EVALUATION OF PERFORMANCE AND MANAGEMENT STRATEGIES FOR A NURSERY IRRIGATION RECYCLING SYSTEM DESIGNED FOR POLLUTION CONTROL

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INTRODUCTION

Located in east-central Oklahoma, Greenleaf Nursery Company is a commercial nursery involved in the propagation and wholesale distribution of container plants (see General Location Map of Study Site, Figure 1). Qualifying as the largest plant nursery in the State of Oklahoma and the third largest in the United States (Sand, 1999), Greenleaf owns and operates approximately 267 hectares (660 acres) of hilly land adjacent to the Illinois River and Lake Tenkiller (see Site Map, Figure 2). This facility was selected for research for several reasons including its size, years of operation at its present location (1955 to present), topography, known site history, accessibility, uniqueness, and proximity to sensitive receptors.

From 1990 to 1998, a recycling irrigation system was installed at the nursery that, as of 1999, included the design and construction of eight (8) strategically located retention basins and an elaborate pump and piping system. Regarded by the regulatory agencies as a pollution control technology, the recycling irrigation system serves many purposes, including:

- It reduces the overall discharge of surface waters from the facility and minimizes offsite impacts to sensitive receptors,
- It provides a means to recycle nutrient-enriched surface water back to containerized plants,
- It increases the facility's reserve reservoir of stored water,
- It captures irrigation water at higher elevations than its usual source, and
- It enhances the facility's ability to control storm water discharges during rainfall events.

Both the regulatory agencies that govern the facility and the nursery industry recognize water recycling activities as a best management practice (BMP). However, Greenleaf has the only functional and operational recycling irrigation system in the State of Oklahoma. Additionally, while a few nurseries in other states may use a single retention basin system, no other competitive nursery facility could be found that approaches the magnitude or uniqueness of this facility's eight (8) retention basins and its associated recycling system (see Site Map with Basin Pipe Interconnections, Figure 3).

There are many studies that document the complexity and heterogeneity of surface water conditions in a given watershed, basin, or catchment as they respond to various climatic, hydrologic, and anthropogenic inputs (Larsen et al, 1994, Jordan et al, 1997, Takyi et al, 1999). However, no information was found regarding the specific complexities and heterogeneities of nitrate as nitrogen (NO3-N), total dissolved phosphorus (TP), and other dissolved chemical constituents associated with recycling irrigation systems from a plant nursery that contains multiple retention basins. Additionally, no information could be found regarding the use of computer modeling to evaluate a complex irrigation system's performance and its management as a viable pollution control technology. Thus, research conducted in this study began with the general purpose of assessing and identifying, during both storm and non-storm conditions, the spatial and temporal patterns of NO3-N, TP, and other dissolved minerals of irrigation return flows (or tailwaters) and rainfall runoff in the "Greenleaf Watershed." This information was then used to develop a computer model that could simulate numerous site-specific variables and, in turn, be used to evaluate the irrigation system's performance and management strategies for varying climatological scenarios.

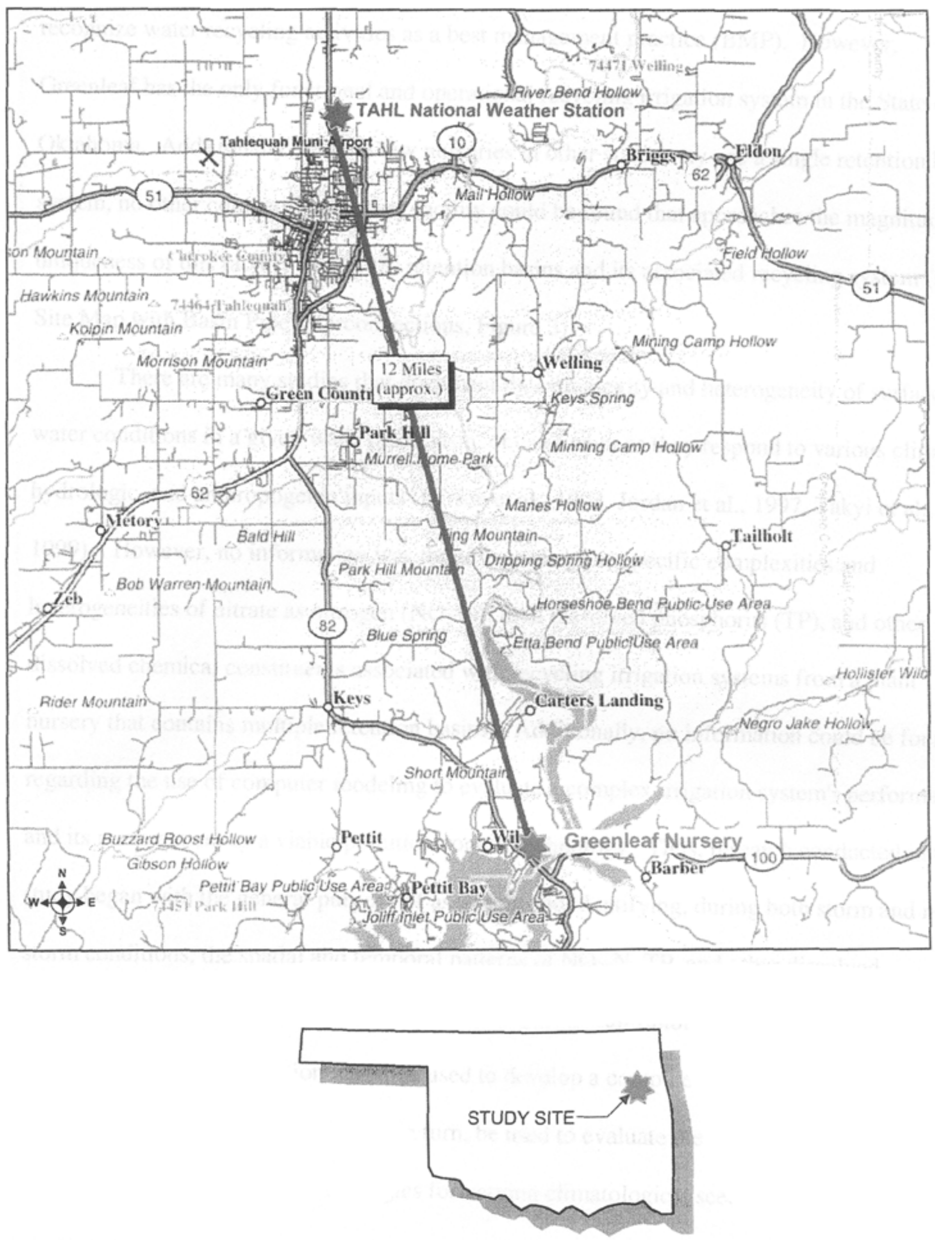

Figure 1. General Location Map of Study Site, with distance and direction to Tahlequah (TAHL) National Weather Station

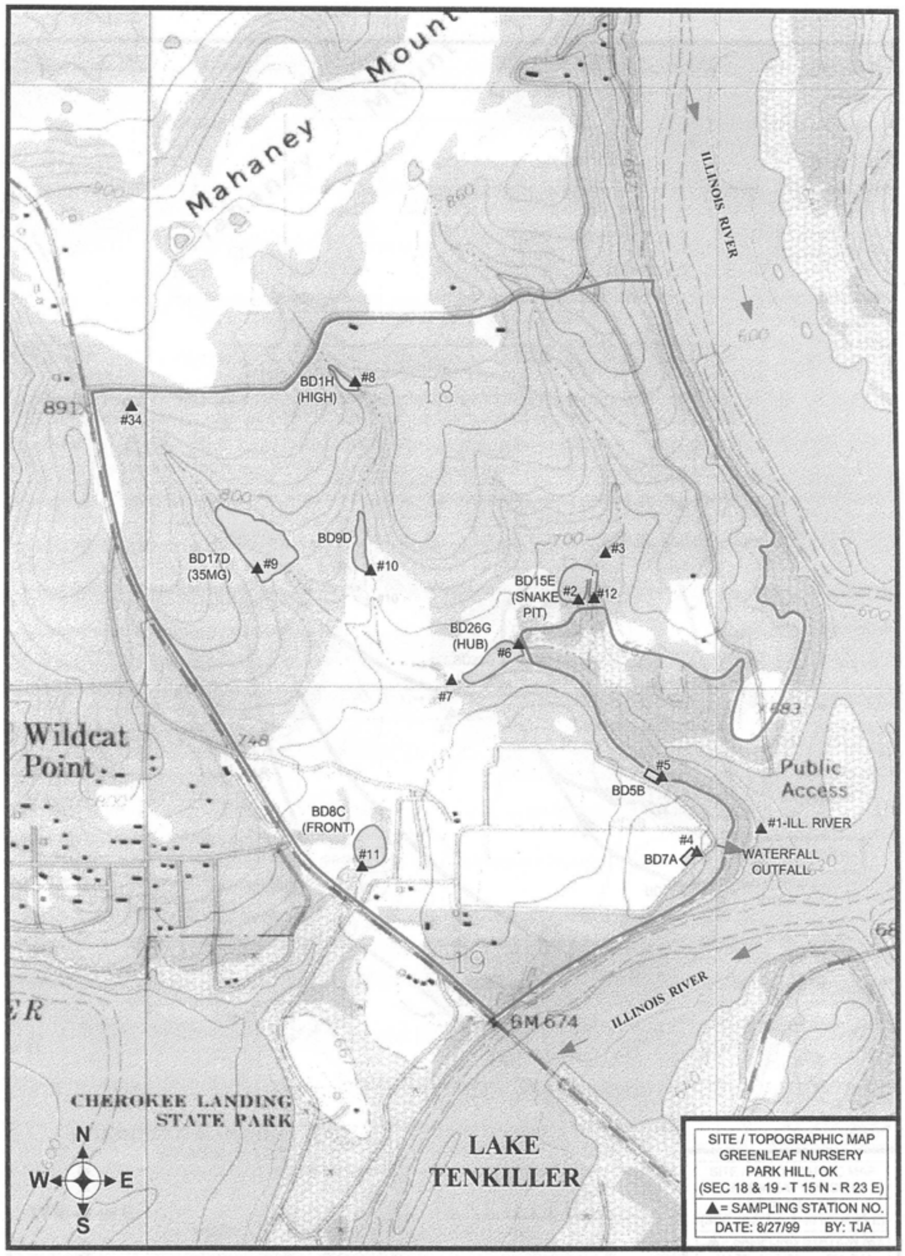

Figure 2. Site/Topographic Map of Study Site

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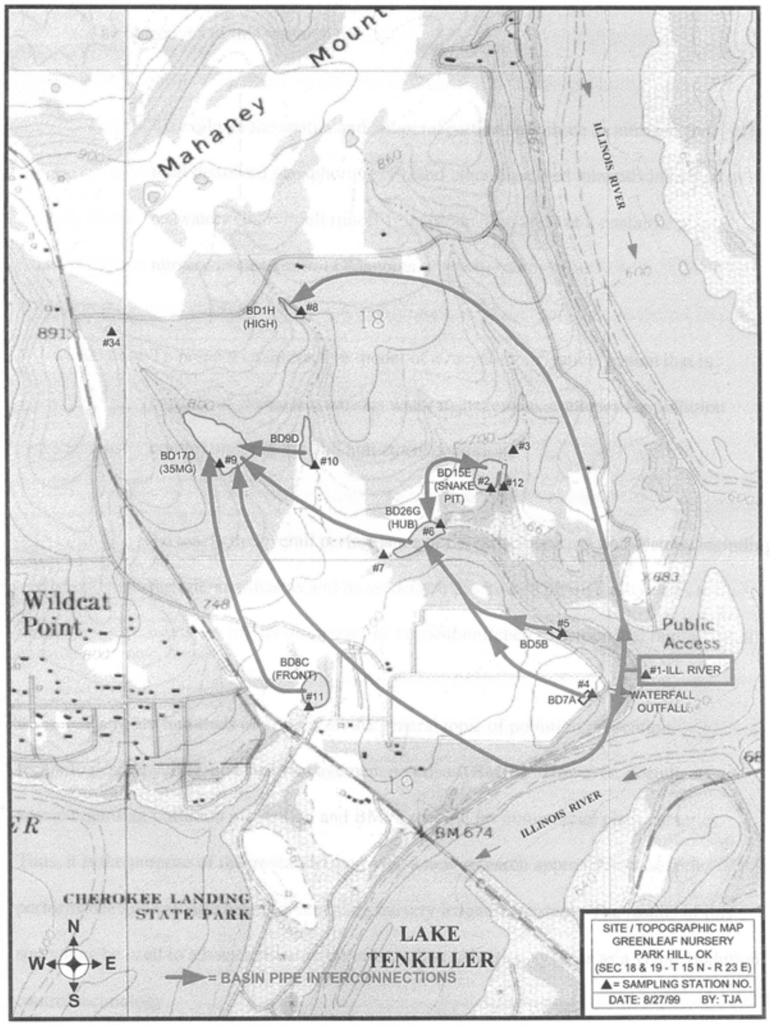

Figure 3. Site/Topographic Map of Study Site with Basin Pipe Interconnections

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Project Objectives

1. To evaluate the spatial and temporal patterns of nitrate as nitrogen (NO3-N), total dissolved phosphorus (TP), and other dissolved minerals in irrigation tailwaters and rainfall runoff from production areas at a container plant nursery in east-central Oklahoma.
2. To prepare an interactive model of a recycling irrigation system that is capable of evaluating various water management strategies for pollution control under storm and non-storm conditions.
3. To assess the overall performance of the recycling irrigation system, including the retention basins and its associated pumps and piping, as a means to minimize offsite discharges of nutrient-enriched irrigation and rainfall runoff.

There are hundreds of articles on the general topic of pollution prevention technologies, recycling, and best management practices (BMPs). However, documents are sparse regarding pollution prevention and BMPs specific for commercial plant nurseries. Thus, it is the purpose of this research to provide a new research approach to assess the performance and management of a recycling nursery irrigation system. The results of this study may be used to advance the science of recycling irrigation systems as a viable pollution control technology.

To accomplish the research objectives, surface water from a total of twelve (12) stations were sampled and analyzed on a monthly basis for one (1) year starting on August 4, 1998 and ending on July 30, 1999. Sampling station numbers are identified on the Site & Topographic Map (see Figure 2). In addition to the periodic sampling events, storm water samples, in the form of overflow discharges, were also collected on various dates throughout the year at the facility's five (5) outflows. All liquid samples were delivered under chain-of-custody documentation to the Soil, Water, & Forage Analytical Laboratory (SWFAL), a state-certified laboratory in Stillwater, OK, and tested for nitrate as nitrogen (NO3-N), total dissolved phosphorus (TP), and other selected major and minor ions. The analytical test results reported by the laboratory were then evaluated to determine spatial and temporal patterns of the constituents and to identify the factors and processes that influence those patterns.

The objective for the development of an interactive computer model was to provide a user-friendly yet flexible means to simulate several onsite variables. Due to the study site's complexity, a computer model was necessary to assist in the understanding of the inherent dynamics of the recycling irrigation system. Onsite variables included, but were not limited to, inflow or overland surface water originating from upgradient properties, observed changes of NO3-N, TP, and other constituent concentrations in the captured water over time and seasons, changes in the volume of water pumped from basin to basin, and precipitation amounts.

The research also included a review of other past or historic site documents. This was necessary to observe the changes of NO3-N, TP, and other constituent concentrations over a time period that was in excess of one (1) year. Such variables also included the changes over time of the allowable NO3-N and TP concentrations per State of Oklahoma Discharge Permits. It further included changes in fertilizer usage rates by the nursery, especially the facility's use of liquid ammonium nitrate, and historic test results of onsite water samples reported by others. When evaluated in conjunction with data collected in this study, it was anticipated that the historic findings would provided additional information regarding the performance of the facility's irrigation system as a viable pollution prevention technology and a BMP for the nursery industry.

