
| Wetland 2 | 0.21 | 1.22 m | 30 | school/playground | 0 | none |

## METHODS

Vegetation and soil data were collected at the peak of the growing season (July-August 1997). Vegetation percent cover, species richness, diversity, and evenness were estimated using 1 $m^2$ quadrats at 3 m intervals along transects systematically positioned every 15 m perpendicular to shoreline to ensure a minimum of 40 quadrats per site and an estimate of vegetation percent coverage along the shorelines in relation to open water (Horner and Raedeke 1989). A weighted average score (WA score) as proposed by Wentworth et al. (1988) was calculated for the two created wetlands using the percent cover data. The WA score is calculated by weighting each species by it's NWI species categories (Reed 1988) and ranging from 1.0 (all obligate wetland plants) to 5.0 (all obligate upland plants).

Soil analyses included the determination of soil texture, Munsell soil color, porosity, water content, bulk density, organic content (loss by ignition), pH, nitrate-nitrogen ($NO_3^{-}N$), available phosphorus (P), and potassium (K). Soil texture was estimated by using a LaMotte Soil Texture Unit. Munsell soil color was determined in the field at depths of 0, 15 and 30 cm. Soil samples collected for laboratory analyses were kept on ice in the dark until analyzed. Soil testing protocols for porosity, water content, bulk density, and loss on ignition followed Standard Methods protocols (Carter and Ball 1993, Culley 1993, Karam 1993, Topp 1993). Soil nutrient and pH analyses were conducted on composite samples by the Oklahoma State University Soil, Water and Forage Laboratory.

Water levels were measured at a benchmark during each monitoring event (quarterly). Monthly rainfall in Oklahoma City, Oklahoma was compiled from data collected by the

National Weather Service Forecast Office, Norman, Oklahoma. Avian usage of each site was calculated from avian presence/absence surveys conducted during each monitoring event. A photographic record of seasonal conditions of the site was established utilizing fixed-point photo stations.

Water samples were collected in 500-ml glass bottles washed with 50% HCl and triple-rinsed with distilled water prior to collection (APHA 1992). Discrete samples were taken by manual grab sampling from shore at a depth approximately one third above the bottom (Horner and Raedeke 1989). Three samples were collected at each site quarterly for water quality analysis from August 1997 to May 1998. Stormwater influent was also collected in August 1997 after a representative storm event (depth > 0.1 inch, preceded by a minimum of 72 hours of dry weather, and not varying more than 50% from the average rainfall and duration) (Dennison 1996). Water quality variables included: pH, turbidity/total suspended solids (TSS), temperature, conductivity/total dissolved solids (TDS), dissolved oxygen (DO), nitrate-nitrogen, ammonia-nitrogen, orthophosphate, alkalinity, hardness, and free and total chlorine. Electronic meters were used to measure pH, conductivity, temperature and turbidity. A portable HACH water quality testing kit was used to analyze all other water quality parameters. Water samples not analyzed on site were stored in the dark on ice and analyzed within 24 hours. Field replicates and transport blanks were analyzed at a rate no less than 5% to ensure quality assurance/quality control (Horner et al. 1994). Water quality testing procedures followed the Standard Methods for the Examination of Water and Wastewater (APHA 1992).

Any visible water quality problems (e.g., floating algal mats, trash, unpleasant odors, etc.) were noted. Water was collected for plankton biomass estimation during each sampling event in 1-liter polyethylene bottles. Plankton biomass was estimated by determining chlorophyll *a* concentration using the trichromatic spectrophotometric procedure (APHA 1992).

Statistical analyses were conducted in Microsoft EXCEL and the statistical analysis software SAS for Windows, release 6.11. Analysis of variance was used to test differences in treatment means provided Levene's test for homogeneity of variances was nonsignificant. If the ANOVA was significant at $p<.05$, pairwise comparisons were made using a least significant difference (LSD) criterion and Tukey's honestly significant difference (HSD) criterion. Data were transformed when necessary using logarithmic, square root or angular transformations (Steel et al. 1997). When Levene's test for homogeneity of variances was significant, t-tests assuming unequal variances were used to test differences between means.

## RESULTS

Plant taxa present at the urban ponds and created wetlands during the summer of 1997 and their corresponding Region 6 indicator status are listed in Table 1.2. Vegetation percent coverage, species richness, and diversity was significantly greater in the two created wetlands than the urban ponds ($p<0.001$). The weighted average (WA) score, based on indicator status, for the created wetlands revealed more percent obligate wetland species in Wetland 2 (WA score = 1.1) versus Wetland 2 (WA score = 1.9).

Soil association, soil texture and soil color can be found in Table 1.3. None of the soil associations were classified as hydric. Low chroma numbers ($\leq 2$ for mottled soils or $\leq 1$ for unmottled soils) are characteristic of mineral hydric soils (USACOE 1987). None of the sites met this criterion, but had relatively low chroma just below the A horizon (25 cm or shallower). Higher organic content and organic streaking in the upper part of the soil was found in all the soils and is also indicative of soil inundation. Soil analysis of composite samples from each site demonstrated that pH ranged from 6.6 to 8.1, nitrate nitrogen 1-9 kg/ha, phosphorus availability 33-66 kg/ha and potassium index of availability 261-618 kg/ha (Table 1.4) with no significant difference between urban ponds and created wetlands ($p=0.14$, $p=0.50$ , $p=0.79$, and $p=0.24$ , respectively). Soil bulk density, porosity and water content were not significantly different between the urban ponds and created wetlands ($p>0.05$). Soil organic analysis ranged from $1.4 \pm 0.1\%$ (Pond A) to $7.9 \pm 1.1\%$ (Wetland 2). There was a significant difference between soil organic content in the urban ponds and created wetlands ($p=0.0054$).

**Table 1.2. Vegetation characteristics of urban ponds and created wetlands, summer 1997.**

| Common Name | Scientific Name | Region 6 Indicator | Percent Cover Pond 1 | Pond 2 | Pond 3 | Pond 4 | Wetland 1 | Wetland 2 |
|---|---|---|---|---|---|---|---|---|
| Alligator-weed | *Alternanthera philoxeroides* | OBL | | | | | 1.8% | 5.2% |
| American lotus | *Nelumbo lutea* | OBL | | | | | 0.4% | |
| Arrowhead | *Sagittaria latifolia* | OBL | | | | | | 1.5% |
| Bermuda grass | *Cynodon dactylon* | FACU+ | | | | | 4.0% | 0.6% |
| Black willow | *Salix nigra* | FACW+ | 0.9% | | | | | 1.5% |
| Cattail | *Typha latifolia* | OBL | | | | | 2.4% | 29.2% |
| Creeping spikerush | *Eleocharis palustris* | OBL | | | | | | 5.8% |
| Knotgrass | *Paspalum distichum* | FACW+ | | | | | | 0.8% |
| Marsh purslane | *Ludwigia palustris* | OBL | | | 1.4% | 4.7% | | 6.5% |
| Musk-grass | *Chara* sp. | ---- | | | | | 1.6% | 1.3% |
| Naiad | *Najas* sp. | ---- | | | | | 0.9% | |
| Pickerelweed | *Pontederia chordata* | OBL | | | | | 3.6% | 1.5% |
| Purple ammannia | *Ammania coccinea* | OBL | | | | | | 0.4% |
| Spatterdock | *Nuphar luteum* | OBL | | | | | 2.0% | |
| Stonewort | *Nitella hydralina* | ---- | | | | | 0.4% | |
| Sweet flag | *Acorus calamus* | OBL | | | | | 0.9% | |
| Waterweed | *Elodea cadensis* | OBL | | | | | | 5.4% |
| | **% vegetation cover** | | 0.9% | 0.0% | 1.4% | 4.7% | 18.0% | 59.7% |
| | **% bare ground** | | 25.6 % | 22.7 % | 18.8 % | 14.3 % | 10.3% | 6.0% |
| | **% open water** | | 73.5 % | 77.3 % | 79.8 % | 81.0 % | 71.7% | 34.3% |
| | **# of plots** | | 103 | 66 | 52 | 57 | 45 | 48 |
| | **species richness** | | 1 | 0 | 1 | 1 | 10 | 12 |
| $H'=\sum p_i \log_{10} p_i$ | **Shannon-Weaver Index** | | 0.00 | | 0.00 | 0.00 | 0.83 | 0.76 |
| $D=1/\text{sum}(p^2_i)$ | **Simpson's Diversity Index** | | 1.00 | | 1.00 | 1.00 | 6.97 | 3.58 |
| $=H'/\ln(S)$ | **Evenness Index** | | | | | | 0.36 | 0.31 |
| $WA=\sum(C_i x E_i)/\sum C_i$ | **Weighted Average Score** | | | | | | 1.9 | 1.1 |

*Region 6 Indicators: OBL=obligate wetland, FACW=facultative wetland, FAC=facultative, FACU=facultative upland, UPL=obligate upland (Reed 1988)

**Table 1.3. Soil characteristics in urban ponds and created wetlands summer 1997.**

| | SOIL ASSOCIATION | | SOIL TEXTURE | | | | SOIL COLOR | | |
|---|---|---|---|---|---|---|---|---|---|
| *site* | *general soil association* | *specific soil association* | *sand* | *silt* | *clay* | *soil texture* | *0 cm* | *15 cm* | *30 cm* |
| Pond A | Renfrow-Vernon Bethany | Vernon-Zaneis complex, 3-5 percent slopes | 60% | 27% | 13% | sandy loam (gravelly) | 10R4/4 | 10R4/4 | 10R3/6 |
| Pond B | Renfrow-Vernon Bethany | Vernon-Zaneis complex, 3-5 percent slopes | 30% | 17% | 53% | clay (gravelly) | 10R3/2 | 10R4/3 | 10R4/6 |
| Pond C | Dale-Canadian Port | Lela clay | 20% | 50% | 30% | silty clay loam | 10R3/2 | 10R3/2 | 10R4/6 |
| Pond D | Dale-Canadian Port | Lela clay | 53% | 33% | 13% | sandy loam | 5YR2.5/1 | 5YR4/4 | 5YR5/8 |
| Wetland 1 | Norge-Bethany | Grant-Hinkle complex, 1- 3 percent slopes | 40% | 27% | 33% | clay loam | 10R3/2 | 10R3/2 | 10R3/4 |
| Wetland 2 | Doolin-Bethany-Urban Land | Renfrow-Huska complex, 1-5 percent slopes, eroded | 27% | 10% | 63% | clay | 2.5YR3/3 | 2.5YR3/4 | 2.5YR3/6 |

**Table 1.4. Soil composition of urban ponds and created wetlands, summer 1997.**

| Site | Bulk Density (g/cm$^3$) | Total Porosity | Water Content (% volume) | Organic Content | Soil Analysis (composite sample) pH | NO$^3$-N (kg/ha) | P (kg/ha) | K (kg/ha) |
|---|---|---|---|---|---|---|---|---|
| Pond A | 1.73 ± 0.03 | 34.61± 0.56% | 42.82 ± 0.92% | 1.4 ± 0.1% | 7.4 | 1 | 33 | 261 |
| Pond B | 1.55 ± 0.05 | 41.48 ± 1.70% | 40.86 ± 0.81% | 4.4 ± 0.7% | 7.6 | 1 | 37 | 327 |
| Pond C | 1.25 ± 0.04 | 52.82 ± 1.40% | 50.22 ± 1.66% | 5.3 ± 0.2% | 7.7 | 1 | 58 | 618 |
| Pond D | 1.50 ± 0.04 | 43.12 ± 1.42% | 42.88 ± 1.19% | 1.9 ± 0.2% | 8.1 | 1 | 56 | 503 |
| Wetland 1 | 1.63 ± 0.02 | 38.50 ± 0.70% | 45.04 ± 0.69% | 3.8 ± 0.6% | 7.5 | 1 | 34 | 576 |
| Wetland 2 | 1.44 ± 0.03 | 45.65 ± 1.03% | 45.10 ± 2.39% | 7.9 ± 1.1% | 6.6 | 9 | 66 | 618 |

Water levels at all six sites varied seasonally (Figure 1.2) and reflected the rainfall amounts received in Oklahoma City, Oklahoma (Figure 1.3). Twenty-two (22) different bird species were observed at urban ponds and created wetlands over the course of the study (Table 1.5). The only nesting species observed were at created wetlands (Canada goose and European starling). Species richness varied between seasons, with significant differences in species richness between urban ponds and created wetlands only in winter 1998 ($p=.018$) and spring 1998 ($p<.001$) (Figure 1.4).

Summary statistics for the water quality parameters monitored seasonally at the four urban ponds and two created wetlands are presented in Table 1.6. Stormwater influent into Ponds A, C and D and Wetlands 1 and 2 were also tested for these parameters during the summer monitoring event (August 1997) (Table 1.7).

Mean water temperature and pH did not differ significantly between sites ($p=0.8412$ and $p=0.1531$, respectively), although they did vary by season (Figures 1.5 and 1.6). Hardness and alkalinity measurements exhibited wide fluctuations. Alkalinity was significantly higher in Pond B versus other urban ponds and created wetlands ($p<0.01$). Conductivity in Wetland 2 was significantly higher than urban ponds and Wetland 1 ($p<0.001$) (Figure 1.7). Turbidity was consistently highest at Pond A and Wetland 1 and lowest at Wetland 2 and Pond B (Figure 1.8). Mean turbidity was significantly higher in Pond A than the other urban ponds and created wetlands ($p<0.01$). Considerable shoreline erosion has occurred at all four urban ponds, but not at either created wetland.

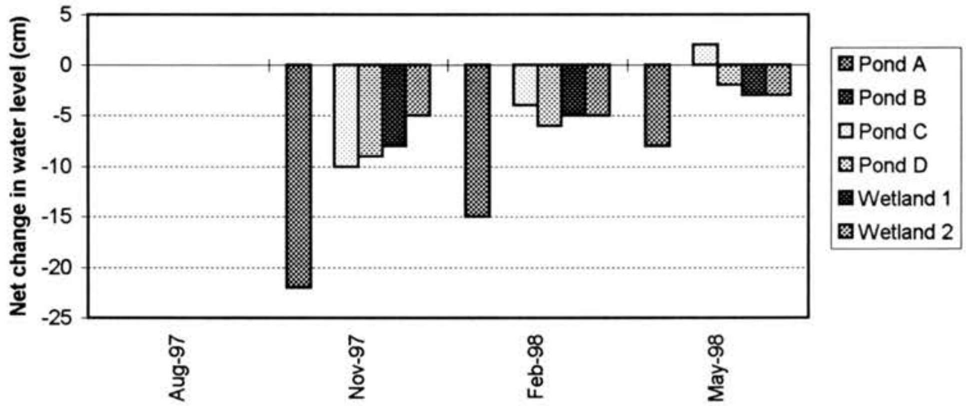


**Figure 1.2. Net water level changes in urban ponds and created wetlands as measured at benchmarks during seasonal monitoring events, 1997-1998.**

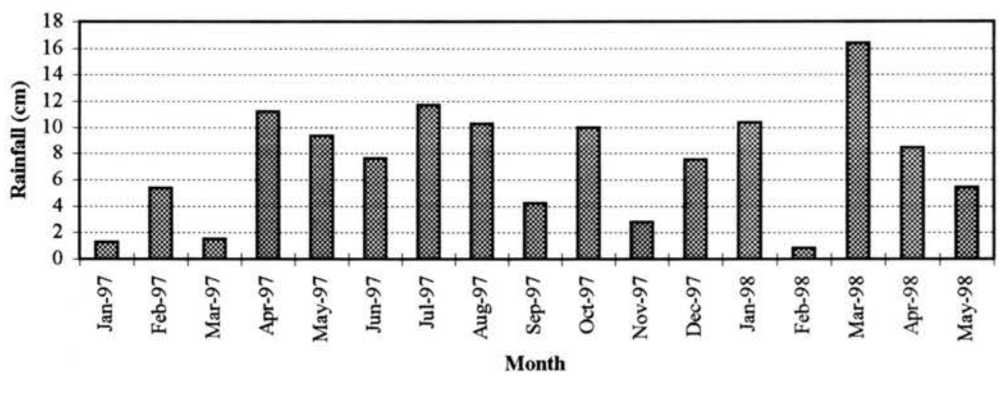


**Figure 1.3. Rainfall amounts in 1997 and 1998 in Oklahoma City, Oklahoma. (National Weather Service Forecast Office, Norman, Oklahoma)**

