Wetland Augmentation in North Carolina:

An Emerging Technique for Wastewater Management

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Abstract

During times of seasonal population influx, increased demand is placed on wastewater treatment plants. Due to the volume of wastewater created and limited treatment plant capacities, alternate methods of responsible treatment and disposal must be examined. In coastal North Carolina, the use of "wetland augmentation" is a viable response to the increased demand for wastewater treatment. A literature review suggests that utilizing natural wetlands in the acceptance of wastewaters while obeying federal and state guidelines may enhance the receiving wetlands and improve surrounding water quality. Florida and Louisiana wastewater wetland regulations are compared to the proposed North Carolina regulations. Intentionally chosen, the comparison states operate experienced natural wastewater wetlands and maintain an abundance of documented literature on the subject. The criteria of proposed North Carolina wetland augmentation systems are reviewed and challenged, citing established regulations of the comparison states and data retrieved from a potential wetland augmentation site. Located in Brunswick County North Carolina, the Supply spray site has been in operation as a reclaimed water upland drip irrigation system since February of 2008. Water level monitoring instruments were installed at the site to capture the hydrologic wetland fluctuations during the complete 2009 growing season. A sample of the monitoring data is represented graphically. Wetlands at monitoring locations 6 & 7 were particularly suitable to the acceptance of wastewaters. Tables list the acceptable number of days that reclaimed wastewater could be dispersed at all study areas under -12" depth to water table restriction. Also reviewed in tables are proposed -6" and -2" depth to water table restrictions. The site study and literature review further indicate that the proposed one foot depth to water table restriction should be re-examined, and that natural wetland systems are an acceptable repository for wastewaters in North Carolina.

Introduction

In Coastal North Carolina (NC), a noted increase in population occurs during the summer months due largely to tourism (Crawford, 2007). During these peak summer months, the population influx catalyzes an increasing demand for wastewater management, treatment, and dispersion. Existing local wastewater treatment plants (WWTP) are placed under intense strain during these times of high demand. Conversely, the costs associated with construction of a new WWTP is such that a positive cost return is immediately unlikely or dated so far into the future that municipalities will remain complacent in the reduced quality and efficiency of existing WWTP operations (Verhoeven & Meuleman, 1999). Recent research has suggested a new application of wastewater disposal and treatment that may be equally advantageous to both coastal municipalities and the wetland systems of Coastal North Carolina. The term applied to this emerging study of wastewater treatment and dispersion is “wetland augmentation.” Wetland augmentation is a newly introduced method of wastewater treatment in which Class A or B (both tertiary treated) reclaimed wastewater is pumped directly into terrestrial wetland systems deemed appropriate by the North Carolina Environmental Management Commission (NC EMC). The NC EMC is a commission associated with the Division of Water Quality (DEQ), which is contained within the NC Department of Environment and Natural Resources (NC DENR). The currently proposed NC EMC regulations under North Carolina Administrative Code 15A NCAC 02U (2010) lists three baseline stipulations:

(1) Wetland augmentation must be limited to freshwater wetlands excluding riparian zones and pocosins,

(2) Reclaimed water discharge to Salt-Water Wetlands or Unique Wetlands is not permitted

(3) Reclaimed water discharge to wetlands areas must be limited to times when the vertical separation distance to the groundwater table is greater than or equal to one foot. (D-29)

It is noted that stipulation #3 is an untested parameter to which proposed North Carolina wetland augmentation projects must adhere. This stipulation is the main point of contention driving the subsequent literature review and site examination because supporting science for the -12 inch restriction is severely lacking. Additionally, all proposed treatment systems utilizing this technique must first provide one year of baseline studies sufficient to determine reference conditions and demonstrate that a net environmental benefit will occur from the dispersion of reclaimed water into selected wetlands. A net environmental benefit is defined as “the continued existence of current wetland conditions and the protection of endangered species” (Commission, 2010, p. D-2). This vague definition is also a source of contention with regard to wetland augmentation practices due to its subjectivity and undefined parameters, and may present difficulties in quantifying and demonstrating a net environmental benefit.

Land Management Group, Inc. (LMG), an Environmental Consultant firm in Wilmington, North Carolina, has been engaged in several potential wetland augmentation projects throughout 2009. Resulting baseline wetland monitoring has indicated that coastal freshwater wetlands are hydrologically dynamic systems which can be completely absent of surface water in the summer months, while remaining saturated in the winter months. Based on this conclusion, an ideal marriage of increased wastewater demand and fluctuating wetland hydrology could prove resourceful for coastal communities which experience peak summertime demands for wastewater treatment and dispersion. However, in North Carolina limited research has been conducted on wetland augmentation practices. Therefore, the following literature review will provide a synopsis of the wetland augmentation practice, compare constructed wetlands to natural wetlands within the subject of wastewater treatment and briefly examine successful regulations that neighboring states that have implemented regarding wetland wastewater treatment systems. At the conclusion of the literature review, a site specific analysis will further challenge the contentious -12 inch depth to water threshold at a potential southeastern North Carolina wetland augmentation site.

Background on Wetlands

According to the Environmental Laboratory's 1987 US Army Corps of Engineers (USACOE) Wetlands Delineation Manual, The Corps of Engineers (Federal Register 1982) and the Environmental Protection Agency (EPA)(Federal Register 1980) jointly define wetlands as:

> Those areas that are inundated or saturated by surface or groundwater at a frequency and duration sufficient to support, and that under normal circumstances do support, a prevalence of vegetation typically adapted for life in saturated soil conditions. Wetlands generally include swamps, marshes, bogs, and similar areas. (p. 9)

The Corps manual further states three criteria used to confirm the existence of wetlands; hydrophytic vegetation, hydric soils, and hydrology which may saturate or inundate the surface layer (Laboratory, 1987). Based on these criteria, natural wetlands are estimated to cover roughly 6% of the earth's surface, and their true value had been underestimated until the past 50 years (Gopal, Ghosh, Sven Erik, & Brian, 2008). Unfortunately, wetland systems of the United States have been significantly impacted, altered, ditched, drained, and converted mostly for agricultural purposes (approximately 91% of wetland losses). Expansion of urban areas and other land uses has accounted for 6% and 3% of wetland losses, respectively (Hickman, 1990).

As previously indicated, wetlands are highly productive and valuable ecosystems that serve as important sources of timber, essential habitat for fish and wildlife, natural water filters, flood abatement, groundwater aquifer recharge, recreational exploration, and educational advancement. They also support a variety of biota disproportionate to their aerial extent, often including federally listed threatened or endangered species (Gopal, 1999; Gopal, et al., 2008; Hickman, 1990). While academic research provides greater understanding of wetland systems and their functions, one particular practice emerges as a mutually advantageous relationship between anthropogenic demands and natural resource management. Specific nomenclatures of the action may change through the United States territories (wetland assimilation, wetland augmentation, etc.), but the actual practice remains constant: utilizing natural wetlands in the treatment of wastewater.

The ability of wetlands to chemically, biologically, and physically remove contaminants from surface waters, including anthropogenic wastewater, has long been recognized (Brantley et al., 2008; Breaux, Farber, & Day, 1995; Day et al., 2004; Gopal, 1999; Gopal, et al., 2008; Hickman, 1990; Jeng & Hong, 2005; Verhoeven & Meuleman, 1999; Zhang et al., 2000). In fact, wetlands have been likened to the “global kidneys” because of their highly efficient filtering mechanisms (Gopal, 1999; Gopal, et al., 2008). Wetlands across the earth have been used for wastewater treatment for centuries, though only in the past decades has the response to such use been documented in a comprehensive and scientific manner (Brantley, et al., 2008). Recent scientific studies on wetland wastewater treatment systems have indicated nutrient removal rates consistent with those of a modern WWTP (Brantley, et al., 2008; Breaux, et al., 1995; Couillard, 1994; Day, et al., 2004; Hunter et al., 2009; Jeng & Hong, 2005; Ko, Day, Lane, & Day, 2004; Verhoeven & Meuleman, 1999; Zhang, et al., 2000) at a fraction of the cost (Breaux, et al., 1995;

Day, et al., 2004; Ko, et al., 2004). Authors Verhoeven and Meuleman (1999) recognize that natural wetland systems have special characteristics which make them particularly suitable for wastewater purification, such as:

> -Wetlands are semi-aquatic systems that normally contain large amounts of water. These systems are also prone to flooding, which may be achieved through the addition of wastewater.
>
> -Wetlands contain partly oxic, partly anoxic soils that allow pathways for the chemical fixation of nitrogen and phosphorous.
>
> -Wetlands support highly prolific, stalwart, and resilient vegetation capable of absorbing large amounts of nutrients. (p. 6)

Wetland plant composition, in combination with soil type and hydrologic regime, allow for the uptake, accumulation, and chemical breakdown of a range of nutrients, including those largely found in municipal effluent like NO3, NH4, PO4, and various organics (Brantley, et al., 2008). These nutrients contained in treated wastewater have also been confirmed by numerous studies to stimulate productivity and increase sediment accretion in wetlands (Brantley, et al., 2008; Day, et al., 2004; Hunter, et al., 2009; Ko, et al., 2004).