Capture and Recycle Benefits

Zero pollutant discharge is seen as an increasingly important goal (Alther, 1996). Recent studies by Jeter, et al (1990) and others (Wagner, et al, 1997 and Edwards, et al, 1997) found that storm water discharges, especially those originating from agricultural non-point sources, can be a major contributor of nutrient loading and other pollution to our rivers and lakes. Matthews (1996) states that although zero pollutant discharge is often talked about, it is less frequently pursued or fully achieved.

The United States Congress originally enacted the Clean Water Act (CWA) in 1948 and greatly expanded it in 1972. As enforced by the U. S. Environmental Protection Agency (EPA), the objective of the CWA is to restore and maintain the chemical, physical, and biological integrity of U.S. streams, lakes, estuaries, and other surface waters (Vick, 1997) and to eliminate pollutants by 1985 (USEPA, 1983).

According to Samela et al (1991), when the EPA created its Pollution Prevention Office in 1988, it focused on pollution prevention as a 'first choice option' for environmental protection. Samela et al (1991) further stated that EPA's preferred alternatives for waste management and pollution prevention are reduction and recycling.

Nitrate as nitrogen (NO3-N), total phosphorus (TP), and other dissolved nutrients in surface water captured in the retention basins represent an asset to the facility because they have inherent or intrinsic value as fertilizer and can be reintroduced to potted plants via the irrigation system. However, when allowed to discharge from the facility, these same nutrient enriched waters are a liability that could potentially cause adverse affects to receiving bodies of water. Offsite discharges could also result in an exceedance of the facility's voluntary compliance agreement of State-determined allowable discharge concentrations. The reduction or elimination of irrigation runoff and other nutrient-enriched discharges from the facility provides protection to the waters in the Illinois River and Lake Tenkiller.

The facility's recycling irrigation system, which includes both the retention basins and its appurtenant pumps and piping, was designed to capture all irrigation return flows during non-storm conditions and all rainfall runoff except for the most severe storms. During a storm event, surface water contained in the facility's smaller basins (i.e. BD#5B, BD#7A) and those basins located immediately adjacent to the property boundary (i.e BD#15E, BD#26G, BD#8C) can be pumped into a larger basin (i.e. BD#17D) that has sufficient capacity to contain the water. This provides additional freeboard to those retention basins that discharge water offsite when their storage capacity is exceeded.

LITERATURE REVIEW

The process of evaluating the system performance and management strategies of a recycling irrigation system at a plant nursery is best accomplished using an interdisciplinary approach. The literature review will examine many topics associated with this evaluation including terminology and definitions, previous work conducted by others at the study site, best management practices (BMPs) for nurseries, and chemical behavior of nitrate and phosphorus. Also included are discussions on other relevant issues such as interpretation of inorganic test results, hydrologic analysis, capture and recycle technology, and applicable environmental regulations.

Terminology and Definitions

According to one definition provided by the Oklahoma State Department of Agriculture et al (1984), pollution is an alteration of man's surroundings in such a way as they become unfavorable to him. This definition suggests a dual modality: (1) pollution obviously involves the physical addition of contaminants or pollutants to the environment and (2) pollution can be a result of other direct or indirect consequences of man's actions. As an example of the latter, because humans are terrestrial beings, our perturbations typically and initially affect the land's surface. However, due to the interrelationships between the different media in an ecosystem, terrestrial-borne stresses are often transported offsite and their deleterious affects are reflected and often magnified in adjacent aquatic ecosystems. One such example is the accelerated eutrophication processes of lakes and rivers as a result of excessive use or over-application of fertilizers (i.e. nitrogen, phosphorus, and potassium or N-P-K) on land. For this reason, there is a considerable interest in increasing the efficiency of pollution control programs, especially those involving non-point source control programs, by focusing efforts on small watersheds or sub-basins where the use of pollution control technologies will have the most effect (Smith et al, 1997, Vendinello, 1992).

For nurserymen and other plant growers, optimal moisture of potting soil in plant containers is of utmost concern. Maintaining the ideal soil moisture content in a potted plant typically requires the regular application of water via an irrigation system. Since most plants, especially the younger ones, cannot survive with excessive moisture around their roots, loosening agents such as sand, bark, and mulch are mixed with potting substrate in an attempt to promote gravity drainage of water from the plant's container. The available water that migrates through and ultimately drains from a plant container is known as irrigation tailwater. Tailwaters that are allowed to return to their source or point of origin (in this case, the Illinois River) are known as irrigation return flows. Since fertilizers are typically added to the soil mix or substrate, it is common for both irrigation tailwaters and irrigation return flows to exhibit high concentrations of dissolved nutrients, including nitrogen, phosphorus, potassium (N-P-K), that were not initially consumed by the plant via root uptake.

Previous Work

This section describes past studies, research and publications prepared by others at the subject facility. These past studies, research, and publications relating to the facility include three (3) Master's thesis of the facility, an 'in-house' report, several years of "Curtis Reports" prepared by the Oklahoma State Department of Agriculture (OSDA) Plant Industry Division, and other miscellaneous summaries and circulars.

Houghton (1984) presented a Master of Science Thesis to Oklahoma University entitled, "Investigation of Irrigation Return Flows from Greenleaf Nursery on Tenkiller Reservoir and Midwestern Nursery on the Illinois River, Oklahoma." The thesis was apparently utilized for a subsequent State of Oklahoma Inter-Agency Publication entitled, "The Effect of Irrigation Return Flows on the Illinois River Basin" (OSDA Plant Industry Division, Oklahoma State Department of Health (OSDH), and Oklahoma Water Resources Board Water Quality Division (OWRB-WQD) 1984). The stated objective in Houghton (1984) was to determine the impact of irrigation return flows originating from Greenleaf and another nursery on the Illinois River. At Greenleaf, Houghton sampled and analyzed return flows and irrigation water from a total of six (6) sampling stations, including four (4) onsite and two (2) in the Illinois River immediately adjacent to the study site. In his study, Houghton concluded that the mean concentration of discharge through the facility's Waterfall Outfall (see Figure 2) was 16.4 mg/l for NO3-N and 0.268 mg/l for TP. In 1991, the first year that allowable discharge concentrations were established by OSDA, NO3-N concentrations for offsite discharges were set at 41 mg/l (annual average) and 53 mg/l (not-to-exceed maximum) for the facility (see Table 6). Both the average and maximum discharge limits for NO3-N and TP were gradually reduced by OSDA in their discharge permit on an annual basis. Regardless of past or current discharge concentrations stated in the OSDA compliance permit, Houghton concluded in his study that the discharge of irrigation return flows from Greenleaf did not cause any adverse affects of the water quality in the Illinois River.

The facility has changed and grown significantly since Houghton's study in 1984. Several sampling stations used by Houghton were not present or included in subsequent research. However, whenever possible, NO3-N and TP analytical test results presented by Houghton were summarized and compared to other test results at the same sample location to depict the changes in nutrient concentrations at the facility over time (see Table 11 for NO3-N and Table 12 for TP).

In 1989, the Oklahoma State Department of Agriculture (OSDA) initiated an investigation to determine what pollution reduction measures could be taken by commercial nursery operations on or near the Illinois River and Lake Tenkiller. The project and report, known as The Curtis Reports are an on-going, non-regulatory, and cooperative implementation of best management practices by the nursery industries along the Illinois River. Stated in a letter from the Oklahoma Department of Agriculture in a letter dated October 12, 1988, the threefold objectives of the OSDA investigative study were:

To determine if irrigation tail waters from nursery operations are contributing nutrients and/or pesticide residues to the river in excess of normal watershed runoff.

Should excess effluents be determined, to develop a set of effluent goals which will meet, as a minimum, those established for the City of Tahlequah.

Following the establishment of effluent goals, to supervise the development of best management practice methods to enable the operations to meet the goals.

Since May 18, 1989, OSDA personnel have performed monthly on-site water sampling and analytical testing to determine the concentrations of nitrate as nitrogen, total phosphorus, and pesticides. As a result of on-going investigations conducted by OSDA, Curtis Reports for Greenleaf and other nurseries in the area are available for the years 1989-1992, 1993, 1994, 1995, and 1996.

By starting with a high maximum allowable discharge concentration of NO3-N and TP, then gradually reducing the allowable concentrations over time, OSDA implemented a phased approach that provided time for the nursery industries to develop and test new BMPs (see Table6). According to a review of available information, the BMPs that showed initial promise included the reduction in the use of liquid ammonium nitrate, increased use of slow release (Osmocote) fertilizers, change of substrate or media composition, adherence to a stricter irrigation schedules, and the recycling of detained tailwater. Greenleaf elected to voluntarily comply with the OSDA Compliance Agreement and, in 1989, they initiated several changes to their operations at that time (see Description of Study Site).

Many test results are published in The Curtis Reports. Whenever possible, NO3-N and TP analytical test results presented in The Curtis Reports were summarized and compared to test results in other studies to depict the changes in nutrient concentrations at the facility over time (see Table 11 for NO3-N and Table 12 for TP). Additionally, the annual averages and maximum allowable discharge limits established by the OSDA have decreased over time (see Table 6).

One problem with The Curtis Reports is that the nutrient concentrations of water discharged from the facility represents only a portion of the entire story. Before retention basins, pumps, piping systems, and other BMPs were constructed, installed, or implemented at the nursery, tailwater and irrigation return flows were allowed to discharge continuously into the Illinois River. Since contaminant loading to the River is a product of nutrient concentration multiplied by the volume of water, a report of only the nutrient concentrations does not accurately reflect the entire picture of potential or actual contaminant loading to the Illinois River or Lake Tenkiller.

Regarding other studies, Heaton (1993) prepared an in-house report of the Greenleaf facility. In the report, Heaton compiled NO3-N, TP, and other test results of surface water samples secured from specific sampling sites at the facility. Based on the sampling, testing, and interpretation of the test results, Heaton stated that , "the NO3-N concentrations at Site IT-2 [the Waterfall area] showed a spring/early summer increase for 1989 and 1990 years and had an average of 30.22 ppm and 32.91 ppm, respectively. During the 1991-92 year the levels had dropped to below the compliance agreement maximum and the growing season average of 12.05 ppm for 1991 and 8.58 ppm for 1992 was below the compliance agreement average." Heaton concluded that Greenleaf "has done a good job of reducing the NO3-N concentrations in their tailwaters since signing the compliance agreements" and that they "need to continue to implement best management practices to further lower nutrient concentrations in their tailwater." Nitrate (as N) and total phosphorus test results presented by Heaton were summarized and compared to other test results at the same sample location to show the changes in nutrient concentrations at the facility over time (see Table 11 for NO3-N and Table 12 for TP).

Burks (1995) prepared a report entitled, "The Status of Lake Tenkiller". The conclusions of Burks' research were:

- The head of Lake Tenkiller is eutrophic (aging faster than normal).
- Phosphorus is the limiting nutrient element leading to algal growth which can be controlled in the Lake
- If current nutrient loading continues [from all sources], the entire Lake will be classified as Mesotrophic (fair condition, not accelerated aging like Eutrophic) and algal blooms would be very common.
- To improve Lake water quality, total phosphorus loading should be reduced by 30 –40%.
- To restore the Lake to pristine conditions, it would take a 70-80% reduction, which would be economically impossible to achieve.

Von Broembsen (1998) prepared a document on the capturing and recycling of irrigation water to protect water supplies. Although NO3, TP, or other specific inorganic chemical analyses were not performed on surface water samples, the referenced document provides excellent information regarding capture and recycling technology.

Wilson (1998) presented a Master of Science Thesis to Oklahoma State University on the management of the plant pathogen Phytophthora to improve acceptance of recycling technology in ornamental nurseries. Although some field parameters were collected and discussed, the thesis did not include any NO3-N or TP test results.

Wilson and von Broembsen (1998) prepared a Water Quality Series brochure entitled, "Capturing and Recycling Irrigation Runoff as a Pollution Prevention Measure" (OSU Fact Sheet F-1518).

Also in 1998, Wilson, von Broembsen, and Smolen prepared a paper entitled, "Pathogen Management in Capture and Recycle Irrigation Systems for Nurseries." The referenced paper was presented in July 1998 to the American Society of Agricultural Engineers (ASAE) at the Annual International Meeting in Orlando, Florida.

Sand (1999) presented a Master of Science Thesis to Oklahoma State University entitled, "Hydraulic Modeling of a Runoff Recycling System for a Container Nursery." The stated objective of the treatise was to develop a computer-based model that simulated the hydraulic aspect of the facility's runoff recycling system. However, the thesis did not present any analytical test results on NO3, TP, or other inorganic chemical parameters.

Best Management Practices

Best management practices (BMPs) are defined as the schedules of activities, prohibitions, maintenance procedures, and structural or other management practices found to be most effective and practicable to prevent or reduce the discharge of pollutants to the air or waters of the United States (Southern Nurserymen's Association, 1997). BMPs at plant nurseries typically include operating procedures and practices to control site runoff, spillage or leaks, and drainage from raw material storage. BMPs are evaluated and implemented to provide uniform protection guidelines regardless of the site's acreage or location (Jones et al, 1996).

Management of irrigation tailwater and other surface runoff, during both storm and non-storm events, is an important BMP consideration at plant nurseries. Additionally, since tailwaters are typically rich with soluble nutrients, it makes economic sense to capture and recycle these waters back to the plants at the nursery. While contained in an onsite pond or retention basin, nutrient-rich waters represent an inherently valuable asset and its recycling back to container plants will increase the opportunity for consumption by the plant, its original and intended use. However, these same nutrient rich waters are considered a pollutant or contaminant if they are allowed to migrate offsite, and may be the source of algal blooms, increased eutrophication, and other adverse affects to adjacent water bodies.

The presence of retention basins at a plant nursery represents a BMP for many reasons, including:

Retention basins provide a mechanism to capture and store nutrient-rich tailwaters, a process that ultimately reduces offsite discharge and minimizes offsite loading rates,

An irrigation system, including pumps and appurtenant piping, provides a means to control the water elevation (head) in a retention basin, which is important consideration prior to or during precipitation events.

The capture of nutrient-rich water in retention basins allows for the recycling of nutrient-rich water back to the plants.

Retention basins increase the facility's reserve volume of water during times of drought, and

Retention basins act as a means for sediment control, especially during major storm events that cause significant erosion.

In a study of other BMPs, Edwards et al (1997) concluded that a 1-day detention time of simulated agricultural runoff effluent added to an sedimentation (not recycling) basin resulted in the removal of 94% of the sediment, 76% of the nitrogen, and 52% of the phosphorus. The detention basin's removal efficiency rates for sediment, nitrogen, and phosphorus increased with a 3-day detention time.

Chemical Behavior of Nitrate and Total Phosphorus

In accordance with the Principle of Limiting Factors, rates of ecological processes are controlled by the metabolically essential environmental factor that is present in least supply relative to demand (Freedman, 1995). Based on this principle, nitrate is typically the limiting factor in soil while phosphorus is the limiting factor in water (Conrads, et al, 1997).

Regarding nitrogen compounds, Freedman (1995) states that soils exhibit little capability to absorb nitrate. Smith et al (1997) reveals that reservoir retention time is not a significant factor in the decay of total nitrogen (TN) dissolved in water, but that the removal of nitrate and other nitrogen compounds is much more dependent upon hydraulic loading rates. High rates of precipitation would be expected to increase the transportation rates of nitrogen contaminants to a basin or receiving stream, but would minimize concentration loading in the receiving water body due to dilution.