**Table 1.5. List of bird species identified during seasonal monitoring at urban ponds and created wetlands, July 1997 - May 1998.**

| Species (common name) | Scientific Name | Pond A | Pond B | Pond C | Pond D | Wetland 1 | Wetland 2 |
|---|---|---|---|---|---|---|---|
| American robin | *Turdus migratorius* | | | | | | X |
| blue-winged teal | *Anas discors* | | X | | | X | X |
| brown-headed cowbird | *Molothrus aeneus* | | | | | | X |
| Canada goose | *Branta canadensis* | | | X | | X* | X* |
| cardinal | *Cardinalis cardinalis* | | X | | | | |
| cliff swallow | *Hirundo pyrrhonota* | | | X | | | |
| common grackle | *Quiscalus quiscula* | | | | | X | |
| common yellowthroat | *Geothlypis trichas* | | | | | X | |
| European starling | *Sturnus vulgaris* | | | | | X* | |
| great egret | *Casmerodius albus* | | | X | | | |
| great-tailed grackle | *Quiscalus mexicanus* | X | X | X | X | X | X |
| house sparrow | *Passer domesticus* | | | | | | X |
| killdeer | *Chanadrius vociferus* | | X | X | X | X | |
| mallard | *Anas platyrhynchos* | X | X | | X | | X |
| mockingbird | *Minus polyglottos* | X | | | | X | X |
| mourning dove | *Zenaida macroura* | | | | | X | |
| muscovy duck | *Cairina moschata* | | X | | | | |
| red-tailed hawk | *Buteo jamaicensis* | | | | | X | |
| red-winged blackbird | *Agelaius phoeniceus* | X | | X | | X | X |
| snowy egret | *Egretta thula* | | | | | X | |
| song sparrow | *Melospiza melodia* | | | | | X | X |
| Virginia rail | *Rallus limicola* | | | | | | X |

*** = nesting**

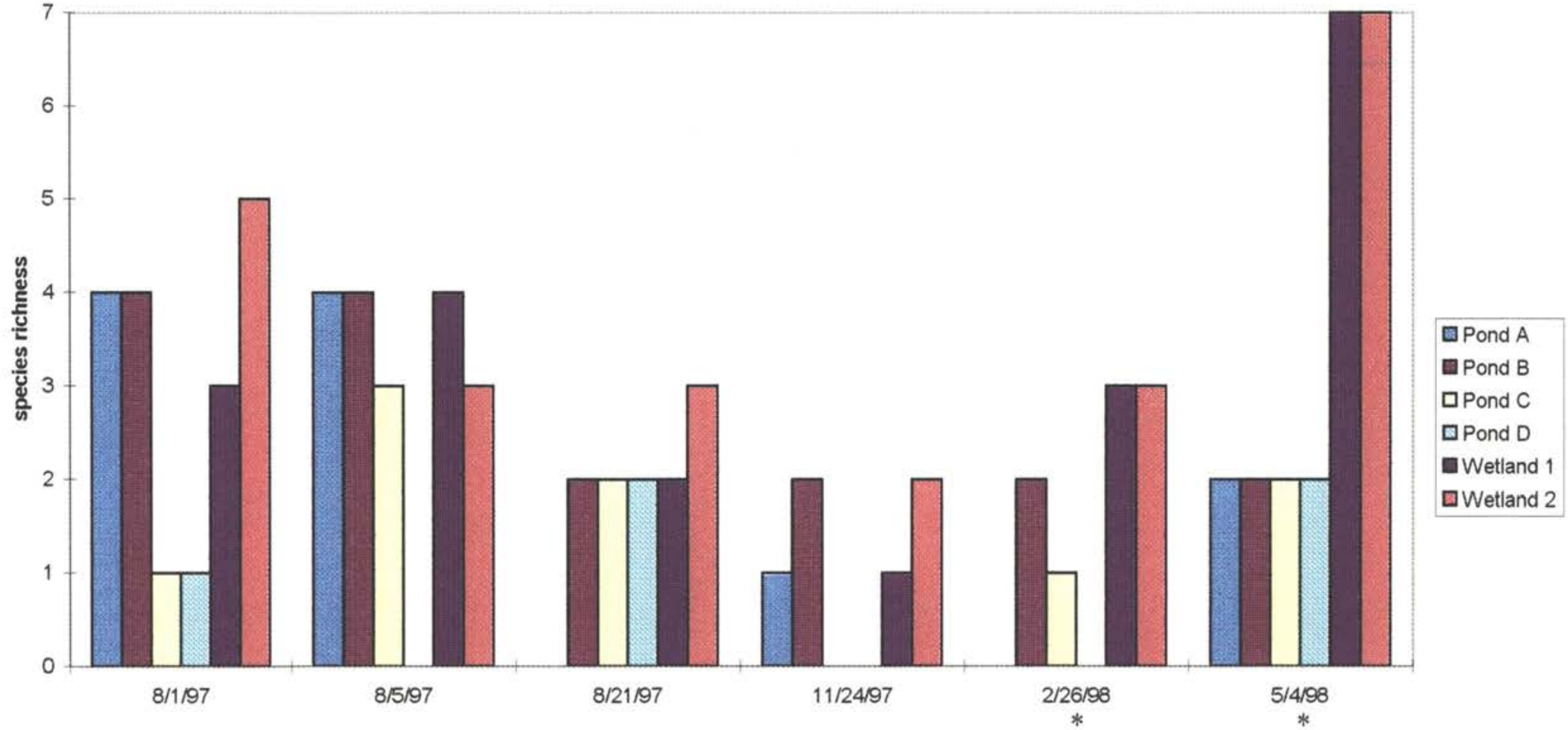


**Figure 1.4. Avian species richness at urban ponds and created wetlands during seasonal monitoring events, 1997-1998.**
(* denotes difference between ponds and wetlands at $p<0.05$.)

**Table 1.6. Summary statistics for seasonal water quality parameters in urban ponds and created wetlands, August 1997 - May 1998. Entries are mean±s.e. (n=12).**

| *Site* | *temp (°C)* | *pH* | *conductivity (µS/cm)* | *DO (mg/L)* | *hardness (gpm)* | *alkalinity (mg/L)* | *TRP (µg/L)* | *amm-N (mg/L)* | *nitrate-N (mg/L)* | *turbidity (NTU)* |
|---|---|---|---|---|---|---|---|---|---|---|
| pond A (F, AC) | 18.58±2.01 | 6.75±0.45 | 302.17±61.06 | 7.42±0.89 | 5.92±0.65 | 85.00±18.36 | 77.78±24.60 | 0.03±0.01 | 0.33±0.26 | 138.83±42.96 |
| pond B (F, AC) | 19.08±2.47 | 8.13±0.53 | 363.83±16.00 | 9.33±0.43 | 9.08±0.22 | 143.08±10.76 | 36.67±6.79 | 0.05±0.03 | 1.25±0.22 | 21.27±4.31 |
| pond C (AC) | 19.33±2.18 | 6.94±0.49 | 254.92±9.03 | 8.08±0.48 | 7.42±0.29 | 90.67±9.20 | 74.09±9.23 | BDL | 1.08±0.19 | 37.91±1.92 |
| pond D | 17.83±2.01 | 6.83±0.44 | 239.17±11.48 | 7.33±0.70 | 5.75±0.43 | 69.42±13.95 | 172.64±27.78 | 0.11±0.06 | 1.00±0.00 | 36.75±3.48 |
| wetland 1 | 19.08±2.11 | 6.95±0.28 | 305.33±36.60 | 10.00±0.65 | 12.58±0.97 | 92.08±15.16 | 106.67±46.65 | 0.07±0.03 | 0.25±0.18 | 73.67±2.32 |
| wetland 2 | 21.92±2.12 | 6.57±0.36 | 834.67±78.70 | 12.67±1.49 | 16.67±0.33 | 85.00±49.07 | 72.78±22.33 | 0.10±0.05 | 1.25±0.39 | 18.84±3.85 |

F = fountain(s), AC = algae control practices employed
BDL = below detectable limit
TRP = total reactive phosphorus, amm-N = ammonium nitrogen, nitrate-N = nitrate nitrogen

**Table 1.7. Summary statistics for storm water quality parameters in urban ponds and created wetlands, August 1997. Entries are mean±s.e. (n=1).**

| *Site* | *Date* | *temp (°C)* | *pH* | *conductivity (μS/cm)* | *DO (mg/L)* | *hardness (gpm)* | *alkalinity (mg/L)* | *TRP (μg/L)* | *amm-N (mg/L)* | *nitrate-N (mg/L)* | *turbidity (NTU)* |
|---|---|---|---|---|---|---|---|---|---|---|---|
| pond A | 8/20 | 23 | 8.6 | 558 | 5 | 10 | 122.4 | 113.33 | BDL | 1 | 24 |
| pond C | 8/19 | 24 | 7.9 | 300 | 6 | 7 | 115.6 | 126.67 | BDL | 2 | 17 |
| pond D | 8/19 | 27 | 9.3 | 165 | 4 | 10 | 136 | 140 | BDL | BDL | 16 |
| wetland 1 | 8/22 | 28 | 6.4 | 134 | 2.4 | 2 | BDL | 900 | 0.3 | 2 | 27 |
| | 8/22 | 29 | 7.3 | 168 | 5 | 3 | 27.2 | 213.33 | 0.1 | 1 | 73 |
| wetland 2 | 8/22 | 29 | 6.9 | 244 | 2.4 | 6 | 47.6 | 4000 | 0.4 | 2 | 26 |

BDL = below detectable limit
TRP = total reactive phosphorus, amm-N = ammonium nitrogen, nitrate-N = nitrate nitrogen

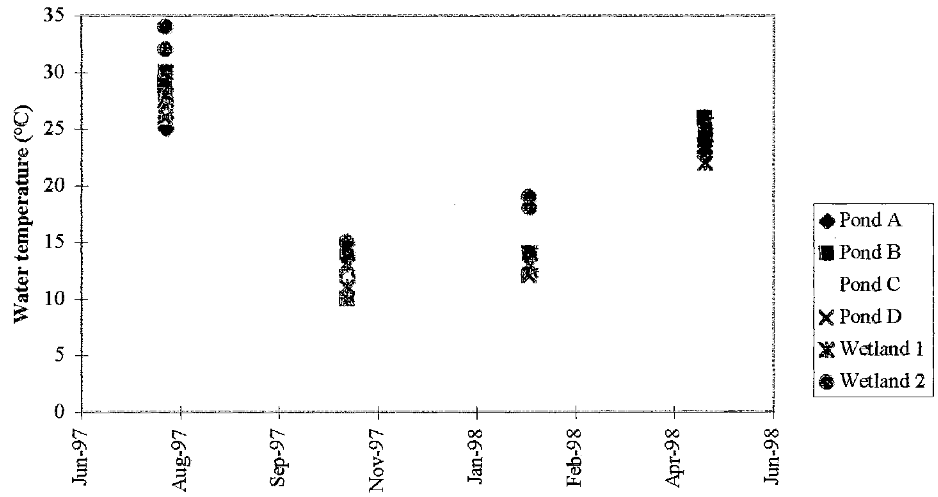


**Figure 1.5. Seasonal water temperatures for urban ponds and created wetlands, August 1997- May 1998.**

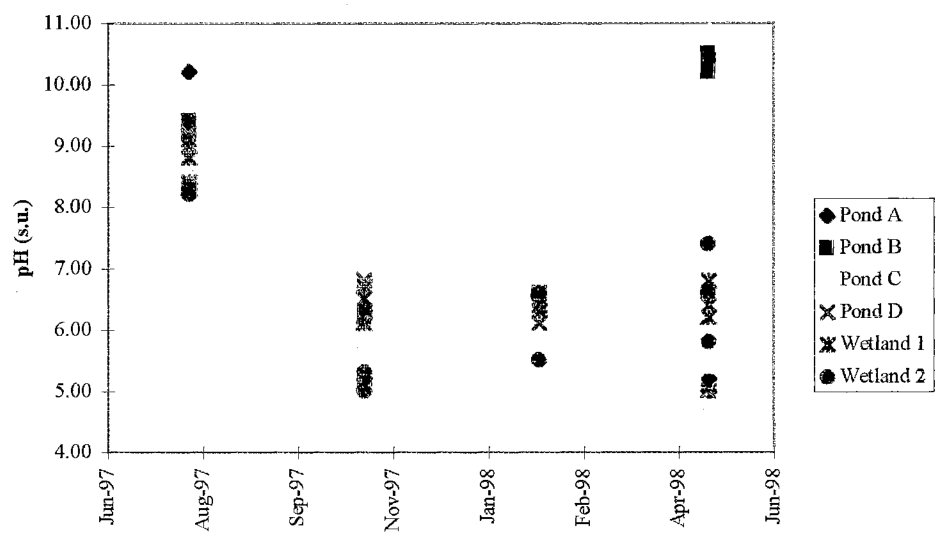


**Figure 1.6. Seasonal pH measurement for urban ponds and created wetlands, August 1997 - May 1998.**

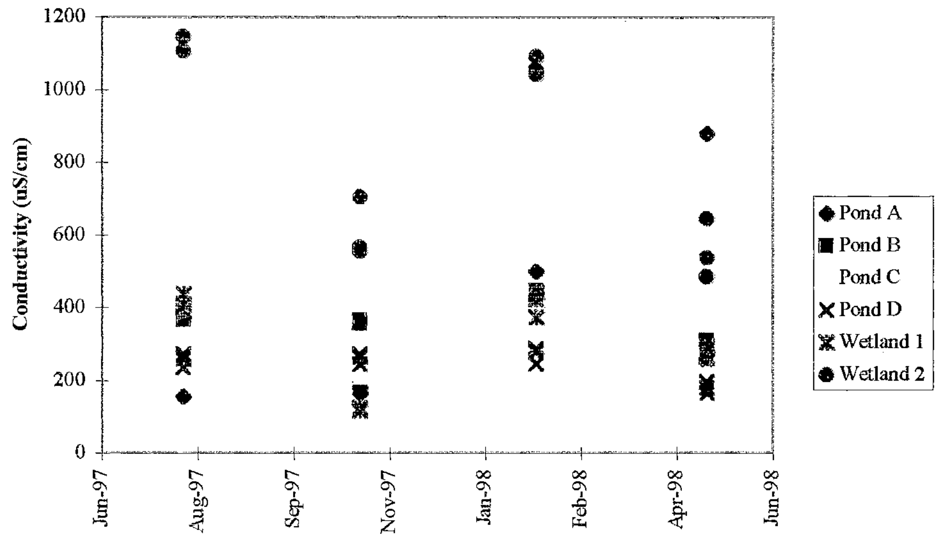


**Figure 1.7. Conductivity of water in urban ponds and created wetlands, August 1997 - May 1998.**

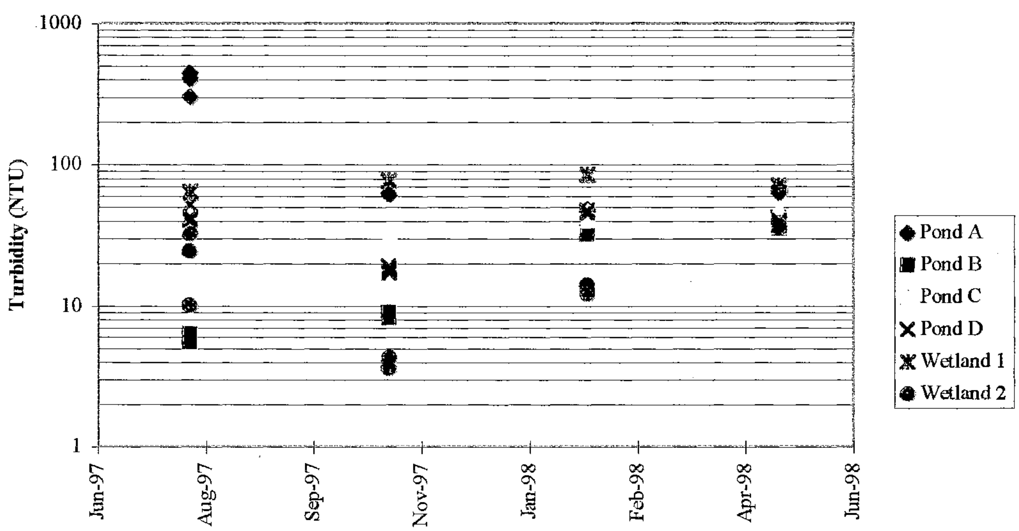


**Figure 1.8. Seasonal turbidity measurements for urban ponds and created wetlands, August 1997 - May 1998 (note log scale).**

Mean dissolved oxygen (DO) was significantly higher in the created wetlands versus the urban ponds with ($p<0.0163$) and without ($p<0.0038$) fountains (Figure 1.9). DO measured in mg/liter was converted to percent saturation for graphical comparisons (Figure 1.10). The amount of DO in water is dependent on atmospheric pressure (or equivalent altitude), water temperature, and salinity (Mitchell and Stapp 1996). Mean percent saturation of DO ranged from 90 to 110% in Wetland 1 and from 100 to 150% in Wetland 2. In the two urban ponds with fountains, the percent saturation of DO ranged from 60 to 100% in Pond A and from 65 to 125% in Pond B. Percent saturation of DO in the urban ponds without fountains ranged from 60 to 115% in Pond C and from 55 to 90% in Pond D.