Wetland Augmentation

Purpose

Many factors drive interests in the purpose of augmenting wetlands including an expanding population leading to a greater demand on existing WWTPs, nutrient transformation and removal (Gopal, 1999; Zhang, et al., 2000), costs associated with constructing new WWTPs (Couillard, 1994), groundwater recharge and flood abatement (Gopal, et al., 2008), and improved effluent of water quality (Day, et al., 2004; Zhang, et al., 2000). Studies also show that wetland augmentation projects provide the same services as conventional treatment plants, while receiving wetlands yield a net increase in primary productivity, leading to sediment accretion (Brantley, et al., 2008; Ko, et al., 2004) and increased vegetative productivity (Day, et al., 2004). It is documented that natural wetlands require an influx of nutrients for biomass growth (Breaux, et al., 1995), and both increased sediment accretion and vegetation productivity assist in combating land subsidence and wetland degradation, often occurring as surrounding lands are altered for agriculture, industry, and housing (Day, et al., 2004). In some cases, the wetland method of treating wastewater also had a higher cost-benefit ratio (1:6) and up to 21.7 times greater energy efficiency than modern WWTPs as well (Ko, et al., 2004).

All of the afore mentioned analyses illuminate an emerging technique of wastewater treatment that must absolutely be examined in response to current population expansion and the continued loss or conversion of existing wetland systems in North Carolina. In fact the EPA estimates that since the 1970's, North Carolina has experienced some of the most substantial wetland losses in the United States (Agency, 2009a). This point is concerning on many levels, as wetland values have been conclusively linked to flood protection, aquifer recharge, fisheries, and numerous economic benefits (Breaux, et al., 1995). Wetland degradation and destruction has also, in part, been responsible for the increases in flood and drought damages, and declining bird populations (Agency, 2009b).

Goal

The ultimate goal of any wetland wastewater treatment system is the successful neutralization of wastewater effluent. This includes the absorption of organic nutrients like Nitrogen and Phosphorous and their associated inorganic compounds ($NO3-$, $NH4+$, $PO4\ 3+$) (Brantley, et al., 2008; Breaux, et al., 1995; Couillard, 1994; Day, et al., 2004; Gopal, 1999;

Gopal, et al., 2008; Hunter, et al., 2009; Jeng & Hong, 2005; Verhoeven & Meuleman, 1999; Zhang, et al., 2000). Another indication of a successful wetland wastewater treatment site is the reduction of chemical oxygen demand (COD), biological oxygen demand (BOD), and any remaining suspended solids (Couillard, 1994; Gopal, et al., 2008; Jeng & Hong, 2005; Ko, et al., 2004; Verhoeven & Meuleman, 1999; Zhang, et al., 2000). Heavy metals have also been monitored and can be successfully removed by a wetland wastewater treatment system (Couillard, 1994; Zhang, et al., 2000).

Once the primary goals have been established and the wetland wastewater treatment system is functioning, additional ecosystem benefits will emerge. These benefits will include, but are not limited to: soil accretion (Brantley, et al., 2008; Day, et al., 2004; Ko, et al., 2004), enhanced quality of surrounding surface waters (Breaux, et al., 1995; Day, et al., 2004; Hickman, 1990; Verhoeven & Meuleman, 1999), stimulated vegetative productivity (Brantley, et al., 2008; Day, et al., 2004; Hunter, et al., 2009), conservation of wildlife habitat (Hickman, 1990), and substantial monetary savings when compared to a modern WWTP (Breaux, et al., 1995; Day, et al., 2004; Ko, et al., 2004). All of the previously listed benefits will count towards the ultimate goal of the North Carolina EMC, which is a demonstrated net environmental benefit (J. P. W. a. G. E. Williams, 2009).

Constructed Wetlands Vs Naturalized Wetlands

When examining the use of wetlands to treat wastewater, two contrasting theories are documented. Authors Verhoeven and Mueleman (1999) believe that constructed wetlands offer better opportunities for treatment than natural wetlands based on the ability to specifically design hydrologic loading rates and species composition in order to maximize nutrient removal. Verhoeven and Mueleman (1999) further discourage the use of natural wetlands to treat wastewater because of the great conservation value of many of these systems, while the author Couillard (1994) questions the effect that long term nutrient loading will have on the immediate and surrounding ecosystem. Opposing views of constructed wetland treatment systems also cite the absence of biodiversity and long-term macrophyte presence (Gopal, 1999) along with the disproportionately high cost associated with a constructed wetland treatment system (Breaux, et al., 1995; Couillard, 1994). Both design options have associated potentials and problems, and the benefits and drawbacks of both treatment methods are briefly addressed in the following paragraphs.

Constructed Wetlands

Constructed wetlands are a mechanical complex of saturated substrates, emergent and submergent vegetation, animal life, and controlled water fluctuations that simulate natural wetlands for human use and benefits (Hammer & Bastian, 1989). The potential applications of constructed wetland systems are expansive, from treating mining effluent to landfill leachate, and from stormwater management to wastewater treatment (Hammer, 1989). Constructed wetland wastewater treatment systems have been studied in depth over the past three decades, and have been regaled with great success. The ability to specifically design and construct a wastewater treatment wetland has many benefits, including known wastewater volumes, nutrient loading rates, and monoculture establishment of vegetation proven to fixate and remove elements included in wastewater (Verhoeven & Meuleman, 1999). The plant selection in a constructed wetland wastewater treatment system is of prime concern, and three main plants proven to remove wastewater nutrients in the monoculture system are cattail, bulrush, and giant reed (Hammer & Bastian, 1989). However, maintaining a monoculture system may require unforeseen operational expenses, as an insect pest outbreak could damage the system and surrounding environments. In these instances, a mixed species system may be more resistant to a pest outbreak, and may be more efficient in removing a broader range of nutrients (Hammer & Bastian, 1989). The juxtaposition in this case is that these three reed plants, while successfully removing harmful contaminants in wastewater, form rhizomes that prevent the establishment of alternate plant species, which encourages monoculture, introducing again the difficulties associated combating monoculture establishment in these systems. The substrate selection is equally important during constructed wetland design, as various soils, sand, or gravel provide physical support for plants, reactive surface area during fluctuating water table conditions, and attachment surfaces for microbial populations (Hammer & Bastian, 1989). A primary benefit of constructed wetland treatment systems, once fully established and correctly functioning, is the relatively low operation and maintenance cost compared to conventional treatment systems (Gopal, 1999). However, the initial cost of a constructed wetland wastewater treatment system is substantial, and if not designed and implemented properly, could negate any future cost savings and environmental benefit (Breaux, et al., 1995). Constructed wastewater treatment wetlands can also be tailored to function year-round in a broader range of climates and on a more demand-based scale (Verhoeven & Meuleman, 1999), whereas natural wastewater treatment wetlands may operate within specific growing-season constraints and climatic conditions. Constructed wastewater treatment wetlands have an obvious potential for success by providing effective and reliable wastewater treatment while remaining tolerant of fluctuating hydrologic loading rates and creating selective wildlife habitats. However, the initial cost of construction and continual maintenance of a constructed wetland system could easily overshadow the future benefits of providing reliable, tolerant, and resilient wastewater treatment.

Natural Wetlands

Wastewaters have been discharged into natural wetlands for centuries (Gopal, 1999; Jeng & Hong, 2005), and have long been viewed as substitutes for traditional wastewater treatment (Breaux, et al., 1995). However, their specific roles have not been fully recognized until the past 60 years (Gopal, 1999). Since 1950, an increased interest in the use of natural wetlands for wastewater treatment has proliferated as a simple and energy-efficient means of removing wastewater nutrients and improving water quality (Zhang, et al., 2000). Currently, three main types of natural wetland systems are used to treat wastewater: facultative ponds, floating aquatic plant systems, and the method primarily examined in this paper, wetland systems. The energy input required for wastewater treatment in natural wetlands and standard WWTPs are the same, but in natural systems, processes such as aeration, biological nitrification, and chlorination are derived through natural energies (ex. sunlight, wind, rain, natural water table fluctuation) rather than mechanical processes that rely on fossil fuels (Kadlec & Knight, 1996). Applications of wastewater into natural wetland systems can also reduce problems associated with wastewaters directly discharged into surface waters (Zhang, et al., 2000), reduce costs associated with the construction of municipal WWTPs and associated sewer infrastructure (Breaux, et al., 1995; Day, et al., 2004; Verhoeven & Meuleman, 1999), and bolster soil accretion and primary productivity of the receiving wetlands (Hunter, et al., 2009; Ko, et al., 2004). Natural wetlands are also confirmed to treat more wastewater per unit of energy and with less financial cost than constructed wetlands and modern WWTPs because the wetland utilizes natural energies such as sunlight, wind, and rain (Ko, et al., 2004). These natural energies drive multiple functions and mechanisms of effluent treatment in wetlands including physical settling, chemical precipitation, adsorption, and biological process such as uptake and denitrification (Ko, et al., 2004). However, natural wastewater treatment wetlands are not without limitations as well. Nutrient overloading is the most common problem among these natural wetland wastewater treatment systems, and can lead to eutrophication (Day, et al., 2004; Kadlec & Knight, 1996). Additionally, if baseline studies and monitoring are improperly initiated or documented, the addition of wastewater could prove catastrophic to a localized wetland ecosystem by hindering vertebrate and invertebrate animals, over-exposing plant matter to nutrients, and causing runoff containing nutrient rich non-potable water. Because natural energies in these systems are utilized, subsequent varying climactic conditions of the subject area must be examined and documented as well. Specific contingency plans should be developed to preemptively address these concerns, which include but are not limited to hurricanes, tornados, floods, and pests (Kadlec & Knight, 1996). Another drawback of the natural wastewater treatment system is the large land mass required for successful retention time and treatment. This stipulation makes the natural wetland wastewater treatment method undesirable for medium to large urbanized cities, but can be used in conjunction with standard methods of wastewater treatment to reduce operational cost and allow for the successful treatment of higher volumes of wastewater without expanding the existing WWTP (Kadlec & Knight, 1996).