The rates of denitrification increase proportionally with increasing temperatures, resulting in an expected decrease of TN delivery to streams during the summer months (Seitzinger, 1988). It is expected that higher temperatures would also increase nitrogen fixation rates. However, because natural fixation is a relatively minor source of new nitrogen in most watersheds compared to agricultural or other anthropogenic sources, and because denitrification is by far the most important sink for TN, an overall negative effect of temperature on TN delivery is expected.

Howarth (1996) states that wetlands are widely recognized as effective filters for removing dissolved nutrients and are especially effective in removing nitrate and other dissolved nitrogen compounds. As detailed further in Chapter 3, a Corps of Engineer's buffer zone established around the site's perimeter is expected to provide further removal of nitrate and other dissolved nutrients in storm water that discharges from the facility.

With a chemical behavior decidedly different than nitrate, the removal of total dissolved phosphorus (TP) is mainly a consequence of adsorption to soils, complexation, and precipitation reaction with aluminum, iron, and calcium (U.S. EPA, 1988). Smith et al (1997) states that the decay of TP in reservoirs, retention basins, ponds, or other structures containing near-stagnant water would behave differently than flowing streams due to differences in settling rates of sediment-bound phosphorus in the two environments. Additionally, because the most important processes affecting the transportation of TP are physical rather than biochemical, ambient air and water temperature is expected to have an insignificant effect on TP delivery (Jordan et al, 1997).

According to Freedman (1995), eutrophication processes of rivers and lakes are predominantly caused by the presence of phosphorus and, to a lesser extent, other nutrients in the water. Common sources of phosphorus include municipal sources, livestock, and runoff from agricultural activities. As discussed, the primary production of most freshwaters is limited by the availability of phosphorus, which is the metabolically essential constituent that is present in the least supply relative to its demand.

The use of retention basins for sediment control is an important consideration due in large part to significant differences in the physical behavior and partitioning coefficients of nitrate as nitrogen (NO3-N) and total dissolved phosphorus (TP). For instance, NO3-N is highly soluble in the aqueous phase and the flow of surface water easily leaches excessive nitrate from the soil (Jordan et al, 1997). By contrast, the rapid flow of surface water encourages surface erosion, a process that increases the transport of TP and other constituents that preferentially and physically bind with sediments and other particulate matter (Smith et al 1997). For this reason, the control of sediments, especially during precipitation events that result in high velocity overland flow and subsequent high erosion of site soils, is an important BMP control for phosphorus.

According to Smith et al (1997), in-stream losses of contaminant mass occur as a function of 3 variables: (1) travel time, (2) streamflow (serving as a surrogate for channel depth), and (3) whether or not the reach is part of the reservoir. Travel time is defined as the ratio of reach length over stream velocity. Because the major processes involved in-stream loss of Total P and Total N (sedimentation and denitrification, respectively) operate at the channel bottom, deeper streams typically exhibit lower rates of decay. Thus, we would expect lower rates of decay for NO3-N and TP in the Illinois River relative to decay rates seen in the study site's channeled creek beds.

Interpretation of Inorganic Test Results

For those water samples that have been subjected to a relatively complete set of inorganic analyses, including all major and most minor ions, calculations can be performed on the test results to determine the correctness of the analyses. Perhaps the most commonly used accept/reject criteria is the calculation of a cation-to-anion (C:A) ratio as described in Standard Method 1030 F in the EPA-approved 1992 Standard Methods for the Examination of Water and Wastewater (Greenberg, et al, eds, 1992, 18th Edition). Entitled "Checking Correctness of Analysis", Standard Method 1030 F presents the following acceptance criteria for C:A ratios:

Anion Summation (meq/l	Acceptable C:A Difference (%)
0.0 - 3.0	0.2%
3.0 - 10.0	2.0%
10.0 - 800.0	5.0%

In addition to a review of C:A ratios, many computer programs are available that further assist in the interpretation of inorganic test results. The program used in this study was the WATEVAL Program (Hounslow, 1995). Further details regarding the WATEVAL Program are provided in Chapter IV.

Hydrologic Analysis

Does the "first flush" of runoff water during a storm contain a higher concentration of dissolved nutrients and other constituents than runoff water after the first flush? According to Adams (1998), this is a source of extensive debate among water quality professionals. By definition, the first flush is simply the first volume of runoff water resulting from a storm event and is readily calculated by multiplying the drainage area of a watershed or sub-basin by the depth of rainfall (Maidment, 1993). Adams (1998) states that pollutants that are readily moved by or dissolved in runoff water (i.e. nitrate) will exhibit higher concentrations in the first flush. Contrary to that viewpoint, Schueler (1994) states that "for certain pollutants, such as nitrate, copper, ortho-phosphorus, bacteria, and sediment, the first flush phenomena effect is weak or absent altogether." Maidment (1993) states that pollution frequently exhibits considerably higher concentrations near the beginning of storm rather than towards the end of the storm. However, Maidment further states that that phenomenon is often due to higher rainfall intensities near the beginning of the storm that result in higher runoff, greater erosion potential, increased sediment transport potential, and a greater "wash-off" potential of those contaminants that built up on solid (soil) surfaces during dry weather.

Because at least some of the research suggests that the first flush of runoff contains the highest concentrations of pollutants, it makes sense from a system performance and management strategy perspective to capture the first flush and minimize offsite discharges. Thus, a BMP would be to optimize the capturing of the greatest amount of polluted runoff (i.e. the first flush), then allow the bypass of the less polluted runoff.

According to Fetter (1994), storm water runoff or overland flow will end at some fixed time after the storm peak. Assuming that direct precipitation in the stream and the baseflow components are collectively inconsequential, this can be approximated by the following empirical formula:

$$D = A0.2 \tag{1}$$

Where: D = number of days between storm peak and the end of overland flow

A = the drainage basin area in square miles.

According to Smith et al (1997), stream density is defined as the ratio of channel length to drainage area, included in the reciprocal form, indicating a positive effect on land-water delivery. A greater stream density implies land-surface contaminants travel shorter distances on an average to reach the receiving streams. Estimates of stream density are computed directly from the length and area attributes of the stream network coverage.

Other field experiments have revealed that hydrological processes and parameters often exhibit considerable spatial variability within a watershed (Merz et al, 1997). Several Rainfall vs. Runoff modeling studies of spatial variability indicate that many chemical parameters act in a complex, even dependent, fashion (Merz et al, 1997, Anderson et al, 1997, and Potter, 1991). Process-oriented rainfall-runoff models have proven successful as a means to predict aberrant hydrologic processes and parameters in watersheds with large areas (Smith et al, 1997, Jordan et al, 1997, Merz et al, 1997, Takyi et al, 1999, Gan et al, 1996, Anderson et al, 1997, Potter, 1991). However, rainfall-runoff studies and modeling of small watersheds where significant amounts of irrigation water is used as a supplement for precipitation typically fail to accurately predict patterns of spatial and temporal variability (Merz et al, 1997 and Smith et al, 1997). In such areas, a poor performance of the curve number approach is also likely. In nursery settings, because surface soils are wetted daily for many consecutive months by irrigation activities, runoff occurs from even small rainfall events (Sands, 1999). In irrigated fields, the amount of runoff is relatively constant (Smith et al, 1997), and separating the varying effects of irrigation vs. precipitation runoff is difficult to accomplished.

Further complications in the use of rainfall-runoff models at Greenleaf arise from the presence of pumps and appurtenant piping systems that distribute water from one basin to another. Additionally, constructed drainage channels, most of which have concrete bottoms and sides, are immediately adjacent to most container beds. The drainage channels are designed to collect and direct excessive surface water (overland flow) to one of the retention basins on the nursery, thus reducing the opportunity for infiltration.

Prediction of Rainfall Runoff Amounts

Predicting the amount of runoff that will occur from a given storm event is a problem commonly addressed in hydrology (Fetter, 1994). According to Chow (1962) and Pilgrim (1976), there are hundreds of different methods, most involving arbitrary formulas or localized expressions applicable to a specific site, that have been used to estimate peak runoff rates and flood in small drainage basins. Pilgrim et al (1993) states that the two most widely used types of methods for estimating peak runoff rates during storm events are the rational method and the U.S. Soil Conservation Service or SCS Method. Both the SCS and rational methods are discussed in the following sections.

The Rational Method. The "Rational Method", often referred to as the 'Traditional Approach' (Pilgrim, 1993), is considered by Lindsley (1986) and Pilgrim (1986) to be the most simple and widely used method to estimate runoff rates and urban drainage design. The rational method is an approximate deterministic model of a flood peak from a given rainfall (Graber, 1989).

With the assumption that a given rainfall event lasts a sufficient length of time, the rational equation states that the peak discharge from a watershed ("q") is the average rate of the rainfall event ("i") times the area of the watershed ("A") and reduced by an infiltration factor ("C"). The Rational Method formula was developed from a simplified analysis of runoff and is defined in Pilgrim et al (1993) by the following equation:

$$q = F\ C\ i\ A \qquad (2)$$

Where: q = the peak discharge (i.e. ft3/second (cfs) or m3/second),

F = unit conversation factor (1.008 for English units and 0.278 for SI units),

C = a dimensionless runoff coefficient (usually between 0.3 and 0.8),

i = rainfall intensity (inches/hour or centimeters/hour), and

A = area of the drainage basin (acres, square meters).

A description of the various "types of areas" and their corresponding runoff coefficient or "C" values used in Equation 2 are provided in numerous documents and hydrology textbooks, including the American Society of Civil Engineers (1969), Chow et al (1988), Pilgrim et al (1993), and Fetter (1994).

The estimation of an accurate "C" value is difficult. The ultimate selection and use of a "C" value introduces the greatest source of bias, uncertainty and source of error in the application of the rational method (Pilgrim, 1993). The problem occurs from the necessity of deriving a single runoff coefficient for a diverse area that appropriately takes into account all factors that affect the relationship of peak flow to average rainfall intensity.

According to Pilgrim (1989), there are several other severe limitations with the rational method. For instance, the rational equation makes the erroneous assumption that rainfall and infiltration rates are constant (Bras, 1990). Additionally, studies conducted by Minshall (1960), French et al (1974), and Graber (1989) suggest that the rational method is most valid when used in drainage basins of 200 acres or less, and becomes increasingly less valid with increased drainage basin size.

The rational method is applicable if the precipitation period exceeds a parameter identified as "the time of concentration". The time of concentration is defined by Fetter (1994) as being the length of time necessary for water to flow from the most distant part of the watershed to the point of discharge. A better definition of the time of concentration, according to Pilgrim (1993), is that it is the time after commencement of rainfall excess when all portions of the drainage basin or watershed are contributing simultaneously to flow at the outlet.

One objective when using the rational method, or any other modified flow equation, is to determine the peak discharge in an open channel. Since discharge equals the flow velocity times the cross sectional area (Fetter, 1994), other methods and equations are available to accomplish this objective.

For open-channel hydraulics (with an effective porosity of 1.0), the average flow velocity of water can be calculated using the Manning Equation as shown in the following equation (Fetter, 1994):

$$V = [\ 1.49 \quad R2/3 \quad S1/2\ ] / n \qquad (3)$$

Where: V = average flow velocity (in feet/second),

R = the cross-sectional area of flow or the hydraulic radius of a pipe

(in ft2) divided by the wetted perimeter (in ft),

S = the slope or energy gradient of the water surface, and

n = the Manning roughness coefficient.

Estimate values of the Manning roughness coefficient ("n") are provided in numerous hydrology and hydrogeology textbooks (Maidment, 1993; Fetter, 1994).

Hydraulic flow formulas, such as Manning's equation, have severe limitations in that they exemplify an average velocity when, in fact, Minshall (1960) discovered evidence for highly nonlinear velocity, especially in basins where the design flow is retained in channels that are formed or have small floodplains.

The estimated flow or discharge of water in a stream ("Q") can be quantified by simply multiplying the average flow velocity ("V") obtained in the Manning Equation by the cross-sectional area of the stream ("A"), as shown by the following equation (Fetter, 1994).

$$Q = V \text{ x } A. \qquad (4)$$

When used with the flow velocity as determined by the Manning Equation, the time of concentration is defined by Pilgrim (1993) as the length of the stream channel in a watershed divided by the average water velocity plus the estimated time for overland flow to reach the channel. Therefore, the evaluation of flow velocities using the Manning Equation in conjunction with the rational method provides an additional level of assurance in estimating peak runoff rates.

Not everyone in the hydrology profession believes that the rational formula is the best method to use when determining peak runoff rates. According to Bras (1990), the rational formula is a limited design tool that is capable of handing, at best, extreme rainfall events. One problem cited by Bras regarding the rational equation is that "it assumes (not generally correctly, because of the effects of antecedent and moisture conditions) that the peak discharge has the same probability of occurring as the corresponding storm". Another problem described by Bras is that the rational and other similar peak discharge formulas fail to provide any information about the time development of discharge. Stated otherwise, the rational and other peak discharge formulas do not provide a full or symmetrical hydrograph with the obtained peak, resulting in an unfavorable skewing of the data and inaccurate results.

Bras (1990) acknowledges that as long as "i" (see Equation 2) is defined for a duration equal to or greater than the concentration time, then the rational formula provides reasonable results. Bras further states that the rational method is most applicable when used in small ("not larger than a few hundred acres") urban areas for the design of storm sewer systems.

The SCS Method. According to Pilgrim et al (1993), the SCS method is widely used for estimating floods in small to medium-sized ungauged drainage basins. Bras (1990) states that the empirical SCS method has enjoyed tremendous popularity because of its more complete database and the manner in which variables are considered and applied. The SCS Method has all but replaced the rational method in the United States and, in fact, has been adopted as the required procedure by many municipal and regional authorities (Pilgrim, 1993).

According to McCuen (1982), the volume of runoff ("Q") is dependent upon the volume of precipitation ("P"), the volume of storage available for retention ("F"), and the potential maximum retention ("S"). Actual retention is defined as the volume of precipitation minus the volume of runoff. With due consideration of retention, the initial abstraction ("Ia"), which is defined as a certain volume of precipitation at the beginning of a storm event, will not appear as runoff. McCuen (1982) provides the SCS rainfall-runoff relationship in the following equation:

$$F / S = Q / (P - Ia) \qquad (5)$$

Where: F = the volume of storage available for retention

S = the potential maximum retention

Q = flow or discharge of runoff water

P = volume of storage available for retention ("F"), and

Ia = the initial abstraction, which is defined as a certain volume of precipitation at the beginning of a storm event, will not appear as runoff.

To develop the SCS rainfall-runoff relation and determine a 'best approximation' from observed data, Pilgrim (1993) states that the following empirical relation has been adopted:

$$Ia = 0.2\ S \qquad (6)$$

McCuen (1982) states that research performed since the adoption of Equation 5 suggests that the empirical relation may not be correct for all circumstances. Nevertheless, according to Pilgrim (1993), the empirical relationship provided in Equation 5 remains the current standard in the industry.

McCuen (1982) states that through rearranging and substitution of Equations 4 and 5, the volume of runoff ("Q") can be determined by the following equation:

$$Q = (P - 0.2S)2 / (P + 0.8S) \qquad (7)$$

To standardize the application of this equation, McCuen (1982) states that empirical studies indicate that S can be estimated by the following equation:

$$S = (1000/CN) - 10 \quad (8)$$

Where: CN = a dimensionless runoff curve number, and

S = the potential maximum retention in inches.

According to Bras (1990), the Curve Number (CN) value is dependent on the soil type, cover, antecedent moisture conditions, and other hydrologic conditions of the land surface. With the Soil Conservation Surveys providing the database, Curve numbers are provided throughout the United States. A detailed description of agriculture land-use Curve numbers can be found in the U.S. SCS National Engineering Handbook (1985) or Bras (1990).