Nutrient concentrations within the urban ponds and created wetlands were highly variable. Orthophosphate phosphorus levels were almost always above 20 μg/liter, the level usually found in natural surface waters (Figure 1.11). Pond D had significantly higher mean orthophosphate phosphorus levels than the other urban ponds and created wetlands ($p<0.05$). Nitrate-nitrogen and ammonia-nitrogen levels were measured at levels greater than 0.2 mg/liter in many cases, levels which can stimulate algal growth in lakes and may suggest eutrophic conditions (Figures 1.12 and 1.13) (Chapman and Kimstach 1992).

Stormwater influent water quality measured in August 1997 indicated high levels of orthophosphate phosphorus and nitrate-nitrogen at all sites (Table 1.7). High levels of ammonia-nitrogen were seen in Wetlands 1 and 2. Dissolved oxygen was lower in the stormwater effluent than the basin at all the sites.

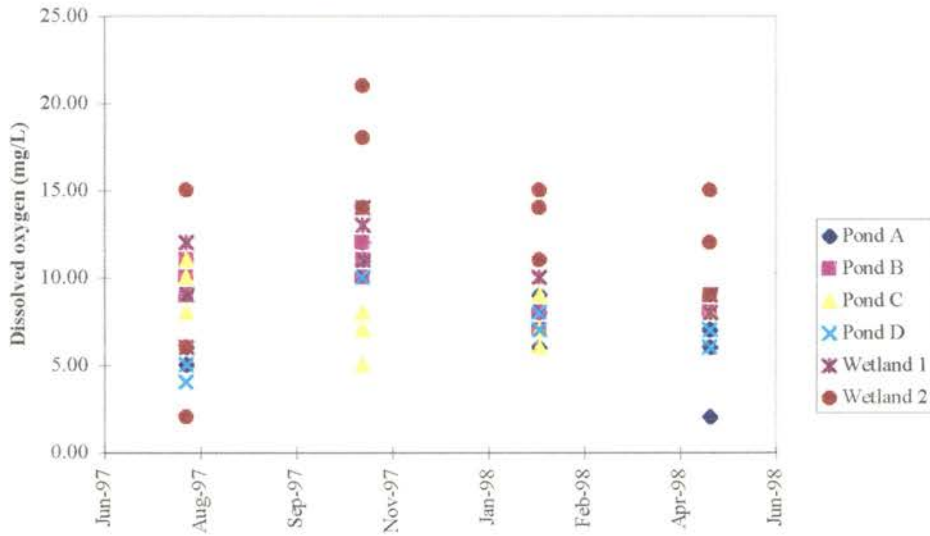


**Figure 1.9. Dissolved oxygen of water in urban ponds and created wetlands, August 1997 - May 1998.**

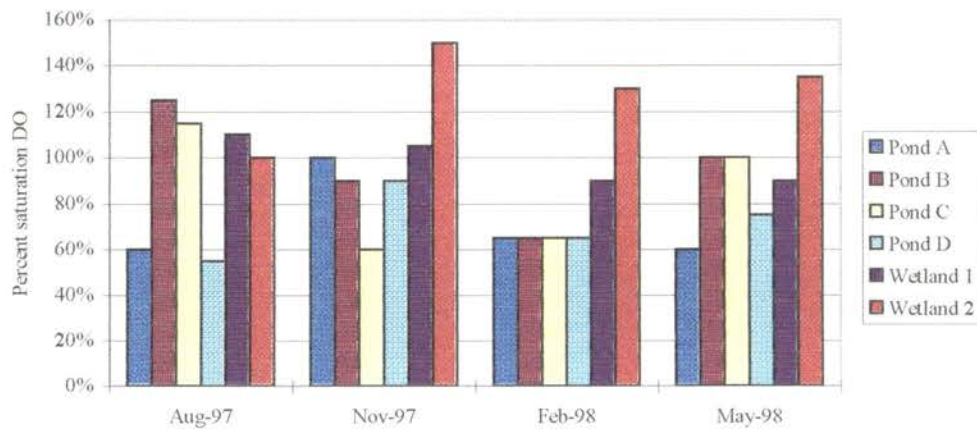


**Figure 1.10. Percent dissolved oxygen (DO) saturation of water in urban ponds and created wetlands, August 1997 - May 1998.**

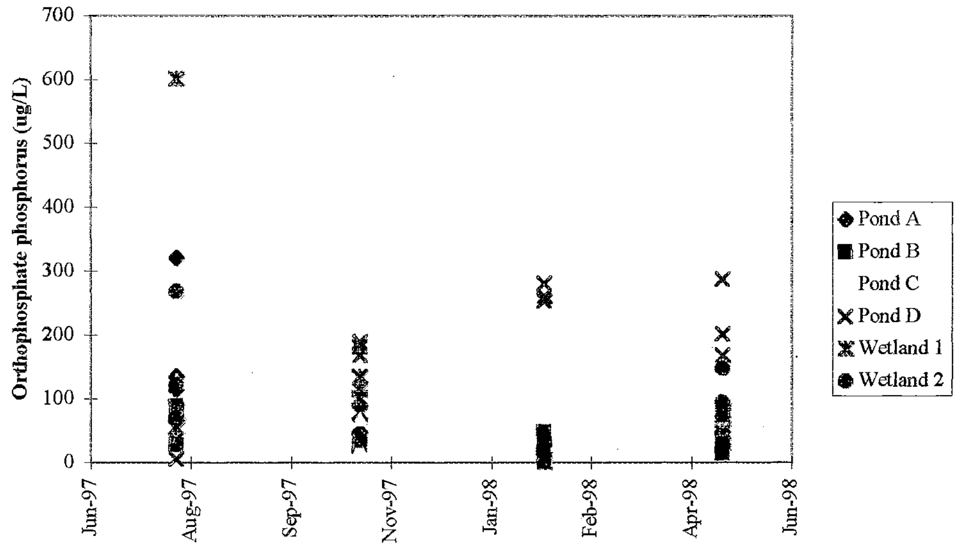


**Figure 1.11. Orthophosphate phosphorus levels in urban ponds and created wetlands August 1997 - May 1998.**

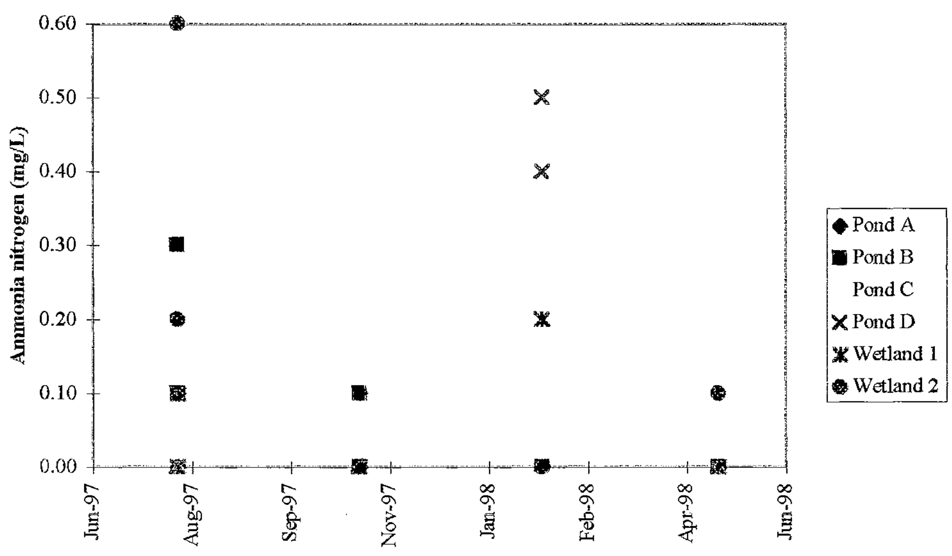


**Figure 1.12. Ammonia nitrogen in urban ponds and created wetlands August 1997 - May 1998.**

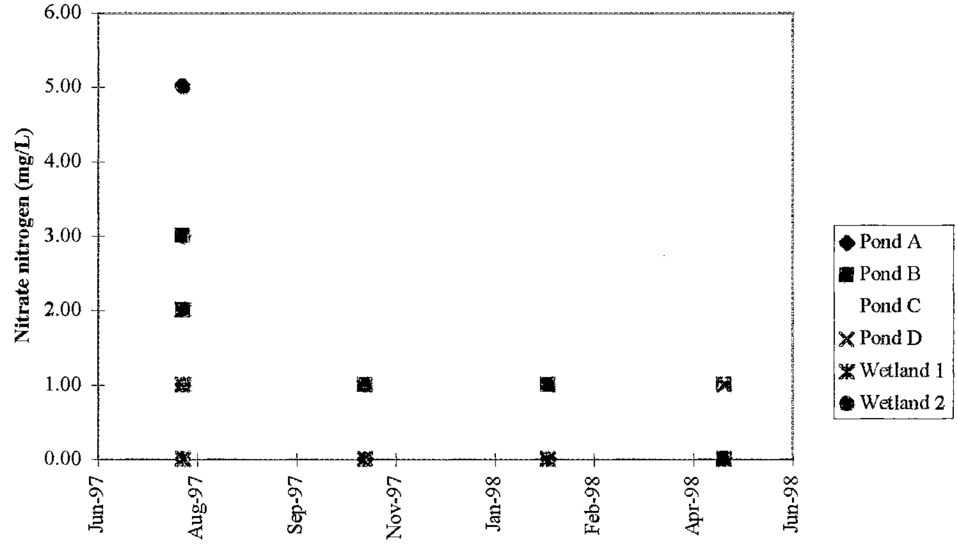


**Figure 1.13. Nitrate nitrogen measurements for urban ponds and created wetlands, August 1997 - May 1998.**

Plankton biomass, as estimated by chlorophyll *a* concentration (μg/liter), varied seasonally (Table 1.8, Figure 1.14). The mean concentration of chlorophyll *a* during the study period was significantly higher in urban ponds than created wetlands, 142.08±33.34 μg/liter and 29.50±9.12 μg/liter, respectively ($p<0.002$). The highest levels of chlorophyll *a* were seen in the spring and summer monitoring events. Visible algal blooms were noted at Ponds B, C, and D during all monitoring events. At Wetland 2, a visible algal bloom was noted during the summer (August 1997) monitoring event.

**Table 1.8. Seasonal chlorophyll *a* measurements (μg/L) at urban ponds and created wetlands August 1997 - May 1998 (mean±s.e., n=3).**

| | *Pond A* | *Pond B* | *Pond C* | *Pond D* | *Wetland 1* | *Wetland 2* |
|---|---|---|---|---|---|---|
| **Aug-97** | 14.24±0.93 | 113.07±1.81 | 226.74±24.56 | 53.03±7.01 | 21.65±1.66 | 142.97±3.14 |
| **Nov-97** | 8.63±0.86 | 26.86±1.42 | 52.95±6.77 | 34.54±0.45 | 6.72±0.23 | 3.08±0.27 |
| **Feb-98** | 24.21±1.83 | 56.99±0.76 | 48.41±3.85 | 20.61±2.63 | 8.45±0.26 | 27.15±0.18 |
| **May-98** | 47.52±3.38 | 675.58±86.71 | 102.57±14.03 | 767.31±52.18 | 20.86±1.84 | 5.09±0.26 |

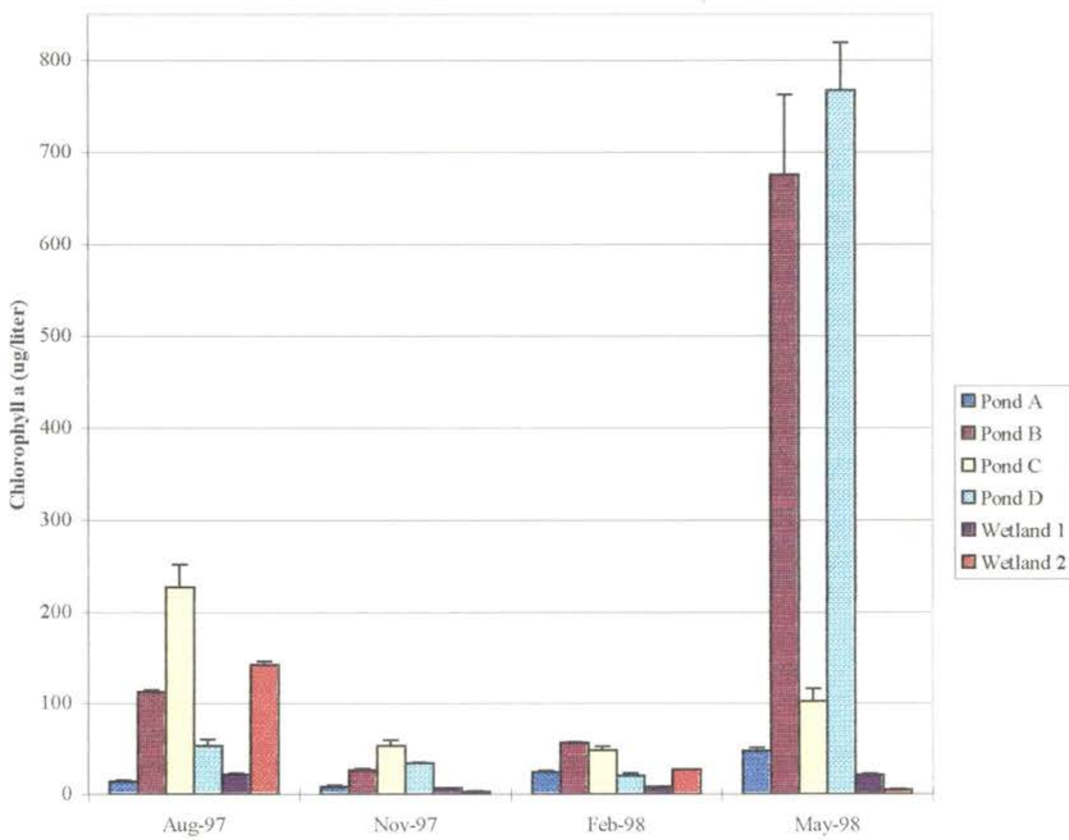


**Figure 1.14. Chlorophyll *a* biomass for urban ponds and created wetlands, August 1997 - May 1998 (mean±s.e.).**

## DISCUSSION

Results demonstrate some of the potential environmental benefits of constructing urban wetlands as an alternative to urban ponds. These benefits include, but are not limited to: better water quality, decreased shoreline erosion, increased wildlife habitat, and the reduction/elimination of the addition of chemicals to treat turbidity and nuisance algal growth.