To conclude, a significant majority of the authors reviewed indicate that natural wetland wastewater treatment systems are both more effective at the removal of nutrients and suspended sediments and provide a substantially greater benefit-to-cost analysis over constructed wetland systems (Breaux, et al., 1995). However, both natural and constructed wetland wastewater treatment nutrient removal efficiencies are determined by loading rate, retention time, and the interaction of soil, water, vegetation, and microorganisms (Zhang, et al., 2000). A majority of authors remain consistent in backing a more holistic, naturalized approach with natural wastewater treatment wetlands as opposed to constructed wastewater wetland treatment systems because naturalized systems take into account the surrounding ecosystem, water quality effluent, land preservation, aquifer recharge, and biodiversity.

Florida, Louisiana, and North Carolina Regulations

While North Carolina currently lags behind in the field of naturalized wastewater treatment, surrounding states such as Florida and Louisiana have been operating these systems for decades. Although authors Verhoeven and Meuleman (1999) doubt the success of long-term wetland wastewater treatment systems, studies by Hunter et al. (2009) have clearly demonstrated that the wetland method of treatment can stimulate productivity while causing no measurable negative impacts to the receiving wetlands or downstream systems after even 60 years of continuous operation. Concern for the utilization of these systems is based on multiple factors, such as shifts in vegetation composition after wastewater is introduced for long durations, nutrient overloading and eutrophication of wetland systems, and the risk of undermining the conservational value of these ecosystems (Gopal, 1999; Gopal, et al., 2008; Verhoeven & Meuleman, 1999). A brief examination of Louisiana and Florida wetland assimilation and augmentation regulations are reviewed in the following paragraphs. This is an important examination of wetland wastewater treatment approaches, because systems in Florida and Louisiana have been operating for up to 80 continuous years, while North Carolina wetland augmentation regulations are still in the hearing and approval phases. Similarities and distinctions to the proposed North Carolina wetland augmentation regulations are noted where appropriate, focusing on the salient point of contention regarding the restrictive -12 inch depth to water threshold in North Carolina.

To limit the concentration of effluent discharged into both natural and constructed wetland wastewater treatment systems, the US EPA has limited discharges to waste which has already undergone secondary treatment (Breaux, et al., 1995). While North Carolina's proposed wetland augmentation guidelines allow only the dispersal of tertiary treated wastewaters, Louisiana has allowed natural wetlands to receive secondarily treated effluent, though only after further approval from the Louisiana Department of Environmental Quality (Jeng & Hong, 2005). The Louisiana landscape is uniquely adapted to the treatment of wastewaters because of its consistently low topography, expansive riverine and riparian environments, and the extensive Mississippi River delta. Also important to note are the disproportionate amount of wetland systems that Louisiana contains when compared to other contiguous states. Today, Louisiana wetlands account for up to 40% of the national inventory of wetlands, but unfortunately also account for the largest national wetland losses, at up to 80% (J.S. Williams, 1995). Rapid wetland losses and the necessity for advanced wastewater treatment and dispersion have driven the utilization of naturalized wastewater wetlands, referred to in Louisiana as wetland assimilation, to the upper echelon of the Louisiana Department of Environmental Quality's (LDEQ) regulatory agenda. Accessed through the Environmental Protection Agency's (EPA) website regarding State, Tribal and Territorial Standards for water quality, specific guidelines for the introduction of wastewaters into wetlands are set forth in Louisiana Administrative Code (LAC) Title 33, Part IX, Chapter 11 - Surface Water Quality Standards (Agency, 2010b). While the document does not specify depth to water table restrictions likened to the proposed North Carolina regulations, it does provide sufficient detail regarding the classification of wetlands, wetlands approved for acceptance of wastewaters, and general, numerical, and biological monitoring guidelines of on-site and discharged water quality. It should also be noted that while North Carolina demands the demonstration of a net environmental benefit regarding wetlands augmentation, Louisiana code outlines biological criteria which states that a wastewater wetland may not exceed a 20% reduction in above-ground wetland productivity over a 5 year period of wastewater dispersion (Agency, 2007; Services, 2008). Similar to the baseline monitoring in proposed North Carolina Regulations, the LDEQ requires an initial feasibility study to assess current wetland uses, establish sampling and reference points, initiate hydrologic analysis, and determine long-term average loading rates (Agency, 2007; Services, 2008). The LDEQ further requires a baseline study after the approval of the feasibility study. The Louisiana baseline study examines the potential assimilation site in detail, after the feasibility study has been reviewed and the area is considered acceptable for the addition of wastewaters. The baseline study consists of a detailed vegetation analysis, sediment analysis, water level measurements and analysis, surface water analysis, and soil accretion measurements (DeHart, 2010; Services, 2008). The LDEQ has accepted that despite a consistently low elevation and largely equivalent landscapes, each wetland system will respond differently to the addition of wastewaters. Therefore, instead of adopting broad regulations which restrict the amount of wastewaters distributed into wetlands, the LDEQ imposes limits on the surrounding environmental effects of wetland assimilation projects. For instance, the assessment of discharged water quality from assimilation projects is measured and strictly enforced, including but not limited to the examination of temperature, pH, total dissolved solids, biological productivity, dissolved oxygen, flow, and specific analysis of variance (ANOVA) tests (Agency, 2007; Services, 2008). This method of regulation may appear responsive as opposed to anticipatory, but decades of research have already documented the wetlands of Louisiana, specifically with regard to the addition of wastewaters. This research has helped to refine and re-define wetland assimilation regulations and appropriately quantified the response of wetlands and the surrounding environment to the addition of wastewaters. In summation, by implementing this manner of regulation and enforcement, the LDEQ can assure that overall water quality is improved and nutrients contained in wastewater are successfully fixated by wetland assimilation projects, while the stimulation of primary wetland productivity may be slightly reduced.

Florida also has a mature wastewater wetland program which has been in operation since 1914, although the first natural wastewater wetland was officially permitted in the mid 1980's (S. Speasfrost, personal communication, March 31, 2010). The EPA lists regulations pertaining to the wastewater wetlands of Florida through the State, Tribal and Territorial Standards for water quality, and are specifically outlined in Administrative Code 62-611 (Agency, 2010a). Classifications of natural wetlands receiving reclaimed water in Florida follow two paths. Advanced water treatment (AWT) standards are equivalent to tertiary treated wastewaters in North Carolina, and wetlands accepting this standard of wastewater are classified as receiving wetlands. Wetlands that accept secondarily treated wastewaters are classified as treatment wetlands for polishing, and are subject to more stringent guidelines and monitoring programs than receiving wetlands (S. Speasfrost, personal communication, March 31, 2010). Immediate distinctions between Florida, Louisiana, and proposed North Carolina regulations emerge when examining the flora in wetlands deemed appropriate for receiving wastewaters. Florida regulations decree that a wetland may receive wastewaters only if the herbaceous ground cover is dominated by at least 50% *Typha* spp., or common cattail (Protection, 1996). This desired parameter is concerning because cattail has been proven to successfully fixate nutrients contained within wastewaters (Nichols, 1983), though numerous other plants such as duckweed, water hyacinth, bulrushes, reeds and sedges also achieve efficient nutrient removal (Gopal, 1999). Wastewaters may be dispersed into Florida's natural wetland systems at an annual average rate of no more than 2 inches per week, and no more than 6 inches per week in hydrologically altered wetlands. Monitoring requirements for treatment and receiving wetlands vary from a monthly to quarterly to yearly timeframe, depending on parameter of measurement. Also in Florida, the vegetation composition is determined at each monitoring station and averaged over the entire project area. Interestingly, the importance value (sum of relative density, relative dominance, and relative frequency converted to a percentage) of plants within the monitoring area may not be reduced more than 50%, and over the entire project area the importance value may not be reduced more than 25% (Protection, 1996). In an overall assessment, the Florida Department of Environmental Protection is more concerned with the retention time of wastewater in wetland systems, the physical and chemical loading rates, and the initial vegetation composition over the physical depth-to-water table in wastewater wetlands.

Previous paragraphs have examined the varied maturities of wastewater wetland regulations of three states. Notable differences between proposed North Carolina, Louisiana, and Florida regulations are found within the desired herbaceous composition and maximum allowable vegetation debility (Florida), varying degrees of preliminary wastewater wetland assessment (Louisiana), and restrictions concerning the water table criteria during wastewater dispersion (North Carolina). However, a consistent and largely unchanged similarity of all regulations examined maintains the high standard to which treatment must occur. The regulations of all three states seek the maximum efficiency of wastewater wetlands by utilizing universal parameters such as reduction in biological oxygen demand, nitrogen and phosphorous fixation, and the removal of total suspended solids. Furthermore, all states are concerned with water quality discharge and the overall effects of wastewater wetlands to their respective surrounding environments, though the means to which these goals are accomplished are diverse and sometimes contradictory.

Site Introduction

The site examined by this study is located in Brunswick County, North Carolina in the township of Supply (Figure 1). When viewing the topographic map (Figure 2), initial traits that verify this site for potential wetland augmentation are its abundance of freshwater wetlands and its absence of unique wetlands or salt water wetlands. The site also borders the Green Swamp preserve, an undeveloped long Leaf pine-dominant system. While the overall site encompasses approximately 1,036 acres, only about 590 acres currently accept reclaimed wastewater through an upland drip irrigation system (J. P. W. a. G. E. Williams, 2009). The wastewater treatment plant is in close proximity to the drip site (< 2 miles), so tertiary treated wastewater is currently transported by non-potable water truck to the spray site and dispersed when appropriate. The Supply WWTP currently serves approximately 2,800 residents from the central and western portions of Brunswick County (R. Worthington, personal communication, October 22, 2010). The spray site is permitted to disperse 1.72 Million Gallons per Day (MGD), but due to the seasonal population flux the amount of wastewater generated varies from 1.2 MGD in an average winter month, to 3.0 MGD in an apex summertime month (J. P. W. a. G. E. Williams, 2009; R. Worthington, personal communication, October 22, 2010). The areas that do not currently receive reclaimed wastewater are primarily 404 jurisdictional wetlands, comprised of Murville and Torhunta soil series (Figure 3) (Barnhill, 1986). It is in the interest of Brunswick County to research the Supply spray site in order to permit wetland augmentation, resolving the increased demand placed on the Supply WWTP during peak summertime utilization. While elements of net primary productivity, nutrient uptake, loading rates, wildlife impacts, metal toxicity, and other deterministic variables must be addressed before implementing a wetland augmentation project, this study seeks to identify solely the hydrologic fluctuation that takes place in wetlands and attempts to draw conclusions regarding the -12 inch threshold postulated by the NC EMC.