According to McCuen (1982), because "S" is a function of the factors that affect "Ia", it is expected that "CN" is a function of land use, antecedent soil moisture, and other factors that affect runoff and retention.

When applying the SCS Method, soils are classified into one of four groups; A, B, C, or D. Soil A is a deep sand or loess and exhibits high infiltration. Soil B is a shallow loess or sandy loam and exhibits moderate infiltration. Soil C is a fine-textured soil, such as clay loam, silty loam, or other soils low in organic content and exhibits slow infiltration. Soil D is a swelling or plastic clay and exhibits very slow infiltration.

Capture and Recycle Technology

The “capture and recycle” technology currently implemented at the study site is considered by many in the nursery industry to be the most appropriate best management practice (American Association of Nurserymen, 1992, Bailey, et al, 1979, and Broner, 1998). At the study site, this technology consists of eight (8) constructed retention basins retrofitted with an engineered hydraulic pump system to reintroduce the captured water, including irrigation tailwater, irrigation runoff, and storm water, back to the plants. Through an elaborate system of hydraulic pumps and appurtenant piping at each basin, surface water captured in the retention basins can be pumped, along with other "fresh" water from the Illinois River, and/or recycled throughout the property for plant irrigation purposes. The recycling of N-P-K enriched irrigation tailwater provides additional opportunities for consumption by the containerized plants via root uptake.

Albiston (1998) states that many plant nurseries throughout Texas are discovering that excess water recycling and reuse is good business because the capture and recycling of tailwater has significantly reduced ground water withdrawals. In Albiston's article, D. Wilkerson, Extension Horticulturist with the Texas Agricultural Extension Service, opines that the biggest challenge is not collecting runoff, but managing the collected water. Wilkerson further states that "the water management system must consider water quality factors how to handle salts, and pesticide residues".

Wilson et al (1998) states that the need for increased control over water availability and water quality has led many nurseries to examine the potential of recycling irrigation runoff as a pollution prevention measure. Additional advantages include the storage of nutrient-enriched water at elevations above a facility's source of fresh water.

Designing a Retention Basin

An important consideration when designing a retention basin is the selection of the type of reactor (or 'basin') based on its expected operational considerations and limitations. According to Metcalf & Eddy (1979), operational factors typically included in the design of a reactor include (1) the nature of the water to be treated, (2) the reaction kinetics governing the expected treatment process, (3) specific process requirements, and (4) local environmental conditions.

In the case of designing an outdoor sedimentation basin specifically for the capture and recycling of irrigation tailwater, a fifth factor should be the consideration of discharged contaminant concentrations caused by overflow. In essence, this consideration can be evaluated by the governing kinetic expression for the reactor.

A plug flow (PF) reactor is a reactor in which all fluid elements enter the reactor at the same time, flow through it with the same velocity, and leave at the same time (Metcalf & Eddy, 1979). The travel time of the fluid elements equals the theoretical detention time and there is no longitudinal mixing. Plug flow is typically demonstrated by flow in long, narrow tanks (Reynolds, 1982). According to Metcalf & Eddy (1979) a perfect plug flow or 'batch' reactor has a dispersion factor of zero.

From Snoeyink et al (1980), the general equation for Plug Flow is:

$$V\,(\Delta C/\Delta t) = Q \times Cin - Q\,(C + \Delta C) - KCV \qquad (9)$$

Where: V = volume

ΔC = change in concentration

Δt = change in time

Q = discharge or flow

C = concentration

K = rate constant

A continuously-stirred reactor (CSR) is a reactor (or basin) in which all fluid elements are dispersed throughout its entire volume, and the reactor's contents are uniform and identical with the effluent stream (Reynolds, 1982). Circular, square, or slightly rectangular geometric shapes in plan view typically demonstrate CSR.

From Snoeyink et al (1980), the general equation for complete mix is:

$$C = Cin \;/\; (K\,dt + 1) \qquad (10)$$

Where: C = concentration

K = rate constant

dt = change in time

Based on chemical kinetic reaction rates, plug flow reactors are more efficient at conversion at higher concentrations than continuously stirred reactors. According to Tao (1998), the integral of dC/r for plug flow is more efficient due to its higher rate of reaction than (CO-C)/r for continuously stirred reactors.

According to Metcalf et al (1979), the following statement is applicable and simplifies the overall picture of both PF and CSR reactors:

Accumulation = inflow – outflow + utilization (11)

Regarding its application to the study site, the retention basins at Greenleaf may be generally classified according to their mode of operation. A basin that emulates a plug flow or batch reactor is one that does not have a continuous stream. In a plug flow basin, the reactants are added, a reaction occurs, and then the products are "discharged". According to Reynolds (1982), all of the various elements (i.e. nutrients, contaminants, other aqueous inorganic constituents) of the fluid that enter the reactor at the same time flow through the reactor with the same velocity and leave at the same time.

A basin that emulates a CSR is one that has a continuous stream of reactants entering and a continuous stream of products leaving. Upon entering the basin, the fluid elements are immediately dispersed throughout the volume of the basin. The contents are dispersed through the basin uniformly, and exhibit identical concentrations as the effluent stream (Reynolds, 1982).

Compared to CSR, a PF reactor operates at higher concentrations, and hence, at higher rates, throughout its length (Tao, 1998). As fluid elements flow through a PF reactor or long, narrow basin, the concentration of fluid elements drops, decreasing the rate, until a final concentration is reached at the end of the reactor. Tao (1998) further states that the CSR operates homogeneously at the final concentration, resulting in a rate at the final concentration that is much lower than anywhere in the PF reactor, except at the exit point.

Stephens (1998) conducted research on the impact of nitrification kinetics from plug flow reactors (PFR) vs. completely stirred reactors (CSTR). Although she found more efficient rates of kinetic reaction with PF reactors, the pH dropped in the plug flow basins appeared to inhibit nitrification processes.

Based on reaction rates and kinetic chemistry, plug flow and continuously-stirred reactor models would be applicable for nutrients (i.e. N-P-K) at the study site, especially during periods of storm events with high flow rates and an increased potential for outflow or storm water discharge. For optimum water quality benefit, design of retention basins should include the consideration of long, trough-like geometries that promote plug flow during storm conditions.

Environmental Regulations

The 1972 enactment of the Federal Water Pollution Control Act (FWPCA), also known as the Clean Water Act (CWA), prohibits the discharge of any pollutant to waters of the U.S. from a point source unless the discharge is authorized by a National Pollution Discharge Elimination System (NPDES) Permit.

After the enactment of CWA, the U.S. Environmental Protection Agency (EPA) recognized the need to control non-point discharges, such as storm water discharges. As a result of that recognition, Congress amended the CWA in 1987 and in 1997.

The EPA first published the original storm water regulations on November 16, 1990 in 55 Federal Register (FR) 47990. These regulations included permit application requirements and storm water sampling protocols for point source discharges involving storm water.

As a general rule, plant nurseries do not generate a process wastewater or other types of regulated discharges. Specifically, Greenleaf does not generate a process wastewater and therefore, is not required to obtain a permit. In fact, the primary waste stream from the facility is irrigation water, which is specifically exempted from permitting under the Clean Water Act (33 USC§1342(l)).

Note that Greenleaf may produce some waste waters which are specifically prohibited from discharge. NPDES generally prohibits a discharge of an oily sheen or anything else that violates established water quality standards from industrial or commercial facilities.

In 1991, Greenleaf voluntarily signed a compliance agreement with the Oklahoma State Department of Health (now Oklahoma Department of Environmental Quality) that, at that time, mandated a maximum nitrate as nitrogen (NO3-N) concentration of 53.0 ppm and a maximum Total Phosphorus (Total P) concentration of 2.0 ppm. The facility's allowable discharge concentration of NO3-N and TP decreased over time to their current annual allowable of 10.0 ppm and 1.0 ppm, respectively. Thus, although Greenleaf is exempt from NPDES reporting requirements due to the agricultural exception, they have agreed to not discharge any equipment washes, pesticide, herbicides, or nutrient-enriched water that exceeds the annual average or maximum allowable concentrations summarized in Table 6.

A NPDES construction storm water permit is currently required for any 'construction activity' that disturbs more than five (5) acres of land and was not completed by October 1, 1992. Construction activity includes clearing, grading, excavation, road building, construction of residential houses, office buildings, industrial buildings, and demolition activity.

Section 404 of the Clean Water Act (CWA) requires a permit for the discharges of dredged or fill material into waters of the United States. These waters include both wetlands and low-lying 'buffer areas' around waters of the United States. In the State of Oklahoma, the U. S. Army Corps of Engineers handles permits to discharge dredged or fill material.

Under Section 404(f), there are certain activities that are exempt from dredge and fill permit requirements including:

Established (ongoing) farming, ranching, and forestry activities,

Plowing, seeding, cultivating, and harvesting food, fiber and forest products,

Minor drainage,

Upland soil and water conservation practices,

Maintenance (but not construction) of drainage ditches,

Construction and maintenance of irrigation ditches,

Construction and maintenance of farm or stock ponds,

Construction and maintenance of farm and forest roads, and

Maintenance of structures, such as dams, dikes, and levees.

Based on the above list, a permit is generally not required if discharges are associated with normal farming, ranching, plowing, cultivating, or other similar activities. Container plants located on nursery grounds are considered a 'farming activity' and therefore exempt from regulations.

If an activity involving a discharge of dredged or fill material represents a 'new use' of a wetland and the activity results in the reduction in reach or impairment of flow or circulation of the wetland waters, then the activity is not exempt and a permit must be obtained. In effect, any activity in Oklahoma that can convert a wetland or low-lying buffer area adjacent to a river into an upland would require a Section 404(f) permit from the U.S. Army Corps of Engineers.

For Greenleaf, and based on a review of the list of exclusions, one (1) activity that would require a Dredge and Fill Permit would be the physical removal of sediment from the retention basins and subsequent disposition of the material directly into the Illinois River or its flood plain. Based on rates of sedimentation in the retention basins (Morisson, personal communication, 1997), the retention basins will undoubtedly require frequent dredging of bottom sediments. However, based on knowledge of state and federal regulations, their sensitivity to the waters of Illinois River and Lake Tenkiller, and overall awareness to the consequences of their acts, it is not likely that facility employees would dispose of bottom sediments or other similar material in the Illinois River. It is more likely that they would dispose of the dredged material onsite. Onsite disposal of dredged materials would exempt Greenleaf from the obligation of a dredge and fill permit, and minimize transportation costs.

To summarize the environmental regulations as they apply to the study site, Greenleaf does not have nor is required to have a National Pollutant Discharge Elimination System (NPDES) permit, Storm Water Permit, a Storm Water Management Plan, or a Dredge and Fill Permit.

DESCRIPTION OF STUDY SITE

The Facility

Located in east-central Oklahoma, Greenleaf Nursery is a commercial nursery involved in the propagation, growing, and wholesale distribution of containerized plants (see General Location Map of Study Site, Figure 1). As of Fall 1999, they own and operate approximately 267 hectares (660 acres) of hilly land near the Illinois River and Lake Tenkiller (see Site Map, Figure 2). Based on this acreage, Greenleaf qualifies as the largest plant nursery in the State of Oklahoma and are the third largest plant nursery in the United States (Sand, 1999).

The facility was chosen for research due in large part to Greenleaf Nursery's progressive attitude towards environmental issues. It was also selected for research due to its size, years of operation at its present location (1955 to present), known site history, accessibility, and proximity to sensitive receptors.

Sensitive receptors include the Illinois River, which borders the subject property on its south and east sides, and Lake Tenkiller located to the southwest of the facility. The Illinois River has been designated as an Outstanding Resource Water and Scenic River in Oklahoma (Oklahoma Scenic Rivers Act, 1970) and serves as the facility's primary source of irrigation water.

In an attempt to implement pollution controls and reduce the potential for offsite discharge of nutrient-enriched waters to the adjacent water bodies, the nursery constructed a total of eight (8) strategically located retention basins on their property from 1987 to 1997. The holding capacities of the four (4) smallest retention basins are less than 1 million gallons of water, while the largest retention basin has a reported maximum holding capacity of 35 million gallons of water. The following table (Table 1) summarizes various information regarding the Basin Designation (BD) number, date of construction, type of construction materials used, and the holding capacities of the eight (8) retention basins (Morrison, personal communication). Additionally, Table 1 provides information regarding the type of flow system (i.e. either flow-through or bypass) that occurs at a given basin during storm water runoff.

An apparent discrepancy in Table 1 exists regarding the maximum holding capacity of BD#17D, which is the largest basin at the site. Morrison (personal communication, 1997) stated that BD#17D has a maximum capacity of 35 million (MM) gallons of water. However, calculations by Sand (1999) indicate a maximum capacity of 11.4 million gallons, or roughly one-third of the originally stated volume. To be conservative with calculations and modeling in this study, a maximum holding capacity of 11.4 million gallons was used for BD#17D.

As shown in Table 1, six (6) retention basins, including Basin Designations BD#1H, #8C, #9D, #15E, #17D, and #26G, exhibit the physical appearance of a natural pond. The remaining two (2) retention basins, BD#5B and BD#7A, were constructed with concrete and do not exhibit a natural appearance.

A pump and piping system has been installed in both concrete basins, and the system utilizes automatic float valves to control the amount or elevation head of stored water. When water in BD#5B and #7A reaches a pre-determined height, water is automatically pumped to BD#26G (see Figure 3).

As stated, one objective for constructing the recycling irrigation system is to minimize the potential for offsite discharges of nutrient-enriched waters by capturing and recycling runoff water. Runoff water is actually a mixture of water from various sources, including irrigation water obtained from the Illinois River, overland flow from topographically high properties, irrigation or tailwater runoff, and storm water runoff.

Minimizing offsite discharges of nutrient-rich water from the facility, an activity considered by State and Federal regulatory agencies to be a preferred pollution prevention technology, reduces algal blooms, eutrophication processes, contaminant loading rates, and minimizes other adverse affects to adjacent water bodies.

Surface waters captured in retention basins are pumped to other retention basins for storage and/or recycled back as irrigation water to potted plants via an elaborate pump and irrigation system (see Site Map depicting Basin Pipe Interconnections, Figure 3). Recycling the water captured in the retention basins provides additional opportunity for nutrient consumption by the potted plants. Surface water captured in the retention basins also serves as a reserve reservoir of water and lowers overall pumping costs. Water contained in the basins can be mixed with fresh water obtained from the Illinois River and used for plant irrigation.

Table 1. Miscellaneous Information Regarding the Eight (8) Retention Basins

Basin No.	Estimated Date of Construction	Type of Construction	Maximum Holding Capacity	Type of Flow System During Storm Water Runoff
#1H	1987	Natural rock bottom and rock sides	< 1 MM	Flow-through
#5B	1995	Concrete	< 0.5 MM	Combination flow-through and basin bypass
#7A	1995	Concrete	< 1 MM	Complete basin bypass via raised curbing
#8C	Originally 1977 rebuilt in 1998	Rock bottom with rock sides	5 MM	Flow-through
#9D	1994	Natural, mud bottom and natural sides	< 1 MM	Flow-through
#15E	1997	Rock bottom, rock sides	7.0 MM	Plug flow through smaller arm
#17D	1993	Natural, mud bottom and natural sides	35 MM	Flow-through
#26 G	1997	Rock bottom with rock sides	4.5 MM	Flow-through

The construction of the retention basins and implementation of the irrigation system were designed and constructed to minimize discharges from the facility's five (5) outfalls. However, no post-construction studies of the recycling nursery irrigation system have been completed to quantify its overall performance as a viable pollution control technology. Nor have there been any studies performed on the system regarding its overall management during both storm and non-storm events.