Soil data collected at the beginning of this study (summer 1997) indicate that the urban ponds and created wetlands have mineral soils with low organic content. The higher organic content found in created wetlands versus the urban ponds cannot be compared since baseline organic content data before the basins were built were not available. Conclusions cannot be made regarding the development of hydric soils without additional sampling over several growing seasons. Sediment accumulation gauging was not performed in this study, but it was evident from the photographic record of site conditions that the urban ponds have significant bank erosion occurring.

Water levels at all six sites fluctuated seasonally and correlated with the amount of precipitation received. Avian species utilizing urban ponds and created wetlands varied seasonally. Greater avian species richness during the winter and spring 1998 in the created wetlands versus urban ponds is most likely attributable to the provision of food, nesting, and shelter by the wetland vegetation. This is supported by the existence of nesting birds at the two wetland sites in May 1998. Created wetlands also had a larger upland buffer area from urban land uses.

High levels of nutrients were found in the stormwater runoff entering the urban ponds and created wetlands from surrounding urban land uses. Nutrient levels in stormwater runoff entering the created wetlands were greater than the runoff entering the stormwater ponds in August 1997, yet the basin water quality parameters measured were not significantly different and sometimes better in the created wetlands. Levels of orthophosphate phosphorus, ammonia nitrogen and nitrate nitrogen were above natural levels in all six basins, further illustrating the likelihood of anthropogenic inputs into these systems. Turbidity was a significant problem in Pond A, most likely due to the lack of shoreline stabilization by vegetation and steep slopes. Even with the employment of fountains in Ponds A and B, dissolved oxygen levels were significantly higher in the created wetlands than the urban ponds.

The trophic status of the urban ponds and created wetlands is classified as eutrophic since the mean summer chlorophyll *a* concentrations for all the sites in August 1997 were greater than 10 $\mu g/L$ (Horner and Raedeke 1989). The mean levels of chlorophyll *a* however, were significantly lower in the created wetlands versus the urban ponds. This would suggest that the wetland vegetation is utilizing the excess nutrients being input to the wetlands via the stormwater runoff. Despite the algae control practices in the ponds, algal blooms were still prevalent in Ponds B, C, and D throughout the study. Pond A had lower chlorophyll *a* concentrations than the other ponds, most likely due to the high levels of turbidity restricting sunlight in the water column. The water treatment benefits of created wetlands versus urban ponds were not measured in this study due to the lack of outlets from five of the six basins.

The surrounding landscape uses were undoubtedly a source of variation between sites as well as between monitoring events. In Chapter III, a Landscape Development Intensity (LDI) index was calculated based on the percent of urban, agricultural, and undeveloped (natural) land uses in an area 0.68 $km^2$ surrounding each site using the methodology developed by Brown (1991). The lowest LDI (on a scale of 1 to 10 with 1 being completely natural and 10 being completely urban) was found in Wetland 1 (LDI=2.64) and the highest LDI was found in Wetland 2 (LDI=7.37). The urban ponds ranged between an LDI of 4.32 and 4.87. Even with the highest LDI, Wetland 2, which had approximately 60% vegetation coverage in the summer of 1997, is likely assimilating the urban stormwater pollution running into it.

Golf courses, residential communities, and office parks typically construct urban ponds for aesthetic value or to fulfill stormwater permit requirements. This study illustrates some of the potential benefits of constructing ponds as urban wetlands. Decreasing shoreline erosion will decrease the turbidity and need for maintenance, improve aesthetic quality and reduce safety risks. Increased wildlife usage will not only increase bequest and existence value, but also increase the aesthetic appeal, especially in highly urbanized areas. Decreasing in the incidence of algal blooms will not only improve water quality and aesthetic appeal, but decrease maintenance costs. In addition, expensive and potentially harmful chemical treatments may not be necessary. Where urban ponds are discharging into natural water courses, increasing the water quality of urban ponds will reduce the impacts of their effluents on these water bodies. Long-term monitoring of the soils, hydrology, wildlife, and water quality is needed to further evaluate the magnitude of the environmental benefits of constructing urban wetlands rather than urban ponds.

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# CHAPTER II

## URBAN CREATED WETLANDS AS AN ALTERNATIVE TO URBAN PONDS: AN ANALYSIS OF ECONOMIC BENEFITS

*Abstract:* Urban stormwater can be responsible for degrading the water quality and wildlife utilization of urban water bodies. Stormwater ponds can be used to remove suspended sediment and nutrients from stormwater, but typically have water quality problems similar to the water bodies they are designed to protect including eutrophication, turbidity and low dissolved oxygen. These water quality problems can result in increased maintenance, deterioration of aesthetic value, and decreased wildlife usage. There is an obvious need for more cost-effective design and management strategies for urban stormwater ponds. This study examines the economic benefits of augmenting urban stormwater ponds with wetland vegetation as a cost-effective management alternative to indefinite aeration, repeated treatments of herbicides and pesticides, turbidity treatments, and basin and shoreline sediment maintenance. Using benefit transfer, the economic value of four urban ponds and created wetlands were estimated. Net present value (NPV) was calculated to assess the value of different maintenance strategies. The created wetlands had higher benefit value and NPV per acre per year than the urban ponds. Hypothetical augmentation of the urban ponds with wetland plants increased the NPV of these ponds by providing greater wildlife and water treatment benefit and thus was more cost-effective than traditional maintenance practices.

*Key Words:* Stormwater runoff, created wetlands, stormwater ponds, benefit transfer, wetland valuation, net present value (NPV), wetland functions, benefit cost analysis.

# INTRODUCTION

Urban stormwater runoff can be responsible for degrading the water quality and wildlife utilization of urban water bodies. Conversion of vegetated land to impermeable surfaces such as roadways and buildings leads to an increase in rainfall runoff, increasing the pollutants received by water bodies (Wren et al. 1997). Typically, urban runoff carries a high sediment load from erosion, high levels of nutrients (nitrogen and phosphorus) and pesticides from gardens and lawns, oil and grease from paved surfaces, bacteria from pet and bird wastes, heavy metals from corroding surfaces, and toxic substances from household materials (Husted 1997, Terrene Institute 1994). Best Management Practices (BMPs) have been employed to reduce the impacts of urban stormwater runoff. These include detention, retention/infiltration devices, vegetative controls, and pollution prevention. Stormwater ponds are considered one of the most effective options and are the most popular (Terrene Institute 1994).

Stormwater ponds are particularly effective at removing suspended sediment and nutrients (Horner et al. 1994), but typically have water quality problems similar to the water bodies they are designed to protect, including eutrophication and low dissolved oxygen (DO), which can result in increased maintenance, deterioration of aesthetic value, and decreased wildlife usage. These water quality problems can be attributed to high nutrient loadings and biological and chemical oxygen demand (BOD and COD) of the influent stormwater runoff. Over-enrichment of these ponds with nitrogen and phosphorus from stormwater runoff can result in algal blooms which can lower DO, reduce the submerged aquatic vegetation by increasing turbidity, and result in changes in plankton and fish composition.

Low DO, resulting from algal blooms or high BOD or COD, can lead to unpleasant odors and fish kills (Boyd 1985, Horner et al. 1994, Husted 1997, McComas 1993, Terrene Institute 1994, Walker 1987).

Another maintenance concern with stormwater ponds is erosion and sedimentation. Steep slopes and lack of proper vegetation on these slopes will result in erosion of the shoreline and increased sedimentation in the basin. With shoreline erosion, turbidity of the water may increase leading to a decline in submerged aquatic vegetation. This can lead to a reduced life span of the basin in addition to aesthetic and safety concerns (Hammer 1997, Horner et al. 1994, McComas 1993, Walker 1987).

Eutrophication and low DO are typically managed by the application of herbicides and aeration of the water with fountains. If mosquitoes are a nuisance, pesticides may also be used. Turbidity is controlled by the addition of calcium carbonate or calcium hydroxide or the installation of filtration devices. Shoreline erosion usually results in rip-rap or detaining wall installation or dirt work. Basin sedimentation requires occasional dredging and removal of the sediments. These measures are usually only temporary "fixes" (McComas 1993).

There is an obvious need for more cost-effective design and management strategies for urban stormwater ponds. It has been proposed that these ponds should be replaced or used in concert with constructed wetlands (Dennison 1996, Horner et al. 1994, Terrene Institute 1994, White and Meyers 1997, Wren et al. 1997). It has been demonstrated that constructed wetlands can be useful in treating stormwater pollution and reducing erosion and sedimentation rates (i.e., Strecker et al. 1992). I propose that urban stormwater ponds be augmented with wetland vegetation as a cost-effective management alternative to indefinite aeration, repeated treatments of herbicides and pesticides, turbidity treatments, and basin and shoreline sediment maintenance. This paper explores the economic benefits of using created wetlands versus the typical stormwater ponds in the urban landscape.

### Applying benefit-cost analysis to wetlands

Decision-making and management regarding natural resources involves the consideration of the possible benefits and costs of impacts to them. Benefit-cost analysis focuses on economic efficiency, the allocation of economic resources for their most valued use. The determination of expected benefits and costs requires the identification and valuation of all goods and functions provided by the natural resource (outputs). Natural resources provide both market and nonmarket goods. Nonmarket goods may be comprised of both use values and nonuse values. Use values include any use of an environmental resource, such as recreation. Nonuse values include existence value (value attributed to the simple existence of a good), option value (value for preserving the option for use a resource in the future), bequest value (value attributed for preserving an environmental resource for the next generation), and altruistic value (value for opportunity for others to enjoy a resource) (Kahn 1995).

The major outputs/goods of wetlands can be characterized as intermediate goods and services, final goods and services, or future goods and services. Intermediate goods and services serve as factors for the production of other goods. These include commercial factors, such as commercial fisheries, timber, or water supply, as well as damage prevention factors, such as pollution assimilation/water purification, flood control, and erosion prevention. Final goods and services produce consumer satisfaction directly and include recreational opportunities and amenities. Recreational opportunities can either be consumptive in the case of fishing and hunting, or nonconsumptive as in the case of camping, hiking, boating or birdwatching. Amenities include scenic value, spiritual value, and education. Future goods and services can fall into any of the above categories and include undiscovered goods, such as flora or fauna to make new medicines, and future high-value development (Scodari 1990).

There are several valuation methods that have been used value wetlands (Anderson and Rockel 1991, Batie and Shabman 1982, Kahn 1995, Scodari 1990, Whitehead 1992-93). These valuation methods include both demand curve and non-demand curve approaches (Turner et al. 1993). Several other valuation methods have been used to value wetlands with limited success. These methods include expenditure analysis, energy analysis, restoration cost, revealed preferences of resource managers and elected officials, market price, and appraisal (Anderson and Rockel 1991).

Demand curve approaches are either revealed preference (indirect) or expressed preference (direct) methods (Turner et al. 1993). Indirect valuation methods attempt to reveal the preference of the consumer by looking at the decisions they make regarding activities that are affected by or utilize an environmental amenity. Indirect methods are primarily used to reveal use values (Kahn 1995).

The net factor income (NFI) method, travel cost method (TCM), and the hedonic pricing method (HPM) are three of the more widely used indirect valuation methods for estimating the value of environmental resources. The NFI method uses market prices to estimate additional profits earned by businesses from the contribution of wetlands (Whitehead 1992-93). Economic profits after payments to all other factors of production, such as labor and capital, are estimated and then correlated to the value of wetlands in the production of that good (Scodari 1990). The TCM measures the value of wetlands in providing the final wetland service of recreation (Batie and Shabman 1982, Freeman 1993). The recreational value of a wetland is derived from the costs incurred by people to visit the site. The HPM is based on the theory of consumer behavior that suggests that the value people ascribe to a good is a function of the attributes of the good rather than the good itself (Freeman 1993, Kahn 1995). The HPM is most commonly applied to property values to reveal implicit prices for environmental amenities such as aesthetics or air quality.

Direct methods attempt to ascertain values directly from individuals by setting up a hypothetical market. Direct methods therefore can be used to reveal use and nonuse values. The contingent valuation method (CVM) is the most widely used direct hypothetical valuation technique used for valuing environmental amenities. The CVM involves the direct questioning of individuals to determine their willingness to pay (WTP) for the value they place on nonmarket goods as well as which mechanism of payment they would be willing to use (Kahn 1995).

Non-demand curve approaches do not provide "true" valuation information but can be very helpful in policy decision-making. These approaches are used when demand curves are not obtainable and include: dose-response, replacement cost, mitigation behavior, and opportunity cost. Dose-response approach relies on data linking the cause and effect of a pollutant on the health of an organism. Replacement cost entails the assessment of the costs of replacing or restoring a damaged resource as a measure of the benefit of restoring it. Mitigation behavior involves assigning a cost to averting a certain damage as a measure of the benefit of avoiding the damage. The opportunity cost approach does not measure benefits directly, but instead identifies the benefits of environmental degradation, which yields an indirect measure of the value of the resource (Turner et al. 1993).

Valuation of wetland goods and services using direct and indirect valuation methods has provided important information for decision-making regarding wetlands. Some estimates have focused on a particular function or use of wetlands while others have considered multiple functions and uses of wetlands. Economic valuation estimates for different wetland functional values range dramatically. Value estimates are confounded by the type of wetland, wetland valuation method used, the functions or services considered and the relevant population (Whitehead 1992-93).

Discounting is a very important facet when deriving values for use benefit-cost analysis. It is a procedure whereby dollars of benefits and costs in different time periods can be expressed by the "present value" (PV). Discounting takes into consideration the "time preference" of the consumers, which suggests that consumers prefer to realize benefits sooner and costs later (Kahn 1995). The higher the discount rate, the less weight is given to future benefits or costs. Net present value is the difference between the discounted benefits and costs summed over each year of the project. A positive NPV indicates a project is economically worthwhile (Turner et al. 1993). When there are multiple alternatives, the alternative with the highest NPV will be the optimal choice (van Kooten 1993).

## METHODS

The study sites included two created wetlands and four stormwater ponds constructed in central Oklahoma in 1995. The created wetlands were designed as ponds with shallower shoreline slopes planted with emergent marsh vegetation. Rainfall and stormwater runoff are the primary sources of water driving the hydrology in these ponds and wetlands. Maintenance practices, size and location of each site are summarized in Table 2.1. The surrounding land uses around these sites are primarily urban, including roadways, commercial, agricultural and residential uses.

Using a benefits transfer technique, the estimated value of the urban stormwater ponds and created wetlands was calculated from values derived in other studies of comparative wetland and pond types. The lowest bound estimate was used when ranges were given. These estimates included waterfowl/habitat, flood/disturbance, groundwater, nutrient/waste, nature study, and amenity/cultural values, and gas regulation. All values were converted to 1997 dollars using the Consumer Price Index (CPI) (U.S. Dept. of Labor 1998).

Wetland value estimates utilized in this study were derived from two primary research studies (Gupta and Foster 1975 and Thibodeau and Ostro 1982) and one benefit transfer study (Costanza et al. 1997). Gupta and Foster (1975) estimated annual nonmarket benefits of freshwater wetlands in Massachusetts through analysis of expenditures by resource agency officials (wildlife and visual-cultural values), cost savings (water treatment supply) and avoided damage costs (flood control) and corrected to 1972 dollars.