Methodology

Wetland water tables are hydrologically dynamic systems, and should be monitored daily to fully represent depth-to-water fluctuations. Shallow water level monitoring devices (wells) manufactured by Remote Data Systems, Inc. (RDS) were utilized to capture the daily depth-to water table readings (Figure 4). Wells utilized on this site are approximately 54 inches in length, with a sensing range of +6 inches to -42 inches below the soil surface. These monitoring devices operate with a lithium battery powered data logger attached to a capacitance based probe (R. George, personal communication, October 18, 2010). The probe is then placed in a 2 inch slotted PVC casing, which is manufactured and installed in accordance with the US Army Corps of Engineers (USACOE) technical guidelines for water table monitoring of potential wetland sites (Engineers, 2005). The researcher obtains logger data through a Palm interface, accessed by a serial cable connection on the top of the well. For site-specific rainfall analysis, a rain gauge, also manufactured by RDS in accordance with USACOE guidelines, was installed at the study area as well.

A total of 12 monitoring devices were installed at select wetland locations within the site during February and March of 2009 (Figure 5). The wells were configured to read once daily at 7:00am in order to produce a descriptive time series design. The rain gauge was configured to continuously record rainfall in .01 inch intervals. This research design most properly analyzed the daily fluctuation of selected wetland water tables in response to rain events and the percolation of water through the surrounding upland reclaimed water drip irrigation system. The sampling design was limited by a variety of factors including physical access to wetlands, distance relationship between uplands and wetlands, and availability of monitoring instruments. Therefore, the selection of monitoring well locations was based on a non-probability purposive sample, strengthened by the expertise of a registered Environmental Consultant, licensed Soil Scientist, and practicing Environmental Scientist with a combined 50+ years of experience in delineating wetlands, soils classification, and monitoring wetland hydrology. Wells were hence installed in the centers of isolated wetlands (wells 1, 5, & 8), or inside 404 jurisdictional wetlands at least 200 feet or greater from the wetland boundary (wells 2, 3, 4, 6, 7, 9, 10, 11 & 12). This was accomplished intentionally to represent the lowest elevation in the wetlands at which reclaimed water is proposed to be applied, to establish parallel and perpendicular transects of wells in relation to ditches and wetland boundaries, and to monitor the response of varying wetland types to the influx of reclaimed water and rain events.

Results

Water level monitor data is most appropriately displayed in graphical form. Figure 6 is a typical hydrograph of the well data obtained at the Supply spray site. Two sub-graphs appear within the standard hydrograph. The graph displayed is only one of several hydrographs, and for the results portion, only wells 6 & 7 will be represented visually. The discussion portion will examine tables which represent all wells that have collected measurable data at the Supply site.

The top sub-graph provides a seasonal context for the well data, and is a representation of daily and 30-day running precipitation totals. The daily and 30-day running precipitation totals were gathered from an on-site rain gauge and compared to the nearest observation station within the North Carolina Climate Retrieval and Observations Network Of the Southeast Database (NC CRONOS). The NC CRONOS database is maintained by North Carolina State University and allows the public to access observations from 12,814 active weather sites throughout North

Carolina and neighboring states (Carolina, 2003-2010). The nearest NC CRONOS station is located approximately 2.4 miles from the Supply spray site, maintained by the Nature Conservancy, and found within the Green Swamp Preserve. This station, identified as NNAC, was selected because of its close proximity to the site, reliable historical data, and the necessity for comparative measures against the on-site rain gauge. The 30-day running total is derived from the on-site rain gauge and is a moving sum of the previous 30 days of on-site precipitation data. Time is graphed on the X-axis, in ten day intervals, in a day-month-year format. Precipitation is graphed on the Y-axis using one inch intervals. The 30th and 70th historic percentiles provide a context for normal rainfall and are inspired by the Natural Resources Conservation Services (NRCS) climate information regarding wetlands tables (WETS) for the Longwood station in Brunswick County North Carolina. Monthly precipitation totals from the Longwood WETS table were gathered beginning in 1972 and ending in the year 2000 (Service, 2010). However, LMG has independently updated the WETS table to reflect data from 1978-2009, providing the most up-to-date assessment of the previous 30 years of precipitation data. These are the historical 30th and 70th historical percentiles displayed on the top portion of the hydrograph. When the historical percentiles are compared against the 30-day running onsite precipitation totals, a context of normal rainfall is established. When the running total ascends above the 70th percentile that period is considered abnormally wet. Conversely, when the running total descends below the 30th percentile that period is considered abnormally dry. The normal range is found when the running total hovers in-between the 30th and 70th percentiles. During the normal periods, well data is relied upon heavily and considered to have the greatest significance by regulatory agencies such as the USACOE and the NC DENR. These agencies utilize precipitation data of this caliber in jurisdictional wetland determinations and the assessment of current climactic conditions.

The lower sub-graph contained within the hydrograph is the graphical representation of measured well data. Time is graphed on the X-axis in ten day intervals, in day-month-year format. The individual daily well readings are graphed on the Y-1 axis in six inch intervals, and are designated by a corresponding colored point, while the daily precipitation totals from the on-site rain gauge are graphed on the Y-2 axis in one inch intervals. The Brunswick County growing season runs from March 7th to November 28th (Barnhill, 1986) and is marked by vertical bolded lines. The currently proposed wetland augmentation regulations will only allow wetlands to accept reclaimed water if the depth of the water table is at or below -12 inches from the soil surface during the growing season (Commission, 2010), which is designated in the graph by a bold line at -12 inches. The data in Figure 6 show that during the growing season, wetlands in these areas retain their fluctuating hydrologic characteristics in response to periodic rain events. Furthermore, the availability to disperse reclaimed water into these areas has maximum potential during periods of abnormally low rainfall. As demonstrated by the graphs in Figure 6, wells 6 & 7 show considerable potential for the acceptance of reclaimed water.

Table 1 has listed the amount of days that reclaimed water would be accepted by the wetlands at designated well locations under current proposed regulations. The well numbers correspond to the locations on Figure 5 in which water table depths would allow the pumping of reclaimed water. A zero in column 2 means that no time within the growing season was the water table depth below the proposed -12 inch threshold. Evaluating by this criteria, areas 1 & 5 are not suitable for wetland augmentation under current proposed regulations. Conversely, areas 6 & 7 display the greatest potential for the acceptance of reclaimed water, as the water table remains below the -12 inch threshold during much of the growing season, and the average depth to the water table during those times is -21.1 and -26.5 inches respectively.

Table 1. Examination of water table at or below -12" during the growing season

Well ID (location)	# of days water table is at or below -12 inches	average depth to water table during days that absolute water table is at or below -12 inches
1	0	0.0
2	59	-15.0
3	22	-17.0
4	143	-24.9
5	0	0.0
6	153	-21.1
7	224	-26.5
8	8	-19.9
9	166	-22.4
10	93	-18.0
11	69	-13.7
12	93	-19.0

Tables 2 and 3 examine the reclaimed water pumping potential if the -12 inch threshold were re-evaluated at -6 inches and -2 inches below the soil surface, respectively. It should be noted that in table 2, the previously exempt wetland at the well 5 location is now available for the acceptance of reclaimed water under the adjusted -6 inch threshold. Additionally, wetland locations at wells 6 and 7 are viable repositories for the acceptance of reclaimed water during a majority of the growing season while maintaining an average depth to water table of greater than -12 inches below the soil surface. In table 3, both previously exempt wetland locations at wells 1 and 5 may receive reclaimed water under the adjusted -2 inch threshold. Also in table 3, wetlands at well locations 2, 4, 6, 7, 9, and 10 may accept reclaimed water for the vast majority of the growing season, regardless of variations in on-site precipitation totals. Furthermore, all wells at designated wetland locations have the capacity to accept some amount of reclaimed water under the -2 inch threshold, greatly extending the potential acceptance of reclaimed water for the proposed wetland augmentation project at the Supply spray field.