The Setting

The setting at the subject facility has many unique and site-specific features. Addressing these features is important for purposes of understanding spatial and temporal NO3-N and P patterns and for purposes of modeling.

Physical, Climate, Geology, Soils

Located in east central Oklahoma, the irregularly shaped property consists of approximately 267 hectares (660 acres) of contiguous land. Most of the subject property is contained in the S/2 of Section 18 and the N/2 of Section 19, Township 15 North, Range 23 East in Cherokee County, Oklahoma (see Site Map, Figure 2).

The property is bound on its west by Oklahoma State Highway 82 and bound on its south and east by the Illinois River. A county road is present along the property's northern boundary, with native undeveloped forestland seen northward towards the top or crest of Mahaney Mountain. These and other features are easily identifiable on both the Park Hill, OK 7.5-minute topographic map dated 1973 (see Site/Topographic Map of Study Site, Figure 2) and the aerial photograph in the Soil Survey of Cherokee County, OK (USDA, 1970).

The property is located south and topographically downgradient of the crest of Mahaney Mountain. The northern portion of the study site is hilly with steep slopes. Terrain analysis of the aerial photographs depicts a coarse dendritic-type pattern with rectangular patterns, V-shaped gullies, and light photo tones, which are typical erosion patterns of sandstone bedrock in humid climates. Conversely, the southern portion of the property is relatively flat with bench-like terraces. Photo tones in the southern half of the property are dull grey and mottled, and the drainage pattern is medium dendritic, which suggest the presence of underlying or interbedded shales.

The subject property ranges in topographic elevation from approximately 880 feet above mean sea level (ASL) near the northwest corner to a fluctuating water level between 630 to 660 feet ASL at the bank of the Illinois River.

According to Mr. Morrison (personal communication, 1997), the land adjacent to the Illinois River below an elevation of 670 feet ASL is controlled by the U.S. Army Corps of Engineers. The Corp's intent with this land is to provide a set-back or buffer zone for the river. Thus, although the subject property appears to be bound on its south and east by the Illinois River, in reality it has zero (0) feet of frontage on the river due to U.S. Army Corps of Engineers' establishment of the buffer zone.

The Greenleaf property, as well as roughly the southern half of Cherokee and Adair Counties and the northern half of Sequoyah County, Oklahoma, is located in a geomorphic province known as the Boston Mountain Geomorphic Province (Johnson et al, 1979). This province is part of the Ozark Uplift and is characterized as having deeply dissected plateaus capped by gently west-dipping Pennsylvanian sandstones.

According to the Soil Survey of Cherokee County, OK (USDA and SCS, 1970), two (2) main soil types exist at the study site. Soils in the southern or bench-like portion of the property consist predominantly of Sallisaw silt loams. The Sallisaw soil series are deep, gently sloping brown silt loams. Soils in the northern or hilly portion of the property consist of the Hector-Linker association. This association has moderately coarse to fine sandy loams that formed on steep sloped (8 to 30%) uplands in sandstone areas. Noted characteristics of this soil type include high erodibility, relatively shallow depth (15 to 30 inches), and a low water-holding capacity.

Based on climatological data described by Pettyjohn et al (1983) representing the interval 1970 to 1979 and the Oklahoma Climatological Survey representing the interval 1980 to present, the average precipitation in southeast Cherokee County, OK is approximately 46 inches per year. The average lake evaporation is less than 60 inches per year and the average annual evapotranspiration is approximately 34 inches.

According to the Oklahoma State Department of Agriculture Plant Industry Division et al (1982), the average annual Class A Pan Evaporation is 70 inches. The mean annual temperature at the study site is approximately 61° Fahrenheit (16.1°C) with a range of approximately 35°F (1.7°C) in January to approximately 81°F (27.2°C) in July.

Located at the facility is an area known as the soil mixing area. In this area, Greenleaf incorporates nutrients, peat, bulking agents, and other materials into a loamy soil-like substrate or "soilless artificial media" used to fill the containers. As part of their voluntary compliance with best management practices (BMPs), Greenleaf gradually converted to using a slow release (Osmocote) fertilizer with a N-P-K ratio of 18-6-12 in late 1990 or early 1991. The fertilizer is typically added or incorporated as substrate into the artificial media. However, on infrequent occasions, slow release fertilizer is added as a top dressing (Morrison, personal communication, 1997).

If a bed of plants exhibit adverse affects resulting from nutrient deficiencies, field personnel can add liquid ammonium nitrogen to above ground tanks that are connected to the facility's irrigation system. Elevated spray nozzles can then direct the concentrated mixture to specific beds as necessary. This type of system is referred to as "fertigation" as it involves injecting a liquid ammonium nitrate (NH4-NO3) fertilizer directly to the irrigation system. The facility's fertigation system was operable as of Fall 1999.

As shown in Table 2, there has been a significant reduction in Greenleaf's purchase and application of liquid ammonium nitrate (NH4-NO3) in the last decade relative to an increase in the facility's number of container beds. By definition, a container bed is a row of containers that measures 8 feet wide by 100 feet long.

Table 2 Historic Purchase and Application Rates of Liquid Ammonium Nitrate at Greenleaf Nursery

Year (Ending Oct.)	NH4-NO3 Purchased (gal)	Number of Container Beds	Application Rate (gals/bed)
1991	161,290	12,211	13.2
1992	112,526	12,787	8.8
1993	97,459	12,657	7.7
1994	40,199	12,843	3.1
1995	40,200	13,400	3.0
1996	35,548	13,314	2.7
1997	40,304	13,898	2.9
1998	31,763	13,810	2.3
1999	23,508	13,828	1.7

The decrease in the use of liquid ammonium nitrate is an indicator of the effectiveness of the facility's retention basins and recycling system. It further suggests that the facility has placed a greater reliance over the past decade on the use of the more expensive but easier-managed slow release (Osmocote) fertilizer.

Prior to the construction of the retention basins and implementation of the irrigation system, tailwaters and storm water runoff discharged unimpeded and directly to the Illinois River or Lake Tenkiller from a total of five (5) outfalls on the property. The current (1999) outfalls identified on the facility are BD#15E (SnakePit), BD#26G (Hub), BD#5B, BD#11C (Front Basin), and the Waterfall Outfall near BD#7A.

In addition to direct root uptake by the potted plants, there are other means, both onsite and offsite, in which nutrient losses in tailwater could occur. Onsite, losses of N-P-K constituents in the recycled water are expected via aeration during irrigation processes, adsorption to site soils, evapotranspiration processes, and infiltration or percolation of surface waters. Other opportunities for onsite N-P-K loss include the uptake of nutrients by the indigenous plant species that are located near the drainage systems (creeks) and biological consumption from biota present in the streams or basins. Upon offsite discharge, it is expected that the indigenous plant species located in the "buffer zone" would provide another opportunity for additional N-P-K losses prior to confluence with the receiving river. The buffer zone, controlled by the U.S. Army Corp of Engineers, is a narrow strip of land between the study site's outfall locations and the Illinois River.

Source and Significance of Irrigation Water

The Illinois River is immediately east and south of the facility (see Figure 2). According to Corp of Engineers' Maps, the Highway 82 bridge immediately southwest of the study site serves as the structural dividing line between the south portion of the Illinois River and the north portion of Lake Tenkiller. As discussed, the Illinois River is designated as an Outstanding Resource Water and Scenic River in Oklahoma (Oklahoma Scenic Rivers Act, 1970).

The Illinois River serves as Greenleaf's primary source of irrigation water for their potted plants, and the facility has a permit from the State of Oklahoma to pump water directly from it. For irrigation purposes, Greenleaf installed four (4) pumps in the Illinois River. Each pump is capable of delivering 1,500 gallons per minute (gpm), resulting in a theoretical maximum water volume usage at the facility of 8.6 million gallons per 24-hour day.

To determine the concentration of nitrate as nitrogen (NO3-N), total dissolved phosphorus, (TP), and other chemical constituents of the source of irrigation water used at the study site, a grab sample of water was collected from the Illinois River in conjunction with other onsite sampling stations. On a monthly basis for twelve (12) months, water from the Illinois River was collected from Sample Station #1 (see Figure 2). This station was located on the walkway to the private floating dock on the Illinois River that contains the facility's main pumps.

Onsite Sampling Stations

The following table (Table 3) provides miscellaneous information regarding the sampling stations that were sampled on a monthly basis for a period of twelve (12) months per this study. The Sample Station Numbers listed in Table 3 are depicted in Figure 2.

Inflow to the Study Area

As shown in Figure 2, the crest of Mahaney Mountain is topographically high to and north of the study site. South of the crest of Mahaney Mountain are two (2) intermittent or ephemeral creeks that transport rainfall and overland flow onto the study site. Dissolved NO3-N, TP, and other constituents in the water transported onsite by these two (2) creeks, combined with overland flows from topographically upgradient positions not associated with the creeks, would represent the facility's background concentrations.

One source of information for background concentrations is test results from Sample ID Numbers IT-4 and IT-5 contained in The Curtis Reports of 1995 and 1996. In addition to information provided in the Curtis Reports, a total of eight (8) inflow or "run-on" samples from the northwest corner of the Greenleaf property were collected and analyzed per this study (see Sample Station #34, Figure 2).

The upgradient area on the south side of Mahaney Mountain that inflows onto Greenleaf measures approximately 160 acres (~0.25 square miles). Based on the soil type, type of cover, steep topographic gradient, and other features, the coefficient of runoff from the upgradient property is expected to be moderately high (~0.75). Since 1 acre-inch equals 27,154 gallons of water, then a 1" rainfall over 160 acres with a 0.75 runoff coefficient would produce as 3.25 million gallons of water (27,154 gallons x 160 acres x 0.75) that inflows onto the study site.

Outflow from the Study Area

Unfortunately, the historic or current contaminant loading that outflows or discharges from the study area cannot be determined with any degree of certainty. Maidment (1993) states that contaminant loading equals concentration (C) times discharge (Q). Therefore, without reliable discharge (Q) volumes, estimates of annual contaminant loading rates to the Illinois River or other bodies of water cannot be accurately determined.

Table 3 General Location and Other Descriptions Regarding Onsite Sampling Stations

Sample Sta. No.	Flowing Creek or Basin Designation (BD) No.	Additional Sampling Station Descriptions
#1	Illinois River. On private dock containing pumps.	The Illinois River is Greenleaf's source of fresh irrigation water.
#2	BD #15E "Snake Pit"	Near the pumps of the larger body of water.
#3	Flowing Creek, Flows into BD#15E	This is the creek that flows into smaller arm (above the weir) of BD#15E.
#4	BD #7A	Concrete basin near propagation area. It is up-gradient of waterfall outfall.
#5	BD #5B	Smaller concrete basin located between waterfall outfall and BD#26G ('Hub').
#6	BD#26G "Hub"	Samples were collected at the NE end of the basin at the concrete spillway/road.
#7	Flowing Creek, Flows into BD#26G	Water in this creek flows into BD#26G and is up-gradient of the soil mixing area
#8	BD #1H	This is the topographically highest basin at the study site.
#9	BD #17D "35 MMG"	This is the pond or basin that has the highest holding capacity at the study site.
#10	BD #9D	This medium-size basin is up-gradient of BD#15E and has a concrete discharge weir.
#11	BD #8C "Front Basin"	This recently completed basin is near the main entrance of the facility.
#12	BD #15E At weir of SnakePit	This is the smaller eastern arm of the BD#15E. Samples were collected immediately above the weir. This is in direct hydraulic communication with Sta. #2.
#34	"Run-on" water from up-gradient property	This station is near the northwest corner of the study site and receives inflow (overland flow or 'run-on') from up-gradient properties (DelRancho, Hwy 51, etc).

Prior to construction of the retention basins and its pumping system, all surface water, including tailwaters, irrigation return flows, and storm water runoffs, on the subject property flowed unimpeded off the site. The historic volume of water that discharge undoubtedly increased as the facility grew in size and increased pumping rates of fresh water. As discussed, test results of NO3-N and TP exist in historic reports (i.e. Houghton and The Curtis Reports), but no information was found in these or other reports regarding the estimate volume of surface water discharge or outflows.

Construction of the facility's retention basins and pumping system took place over the span a decade or more. During that interval of time, gauging stations with constant recorders were not installed at any of the facility's outfalls, nor were any other flow records kept of offsite discharges.

As discussed, one objective for the design of holding capacities of the retention basins was to capture all surface water on the site except for storm water runoff resulting from the most significant and intense storm events (Sand, 1999). As an indirect measure that that objective was accomplished, the author, over a year's time, made a total of five (5) "dry runs" to the site for the expressed purpose of collecting storm water discharge samples only to find that surface water discharges from the facility were not occurring. This indirect information perhaps provides the best testament that the facility has indeed reduced its volume of offsite discharges

Based on interviews with knowledgeable personnel at Greenleaf, it has been estimated that the retention basins and pumping system has resulted in at least a 95% reduction in the total volume of discharge water. Again, based on the number of variables associated with the site and the lack of constant-monitoring equipment at all outfalls, it is not possible to quantify the percent reduction of water discharged offsite over time.

As of Fall 1999, there were a total of five (5) outfalls for storm water runoff at the facility, including BD#15E (SnakePit), BD#26G (Hub), BD#5B, BD#11C (Front Basin), and the Waterfall Outfall near BD#7A. In this research, an emphasis was placed on sampling storm water discharges from BD#15E and BD#26G. However, at least one (1) storm water sample was collected and analyzed from each of the five (5) outfalls. Further discussions regarding the spatial and temporal patterns during storm conditions are discussed in Chapter 5. The analytical test results and statistical analyses of all data, including the storm water data, are provided in Appendix A, while test results and statistics of the reliable data are provided in Appendix B of this report.

Climatological Conditions

Because the facility's retention basins were designed and constructed to contain all surface water except for the most intense storms (Sand, 1999), the amount of rainfall is important as it provides the primary driving force at the facility for constituent fate and transport mechanisms. As such, understanding site-specific patterns of flow and recognizing spatial distributions of NO3-N, TP, and other constituents at the site during storm conditions is a main focus of this project.

The nearest State of Oklahoma Climatological Weather Service Station to the study site is north of Tahlequah, OK. Known as the "TAHL" Weather Station, it is located approximately twelve (12) miles to north/northwest of the Greenleaf facility (see General Location Map, Figure 1).

For this study, daily climatological data was secured from the TAHL Weather Station from July 1, 1998 to July 1, 1999. The data included daily air temperatures, including maximums, minimums, and daily averages, and daily 24-hour rainfall measurements.

As a general overview of the weather conditions over the year that field research was conducted, the study site experienced an extremely wide range of climatological conditions. In June, July, and August 1998, conditions were very hot and very dry. According to the Oklahoma Climatological Survey (OCS, 1998), the summer of 1998 ranked as the 8th hottest and 9th driest summer of the 107 years on record. Summertime drought conditions at the site prevailed until mid-September. In late September and October 1998, temperatures became more moderate for that time of the year, but significant rainfall events were seen. The OCS (1998) stated, "…that 1998 was one of the strangest weather years in memory." In late December 1998, and enduring to the end of January 1999, site conditions were very cold and very dry. On January 3, 1999 (Sampling Event #6), as much as 3" of ice had to be broken on the surfaces of many basins before water samples could be collected. February 1999 was warmer and drier than average, but was followed by a cool and wet March 1999. In April, May, and June 1999, temperatures were once again moderate, but significant amounts of rain fell at the site. June 1999 was the 17th wettest since records were kept beginning in 1892. The "strange weather" discussed by the OCS should not adversely affect the general applicability of models used to evaluate the system performance and management strategies at this site.