**Table 2.1. Site information for urban stormwater ponds and created wetlands in central Oklahoma.**

| Site | Area (acres) | Maximum Depth | Average Slope | Location | Maintenance Practices | |
|---|---|---|---|---|---|---|
| | | | | | fountain(s) | algae control |
| Pond A | 1.03 | 1.83 m | 23% | apartment complex | 3 | AquaShade |
| Pond B | .53 | 1.83 m | 16% | office park | 1 | Manual removal |
| Pond C | .75 | 1.98 m | 15% | golf course | 0 | AquaShade |
| Pond D | .75 | 1.83 m | 23% | golf course | 0 | none |
| Wetland 1 | .62 | 1.83 m | 11% | school/playground | 0 | none |
| Wetland 2 | .53 | 1.22 m | 8% | school/playground | 0 | none |

Wildlife benefit values ranged from \$36 to \$66/acre/year and visual-cultural values from \$74 to \$252/acre/year. The estimated wildlife and visual-cultural values were \$54 and \$155/acre/year for a pond and \$40 and \$74/acre/year for freshwater marsh, respectively. Water supply values were estimated at \$2,800/acre/year and flood control at \$80/acre/year.

Thibodeau and Ostro (1981) estimated the values of freshwater wetland services (affects on land value, pollution reduction, and recreation) in Massachusetts to range between \$153,535 - \$190,009 per acre (adjusted to 1978 dollars). The value of the effects of wetlands on land value by flood control equaled \$2,000/acre/year and increased privacy and open space equaled \$480/acre/year (total increment to property values equaled \$150/acre/year of marsh or wooded swamp plus appraisers' valuation of wetland benefits). Estimates of the value of pollution reduction were based on an acre of marsh as a substitute for plant costs of \$85 and annual operation and maintenance costs of \$1475/acre/year (for reduction in nutrients and BOD). Values for recreation and aesthetics ranged between \$187.74/acre/year (WTP) and \$3366/acre/year (willingness to accept, WTA). Nature study was a component of this estimate and ranged between \$102.02/acre/year (WTP) and \$1833/acre/year (WTA).

Costanza et al. (1997) transferred wetland benefit values from an exhaustive literature review to derive an average total value of wetland ecosystem services equal to \$14,785/ha/year (corrected to 1994 dollars). Freshwater wetland ecosystem services were estimated to be \$19,560/ha/year. This value included \$265/ha/year for gas regulation,

$7,240/ha/year for disturbance regulation, $30/ha/year for water regulation, $7,600/ha/year for water supply, $1,659/ha/year for waste treatment, $439/ha/year for habitat/refugia, $47/ha/year for food production, $49/ha/year for raw materials, $491/ha/year for recreation, and $1,761/ha/year for cultural values.

In this study, maintenance costs were calculated from data provided by personnel maintaining each of the sites. Costs of vegetating each of the sites with wetland vegetation were estimated. For the created wetlands, this was based on the current vegetation percent coverage extrapolated back two years and priced at 1997 commercial prices. For the stormwater ponds, the mean slope of the banks was used to estimate the acreage of shoreline available for wetland planting using planting depths of 0 to -3 feet below mean water elevation. The number of plants was based on three foot center plantings and priced at 1997 commercial prices.

The benefits and costs for each site were compared to determine which alternative was more cost effective by calculating net present value (NPV) for each site over a 20 year horizon at both 5% and 10% discount. Hypothetical NPV for the stormwater ponds augmented with wetland vegetation without current maintenance practices was also estimated to determine if the conversion of these ponds would increase NPV and thus be more cost effective.

## RESULTS

For this analysis, the benefit value for created wetlands was estimated $5,286/acre/year (1997 dollars), based on the lowest value estimate for each function compiled from Gupta and Foster (1975) and Thibodeau and Ostro (1981) and Costanza et al (1997) (Table 2.2). A higher bound benefit value of created wetlands was also calculated using the highest value found for each of the functions ($25,043/acre/year). Stormwater pond benefit value was estimated to be $4,848/acre/year. This estimate was based on the lower bound estimates for the wetlands with the following exceptions: (1) ignoring nature study value, (2) substituting the nutrient/waste value estimate for lakes from Costanza et al. (1997) and (3) substituting the waterfowl/habitat and amenity/cultural values for ponds from Gupta and Foster (1975). The per year benefit value for each stormwater pond and created wetland are summarized in Table 2.3.

The water quality and avian usage data of these urban ponds and created wetlands are summarized in Chapter I. Based on data collected, the two created wetlands function at least as well as or better in maintaining water quality and in providing waterfowl habitat without the maintenance costs incurred for the stormwater ponds. High levels of nutrients were found in the stormwater runoff entering the urban ponds and created wetlands from the surrounding urban land uses, yet the basin water quality was not significantly different and sometimes better in the created wetlands. Even with the employment of expensive maintenance practices in Ponds A and B (algae control and aeration fountains), algal blooms were still prevalent in Pond B throughout the study and dissolved oxygen levels were significantly higher in the created wetlands. Turbidity was a significant problem in

**Table 2.2. Wetland and stormwater pond estimated economic values (1997 dollars/acre/year). Pond value estimated from pond data where available as well as wetland data.**

| function | study | wetland ($) | pond ($) |
|---|---|---|---|
| **waterfowl/habitat** | Gupta & Foster (1975) | 269 | 207 |
| **flood/disturbance** | Costanza et al. (1997) | 3,174 | |
| | Thibodeau & Ostro (1981) | 4,922 | |
| | Gupta & Foster (1975) | 307 | * |
| **groundwater recharge** | Costanza et al. (1997) | 3,332 | * |
| | Thibodeau & Ostro (1981) | 14,874 | |
| | Gupta & Foster (1975) | 10,744 | |
| **nutrient/waste** | Costanza et al. (1997) | 727 | 291 |
| | Thibodeau & Ostro (1981) | 3,839 | |
| **nature study** | Thibodeau & Ostro (1981) | 251 | |
| **amenity/ cultural** | Costanza et al. (1997) | 772 | |
| | Thibodeau & Ostro (1981) | 369 | |
| | Gupta & Foster (1975) | 284 | 595 |
| **gas regulation** | Costanza et al. (1997) | 116 | * |
| **TOTAL** | | 5,286 - 25,043 | 4,848 |

* Wetland value estimate used.

**Table 2.3. Estimated values for stormwater ponds and created wetlands (1997 dollars/acre).**

| *Site* | *Total acreage* | *Value acre/year* | *Economic value (1997 US $) per year* |
|---|---|---|---|
| **Pond A** | **1.03** | **$4,848** | **$4,993** |
| **Pond B** | **0.53** | **$4,848** | **$2,569** |
| **Pond C** | **0.75** | **$4,848** | **$3,636** |
| **Pond D** | **0.75** | **$4,848** | **$3,636** |
| **Wetland 1** | **0.62** | **$5,286** | **$3,277** |
| **Wetland 2** | **0.53** | **$5,286** | **$2,802** |

Pond A, most likely due to the lack of shoreline stabilization by vegetation and steep slopes. Twenty-two (22) bird species were identified utilizing the urban ponds and created wetlands over the course of the study with significantly higher numbers of species observed in created wetlands than urban ponds during the winter and spring.

The maintenance practices and costs per site are summarized in Table 2.4. The highest initial and maintenance costs were found at Pond A, which utilizes three fountains. Pond D had the lowest initial and maintenance costs, however significant shoreline erosion is occurring at this site and these estimates do not include sediment removal or stabilization of eroding slopes. The initial planting costs for the two created wetlands were based on vegetation percent cover of approximately 18% in Wetland 1 and 58% in Wetland 2. Estimates for the cost of vegetating each site were based on an estimate of $6,000 per acre (Miller, personal communication) (Table 2.5). Due to the steeper shoreline slopes of the already constructed stormwater ponds (Table 2.1), a lower percentage of the site is available for wetland planting than at the created wetland sites.

**Table 2.4. Estimated costs for maintenance of water quality/aesthetics for four urban stormwater ponds and two created wetlands in central Oklahoma.**

| | Pond A | Pond B | Pond C | Pond D | Wetland 1 | Wetland 2 |
|---|---|---|---|---|---|---|
| **initial costs** | | | | | | |
| *fountains* | $19,500 | $6,500 | | | | |
| *wetland plants** | | | | | $900 | $1,900 |
| **TOTAL** | **$19,500** | **$6,500** | **$0** | **$0** | **$900** | **$1,900** |
| | | | | | | |
| **maintenance costs** | | | | | | |
| *electricity (for fountains)* | $1,800/yr. | $420/yr. | | | | |
| *fountain maintenance* | $200/yr. | $80/yr. | | | | |
| *aquashade treatment* | $100/yr. | $50/yr. | $100/yr. | | | |
| *plankton removal* | | $200/yr. | | | | |
| **TOTAL** | **$2,100/yr.** | **$750/yr.** | **$100/yr.** | **$0/yr.** | **$0/yr.** | **$0/yr.** |

* Wetland plants for the created wetland outdoor classrooms was provided by the U.S. Fish and Wildlife Service from wild collections. These values are estimates based on current percent cover and commercial prices.

**Table 2.5. Estimated installation costs of wetland plants for stormwater ponds and created wetlands.**

| Site | Total acreage | Estimated acreage available for wetland plantings* | Estimated price for wetland planting (at $6,000/acre) |
|---|---|---|---|
| **Pond A** | 1.03 | 0.35 | $2,100 |
| **Pond B** | 0.53 | 0.28 | $1,680 |
| **Pond C** | 0.75 | 0.40 | $2,400 |
| **Pond D** | 0.75 | 0.36 | $2,160 |
| **Wetland 1** | 0.62 | 0.56 | $3,360 |
| **Wetland 2** | 0.53 | 0.50 | $3,000 |

* Acreage available for wetland planting based on planting from 0 to -3 feet below control elevation and derived from basin morphometry measurements.

The net present values (NPV) for each site over a 20 year horizon at 5% and 10% discount rates are summarized in Table 2.6. The horizon was based on a minimum longevity of wet ponds and stormwater wetlands of 20 years (Terrene Institute 1994). The NPV per acre was higher for the created wetlands versus the stormwater ponds. Within the management options of the stormwater ponds, the ponds with the highest maintenance costs (primarily attributed to the installation, maintenance and powering of the aeration fountains) had the lowest NPV.

If the stormwater ponds were vegetated along their banks with wetland vegetation instead of utilizing maintenance practices to maintain water quality, the NPV of the ponds would dramatically increase to approximately match the NPV/acre estimated for the created wetlands above, due to the lower maintenance costs (zero) and the higher value of wetland functions (Table 2.7).

**Table 2.6. NPV of stormwater ponds and created wetlands (1997 dollars).**

| *Site* | *Total acreage* | *NPV total* | | *NPV/acre* | |
|---|---|---|---|---|---|
| | | *5%* | *10%* | *5%* | *10%* |
| **Pond A*** | 1.03 | $23,053 | $11,630 | $22,382 | $11,291 |
| **Pond B*** | 0.53 | $16,169 | $ 8,986 | $30,507 | $16,955 |
| **Pond C** | 0.75 | $44,066 | $30,104 | $58,755 | $40,139 |
| **Pond D** | 0.75 | $45,313 | $30,955 | $60,417 | $41,274 |
| **Wetland 1** | 0.62 | $39,939 | $26,999 | $64,417 | $43,547 |
| **Wetland 2** | 0.53 | $33,019 | $21,955 | $62,300 | $41,425 |

* have fountains

**Table 2.7. Hypothetical NPV for ponds augmented with wetland vegetation (1997 dollars).**

| *Site* | *Total acreage* | *NPV total* | | *NPV/acre* | |
|---|---|---|---|---|---|
| | | *5%* | *10%* | *5%* | *10%* |
| **Pond A** | 1.03 | $65,757 | $44,256 | $63,841 | $42,967 |
| **Pond B** | 0.53 | $33,239 | $22,175 | $62,715 | $41,840 |
| **Pond C** | 0.75 | $47,013 | $31,356 | $62,683 | $41,808 |
| **Pond D** | 0.75 | $47,253 | $31,596 | $63,003 | $42,128 |

## DISCUSSION

Although each of the above maintenance alternatives has a positive NPV and are therefore economically worthwhile (Turner et al. 1993), created wetlands have economic benefits greater than the costs of constructing them and as such are the most efficient allocation of resources to maximize welfare (Anderson and Rockel 1991). The economic benefits are both private, such as reduced maintenance costs, and social, such as increased wildlife usage. Secondary benefits of created wetlands not captured by the value estimates include bequest, option, and existence values (Kahn 1995). Safety concerns encountered with stormwater ponds can be reduced with created wetlands since they are typically constructed with shallower slopes and depths. Created wetlands can also provide noise pollution buffering, diverse and attractive scenery, and bird watching and educational opportunities (Horner et al. 1994).

Algal blooms, lower dissolved oxygen and turbidity are still inherent water quality problems in the stormwater ponds in this study, even with intensive management, so aesthetic values for these ponds may actually be lower than those estimated. In addition, stabilization of eroding shoreline of the ponds was not included in the maintenance costs and therefore they are probably underestimated.

It is important to remember that the estimates calculated in this paper are derived from studies from different regions of the country with different socioeconomic and environmental characteristics. In addition, no estimate of the accuracy or uncertainty of these values is available. The lowest value for each identified function was used so the values calculated in this paper are most likely underestimates. Care was taken, however to choose studies with similar wetlands and only to include those values representing probable functions in the study wetlands. Benefit-transfer can provide timely, inexpensive benefit estimates when neither time nor resources are available to conduct a valuation study (Bingham 1992, Boyle and Bergstrom 1992, Brookshire 1992, Kahn 1995). Additional primary wetland and stormwater pond valuation studies, especially in urban areas, are necessary to further refine these estimates.

Golf courses, residential communities, office parks typically construct urban ponds for aesthetic value or to fulfill stormwater permit requirements. This study illustrates some of the potential economic benefits of constructing these ponds as urban wetlands. Reducing shoreline erosion will improve the turbidity, lower the need for maintenance, improve aesthetic quality and reduce safety risks. Increased wildlife usage will not only increase bequest and existence value, but also increase the aesthetic appeal, especially in highly urbanized areas. The reduction in the incidence of algal blooms will not only improve water quality and aesthetic appeal, but decrease maintenance costs. In addition, expensive and potentially harmful chemical treatments may not be necessary. As the development of land intensifies, there will be a need to institute more cost-effective management strategies to minimize impacts on the environment. This study illustrates the stormwater treatment and wildlife benefits of created urban wetlands as an alternative to traditional stormwater ponds.

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# CHAPTER III

# ASSESSMENT OF POND AND WETLAND TOPOGRAPHY AND LANDSCAPE DEVELOPMENT INTENSITY UTILIZING A GEOGRAPHIC INFORMATION SYSTEM

***Abstract:*** Geographic information systems (GIS) can be instrumental in urban planning and environmental decision-making. Aerial photography and water depths along transects were used in conjunction with a GIS to quickly estimate erosion-potential of shoreline slopes and area available for wetland planting in four urban ponds and two created wetlands in central Oklahoma. A Landscape Development Intensity (LDI) index was also calculated from percent urban, agricultural, and undeveloped land in a 0.25 $mile^2$ area surrounding each pond and wetland to assess potential impact from urban stormwater runoff pollution. The area available for wetland planting was much lower in the urban ponds than the created wetlands due to the steeper shoreline slopes. The LDI ranged from 2.64 to 7.37 and 4.07 to 7.62, for two different weighting schemes respectively. The created wetlands represented the highest and lowest LDI values with the urban ponds all ranging between 4.25 to 4.87. This study illustrates that the integration of a GIS can quickly and easily provide essential information for into urban planning and environmental decision-making.

***Key Words:*** Geographic information system (GIS), wetlands, landscape development index (LDI), land use, urban landscape, created wetlands.

# INTRODUCTION

Quantifying the land uses surrounding water bodies and wetlands in the urban landscape can assist in evaluating the potential impacts of further development or identifying the source of current impacts. Urban stormwater runoff can be responsible for degrading the water quality and wildlife utilization of urban water bodies. Conversion of vegetated land to impermeable surfaces such as roadways and buildings leads to an increase in rainfall runoff, increasing peak flows in water bodies as well as increasing the pollutants received by them (Horner et al. 1994, Wren et al. 1997). Typically, urban runoff has a high sediment load from erosion, high levels of nutrients (nitrogen and phosphorus) and pesticides from gardens and lawns, oil and grease from paved surfaces, bacteria from pet and bird wastes, heavy metals from corroding surfaces, and toxic substances from household materials (Husted 1997, Terrene Institute 1994). A Landscape Development Intensity (LDI) index has been developed in Brown and Tighe (1989) and Brown (1991) to provide a numerical measurement of the impact of land uses on wetlands. This index was primarily developed to facilitate the selection of reference wetlands for environmental monitoring studies. This LDI index could be applied to conservation, planning and decision-making in the urban environment.