Table 2. Examination of water table at or below -6" during the growing season

Well ID (location)	# of days water table is at or below -6 inches	average depth to water table during days that absolute water table is at or below -6 inches
1	0	0
2	236	-9.9
3	52	-12.2
4	192	-20.9
5	26	-7.7
6	208	-17.9
7	246	-24.9
8	38	-9.9
9	186	-21.0
10	138	-15.0
11	108	-12.1
12	131	-16.1

Table 3. Examination of water table at or below -2" during the growing season

Well ID (location)	# of days water table is at or below -2 inches	average depth to water table during days that absolute water table is at or below -2 inches
1	16	-3.8
2	265	-9.5
3	85	-8.7
4	208	-20.6
5	162	-4.0
6	250	-15.6
7	264	-23.6
8	120	-5.8
9	222	-18.3
10	217	-10.9
11	146	-9.9
12	196	-11.8

Discussion

The data in tables 1, 2, and 3 display the potential pumping capacity in which the Supply spray site may utilize the wastewater treatment method of wetland augmentation under varying water table depth restrictions. However, under the currently proposed -12 inch depth to water table restriction, severe limitations are placed on the treatment capacities of these systems. A noted increase of wastewater treatment capacity occurs as the water table depth restriction is moved closer to the soil surface. Reducing the depth to water table restriction to -6 inches below the soil surface greatly increases the potential for the acceptance of reclaimed water and allows the achievement of wetland hydrology, a critical factor in determining net environmental benefit. Previously presented monitoring well hydrograph data have revealed that ponding takes place with some regularity in these wetland systems without producing overland flow, indicating that the basic storage capacity of these wetlands has been grossly underrated. In the proposed re-evaluation of the water table restriction, sufficient separation between the soil surface and the water table verifies that overland flow would not take place, even under the most liberal -2 inch depth to water table restriction.

In addition, the climactic conditions of the southeast vary with great degree from year to year, so it is difficult to identify cost effective, annually reliable sites to which wetland augmentation may operate. Under the proposed rules, pumping may be allowed during the entire growing season of one year and then be completely restricted during the growing season of the next. This leads to difficulties in the design of appropriate holding basins and pumping systems involved in wetland augmentation projects due to the seasonal climactic irregularities and varying demand for wastewater treatment and dispersion.

The specific volume of acceptance for reclaimed water in these wetlands is yet to be determined, and will require further testing and assessment by hydro geologists, soil scientists, and engineers to determine loading rates that will maximize the net environmental benefit of the Supply spray site wetlands. However, it is confirmed, based solely on physical parameters that the Supply spray site wetlands are a viable repository for the disposal of tertiary treated wastewater.

Conclusions

Throughout this paper, the author has analyzed and documented numerous techniques of wastewater wetlands throughout the neighboring states of North Carolina. A significant portion of the literature reviewed demonstrated that natural wetlands can be utilized successfully in the treatment of secondary and tertiary waste effluent in accordance with modern WWTP standards. Additionally, environmental benefits associated with the enhancement of wetland hydrology and nutrient loading have proven to be extensive, including but not limited to: soil accretion, increases in primary productivity, improvement of surface waters, ecosystem preservation, and a substantial benefit to cost analysis. However, natural wetlands receiving wastewaters have their opportunities and limitations, and each system functions differently. Therefore, a minimum of one year of baseline studies to analyze vegetation composition, hydrology, loading rates, topography, surrounding surface waters, and climate is confirmed and recommended to all proposed wetland augmentation sites.

While surrounding states differ in the approaches used in their wastewater wetlands, the overall goals are directed at the reduction of biological oxygen demand, fixation of nitrogen and phosphorous, and the removal of total suspended solids. Louisiana and Florida have the strength of maturity regarding wastewater wetland regulations and are less concerned with the application site conditions than the overall improvement of discharged water quality. This is in contrast to proposed North Carolina wetland augmentation regulations which clearly state that a net environmental benefit must be demonstrated on the application site before the addition of wastewaters is permitted. This requirement may create confusion within the regulatory commission and environmental firms who are charged with permitting, designing, and monitoring the effects of wastewater wetlands because of its subjectivity. As directed by the NC EMC, a net environmental benefit includes the continued maintenance of existing wetland conditions and the protection of endangered species. However, a contradiction may be found in the NC EMC requirement that a wetland augmentation project must maintain existing wetland conditions while contrarily restricting the achievement of those conditions through the addition of wastewaters. Wetland hydrology is a critical factor in determining the existence of a wetland, and environmental benefits associated with wetlands require periodic flooding, ponding, or a water table fluctuating within -12 inches below the soil surface for 14 consecutive days of the defined growing season. Through the addition of wastewaters, wetlands may achieve the hydrologic criterion, hence promoting the continued existence of wetland conditions and encouraging environmental benefits associated with wetlands.

The previous point illustrates that a volume of reclaimed water should be dispersed into the wetlands in order to raise the depth of the water table to within -12 inches of the soil surface to demonstrate a net environmental benefit. This can be accomplished by critically reviewing the -12 inch depth to water table restriction, or by adopting techniques of neighboring states which have successfully operated similar wastewater wetland projects with no arbitrary -12 inch depth to water table restriction, for up to 80 continuous years.

Future studies would serve the NC EMC well to examine the maximum potential chemical loading rates for successful wastewater wetland treatment in order to permit the application of secondary treated wastewaters into wetland systems. This would eliminate another mechanical step in the treatment of wastewaters, further relaxing the burden placed on coastal WWTPs during the populous summer months. A hydrologic assessment of the currently operational upland wastewater drip irrigation system of Supply would further reveal water table fluctuations in response to rain events and the addition of wastewaters. These data could be combined with wetland monitoring device data to visualize the subsurface flow of wastewaters percolating through the soil as reclaimed water travels from the uplands to wetlands in order to ultimately maximize upland and wetland loading rates. Another beneficial study would involve a detailed cost-benefit analysis for the Supply spray site and the use of wetlands to treat wastewater and the site's ability to successfully manage peak summertime demands for wastewater treatment and dispersion. Chemical analysis should also be initiated to evaluate current benefits to surrounding water quality of the Supply spray site as a result of the increased volume of reclaimed water treated by upland and wetland systems. Chemical analysis would also indicate the potential for upland and wetland systems to successfully filter nutrients contained in secondary treated waste effluent.

References

Agency, U. S. E. P. (2007). Louisiana Administrative Code (LAC) Title 33, Part IX, Chapter 11 - Surface Water Quality Standards. *Repository of Documents: Louisiana.* Retrieved October 25, 2010, from http://www.epa.gov/waterscience/standards/wqslibrary/la/la_6_wqs.pdf

Agency, U. S. E. P. (2009a, Monday, January 12, 2009). Percentage of Wetlands Acreage Lost, 1780's-1980's. Retrieved April 15, 2010, from http://www.epa.gov/wetlands/vital/epa_media/usa.gif

Agency, U. S. E. P. (2009b, Monday January 12, 2009). Status and Trends. Retrieved April 15, 2010, from http://www.epa.gov/wetlands/vital/status.html

Agency, U. S. E. P. (2010a, Monday, April 5 2010). Repository of Documents: Florida. *State, Tribal & Territorial Standards.* Retrieved October 25 2010, from http://water.epa.gov/scitech/swguidance/waterquality/standards/wqslibrary/fl_index.cfm

Agency, U. S. E. P. (2010b, Monday, April 5 2010). Repository of Documents: Louisiana. *State, Tribal & Territorial Standards*. Retrieved October 25 2010, from http://water.epa.gov/scitech/swguidance/waterquality/standards/wqslibrary/la_index.cfm

Barnhill, W. L., United States. Soil Conservation Service., & North Carolina. Dept. of Natural Resources and Community Development. (1986). *Soil Survey of Brunswick County, North Carolina*. [Washington, D.C.]: United States Department of Agriculture.

Brantley, C. G., Day, J. W., Lane, R. R., Hyfield, E., Day, J. N., & Ko, J. Y. (2008). "Primary Production, Nutrient Dynamics, and Accretion of a Coastal Freshwater Forested Wetland Assimilation System in Louisiana. *Ecological Engineering, 34*(1), 7-22.

Breaux, A., Farber, S., & Day, J. (1995). Using Natural Coastal Wetland Systems for Waste-Water Treatment - An Economic Benefit Analysis. *Journal of Environmental Management, 44*(3), 285-291.

Carolina, S. C. O. o. N. (2003-2010). State Climate Office of North Carolina. *NC CRONOS Database.* Retrieved October 19, 2010, from http://www.nc-climate.ncsu.edu/cronos

Commission, N. C. E. M. (October 2010) *Wastes Not Discharged to Surface Waters, NC Administrative Code .02U .0900, Wetlands Augmentation (proposed).* Raleigh, NC: Department of Environment and Natural Resources, Division of Water Quality.

Couillard, D. (1994). The Use of Peat in Waste-Water Treatment. *Water Research, 28*(6), 1261-1274.

Crawford, T. W. (2007). Where Does the Coast Sprawl the Most? Trajectories of Residential Development and Sprawl in Coastal North Carolina, 1971-2000. *Landscape and Urban Planning, 83*(4), 294-307.

Day, J. W., Ko, J. Y., Rybczyk, J., Sabins, D., Bean, R., Berthelot, G., et al. (2004). The Use of Wetlands in the Mississippi Delta for Wastewater Assimilation: A Review. O*cean & Coastal Management, 47*(11-12), 671-691.

DeHart, E. (2010). Louisiana Wetland Assimilation Projects. *DIVISIONS > Water Permits.* Retrieved October 25 2010 from http://www.deq.state.la.us/portal/DIVISIONS/WaterPermits/WetlandAssimilationProjects.aspx

Engineers, U. S. Army Corps of. (2005). *Technical Standard for Water-Table Monitoring of Potential Wetland Sites.*

Gopal, B. (1999). Natural and Constructed Wetlands for Wastewater Treatment: Potentials and Problems. *Water Science and Technology, 40*(3), 27-35.

Gopal, B., Ghosh, D., Sven Erik, J., & Brian, F. (2008). Natural Wetlands. *Encyclopedia of Ecology* (pp. 2493-2504). Oxford: Academic Press.

Hammer, D. A. (1989). *Constructed Wetlands for Wastewater Treatment: Municipal, Industrial, and Agricultural*. Boca Raton, FL: Lewis Publishers.