From July 1, 1998, to July 1, 1999, a compilation of the daily data provided by the Oklahoma Climatological Survey for the TAHL Weather Station is in Appendix C of this report. The daily information was then summarized in Table 4 with an emphasis placed on 30-day and 5- day periods prior to the date that monthly water samples were collected at the site.

The "Facility Mean Water Temperature" (see column heading in Table 4), is defined as the average of all twelve (12) water samples, including the Illinois River, that were collected during a single sampling event. The rainfall totals are presented for 30-days and 5-days prior to the associated sampling event. The percent of total rainfall for the month prior to the sampling date was calculated by dividing the 5-day rainfall total by the 30-day rainfall total.

As expected, a graph of the climatological data depicts a good correlation between the ambient air temperature at the TAHL Weather Station versus the facility mean water temperature at the study site (see Figure 4). The graph further depicts the high rainfall peaks that occurred in September and October 1998, and also in April, May, and June 1999.

Information provided by OCS on the TAHL Weather Station was also reviewed and summarized to determine, among other items, the number of days that experienced an exceedance of 1.0 and 2.0 inches of precipitation within a 24 hour period (see Table 5). The data shown in Table 5 further depicts stormy conditions prevailed for Sample Events #3 (10/1/98), #4 (11/1/98), and Events #9, #10, #11, and #12 (3/28/99, 5/2/99, 5/31/99, and 6/30/99, respectively).

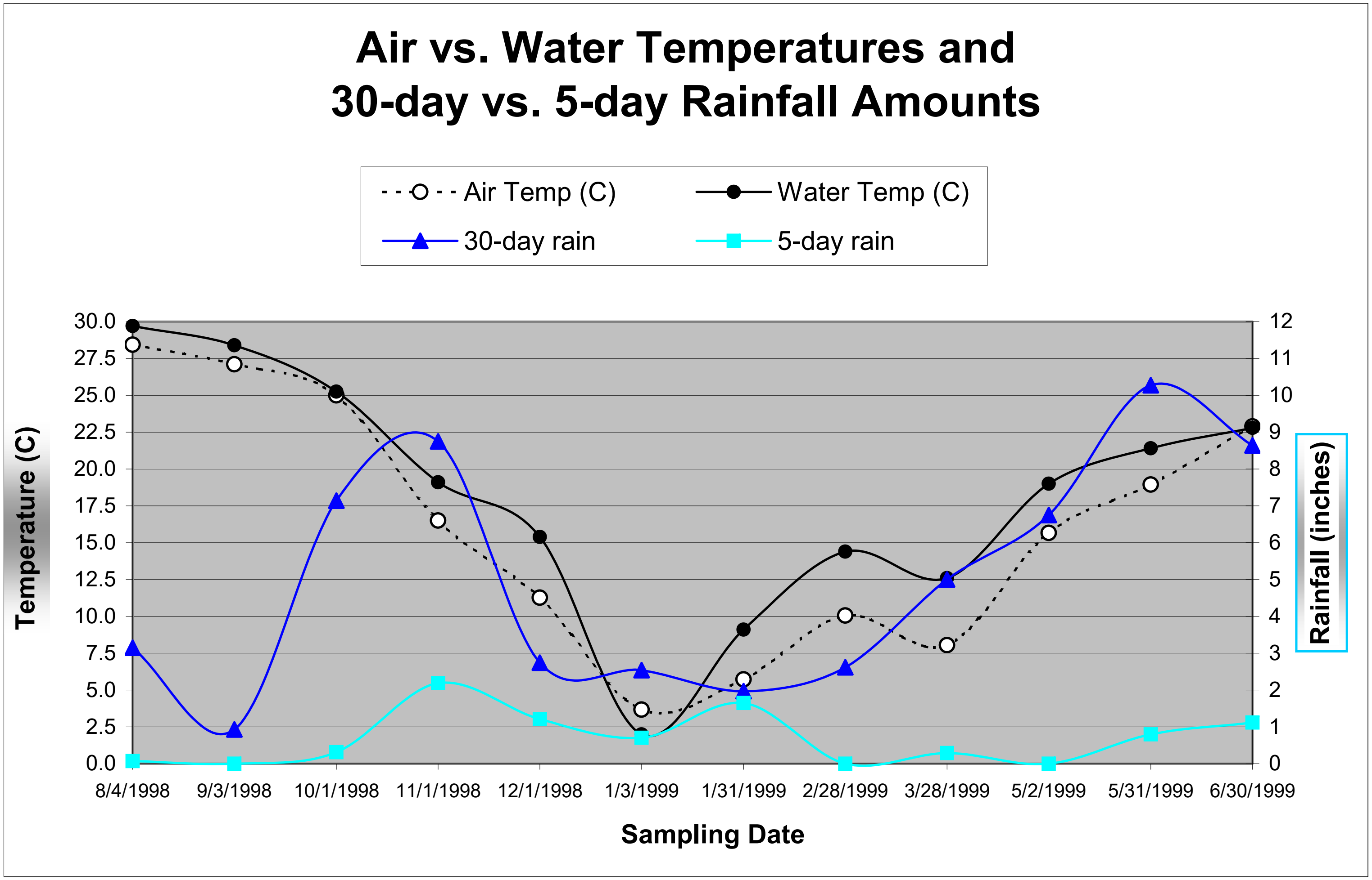


Figure 4. Air vs. Water Temperature and 30-Day vs 5 Day Rainfall.1

Rainfall Comparison: Greenleaf vs. TAHL Weather Station

The distance from the study site to the TAHL Weather Station north of Tahlequah, OK is approximately 12 miles (see Figure 1). Although that distance does not appear to be significant, the actual amount of total precipitation often exhibits significant changes over short geographical distances (Maidment, 1993). This is especially true for mid-latitude thunderstorms that originate from convective-type currents and typically produce large amounts of high intensity rainfall over relatively small areas.

To gain confidence with data from the TAHL Weather Station and its application to the Greenleaf facility, a comparative study was performed of the recorded rainfall between the two sites. As described by Heath (1999), Greenleaf personnel collected daily rainfall data at their site over a 10-week span starting August 17, 1998, and ending October 30, 1998. The following table (Table 6) shows that the rainfall amounts recorded at Greenleaf are quite comparable in both amount and duration to the TAHL data.

Although some minor differences were seen, there is generally a good correlation between the rainfall amount at Greenleaf versus that at the TAHL Weather Station over a 10-week period in late Summer 1998 (see Rainfall Comparative Chart, Figure 5). The good correlation of rainfall data provided confidence with this study's use and reliance upon the rainfall data recorded at the TAHL Weather Station.

Table 4 Ambient Air Temperature vs. Facility Mean Water Temperature and 30-day vs. 5-day Rainfall Amounts. (Source: TAHL Weather Station)

Sample Event No. and Date		Avg. Ambient Air Temp. (F)	(C)	Facility Mean Water Temp. (C)	Total Rainfall (30-days prior to sampling)	Total Rainfall (5-days prior to sampling)	Ratio of 5-day to 30-day rainfall
1	8-4-98	83.2	28.4	29.7	3.15"	0.07"	2.22%
2	9-3-98	80.8	27.1	28.4	0.93"	0.00"	0.00%
3	10-1-98	77.0	25.0	25.3	7.14"	0.31"	4.34%
4	11-1-98	61.7	16.5	19.1	8.75"	2.19"	25.03%
5	12-1-98	52.3	11.3	15.4	2.74"	1.21"	44.16%
6	1-3-99	38.6	3.7	2.0	2.54"	0.70"	27.56%
7	1-31-99	42.3	5.7	9.1	1.97"	1.65"	83.76%
8	2-28-99	50.1	10.1	14.4	2.62"	0.00"	0.00%
9	3-28-99	46.5	8.1	12.6	5.00"	0.29"	5.80%
10	5-2-99	60.2	15.7	19.0	6.75"	0.00"	0.00%
11	5-31-99	66.1	18.9	21.4	10.27"	0.80"	7.79%
12	6-30-99	73.2	22.9	22.8	8.64"	1.12"	12.96%

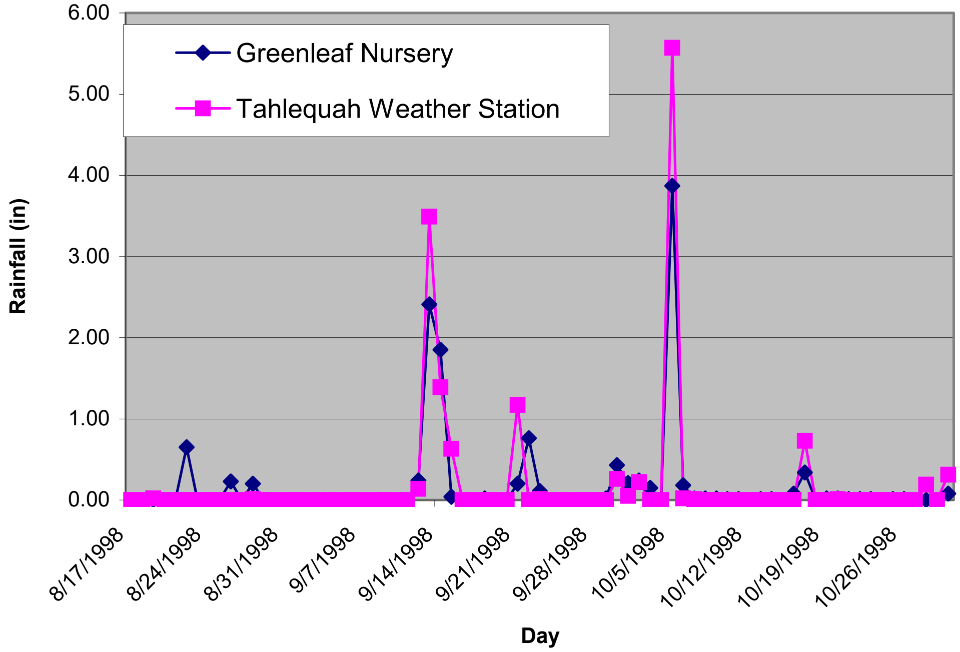


Figure 5. Rainfall comparative Chart. Greenleaf Nursery vs. Tahlequah Weather Station.

Historic OSDA Discharge Permit Limits

Under general provisions of the Oklahoma Pesticide Law and the Oklahoma Fertilizer Law, the Oklahoma State Department of Agriculture (OSDA) assumed primary jurisdiction of discharges from Greenleaf and other plant nurseries on the Illinois River in 1988. OSDA then developed a Compliance Agreement that established an average annual and maximum allowable concentration goal for NO3-N and TP of discharge water from nurseries. With an overall intent to protect the Illinois River as well as to provide the nurseries with a "grace period" to implement best management practices, the Compliance Agreement used a phased approach for NO3-N and TP concentrations. Specifically, high concentrations were allowed at first with incremental lowering of constituent concentrations over time. The data are summarized in Table 6, showing a decrease of NO3-N and TP concentrations over time.

Historic Test Results

There are five (5) sampling stations at the study site that appear to be consistent over time and are identifiable throughout various studies (Houghton, 1984 and The Curtis Reports, 1989-1996, Alexander, 1998-99). These stations include:

the Illinois River,

the Waterfall Outfall (discharge)

the creek near the front gate and/or discharge from the Front Basin.

Upgradient (inflow or background) samples from the south slope of Mahoney Mountain, and

Collective offsite discharges (outflows) from the southeast portion of the property to the Illinois River.

Table 5. Other Summaries from Tahlequah Weather station

Table 5						
Other Summaries From TAHL Weather Station						
Sample Round No. and Date	Max. Ppt. 1 month prior to sample date	Min. Ppt. 1 month prior to sample date	1 month prior, number of days With No Ppt.	1 month prior, number of days With Ppt.	1 month prior, number of Days with Ppt. >1.0"	1 month prior, number of days with Ppt. >2.0"
#1 (8-4-98)	1.84" (7-8-98)	0.01"	26	5	2 (7-8-98) (7-12-98)	0
#2 (9-3-98)	0.65" (8-13-99)	0.01"	25	5	0	0
#3 (10-1-98)	3.49" (9-13-98)	0.01"	20	8	3 (9-13-98) (9-14-98) (9-21-98)	1 (9-13-98)
#4 (11-1-98)	5.57" (10-5-98)	0.01"	22	9	2 (10-5-98) (11-1-98)	1 (10-5-98)
#5 (12-1-98)	0.89" (11-29-98)	0.01"	20	10	0	0
#6 (1-3-99)	0.7" (1-1-99)	0.01"	23	10	0	0
#7 (1-31-99)	0.91" (1-30-99)	0.11"	20	8	0	0
#8 (2-28-99)	2.31" (2-6-99)	0.01"	23	5	1 (2-6-99)	1 (2-6-99)
#9 (3-28-99)	1.86" (3-12-99)	0.01"	16	12	2 (3-8-99) (3-12-99)	0
#10 (5-12-99)	1.6" (4-26-99)	0.11"	26	9	3 (4-3-99) (4-22-99) (4-26-99)	0
#11 (5-31-99)	1.69" (5-12-99)	0.01"	15	14	2 (5-12-99) (5-17-99)	0
#12 (6-30-99)	2.79" (6-20-99)	0.01"	14	16	3 (6-20-99) (6-24-99) (6-30-99)	1 (6-20-99)

Table 6. Greenleaf's Permit History: Average Annual and Maximum Allowable Concentrations, of Nitrate (as N) and Total Phosphorus Discharges per OSDA Compliance Agreement

Year	Average Allowable NO3-N Conc. (ppm)	Maximum Allowable NO3-N Conc. (ppm)	Average Allowable TP Conc. (ppm)	Maximum Allowable TP Conc. (ppm)
1991	41.0	53.0	1.0	2.0
1992	27.0	41.0	1.0	2.0
1993	18.5	23.3	1.0	2.0
1994	15.5	21.8	1.0	1.5
1995	14.5	15.0	1.0	1.5
1996	10.0	15.0	1.0	1.5
1997	10.0	15.0	1.0	1.5
1998	10.0	15.0	1.0	1.5
1999	10.0	15.0	1.0	1.5

Historic test results of NO3-N and TP from the five (5) sampling stations identified above have been summarized in Tables 11 and 12, respectively. For comparative purposes, the test results reported and described in this study have been included in Tables 11 and 12 with historic results.

Regarding the collective offsite discharges, an historic sample station was located near the edge of the Illinois River where several historic outflows from the study site converged together. This station was located immediately north of Sample Station #5 at BD#5B in this report (see Figure 2), but was identified as Station #2 in Houghton (1984) and Station IT-6 in The Curtis Reports (1989-1996). For purposes of comparison, all storm water discharges in this report that outflow to this general area (i.e. the southeast portion of the property) were averaged. The average annual NO3-N concentration in Table 11 and the average annual TP concentration in Table 12 represent an average of 1998 and 1999 discharges from BD#15E, BD#26G, and BD#5B.

MATERIALS AND METHODS

Experimental Design

The experimental design for this study consisted of the collection, analyses, and interpretation of various surface water samples collected from the study site. Analytical testing was performed on water samples collected from the following sample stations:

Surface water contained in the each of the eight (8) retention basins,

Surface water in creeks, constructed ditches, or other onsite drainage systems that carried excess runoff water to a retention basin,

Inflow surface water (overland flow) that 'runs-on' to the facility from topographically upgradient properties following a storm event,

Storm water discharges from the five (5) known outfall points on the facility, and

Surface water of the Illinois River as collected near the nursery's pump station.

Due to its horseshoe shape and the configuration of its contributing creeks, a second sampling station was established for Basin Designation BD#15E (Snake Pit). Thus, Sample Station #2 was located in the main body of water near the pumps of BD#15E, while Sample Station #12 was located immediately above the weir in the eastern and smaller arm of the retention basin. Water from these two sampling stations are in direct hydraulic communication with each other.