There is an obvious need for more cost-effective design and management strategies for urban stormwater ponds. It has been proposed that these ponds should be replaced or used in concert with constructed wetlands (Dennison 1996, Horner et al. 1994, Terrene Institute 1994, White and Meyers 1997, Wren et al. 1997). It has been demonstrated that constructed wetlands can be useful in treating stormwater pollution and reducing erosion and sedimentation rates (i.e., Strecker et al. 1992). In Chapters I and II, the benefit of constructing urban ponds as wetlands was shown to be a cost-effective management alternative to indefinite aeration, repeated treatments of herbicides and pesticides, turbidity treatments, and basin and shoreline sediment maintenance.

Geographic information systems (GIS) have several applications beyond the simple automation of data storage. There are two basic data structures used in a GIS, vector and raster. A vector data structure uses three types of landscape features, points, lines and polygons, whose location is identified by sets of X,Y coordinates. A raster data structure uses an imaginary grid overlaying the landscape comprised of cells, each of which has a value. The data structure selected depends on the nature of the data and the analytic tools required by the application. If we are interested in compiling an inventory where lines are real and the data known, and wish to do descriptive queries, computer mapping, and spatial database management, we would probably choose a vector data model. On the other hand, if we were concerned with performing and analysis using spatial statistics and modeling with the probabilistic data and artificial lines, we would choose a raster data model (Berry 1995, 1996).

With the advent of dual structure GIS software packages (i.e., raster and vector structures available), rapid assessment and modeling of landscape features is becoming both time- and cost-effective for urban planners, environmental scientists and government agencies.

Spatial modeling and quantification of landscape features, such as area, slope and land usage, can aid in environmental planning and decision-making. Maps often speak louder than words when trying to convey information to decision-makers. GIS modeling can go beyond mapping and provide real-time analytic tools that allow the decision-makers to change criteria, weighting of alternative uses, etc. that can aid in consensus building and conflict resolution (Berry 1993, 1996). This paper will illustrate how field measurements and aerial photography, in conjunction with the use of a dual-structure GIS, can provide important information for the comparison of two management alternatives and the assessment of potential landscape stresses.

## METHODS

The study sites included two created urban wetlands and four urban ponds constructed in central Oklahoma 1995. The base layer was comprised of aerial photographs (extent equaling 0.25 mile$^2$) which were scanned and imported into ArcView® GIS (version 3.0) as image files. Pond and wetland boundaries were created as polygons overlaying the aerial photographs. Area and perimeter were calculated using the field calculator within the attribute table of the theme. Water depths were measured every 10 feet along transects systematically positioned every 50 feet perpendicular to the shoreline during the summer 1997. These data were manually input into ArcView® GIS as line and point files for the transect locations and water depths, respectively.

The ArcView® Spatial Analyst program affords the capability to model raster (grid) data in conjunction with the vector data supported by ArcView® GIS (ESRI 1996). The pond and wetland bottom contour surfaces were generated by interpolation of depth measurements using the spline surface interpolation function within the ArcView® Spatial Analyst program (Figure 3.1). A slope surface (measured in degree slope) was then estimated using the slope function within ArcView® Spatial Analyst. The average shoreline slope was estimated by visually identifying the slope surface overlain by the boundary of the basin. In order to estimate the area available for wetland planting, the bottom contour surfaces were reclassed based on water depth (depths $\leq$ 3 feet and depths $>$ 3 feet) and the areas of each determined.

The Landscape Development Intensity (LDI) index was calculated by estimating the percent of urban, agricultural and undeveloped (natural) land uses within a 0.25 $mile^2$ area surrounding each site (Brown 1991). The area each of each of these land uses was estimated by overlaying polygons over the aerial photograph of each site and summing the acreage and converting it to a percentage within ARCVIEW® GIS (Figure 3.2). The LDI was calculated with two different weighting schemes. LDI-1 was calculated using the formula: [(%urban*9)+(%agricultural*2)+(%natural)]/90 (Brown 1991). LDI-2 was calculated using the formula: [(%urban*10)+(%agricultural*5)+(%natural)]/100 (Brown and Tighe 1989). The LDI-1 weighting scheme gives a lower value to the potential impact of stormwater pollution from agricultural land than the LDI-2.

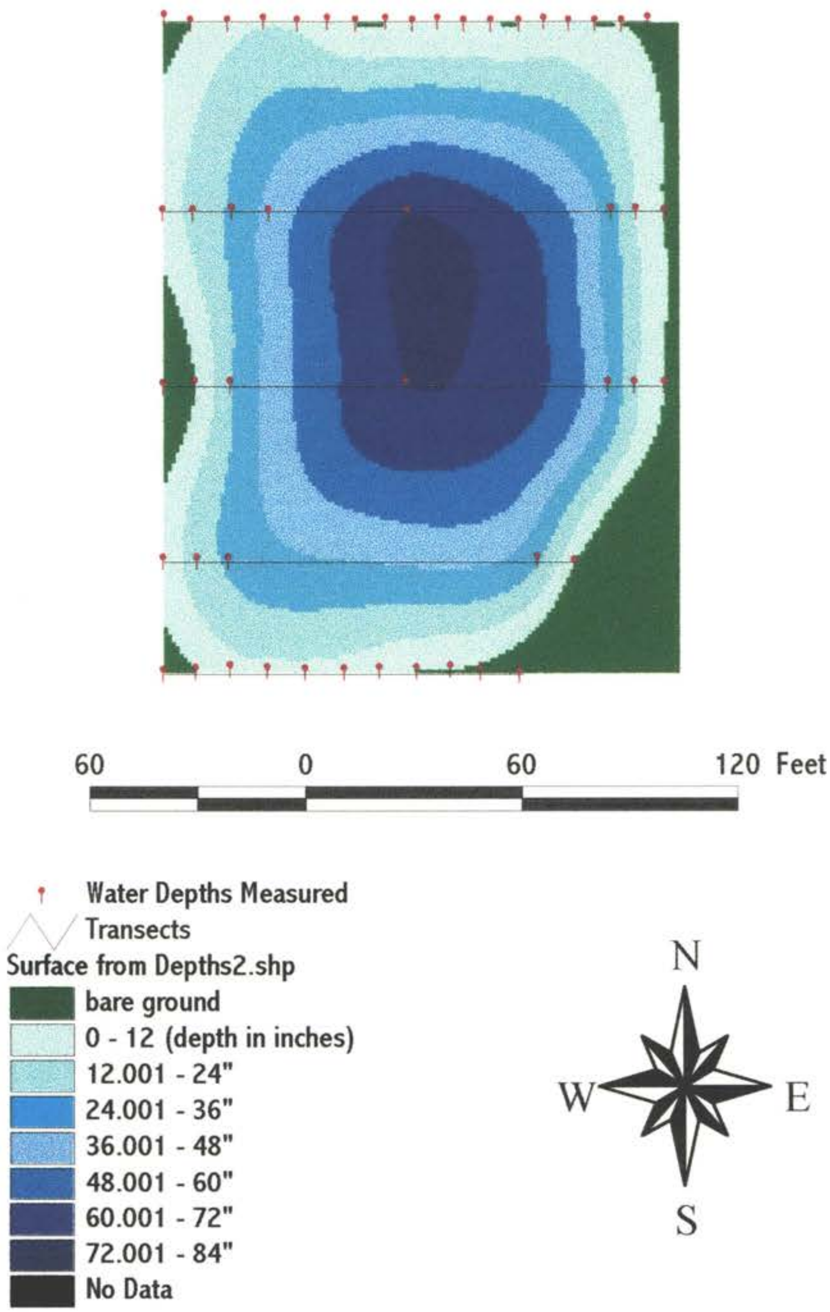


Figure 3.1. Example of bottom surface contours as generated by interpolation of depth measurements in Pond B.

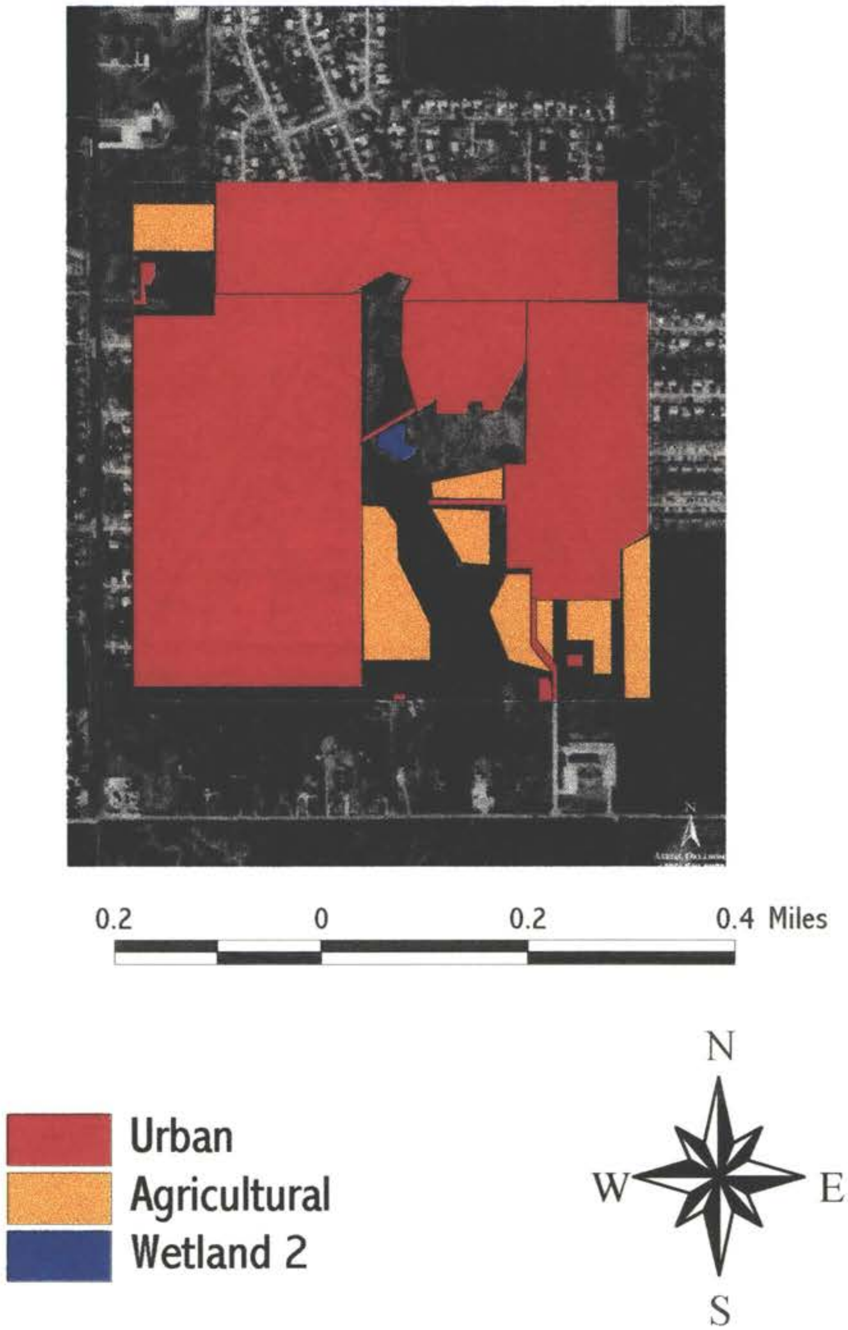


Figure 3.2. Example of land use area estimated for Wetland 2
(Box outlines 0.25 sq. mi.)

## RESULTS

The basin topography measurements for the ponds and wetlands are summarized in Table 3.1. The area of the ponds ranged from 1.03 acres to 0.53 acre and the wetlands ranged from 0.62 to 0.53 acre. All four ponds had steeper shoreline slopes than the created wetlands. The area available for wetland planting at each site as estimated by the bottom contour surfaces is summarized in Table 3.2. The percent of area available for wetland planting was significantly higher in the created wetlands than the ponds.

The LDI-1 and LDI-2 index measurements ranged from 2.64 to 7.37 and 4.07 to 7.62, respectively (Table 3.3). The lowest and highest were represented in the created wetlands. Wetland 1 had the lowest urban and the highest agricultural percent cover surrounding it (Figure 3.3). Wetland 2 had the highest urban and lowest natural percent cover surrounding it. The pond LDI's were similar ranging from 4.25 to 4.87. Both weighting methods yielded similar results, with the exception of Wetland 1 which had a higher LDI-2 value than LDI-1, due to the large percentage of agricultural area.

**Table 3.1. Basin topography measurements.**

| Site | Total Area (acres) | Perimeter (feet) | Maximum Depth (feet) | Average Shoreline Slope (degree slope) |
|---|---|---|---|---|
| Pond A | 1.03 | 1,091 | 6.0 | 50 |
| Pond B | 0.53 | 602 | 6.0 | 40 |
| Pond C | 0.75 | 737 | 6.5 | 40 |
| Pond D | 0.75 | 775 | 6.0 | 40 |
| Wetland 1 | 0.62 | 788 | 6.0 | 30 |
| Wetland 2 | 0.53 | 630 | 5.0 | 30 |

**Table 3.2. Area available for wetland planting (depths 0 to - 3 feet below mean water level).**

| site | total area (acres) | total area (sq. ft.) | area > -3 ft. (sq. ft.) | planting area (sq. ft.) | area available for wetland planting (acres) | % area available for planting |
|---|---|---|---|---|---|---|
| **Pond A** | 1.03 | 44,867 | 29,418 | 15,449 | 0.35 | 34% |
| **Pond B** | 0.53 | 23,087 | 10,715 | 12,372 | 0.28 | 54% |
| **Pond C** | 0.75 | 32,670 | 15,125 | 17,545 | 0.40 | 54% |
| **Pond D** | 0.75 | 32,670 | 17,006 | 15,664 | 0.36 | 48% |
| **Wetland 1** | 0.62 | 27,007 | 2,651 | 24,356 | 0.56 | 90% |
| **Wetland 2** | 0.53 | 23,087 | 1,340 | 2,1747 | 0.50 | 94% |

**Table 3.3. Land uses surrounding urban ponds and created wetlands (area=.25 mi.$^2$) and landscape development intensity indices (LDI). LDI on a scale from 1, completely natural to 10, completely developed (u = weighting for urban, a = weighting for agricultural).**

| *Site* | *% urban* | *% agricultural* | *% undeveloped* | *LDI-1 u=9,a=2* | *LDI-2 u=10,a=5* |
|---|---|---|---|---|---|
| **Pond A** | 40.06% | 3.72% | 56.23% | 4.71 | 4.75 |
| **Pond B** | 42.26% | 0.26% | 57.48% | 4.87 | 4.81 |
| **Pond C** | 41.45% | 0.00% | 58.55% | 4.80 | 4.73 |
| **Pond D** | 36.08% | 0.00% | 63.93% | 4.32 | 4.25 |
| **Wetland 1** | 10.60% | 52.78% | 36.62% | 2.64 | 4.07 |
| **Wetland 2** | 69.19% | 9.89% | 20.93% | 7.37 | 7.62 |

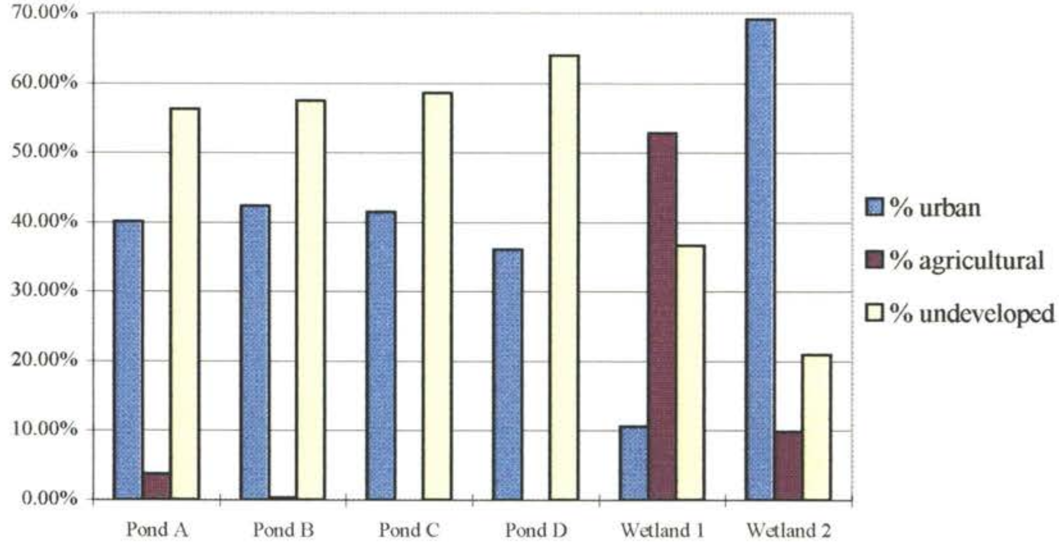


**Figure 3.3. Percent of land uses surrounding urban ponds and created wetlands (area=.25 mi.$^2$).**

# DISCUSSION

The computation of area, perimeter, and slope of the urban ponds and created wetlands provided some invaluable information for assessing two management alternatives presented in Chapters I and II. The bottom contour surfaces derived from water depths measured along transects illustrated that steeper shoreline slopes are used in the construction of urban ponds, heightening the risk for shoreline erosion and accompanying water turbidity problems. It also provided a mechanism to easily estimate the planting area available at each site, which was instrumental in estimating the investment in converting these ponds to wetlands. The percent area available for wetland planting was significantly higher in the created wetlands than the ponds, illustrating the importance of designing these ponds with shallower slopes to facilitate the incorporation of more wetland plants.