Hammer, D. A., & Bastian, R. K. (1989). Wetlands Ecosystems: Natural Water Purifiers? In D. A. Hammer (Ed.), *Constructed Wetlands for Wastewater Treatment:Municipal Industrial, and Agricultural* (pp. 5-19, xxii, 831 p.). Boca Raton, FL: Lewis Publishers.

Hickman, C. A. (1990). Forested-Wetland Trends in the United States - An Economic Perspective. *Forest Ecology and Management, 33-4*(1-4), 227-238.

Hunter, R. G., Day, J. W., Lane, R. R., Lindsey, J., Day, J. N., & Hunter, M. G. (2009). Impacts of Secondarily Treated Municipal Effluent on a Freshwater Forested Wetland After 60 Years of Discharge. *Wetlands, 29*(1), 363-371.

Jeng, H. W., & Hong, Y. J. (2005). Assessment of a Natural Wetland for Use in Wastewater Remediation. *Environmental Monitoring and Assessment, 111*(1-3), 113-131.

Kadlec, R. H., & Knight, R. L. (1996). *Treatment wetlands*. Boca Raton, Fla.: Lewis Publishers. pp 893, p 31-46.

Ko, J. Y., Day, J. W., Lane, R. R., & Day, J. N. (2004). A Comparative Evaluation of Money-Based and Energy-Based Cost-Benefit Analyses of Tertiary Municipal Wastewater Treatment Using Forested Wetlands vs. Sand Filtration in Louisiana. *Ecological Economics, 49*(3), 331-347.

Laboratory, E. (1987). *Corps of Engineers wetlands delineation manual. Technical Report Y-87-1* Vicksburg, MS: US Army Engineers Waterway Experiment Station.

Nichols, D. S. (1983). Capacity of Natural Wetlands to Remove Nutrients from Wastewater. *Journal Water Pollution Control Federation, 55*(5), 495-505.

Protection, Florida Department of Environmental. (1996, September 10 2010). Chapter 62-611: Wetlands Application. *Water Rules by Program Area.* Retrieved October 25 2010, from http://www.dep.state.fl.us/legal/Rules/wastewater/62-611.pdf

Service, N. R. C. (2010, October 21, 2010). Climate Data. *Climate Data Sets (ftp site).*Retrieved October 21, 2010, from http://www.wcc.nrcs.usda.gov/ftpref/support/climate/wetlands/nc/37019.txt

Services, L. D. o. E. Q. O. o. E. (2008). Permitting Guidance Document for Implementing Louisiana Surface Water Quality Standards for Water Quality Management Plan Volume 3. Retrieved October 25 2010, from http://www.deq.state.la.us/portal/Portals/0/permits/lpdes/pdf/Implementation%20 Plan6.pdf

Verhoeven, J. T. A., & Meuleman, A. F. M. (1999). Wetlands for Wastewater Treatment: Opportunities and limitations. *Ecological Engineering, 12*(1-2), 5-12.

Williams, J. P. W. a. G. E. (2009). Environmental Site Testing Requirements to Determine the Net Environmental Benefit of a Proposed Wetland Augmentation Wastewater Dispersal System. Land Management Group, Inc. and HDR Engineering, Inc.

Williams, J. S. (1995, November 3 1995). Louisiana Coastal Wetlands: A Resource At Risk. Retrieved October 25, 2010, from http://marine.usgs.gov/fact-sheets/LAwetlands/ lawetlands.html/landsat.gif

Zhang, X. W., Feagley, S. E., Day, J. W., Conner, W. H., Hesse, I. D., Rybczyk, J. M., et al. (2000). A Water Chemistry Assessment of Wastewater Remediation in a Natural Swamp. *Journal of Environmental Quality, 29*(6), 1960-1968.

Figures 1-6

Figure – 1, Vicinity Map of the Supply Spray Site, Brunswick County, North Carolina

Figure – 2, Topographic Map of the Supply Spray Site, Brunswick County, North Carolina

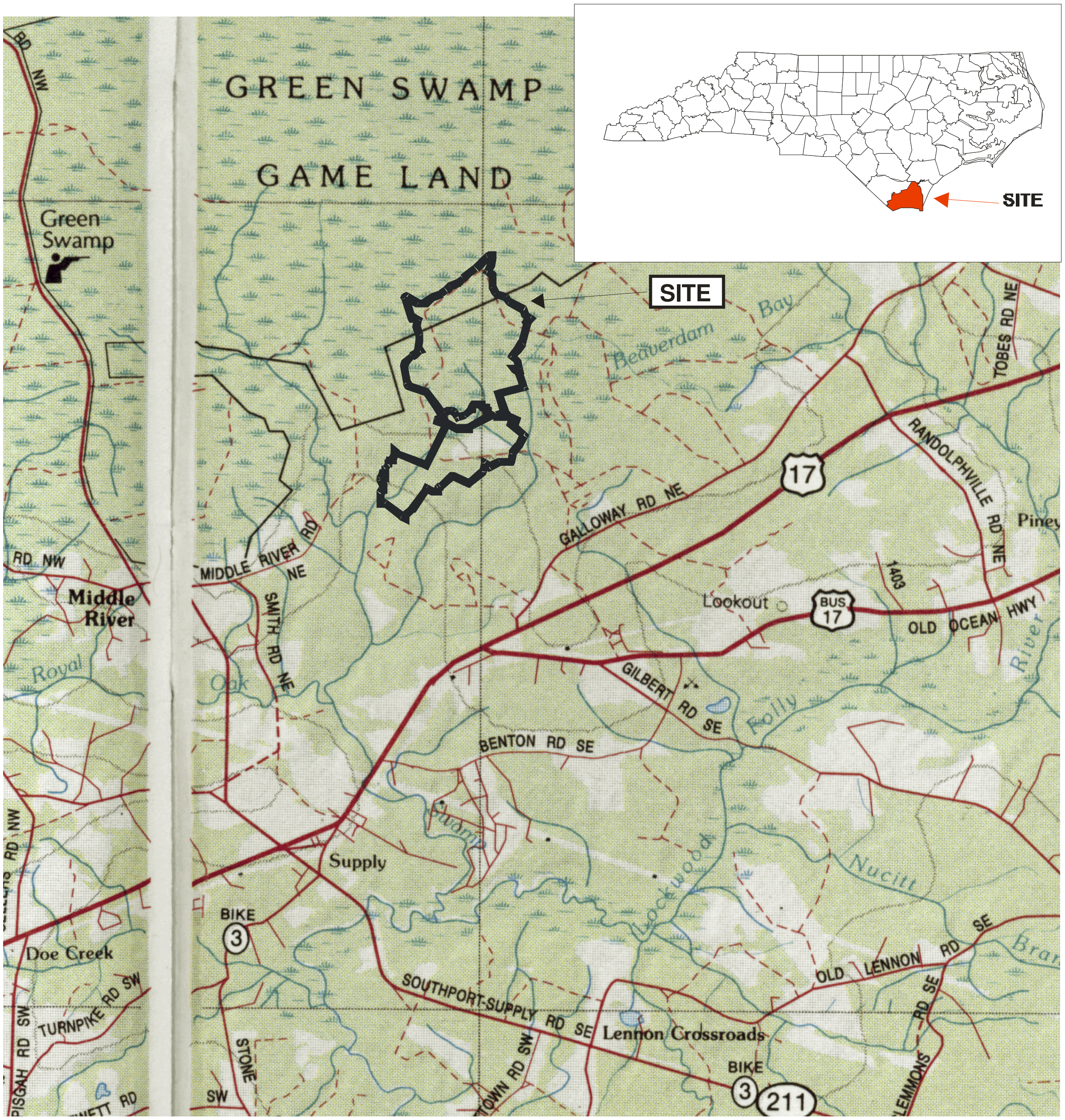
Figure – 3, Soil Map of the Supply Spray Site with Well and Wetland Overlay, Brunswick County, North Carolina

Figure – 4, Electronic Water Table Monitoring Device Diagram, Manufactured by Remote Data Systems, Inc.

Figure – 5, Aerial Photograph of the Supply Spray Site with Well and Wetland Overlay

Figure – 6, Sample Hydrograph of Monitoring Device Data at the Supply Spray Site, Brunswick County, North Carolina

Figure – 1, Vicinity Map of the Supply Spray Site, Brunswick County, North Carolina



*Boundaries are approximate and are
not meant to be absolute.