Surface water samples were collected for analysis on a monthly basis for a period of twelve (12) months. The first sampling event occurred on August 4, 1998 and the final sampling event was July 30, 1999. All samples were transported under chain-of-custody documentation to the Soil, Water, & Forage Analytical Laboratory (SWFAL), a state-certified laboratory in Stillwater, Oklahoma for inorganic chemical analysis.

Field parameters and analytical test results of surface water samples were used to address the objectives of this study, including an evaluation of onsite spatial and temporal patterns in the water quality and an assessment of the overall performance of the recycling irrigation system.

The experimental design also included a review of site documents, prepared by others, which was necessary to observe the changes of NO3-N and TP concentrations over a greater period of time. Information was also obtained on allowable NO3-N and TP concentrations in historic State Discharge permits and past usage rates of liquid ammonium nitrate by the nursery. It was anticipated that the historic findings could be evaluated in conjunction with new information provided in this study to assess the overall performance of the facility's irrigation system as a viable pollution prevention technology and promote this best management practice (BMP) for the nursery industry.

Upon receipt from the laboratory, the *WATEVAL* program was used to calculate other inorganic parameters and to evaluate the reliability of the analytical test results. All field parameters, analytical test results, and other inorganic parameters were summarized in spreadsheets (see Appendices A and B). Test results that exhibited a cation-to-anion ratio in excess of ±5% were identified as suspect. In an attempt to determine the potential effects of unreliable data, statistical analyses, including the minimum, maximum, mean, median, standard deviation, and variance, were calculated for all data and for all data less the suspect data.

The analytical test results were used in various charts and graphs of NO3-N and TP. The charts and graphs were beneficial in visually depicting the spatial and temporal patterns in the water quality parameters at the various retention basins.

Field Instrumentation and Field Parameters

Two (2) field instruments were utilized at each sampling station in the collection of field parameters for this project. A YSI Model 55 Handheld Dissolved Oxygen Instrument was used to secure field dissolved oxygen (DO in %) and water temperature (in ^{o}C) readings. An Extech Oyster Model 341450 instrument was used to secure field pH and Specific Conductivity (SC in umhos/cm) readings. The instruments were inspected and calibrated in the field immediately prior to use and rechecked for accuracy upon completion of sampling. Both instruments were used in accordance to manufacturer's instructions provided in the operations manual. Due to the age of both instruments (<1 year old), maintenance other than routine on the field instruments was not required nor performed.

The following field parameters were secured and recorded in a field log book for each sample collected in the field:

pH,

Dissolved Oxygen (DO in %),

Water Temperature (^{o}C),

Specific Conductance (SC in umhos/cm), and

Time and Date of Sample.

Sample Collection

Sample collection for this project consisted of surface water samples only. Sample locations included the twelve (12) sampling stations identified in Figure 2. Once a sampling station was established in the field, its geographic location did not change. Sampling frequency at each station was performed once per month for a period of twelve (12) months. The author collected all water samples for this project.

Sample containers consisted of 500 ml teflon bottles supplied by Sherry Laboratory, an analytical laboratory in Tulsa, OK. The water samples were not filtered in the field and there were no preservatives included in or added to the containers in the field.

Water samples from standing bodies of water (i.e. ponds, retention basins, and lagoons) were sampled at the nearest delivery point of running water. In the standing bodies of water, samples were secured with the containers by simply submerging an uncapped container approximately 4 to 6 inches below the surface and allowing the sample container to fill up. Care was taken to ensure that floating debris on top of the standing water was not sampled.

Water samples from flowing water (i.e. intermittent creeks, ditches, and overland flow) were secured using a time-weighted average technique. Small (approximately 50 ml) aliquots were collected over a 20-minute period and used to fill the sample container.

For non-discrete samples, storm water runoff samples were collected in the same manner as previously described for the flowing water samples. However, when rainfall runoff occurred from a 'first flush' and several discreet samples were collected from one station to observe if NO3-N and TP changed over time, then grab samples (not time-weighted average or composite samples) were collected.

Storm water discharge samples were usually collected manually. However, an attempt was made by the author to secure storm water discharge samples with an automatic Global Water Stormwater Sampler (Model SS201). According to the operations manual, the SS201 instrument is capable of automatically securing an initial 'grab' sample in one bottle, immediately followed by the collection of a time-weighted sample in a separate bottle. The instrument was of marginal success (only one sample was collected from the Waterfall Outfall), the utilization of the automatic sampler was discontinued.

For purposes of consistency, all storm water or inadvertent discharge samples were subjected to the same analysis as other standard samples.

While in the field, a chain of custody (COC) record was maintained for all samples. Information provided on the COC included the project name, sample dates and times, sample locations, name of the sampler, requested analyses, and type of sample (grab or composite).

All samples were collected in appropriate containers and labels were affixed to each container. Using indelible ink, each sample container was provided with the following information: Sample Station Number, time, date, sampler's initials, and whether the sample was a grab ("G") or a composite ("C"). The sample containers were immediately placed on ice in an ice chest and transported to the laboratory. The chain of custody document accompanied all sample containers to the laboratory and all appropriate signatures were secured on each COC.

Analytical Test Methods

All surface water samples collected in this study were delivered to the Soil, Water, and Forage Analytical Laboratory (SWFAL) at Oklahoma State University in Stillwater, Oklahoma. Requested analyses for all samples included the "Irrigation Water Analyses" plus Total Dissolved Phosphorous (TP) and Dissolved Iron. On three (3) separate sampling events (Sample Events #10, #11, and #12), additional analysis for ammonium as nitrogen (NH4-N) was requested. Table 7 summarizes the analytical methods, detection limits, and acceptable limits for field duplicates.

Table 7. Analytical Methods, Method Detection Limits, and Acceptable Limits for Field Duplicates

Parameter	Analytical Method	Meter or Lab	Acceptable precision for low level fld duplicates	Acceptable precision for high level fld duplicates	Method Detection Level
Dissolved Oxygen	4500-G	YSI-57	90-110%	90-110%	0.1 mg/L
Conductance	2510-B	YSI	90-110%	90-110%	1.0 uS/cm
pH	4500 H-B	Orion	90-110%	90-110%	1.0 S.U.
Temperature		YSI-57	90-110%	90-110%	-5ºC
Alkalinity	2320-B	Hach digit-al titrator		90-110%	15 mg/L
Turbidity	2130-B	Hach 2100P		90-110%	0.01 NTU
Ammonia	4500	SWAFL	75-125%	90-110%	0.015 mg/L
Total Kjeldahl Nitrogen	4500-N-C	SWAFL	75-125%	90-110%	0.01 mg/L
Nitrite-Nitrogen	4500-NO_2-B	SWAFL	75-125%	90-110%	0.068 mg/L
Nitrate-Nitrogen	4500-NO_3-D	SWAFL	75-125%	90-110%	0.5 mg/L
Total Phosphorous	4500-P-B-E	SWAFL	75-125%	90-110%	0.005 mg/L
Total Suspended Solids	2540-O	SWAFL	75-125%	90-110%	1.0 mg/L
Sulfate	4500-SO4-E	SWAFL	75-125%	90-110%	0.1 mg/L
Chloride	4500-C	SWAFL	75-125%	90-110%	0.5 mg/L
Hardness	2340-C	SWAFL	90-110%	90-110%	0.5 mg/L

Quality Assurance

A Quality Assurance Project Plan (QAPP) was prepared prior to the initiation of field activities for this project. The intent of the QAPP document was to provide the U.S. Environmental Protection Agency or other interested parties with specific details such as a Sampling and Analysis Plan (SAP), Data Quality Objectives (DQO), and an overall assurance that all aspects of the project were consistently and appropriately performed.

Dr. Michael D. Smolen, Project Director for this study and Water Quality Director at the Biosystems Engineering Department at Oklahoma State University (OSU), prepared the QAPP. Other OSU investigators listed on the QAPP included Dr. Sharon L. von Broembsen, Dr. Ronald L. Elliott, and Dr. Michael A. Schnelle.

The QAPP was implemented for this project and research conducted per this investigation met or exceeded the plan's requirements.

Regarding quality assurance at the analytical laboratory, the Soil, Water, and Forage Analytical Laboratory (SWFAL) at Oklahoma State University (OSU) adhered to their internal QA procedures specified in the Laboratory Procedures Manual (Zhang, et al, 1997). According to OSU Extension Facts Document F-2901 (Zhang, et al), *"accurate laboratory results are maintained through the use of laboratory standards, blank samples, internal and external check samples, and technical review of all results. All methods and procedures used in the lab are approved by either national or regional professional organizations. All instruments are calibrated daily and check with high quality standards. Blank samples are routinely used to check each day's analyses. Internal check samples are used every 20 samples. All results are double-checked for data entry accuracy and reviewed for any apparent problems*."

Blind Field Duplicate Samples. By definition, a blind field duplicate (BFD) is an exact duplicate sample of water secured at the same time and place as its original sample. A fictitious sample identification number and fictitious sampling time is listed on both the BFD's container label and on the chain-of-custody (COC) ensure that the analytical laboratory cannot trace the BFD sample to its original sample.

The intent of a BFD sample is to provide quality assurance (QA) by assessing the precision of test results reported by the analytical laboratory (Greenberg, et al, Eds, 1992). Precision is defined as random variation in data (Keith, 1991). Although acceptable limits of analytical precision vary from parameter to parameter (Greenberg et al, Eds, 1992, Table 1030:I), the acceptable precision values of several individual constituents analyzed in this study are provided in Table 7.

Duplicate water samples were obtained by alternatively filling the two sample containers (one original, one BFD) from the same sampling device. To ensure that the laboratory could not trace the duplicate samples, BFD samples were collected from different sampling stations selected at random during different sampling events.

The WATEVAL Program. Written by Hounslow (1995), *WATEVAL* is a basic computer program designed to intensively evaluate water quality data using a variety of subroutines and methods. The *WATEVAL* subroutines used in this study include the calculation of cation to anion ratios for all samples, the generation of piper plots and stiff diagrams, and the 3-sample mixing routine. Following is a brief description of each subroutine and a discussion of the general findings.

Cation-to-Anion Ratios. The reliability of an individual water sample's test result may be determined by calculating and comparing the summation of cation-to-anion (C:A) ratios (in meq/l). Hem (1996) states that all potable waters are electrically neutral. Thus, if an analytical test result is considered to be reliable, the C:A ratio should be within a specified percent of zero. Although the Standard Methods for the Examination of Water and Wastewater (Greenberg et al, eds, 1992) uses a sliding scale for acceptance criteria that is more restrictive with decreasing anion summation (in meq/l), the acceptance criteria for the C:A ratio used in this study was held at a constant ±5%.

Piper Plots and Stiff Diagrams. Another commonly used subroutine in WATEVAL is the graphic program. Using the test results as input, the graphic subprogram is capable of graphing Piper Plots and Stiff Diagrams. According to Piper (1944), after plotting the analytical data on trilinear cation and anion diagrams, the two points can be extrapolated to a single point on the diamond portion of a Piper diagram.

3-Sample Mixing Routines. Another subprogram in WATEVAL is the 3-sample Mixing Routine. Hounslow (1995) states that the main objective of the Mixing routine is to determine if one analysis is related to two others by mixing. The Mixing Routine sorts the input analyses into two end members based on their TDS values calculated from 7 major ions, and then calculates how much each of the two end members would have to be mixed to obtain the third analysis. Based on the computed mix, a correlation coefficient (R) and its square (R^2) are reported. According to Hounslow (1995), the possibility of a mix is tenuous if the R value is below 0.95 (or if R^2 is below 0.90).

Based on the high degree of mixing that was expected to occur at the study site resulting from the intra-basin pumping and recycling activities of captured water, a stringent standard of acceptance was established for this study. The acceptance criteria selected for this study was a strict $R \geq 0.98$ or $R^2 \geq 0.96$.

The Sanitas™ Program. The Sanitas™ Program (Intelligent Decision Technologies, 1997) was used to generate graphics and perform statistical evaluations of the data. The program is capable of generating Histograms, Box and Whisker Plots, and other graphics.

A histogram displays a frequency distribution of a select constituent concentration. Box and Whisker Plots provide a quick way to visualize the distribution of data at a given sample station. The box portion of the plot graphically locates the mean, median, and 25th and 75th percentiles of the data set, while the "whiskers" or horizontal lines extend from the box to minimum and maximum values of the data set. Located within the box, the plus sign ("+") depicts the mean value and the solid horizontal line depicts the median for the select concentration and sample station. The distance between the ends of the box represents the Interquartile Range, which is useful in graphically depicting the spread or variability in the data set.

RESEARCH FINDINGS

Analytical Test Results and Interpretation

Surface water samples from Stations #1 - #12 were sampled at the study site on a monthly basis from August 4, 1998 through July 30, 1999. The test results and statistics of all data are presented in Appendix A and all data less the suspect data are presented in Appendix B. Suspect data is defined as those analytical test results with cation-to-anion ratios that exceeded ±5%.

General Discussion

In this study, SWFAL performed twelve (12) separate and complete sets of inorganic analyses for sampling stations #1 - #10. Eleven (11) sets of analyses were completed at sampling station #11 and ten (10) sets of analyses were completed at sampling station #12. This resulted in total of 141 sets of analyses at the sampling stations. The total number of sets (141) does not include 11 blind field duplicate (BFD) samples for quality assurance (QA) purposes, 12 sets of storm water samples, and 8 upgradient or background samples at Station #34Of 141 analyses of the regular monthly samples, there were 12 analyses that had cation-to-anion ratios that exceeded ±5%, resulting in 8.5% (12/141 x 100) suspect data. Stated otherwise, 91.5% of the test results were deemed reliable or non-suspect using a cation-to-anion ratio of ±5%. Due to low concentrations of the major ions that were reported in many samples, this is an acceptable percentage of reliable or non-suspect data and provides confidence with the test results presented by the laboratory.

With a single exception, a review of the NO3-N and TP test results summarized in Appendix A and B indicated no significant difference between the statistics of all data vs. all data less the suspect data. The noted exception was NO3-N test results at Sample Station #2. Using all data (see Appendix A), the standard deviation of NO3-N for twelve (12) sample events at Station #2 was 10.68. Removal of two (2) sampling events that exhibited suspect data lowered the standard deviation of NO3-N to 3.23. The average NO3-N concentration was 12.67 ppm for all data and 9.30 ppm for all data less the suspect data. For TP at Sample Station #2, the differences in the statistics were not significant. At Station #2, the standard deviation for TP was 0.287 for all data and 0.316 for all non-suspect data. The average TP concentration at Station #2 using all data was 0.672 ppm and 0.679 ppm for all data less the suspect data. Thus, the removal of the two (2) sample events from Sample Station #2 that contained suspect data had a greater affect on NO3-N statistics than it did for TP.

Quality Assurance, Blind Field Duplicates

For purposes of QA, there were eleven (11) BFD samples collected and analyzed. This resulted in a QA/BFD of 7.8% (11/141 x 100) for this project, which exceeded the minimum BFD of 5% listed in this project's QAPP.

The analytical test results of all original and their associated BFD samples were summarized in spreadsheet (see Appendix A and B). Calculations of the analyzed constituents were performed on the Original vs. BFD samples to determine if the differences were within acceptable precision limits.