Calculation of a LDI can be instrumental in evaluating current and potential stresses to urban ponds and created wetlands. All four ponds had similar magnitudes of landscape development as calculated by the two weighting methods. The created wetlands were significantly different regarding the land uses surrounding them, Wetland 1 being highly agricultural and Wetland 2 being highly urbanized. This provided important information in the evaluation of stormwater and basin water quality in Chapter 1.

Dual-structure GIS systems can combine the descriptive query, computer mapping, and spatial database management capabilities of a vector data structure with the spatial analysis and modeling capabilities of a raster data structure. Incorporation of a GIS into decision-making and planning can yield timely and inexpensive information that can help in evaluating alternative environmental management alternatives. Further research on land use indices as related to environmental quality and the automation of landscape planning tools will help ensure the availability and application of GIS analyses in environmental and land-use decision-making.

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# Appendix A

**Seasonal water quality measurements at urban ponds and created wetlands August 1997 - May 1998 (mean±s.e., n=3).**

| *Site* | *Date* | *temp* (°C) | *pH* | *conductivity* (µS/cm) | *DO* (mg/L) | *hardness* (gpm) | *alkalinity* (mg/L) | *OP-P* (µg/L) | *amm-N* (mg/L) | *nitrate-N* (mg/L) | *turbidity* (NTU) |
|---|---|---|---|---|---|---|---|---|---|---|---|
| pond A | 8/20 | 26.00±0.58 | 9.00±0.60 | 1863.33±333.33 | 5.33±0.33 | 4.33±0.33 | 31.73±15.87 | 188.89±65.81 | 0.07±0.03 | 1.33±.88 | 380.00±41.63 |
| (F, AC) | 11/24 | 12.00±0.00 | 6.37±0.03 | 1766.67±81.10 | 11.67±0.33 | 5.67±0.67 | 51.00±25.97 | 66.67±11.55 | 0.03±0.03 | BDL | 61.33±0.33 |
| | 2/26 | 12.00±0.00 | 6.57±0.03 | 3993.33±667.97 | 7.67±0.88 | 6.67±0.33 | 113.33±14.99 | 24.44±5.88 | BDL | BDL | 47.33±0.33 |
| | 5/4 | 24.33±0.88 | 5.07±0.07 | 4463.33±2160.70 | 5.00±1.53 | 7.00±2.52 | 141.67±48.42 | 31.11±8.01 | BDL | BDL | 66.67±1.86 |
| pond B | 8/20 | 28.67±0.33 | 9.30±0.06 | 3680.00±30.55 | 10.00±0.58 | 9.00±0.00 | 92.93±12.62 | 64.44±18.99 | 0.17±0.07 | 2.33±0.33 | 5.87±0.20 |
| (F, AC) | 11/24 | 10.00±0.00 | 6.27±0.03 | 3580.00±28.87 | 11.00±0.58 | 10.33±0.33 | 158.67±20.43 | 24.44±4.44 | 0.03±0.03 | 1.00±0.00 | 8.53±0.20 |
| | 2/26 | 12.00±0.00 | 6.60±0.00 | 4380.00±34.64 | 7.67±0.33 | 11.00±0.00 | 181.33±5.67 | 31.11±8.01 | BDL | 1.00±0.00 | 32.67±0.33 |
| | 5/4 | 25.67±0.33 | 10.37±0.09 | 2913.33±141.93 | 8.67±0.33 | 6.00±0.58 | 130.33±5.67 | 26.67±6.67 | BDL | 0.67±0.33 | 38.00±2.08 |
| pond C | 8/19 | 27.00±0.58 | 8.57±0.09 | 2753.33±75.13 | 9.67±0.88 | 6.33±0.33 | 92.93±6.00 | 88.89±18.99 | BDL | 0.67±0.67 | 37.33±1.45 |
| (AC) | 11/24 | 12.00±0.58 | 5.53±0.18 | 2360.00±179.26 | 6.67±0.88 | 6.33±0.88 | 34.00±17.00 | 34.00±17.00 | BDL | 1.00±0.00 | 29.67±1.76 |
| | 2/26 | 12.33±0.33 | 6.67±0.03 | 2700.00±30.55 | 7.33±0.88 | 6.33±0.33 | 96.33±11.33 | 95.56±9.69 | BDL | 1.67±0.33 | 43.67±2.03 |
| | 5/4 | 26.00±0.00 | 7.27±1.82 | 2383.33±277.39 | 8.67±0.33 | 6.33±0.33 | 124.7±5.67 | 84.44±9.69 | BDL | 1.00±0.00 | 41.00±4.04 |
| pond D | 8/19 | 28.00±0.00 | 9.10±0.06 | 2526.67±105.25 | 4.33±0.33 | 8.33±0.33 | 104.27±6.00 | 42.22±5.88 | BDL | 1.00±0.00 | 44.67±3.71 |
| | 11/24 | 10.00±0.00 | 5.70±0.55 | 2573.33±78.60 | 10.67±0.33 | 8.00±0.00 | 62.33±31.55 | 177.78±5.88 | BDL | 1.00±0.00 | 18.00±0.58 |
| | 2/26 | 12.33±0.33 | 6.33±0.15 | 2680.00±122.20 | 7.67±0.33 | 7.33±0.33 | 96.33±14.99 | 264.44±8.01 | 0.43±0.03 | 1.00±0.00 | 46.00±0.58 |
| | 5/4 | 22.00±0.00 | 6.20±0.60 | 1786.67±86.67 | 6.67±0.33 | 6.00±0.00 | 96.33±5.67 | 217.78±35.76 | BDL | 1.00±0.00 | 38.33±0.88 |
| wetland 1 | 8/21 | 28.67±0.67 | 8.50±0.15 | 4113.33±145.30 | 9.00±1.73 | 7.67±0.33 | 11.33±11.33 | 244.44±177.94 | 0.07±0.03 | 1.00±0.58 | 63.33±0.33 |
| | 11/24 | 11.67±0.67 | 6.43±0.18 | 1193.33±31.80 | 12.67±0.88 | 4.00±0.00 | 56.67±31.55 | 115.56±9.69 | BDL | BDL | 76.33±0.33 |
| | 2/26 | 13.33±0.33 | 6.40±0.06 | 4110.00±208.17 | 10.00±0.00 | 6.33±0.33 | 107.67±11.33 | BDL | 0.20±0.00 | BDL | 84.33±0.33 |
| | 5/4 | 22.67±0.67 | 6.47±0.18 | 2803.33±95.28 | 8.33±0.33 | 5.00±0.00 | 102.00±0.00 | 67.67±10.18 | BDL | BDL | 70.67±0.33 |
| wetland 2 | 8/21 | 32.00±1.15 | 8.27±0.03 | 11173.33±133.33 | 7.67±3.84 | 16.67±0.33 | 85.00±49.07 | 151.11±59.79 | 0.30±0.15 | 3.00±1.00 | 22.00±6.43 |
| | 11/24 | 14.33±0.33 | 5.17±0.09 | 6060.00±480.87 | 17.67±2.03 | 9.67±0.67 | 62.33±29.99 | 35.56±2.22 | BDL | 1.00±0.00 | 4.03±0.22 |
| | 2/26 | 17.00±1.53 | 6.23±0.37 | 10616.67±148.14 | 13.33±1.20 | 14.67±0.33 | 136.00±0.00 | BDL | BDL | 1.00±0.00 | 13.00±0.58 |
| | 5/4 | 24.33±0.33 | 6.60±0.46 | 5536.67±471.22 | 12.00±1.73 | 9.33±0.33 | 85.00±17.00 | 104.44±21.89 | 0.10±0.00 | BDL | 36.33±0.67 |

F = fountain(s), AC = algae control practices employed, BDL = Below detectable limit

# Appendix B

## Net present value calculations for 20 year time horizon for urban ponds and created wetlands.

| *POND 1* | | | | | | *POND 2* | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| **Year** | **Benefits** | **Costs** | **B - C** | **5%** | **10%** | **Year** | **Benefits** | **Costs** | **B - C** | **5%** | **10%** |
| 0 | 0 | 19500 | -19500 | -13000.00 | -13000.00 | 0 | 0 | 6500 | -6500 | -6500.00 | -6500.00 |
| 1 | 4993 | 2100 | 2893 | 2755.24 | 2630.00 | 1 | 2569 | 750 | 1819 | 1732.38 | 1653.64 |
| 2 | 4993 | 2100 | 2893 | 2624.04 | 2390.91 | 2 | 2569 | 750 | 1819 | 1649.89 | 1503.31 |
| 3 | 4993 | 2100 | 2893 | 2499.08 | 2173.55 | 3 | 2569 | 750 | 1819 | 1571.32 | 1366.64 |
| 4 | 4993 | 2100 | 2893 | 2380.08 | 1975.96 | 4 | 2569 | 750 | 1819 | 1496.50 | 1242.40 |
| 5 | 4993 | 2100 | 2893 | 2266.74 | 1796.33 | 5 | 2569 | 750 | 1819 | 1425.23 | 1129.46 |
| 6 | 4993 | 2100 | 2893 | 2158.80 | 1633.02 | 6 | 2569 | 750 | 1819 | 1357.37 | 1026.78 |
| 7 | 4993 | 2100 | 2893 | 2056.00 | 1484.57 | 7 | 2569 | 750 | 1819 | 1292.73 | 933.43 |
| 8 | 4993 | 2100 | 2893 | 1958.10 | 1349.61 | 8 | 2569 | 750 | 1819 | 1231.17 | 848.58 |
| 9 | 4993 | 2100 | 2893 | 1864.85 | 1226.91 | 9 | 2569 | 750 | 1819 | 1172.54 | 771.43 |
| 10 | 4993 | 2100 | 2893 | 1776.05 | 1115.38 | 10 | 2569 | 750 | 1819 | 1116.71 | 701.30 |
| 11 | 4993 | 2100 | 2893 | 1691.48 | 1013.98 | 11 | 2569 | 750 | 1819 | 1063.53 | 637.55 |
| 12 | 4993 | 2100 | 2893 | 1610.93 | 921.80 | 12 | 2569 | 750 | 1819 | 1012.89 | 579.59 |
| 13 | 4993 | 2100 | 2893 | 1534.22 | 838.00 | 13 | 2569 | 750 | 1819 | 964.65 | 526.90 |
| 14 | 4993 | 2100 | 2893 | 1461.16 | 761.82 | 14 | 2569 | 750 | 1819 | 918.72 | 479.00 |
| 15 | 4993 | 2100 | 2893 | 1391.58 | 692.56 | 15 | 2569 | 750 | 1819 | 874.97 | 435.45 |
| 16 | 4993 | 2100 | 2893 | 1325.32 | 629.60 | 16 | 2569 | 750 | 1819 | 833.30 | 395.87 |
| 17 | 4993 | 2100 | 2893 | 1262.21 | 572.36 | 17 | 2569 | 750 | 1819 | 793.62 | 359.88 |
| 18 | 4993 | 2100 | 2893 | 1202.10 | 520.33 | 18 | 2569 | 750 | 1819 | 755.83 | 327.16 |
| 19 | 4993 | 2100 | 2893 | 1144.86 | 473.03 | 19 | 2569 | 750 | 1819 | 719.84 | 297.42 |
| 20 | 4993 | 2100 | 2893 | 1090.34 | 430.03 | 20 | 2569 | 750 | 1819 | 685.56 | 270.38 |
| | | | ***total*** | **23053.17** | **11629.74** | | | | ***total*** | **16168.76** | **8986.17** |
| | | | ***per acre*** | **22381.72** | **11291.01** | | | | ***per acre*** | **30507.10** | **16955.04** |

## Appendix B continued

| POND 3 | | | | | | POND 4 | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| **Year** | **Benefits** | **Costs** | **B - C** | **5%** | **10%** | **Year** | **Benefits** | **Costs** | **B - C** | **5%** | **10%** |
| 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0.00 | 0.00 |
| 1 | 3636 | 100 | 3536 | 3367.62 | 3214.55 | 1 | 3636 | 0 | 3636 | 3462.86 | 3305.45 |
| 2 | 3636 | 100 | 3536 | 3207.26 | 2922.31 | 2 | 3636 | 0 | 3636 | 3297.96 | 3004.96 |
| 3 | 3636 | 100 | 3536 | 3054.53 | 2656.65 | 3 | 3636 | 0 | 3636 | 3140.91 | 2731.78 |
| 4 | 3636 | 100 | 3536 | 2909.08 | 2415.14 | 4 | 3636 | 0 | 3636 | 2991.35 | 2483.44 |
| 5 | 3636 | 100 | 3536 | 2770.55 | 2195.58 | 5 | 3636 | 0 | 3636 | 2848.90 | 2257.67 |
| 6 | 3636 | 100 | 3536 | 2638.62 | 1995.98 | 6 | 3636 | 0 | 3636 | 2713.24 | 2052.43 |
| 7 | 3636 | 100 | 3536 | 2512.97 | 1814.53 | 7 | 3636 | 0 | 3636 | 2584.04 | 1865.84 |
| 8 | 3636 | 100 | 3536 | 2393.30 | 1649.57 | 8 | 3636 | 0 | 3636 | 2460.99 | 1696.22 |
| 9 | 3636 | 100 | 3536 | 2279.34 | 1499.61 | 9 | 3636 | 0 | 3636 | 2343.80 | 1542.02 |
| 10 | 3636 | 100 | 3536 | 2170.80 | 1363.28 | 10 | 3636 | 0 | 3636 | 2232.19 | 1401.84 |
| 11 | 3636 | 100 | 3536 | 2067.43 | 1239.35 | 11 | 3636 | 0 | 3636 | 2125.89 | 1274.40 |
| 12 | 3636 | 100 | 3536 | 1968.98 | 1126.68 | 12 | 3636 | 0 | 3636 | 2024.66 | 1158.54 |
| 13 | 3636 | 100 | 3536 | 1875.22 | 1024.25 | 13 | 3636 | 0 | 3636 | 1928.25 | 1053.22 |
| 14 | 3636 | 100 | 3536 | 1785.92 | 931.14 | 14 | 3636 | 0 | 3636 | 1836.43 | 957.47 |
| 15 | 3636 | 100 | 3536 | 1700.88 | 846.49 | 15 | 3636 | 0 | 3636 | 1748.98 | 870.43 |
| 16 | 3636 | 100 | 3536 | 1619.88 | 769.54 | 16 | 3636 | 0 | 3636 | 1665.69 | 791.30 |
| 17 | 3636 | 100 | 3536 | 1542.75 | 699.58 | 17 | 3636 | 0 | 3636 | 1586.37 | 719.36 |
| 18 | 3636 | 100 | 3536 | 1469.28 | 635.98 | 18 | 3636 | 0 | 3636 | 1510.83 | 653.97 |
| 19 | 3636 | 100 | 3536 | 1399.32 | 578.16 | 19 | 3636 | 0 | 3636 | 1438.89 | 594.52 |
| 20 | 3636 | 100 | 3536 | 1332.68 | 525.60 | 20 | 3636 | 0 | 3636 | 1370.37 | 540.47 |
| | | | ***total*** | **44066.38** | **30103.96** | | | | ***total*** | **45312.60** | **30955.32** |
| | | | ***per acre*** | **58755.17** | **40138.62** | | | | ***per acre*** | **60416.80** | **41273.76** |