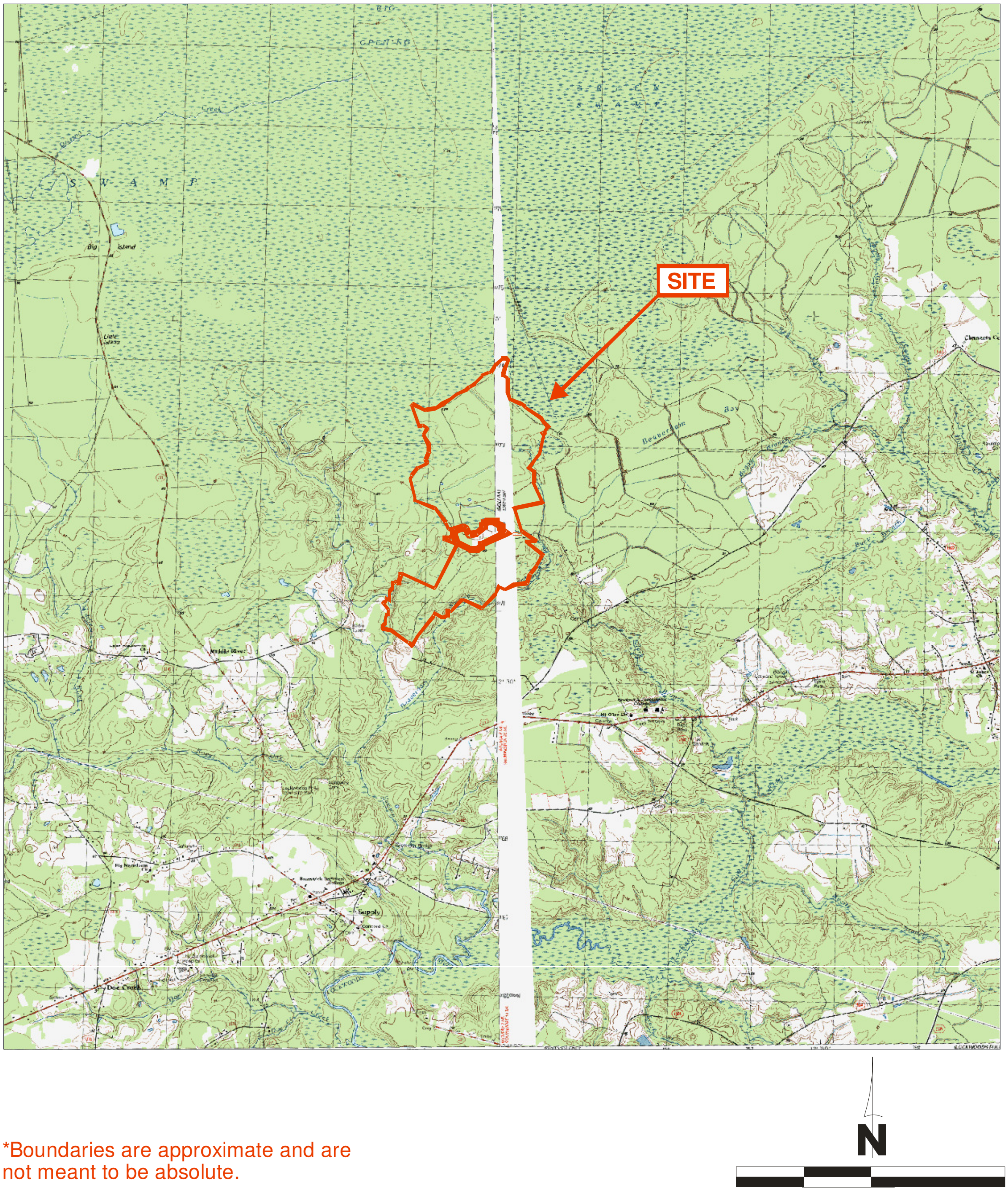
Map Source: North Carolina Atlas & Gazetteer. Pg 87. 2003

N

SCALE 1" = 1 Mile

Supply Spray Field Potential Wetland Augmentation Brunswick County, NC October 2010	William Dortch Environmental Scientist UNCW EVS M.A. Capstone Project	Figure 1 Vicinity Map

Figure – 2, Topographic Map of the Supply Spray Site, Brunswick County, North Carolina



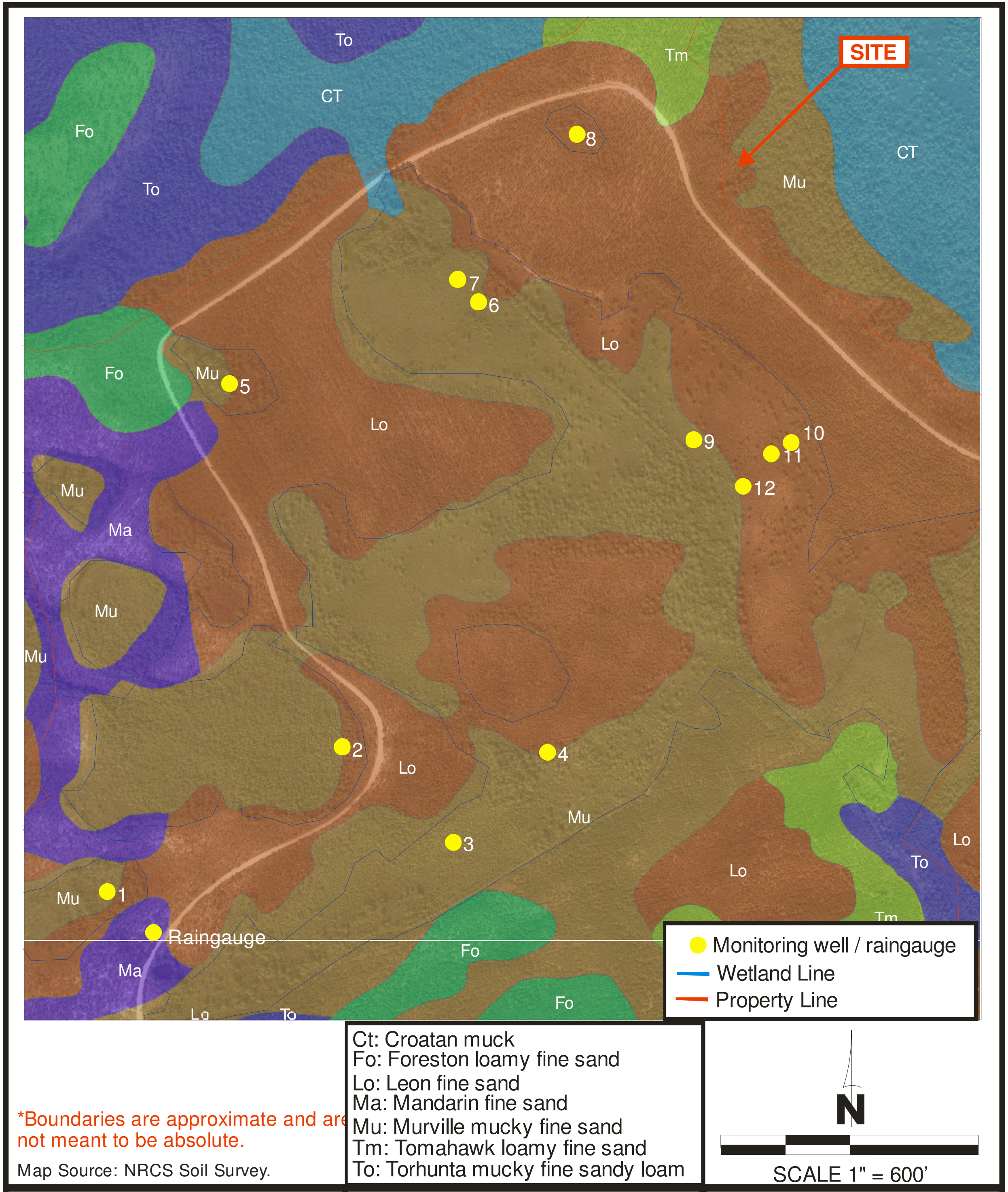
*Boundaries are approximate and are not meant to be absolute.

Map Source: Bolivia and Supply Quadrangles 7.5 minute (topographic) 1990.

SCALE 1" = 1 Mile

Supply Spray Field Potential Wetland Augmentation Brunswick County, NC October 2010	William Dortch Environmental Scientist UNCW EVS M.A. Capstone Project	Figure 2 USGS Topographic Map

Figure – 3, Soil Map of the Supply Spray Site, Brunswick County, North Carolina



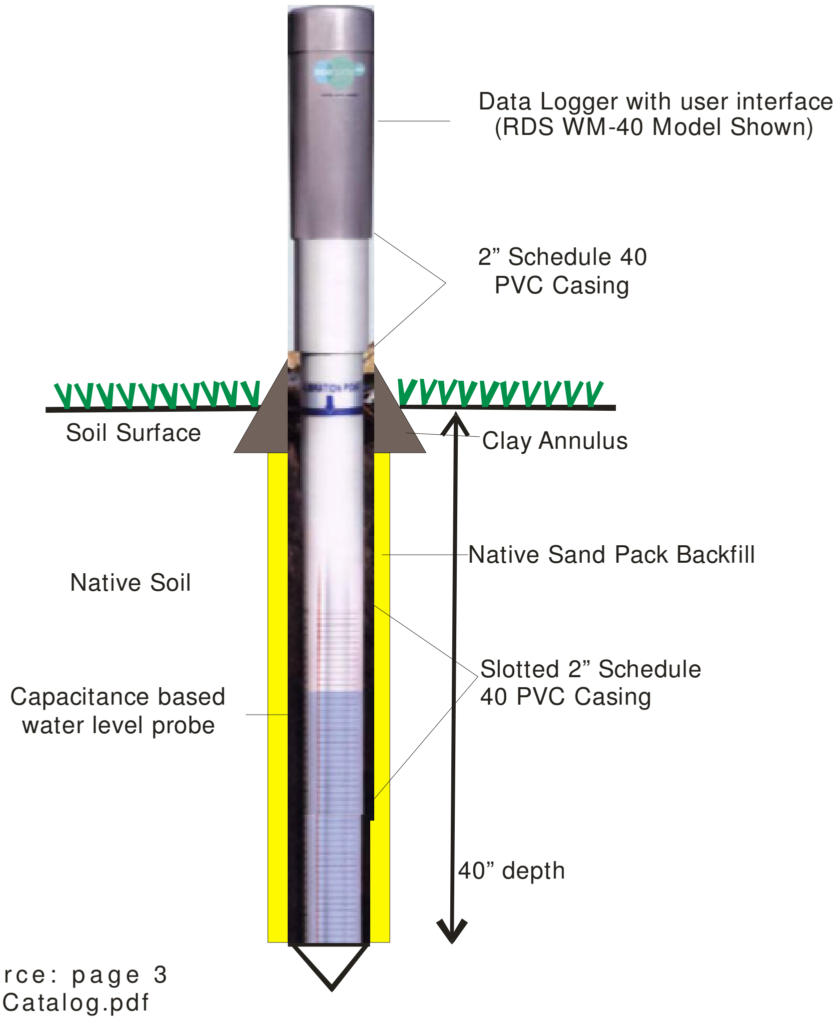
Ct: Croatan muck
Fo: Foreston loamy fine sand
Lo: Leon fine sand
Ma: Mandarin fine sand
Mu: Murville mucky fine sand
Tm: Tomahawk loamy fine sand
To: Torhunta mucky fine sandy loam

*Boundaries are approximate and are not meant to be absolute.