## Appendix B continued

| Wetland 1 | | | | | | Wetland 2 | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| Year | Benefits | Costs | B - C | 5% | 10% | Year | Benefits | Costs | B - C | 5% | 10% |
| 0 | 0 | 900 | -900 | -900.00 | -900.00 | 0 | 0 | 1900 | -1900 | -1900.00 | -1900.00 |
| 1 | 3277 | 0 | 3277 | 3120.95 | 2979.09 | 1 | 2802 | 0 | 2802 | 2668.57 | 2547.27 |
| 2 | 3277 | 0 | 3277 | 2972.34 | 2708.26 | 2 | 2802 | 0 | 2802 | 2541.50 | 2315.70 |
| 3 | 3277 | 0 | 3277 | 2830.80 | 2462.06 | 3 | 2802 | 0 | 2802 | 2420.47 | 2105.18 |
| 4 | 3277 | 0 | 3277 | 2696.00 | 2238.24 | 4 | 2802 | 0 | 2802 | 2305.21 | 1913.80 |
| 5 | 3277 | 0 | 3277 | 2567.62 | 2034.76 | 5 | 2802 | 0 | 2802 | 2195.44 | 1739.82 |
| 6 | 3277 | 0 | 3277 | 2445.35 | 1849.78 | 6 | 2802 | 0 | 2802 | 2090.90 | 1581.66 |
| 7 | 3277 | 0 | 3277 | 2328.90 | 1681.62 | 7 | 2802 | 0 | 2802 | 1991.33 | 1437.87 |
| 8 | 3277 | 0 | 3277 | 2218.00 | 1528.74 | 8 | 2802 | 0 | 2802 | 1896.50 | 1307.15 |
| 9 | 3277 | 0 | 3277 | 2112.38 | 1389.77 | 9 | 2802 | 0 | 2802 | 1806.19 | 1188.32 |
| 10 | 3277 | 0 | 3277 | 2011.79 | 1263.43 | 10 | 2802 | 0 | 2802 | 1720.18 | 1080.29 |
| 11 | 3277 | 0 | 3277 | 1915.99 | 1148.57 | 11 | 2802 | 0 | 2802 | 1638.27 | 982.08 |
| 12 | 3277 | 0 | 3277 | 1824.76 | 1044.15 | 12 | 2802 | 0 | 2802 | 1560.26 | 892.80 |
| 13 | 3277 | 0 | 3277 | 1737.86 | 949.23 | 13 | 2802 | 0 | 2802 | 1485.96 | 811.64 |
| 14 | 3277 | 0 | 3277 | 1655.11 | 862.94 | 14 | 2802 | 0 | 2802 | 1415.20 | 737.85 |
| 15 | 3277 | 0 | 3277 | 1576.29 | 784.49 | 15 | 2802 | 0 | 2802 | 1347.81 | 670.78 |
| 16 | 3277 | 0 | 3277 | 1501.23 | 713.17 | 16 | 2802 | 0 | 2802 | 1283.63 | 609.80 |
| 17 | 3277 | 0 | 3277 | 1429.74 | 648.34 | 17 | 2802 | 0 | 2802 | 1222.50 | 554.36 |
| 18 | 3277 | 0 | 3277 | 1361.66 | 589.40 | 18 | 2802 | 0 | 2802 | 1164.29 | 503.96 |
| 19 | 3277 | 0 | 3277 | 1296.82 | 535.82 | 19 | 2802 | 0 | 2802 | 1108.85 | 458.15 |
| 20 | 3277 | 0 | 3277 | 1235.07 | 487.11 | 20 | 2802 | 0 | 2802 | 1056.04 | 416.50 |
| | | | ***total*** | **39938.66** | **26998.95** | | | | ***total*** | **33019.11** | **21955.01** |
| | | | ***per acre*** | **64417.20** | **43546.69** | | | | ***per acre*** | **62300.21** | **41424.54** |

# Appendix C

## Hypothetical net present value calculations for 20 year time horizon for urban ponds augmented with wetland vegetation.

| *POND 1* | | | | | | *POND 2* | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| **Year** | **Benefits** | **Costs** | **B - C** | **5%** | **10%** | **Year** | **Benefits** | **Costs** | **B - C** | **5%** | **10%** |
| 0 | 0 | 2100 | -2100 | -2100.00 | -2100.00 | 0 | 0 | 1680 | -1680 | -1680.00 | -1680.00 |
| 1 | 5445 | 0 | 5445 | 5185.71 | 4950.00 | 1 | 2802 | 0 | 2802 | 2668.57 | 2547.27 |
| 2 | 5445 | 0 | 5445 | 4938.78 | 4500.00 | 2 | 2802 | 0 | 2802 | 2541.50 | 2315.70 |
| 3 | 5445 | 0 | 5445 | 4703.60 | 4090.91 | 3 | 2802 | 0 | 2802 | 2420.47 | 2105.18 |
| 4 | 5445 | 0 | 5445 | 4479.61 | 3719.01 | 4 | 2802 | 0 | 2802 | 2305.21 | 1913.80 |
| 5 | 5445 | 0 | 5445 | 4266.30 | 3380.92 | 5 | 2802 | 0 | 2802 | 2195.44 | 1739.82 |
| 6 | 5445 | 0 | 5445 | 4063.14 | 3073.56 | 6 | 2802 | 0 | 2802 | 2090.90 | 1581.66 |
| 7 | 5445 | 0 | 5445 | 3869.66 | 2794.15 | 7 | 2802 | 0 | 2802 | 1991.33 | 1437.87 |
| 8 | 5445 | 0 | 5445 | 3685.39 | 2540.13 | 8 | 2802 | 0 | 2802 | 1896.50 | 1307.15 |
| 9 | 5445 | 0 | 5445 | 3509.90 | 2309.21 | 9 | 2802 | 0 | 2802 | 1806.19 | 1188.32 |
| 10 | 5445 | 0 | 5445 | 3342.76 | 2099.28 | 10 | 2802 | 0 | 2802 | 1720.18 | 1080.29 |
| 11 | 5445 | 0 | 5445 | 3183.58 | 1908.44 | 11 | 2802 | 0 | 2802 | 1638.27 | 982.08 |
| 12 | 5445 | 0 | 5445 | 3031.98 | 1734.94 | 12 | 2802 | 0 | 2802 | 1560.26 | 892.80 |
| 13 | 5445 | 0 | 5445 | 2887.60 | 1577.22 | 13 | 2802 | 0 | 2802 | 1485.96 | 811.64 |
| 14 | 5445 | 0 | 5445 | 2750.10 | 1433.84 | 14 | 2802 | 0 | 2802 | 1415.20 | 737.85 |
| 15 | 5445 | 0 | 5445 | 2619.14 | 1303.49 | 15 | 2802 | 0 | 2802 | 1347.81 | 670.78 |
| 16 | 5445 | 0 | 5445 | 2494.42 | 1184.99 | 16 | 2802 | 0 | 2802 | 1283.63 | 609.80 |
| 17 | 5445 | 0 | 5445 | 2375.64 | 1077.26 | 17 | 2802 | 0 | 2802 | 1222.50 | 554.36 |
| 18 | 5445 | 0 | 5445 | 2262.51 | 979.33 | 18 | 2802 | 0 | 2802 | 1164.29 | 503.96 |
| 19 | 5445 | 0 | 5445 | 2154.77 | 890.30 | 19 | 2802 | 0 | 2802 | 1108.85 | 458.15 |
| 20 | 5445 | 0 | 5445 | 2052.16 | 809.36 | 20 | 2802 | 0 | 2802 | 1056.04 | 416.50 |
| | | | ***total*** | **65756.74** | **44256.35** | | | | ***total*** | **33239.11** | **22175.01** |
| | | | ***per acre*** | **63841.49** | **42967.33** | | | | ***per acre*** | **62715.31** | **41839.63** |

## Appendix C continued

| POND 3 | | | | | | POND 4 | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| Year | Benefits | Costs | B - C | 5% | 10% | Year | Benefits | Costs | B - C | 5% | 10% |
| 0 | 0 | 2400 | -2400 | -2400.00 | -2400.00 | 0 | 0 | 2160 | -2160 | -2160.00 | -2160.00 |
| 1 | 3965 | 0 | 3965 | 3776.19 | 3604.55 | 1 | 3965 | 0 | 3965 | 3776.19 | 3604.55 |
| 2 | 3965 | 0 | 3965 | 3596.37 | 3276.86 | 2 | 3965 | 0 | 3965 | 3596.37 | 3276.86 |
| 3 | 3965 | 0 | 3965 | 3425.12 | 2978.96 | 3 | 3965 | 0 | 3965 | 3425.12 | 2978.96 |
| 4 | 3965 | 0 | 3965 | 3262.02 | 2708.15 | 4 | 3965 | 0 | 3965 | 3262.02 | 2708.15 |
| 5 | 3965 | 0 | 3965 | 3106.68 | 2461.95 | 5 | 3965 | 0 | 3965 | 3106.68 | 2461.95 |
| 6 | 3965 | 0 | 3965 | 2958.74 | 2238.14 | 6 | 3965 | 0 | 3965 | 2958.74 | 2238.14 |
| 7 | 3965 | 0 | 3965 | 2817.85 | 2034.67 | 7 | 3965 | 0 | 3965 | 2817.85 | 2034.67 |
| 8 | 3965 | 0 | 3965 | 2683.67 | 1849.70 | 8 | 3965 | 0 | 3965 | 2683.67 | 1849.70 |
| 9 | 3965 | 0 | 3965 | 2555.87 | 1681.55 | 9 | 3965 | 0 | 3965 | 2555.87 | 1681.55 |
| 10 | 3965 | 0 | 3965 | 2434.17 | 1528.68 | 10 | 3965 | 0 | 3965 | 2434.17 | 1528.68 |
| 11 | 3965 | 0 | 3965 | 2318.25 | 1389.71 | 11 | 3965 | 0 | 3965 | 2318.25 | 1389.71 |
| 12 | 3965 | 0 | 3965 | 2207.86 | 1263.37 | 12 | 3965 | 0 | 3965 | 2207.86 | 1263.37 |
| 13 | 3965 | 0 | 3965 | 2102.72 | 1148.52 | 13 | 3965 | 0 | 3965 | 2102.72 | 1148.52 |
| 14 | 3965 | 0 | 3965 | 2002.59 | 1044.11 | 14 | 3965 | 0 | 3965 | 2002.59 | 1044.11 |
| 15 | 3965 | 0 | 3965 | 1907.23 | 949.19 | 15 | 3965 | 0 | 3965 | 1907.23 | 949.19 |
| 16 | 3965 | 0 | 3965 | 1816.41 | 862.90 | 16 | 3965 | 0 | 3965 | 1816.41 | 862.90 |
| 17 | 3965 | 0 | 3965 | 1729.92 | 784.45 | 17 | 3965 | 0 | 3965 | 1729.92 | 784.45 |
| 18 | 3965 | 0 | 3965 | 1647.54 | 713.14 | 18 | 3965 | 0 | 3965 | 1647.54 | 713.14 |
| 19 | 3965 | 0 | 3965 | 1569.09 | 648.31 | 19 | 3965 | 0 | 3965 | 1569.09 | 648.31 |
| 20 | 3965 | 0 | 3965 | 1494.37 | 589.37 | 20 | 3965 | 0 | 3965 | 1494.37 | 589.37 |
| | | | ***total*** | **47012.66** | **31356.28** | | | | ***total*** | **47252.66** | **31596.28** |
| | | | ***per acre*** | **62683.55** | **41808.37** | | | | ***per acre*** | **63003.55** | **42128.37** |

## Appendix D

OKLAHOMA STATE UNIVERSITY
INSTITUTIONAL REVIEW BOARD
HUMAN SUBJECTS REVIEW

**Date: March 20, 1998** **IRB #: BU-98-017**

**Proposal Title: URBAN CREATED WETLANDS AS AN ALTERNATIVE TO URBAN PONDS: AN ANALYSIS OF ENVIRONMENTAL AND ECONOMIC BENEFITS**

**Principal Investigator(s):** Keith Willett, Lisa M. White

**Reviewed and Processed as:** Exempt

**Approval Status Recommended by Reviewer(s):** Approved

ALL APPROVALS MAY BE SUBJECT TO REVIEW BY FULL INSTITUTIONAL REVIEW BOARD AT NEXT MEETING, AS WELL AS ARE SUBJECT TO MONITORING AT ANY TIME DURING THE APPROVAL PERIOD.
APPROVAL STATUS PERIOD VALID FOR DATA COLLECTION FOR A ONE CALENDAR YEAR PERIOD AFTER WHICH A CONTINUATION OR RENEWAL REQUEST IS REQUIRED TO BE SUBMITTED FOR BOARD APPROVAL.
ANY MODIFICATIONS TO APPROVED PROJECT MUST ALSO BE SUBMITTED FOR APPROVAL.

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**Comments, Modifications/Conditions for Approval or Disapproval are as follows:**

Signature: [signature]
Chair of Institutional Review Board

Date: March 24, 1998

cc: Lisa M. White

VITA

Lisa M. White

Candidate for the Degree of

Doctor of Philosophy

Thesis: URBAN CREATED WETLANDS AS AN ALTERNATIVE TO URBAN PONDS: AN ANALYSIS OF ENVIRONMENTAL AND ECONOMIC BENEFITS

Major Field: Environmental Science

Biographical:

Education: Received Bachelor of Science degree in Marine Biology from Fairleigh Dickinson University, Madison, New Jersey in May 1989; received a Master of Science degree in Biology from University of Houston, Houston, Texas in August 1992. Completed the requirements for the Doctor of Philosophy degree in Environmental Science at Oklahoma State University, Stillwater, Oklahoma in July 1998.

Experience: Adjunct Faculty at the University of Central Oklahoma, Oklahoma City Community College, and Rose State teaching General Biology, Zoology, Nutrition, 1994 to present; Environmental Consultant/Wetland Scientist for Johnson Engineering, Inc., Fort Myers, Florida from 1993 to 1994; Graduate Research and Teaching Assistant Department of Biology, University of Houston from 1989 to 1992. Experience also includes the following certifications: U.S. Army Corps of Engineers Certified Wetland Delineator, Society of Wetland Scientists Certified Wetland Professional In Training, Advanced S.C.U.B.A. Diver and Underwater Photographer.

Professional Memberships: Society of Wetland Scientists, International Society for Ecological Economics, Ecological Society of America, Oklahoma State University Society of Environmental Scientists, Oklahoma Section of the American Water Resources Association, Oklahoma Academy of Science.