Map Source: NRCS Soil Survey.

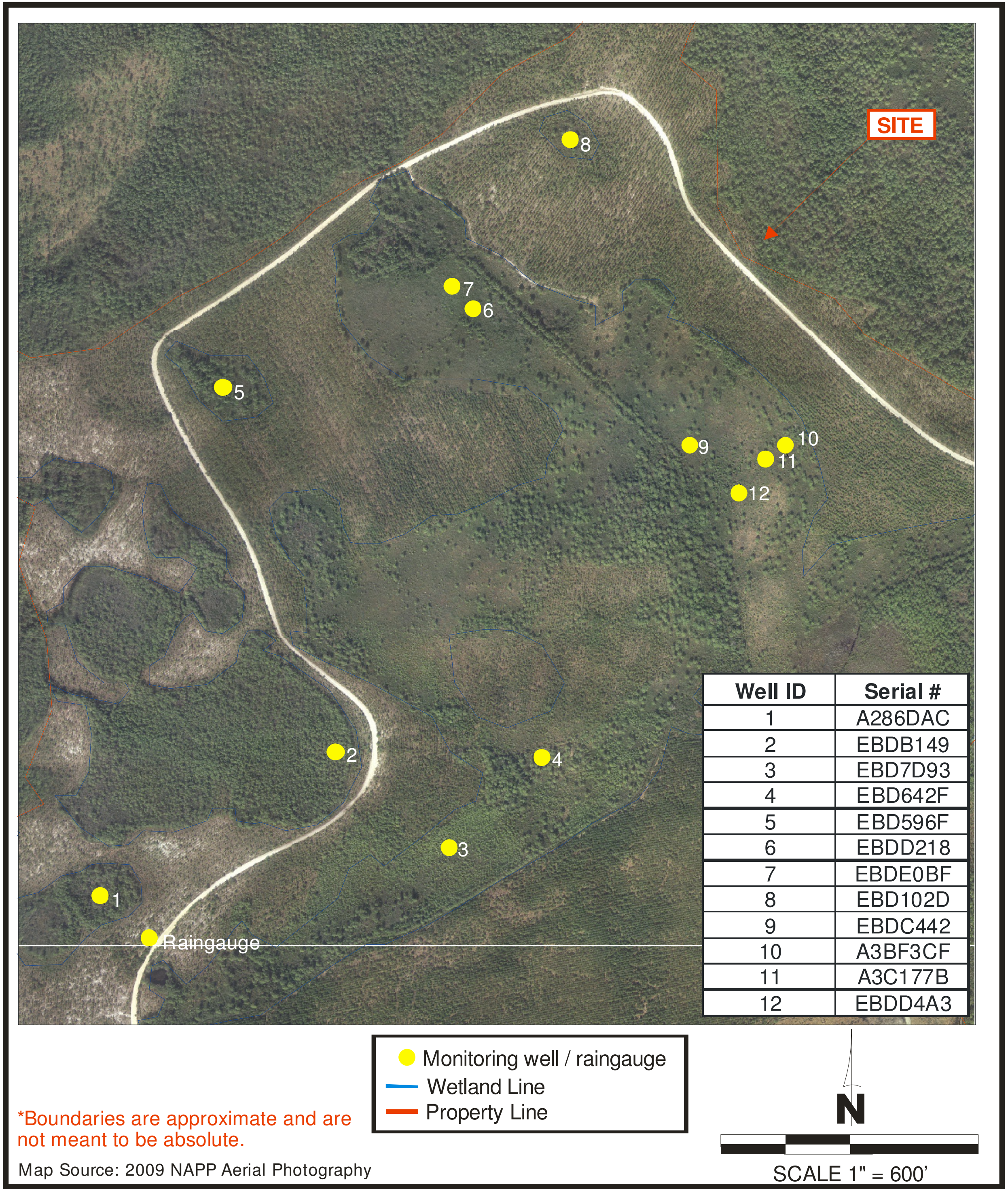
Supply Spray Field Potential Wetland Augmentation Brunswick County, NC October 2010	William Dortch Environmental Scientist UNCW EVS M.A. Capstone Project	Figure 3 Soils Map with wetland lines and well overlay

Figure – 4, Electronic Water Monitoring Device Diagram, Manufactured by Remote Data Systems, Inc.



Data Logger Image Source: page 3
http://www.rdsys.com/RDS_Catalog.pdf

Figure – 5, Aerial Photograph of the Supply Spray Site with Well Overlay



Well ID	Serial #
1	A286DAC
2	EBDB149
3	EBD7D93
4	EBD642F
5	EBD596F
6	EBDD218
7	EBDE0BF
8	EBD102D
9	EBDC442
10	A3BF3CF
11	A3C177B
12	EBDD4A3

● Monitoring well / raingauge
— Wetland Line
— Property Line

*Boundaries are approximate and are not meant to be absolute.

Map Source: 2009 NAPP Aerial Photography

Supply Spray Field Potential Wetland Augmentation Brunswick County, NC October 2010	William Dortch Environmental Scientist UNCW EVS M.A. Capstone Project	Figure 5 Aerial Photograph with wetland lines and well overlay

Figure – 6, Sample Hydrograph of Monitoring Device Data at the Supply Spray Site, Brunswick County, North Carolina

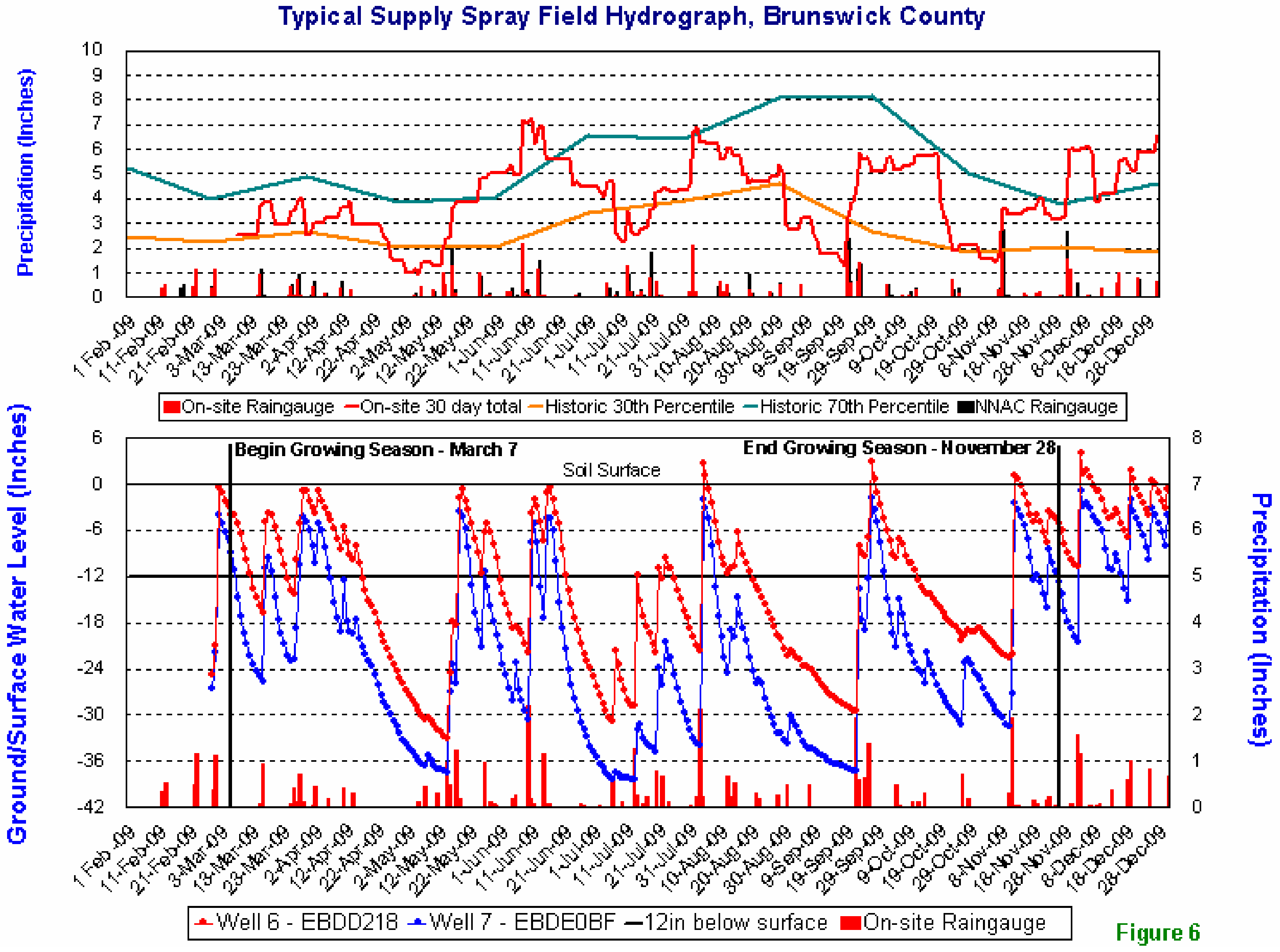


Figure 6