As previously stated, there were a total of eleven (11) BFD samples collected during this study, including one BFD per sampling event except for sample event #1. The BFD sample for sample event #1 was inadvertently omitted. Since the laboratory reported test results for a total of fifteen (15) individual constituents per sample, there were a total of 165 (11 x 15) constituents for this project's QA/BFD. As shown in Table 8, there were 21 constituents in the blind field duplicate samples that were less than a 90% concentration difference. Thus, 12.7% (21/165 x 100) of the QA/BFD results were not within a 90% precision criteria, or 87.3% QA/BFD results were within a 10% precision criteria. As seen in Table 8, the most frequently listed constituents exceeding a 10% precision criteria were boron (B) and dissolved iron (Fe), which were each listed four (4) times.

From Table 7, the acceptable precision for low level field duplicates of most inorganic constituent concentrations was 75 – 125%. Using this criteria, there were a total of six (6) individual inorganic constituents in the BFD samples that were less than a 75% concentration difference (see Table 9). Thus, 3.6% (6/165 x 100) of the QA/BFD test results were not within the acceptable precision criteria for this project, or 96.4% QA/BFD test results were within a 25% precision criteria. As seen in Table 9, dissolved iron (Fe) was listed twice, while specific conductance (SC), total suspended solids (TSS), bicarbonate (HCO3), and boron (B) were each listed once.

Study Findings

The line graphs in Figures 6 and 7 depict the changes of NO3-N concentrations at each station over the 12-month sampling period. Two (2) graphs were used to depict NO3-N changes over time due to the total number of sampling stations (12) that were included in this study.

The line graphs in Figures 8 and 9 plot the same data as Figures 6 and 7, but on an expanded Y-axis scale to show greater detail with lower NO3-N concentrations. The reason for the excessive NO3-N concentrations seen in several samples, especially during Sample Event #1 dated 8/4/98, is most likely related to the application of liquid ammonium nitrate and lack of rainfall at that time. Note in Figures 6, 7, 8, and 9 that the suspect data have been identified with a box around the data point.

Not including suspect data, the average annual NO3-N concentration for all stations (#1-#12, inclusive of the Illinois River) was 8.75 ppm. Exclusive of the Illinois River, the average annual NO3-N concentration for all stations was 9.42 ppm. Both values are below OSDA's average annual compliance agreement of 10.0 ppm for NO3-N.

Table 8. QA: Blind Field Duplicate Constituents Below 90% Difference

Sample Location	Sample No.	Date	Parameter	% Difference
Runoff to BD#15E	#3-2	9/3/98	P	89.52
BD#15E (at weir)	#12-3	10/1/98	Fe	80.00
BD#17D	#9-4	11/1/98	B	85.71
BD#17D	#9-4	11/1/98	Fe	66.67
Runoff to BD#26G	#7-5	12/1/98	K	87.50
BD#8C (front)	#11-6	1/1/99	HCO3	78.88
BD#8C (front)	#11-7	1/31/99	K	87.50
BD#9D	#10-8	2/28/99	Lab S.C.	73.72
BD#9D	#10-8	2/28/99	NO3-N	85.71
BD#9D	#10-8	2/28/99	P	80.95
BD#9D	#10-8	2/28/99	Lab TSS	73.75
BD#7A	#4-9	3/28/99	B	85.71
BD#7A	#4-9	3/28/99	Fe	77.78
BD#5B	#5-10	5/2/99	Na	83.33
BD#5B	#5-10	5/2/99	B	87.50
BD#8C	#11-11	5/31/99	Cl	83.33
BD#8C	#11-11	5/31/99	Fe	46.67
BD#5B	#5-12	6/30/99	Na	83.33
BD#5B	#5-12	6/30/99	HCO3	72.97
BD#5B	#5-12	6/30/99	B	72.72
BD#5B	#5-12	6/30/99	Lab TSS	87.91

Table 9. QA: Blind Field Duplicate Constituents Below 75% Difference

Sample Location	Sample No.	Date	Parameter	% Difference
BD#17D	#9-4	11/1/98	Fe	66.67
BD#9D	#10-8	2/28/99	Lab S.C.	73.72
BD#9D	#10-8	2/28/99	Lab TSS	73.75
BD#8C	#11-11	5/31/99	Fe	46.67
BD#5B	#5-12	6/30/99	HCO3	72.97
BD#5B	#5-12	6/30/99	B	72.72

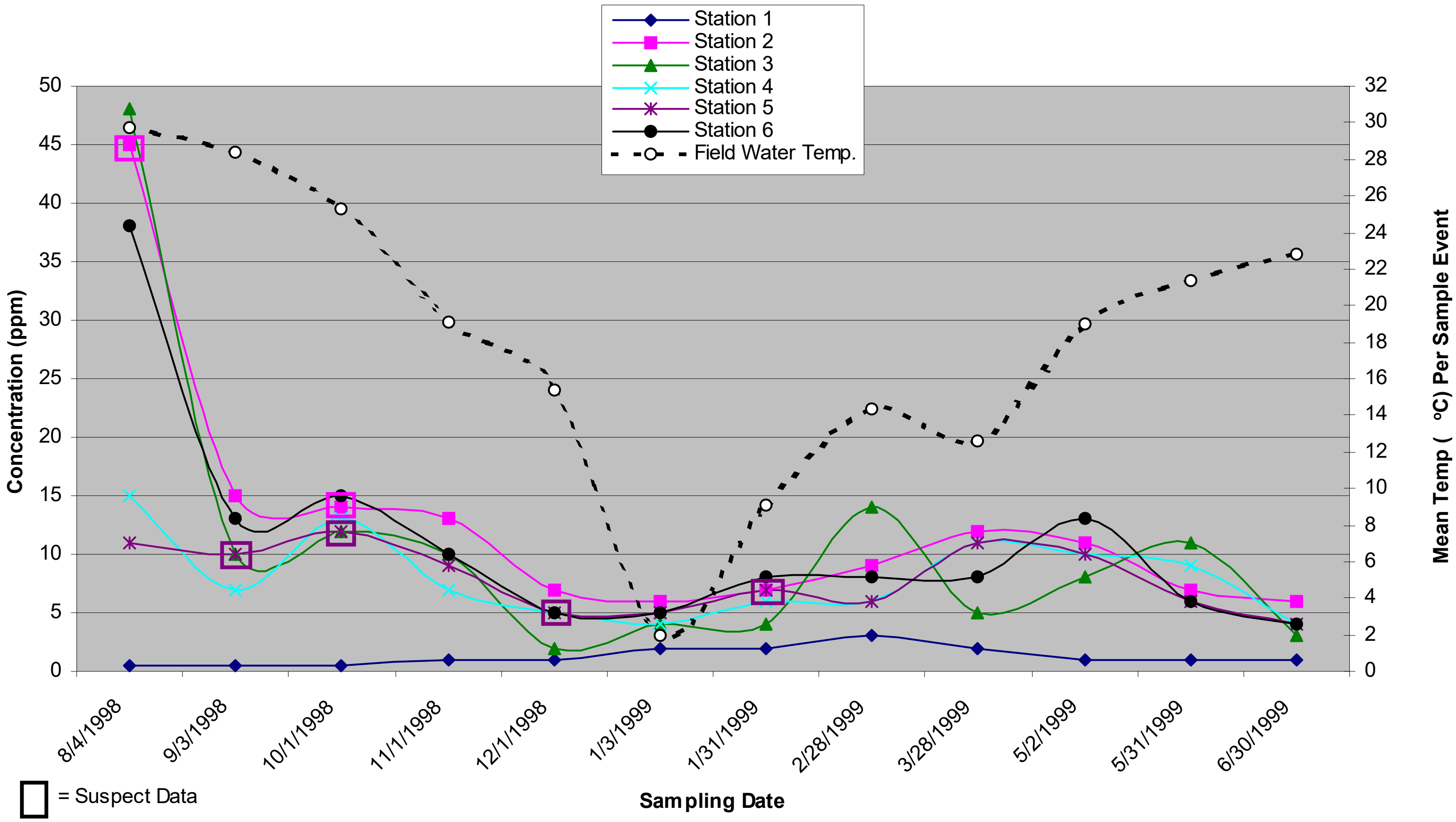


Figure 6. NO3-N Concentrations for Sampling Stations #1 - #6

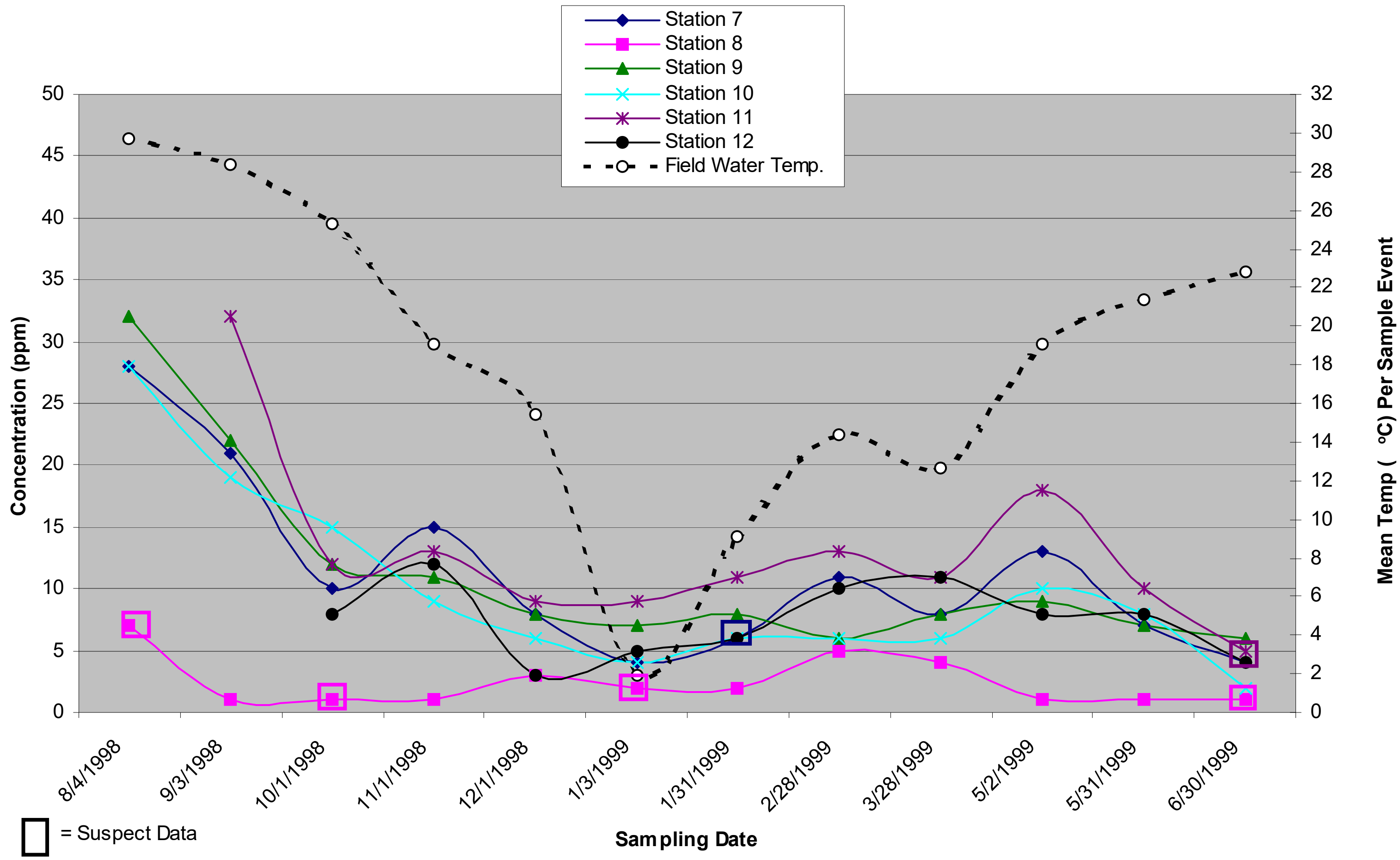


Figure 7. NO3-N Concentrations for Sampling Stations #7 - #12

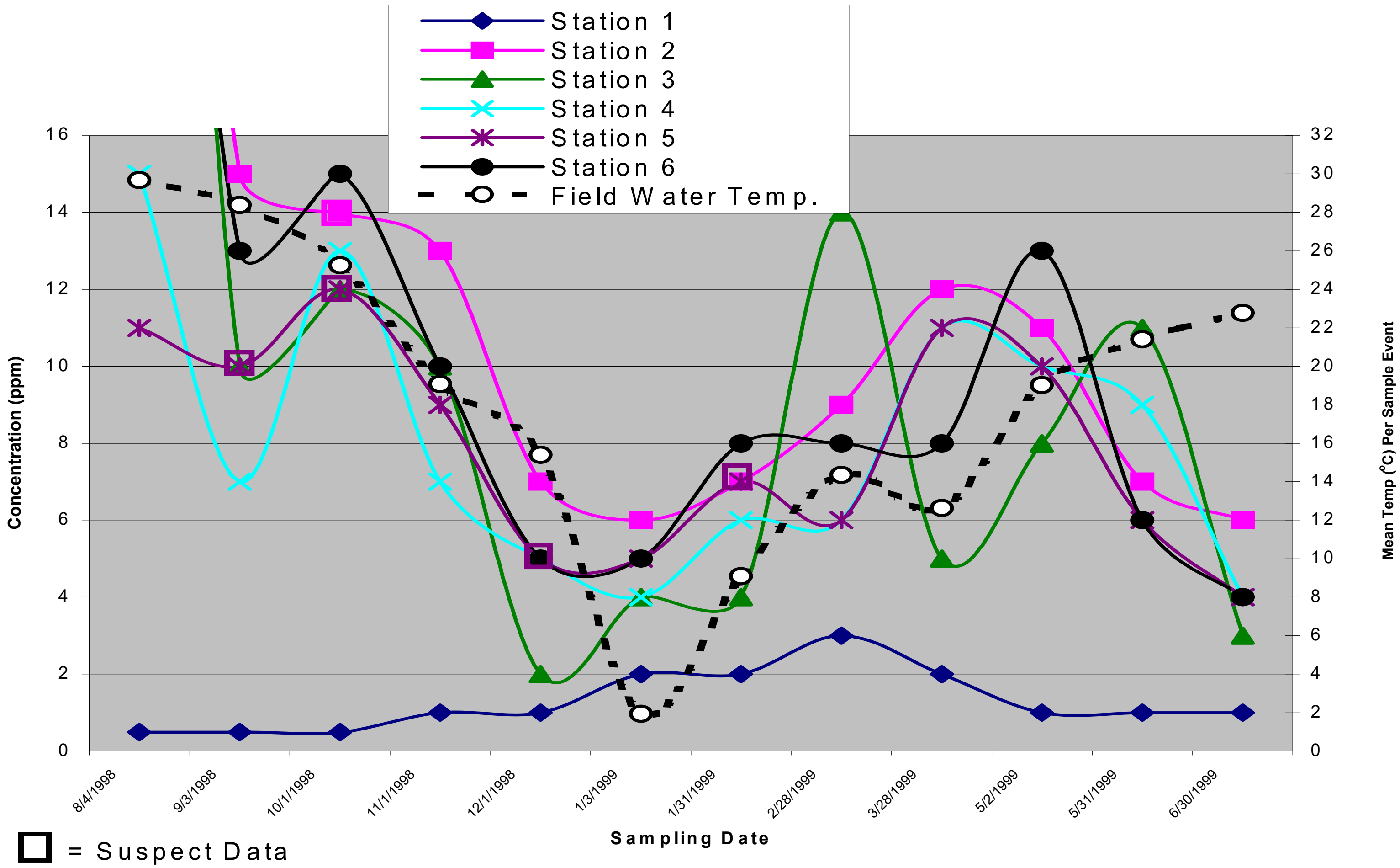


Figure 8 NO3-N Concentration for Sampling Stations #1-#6

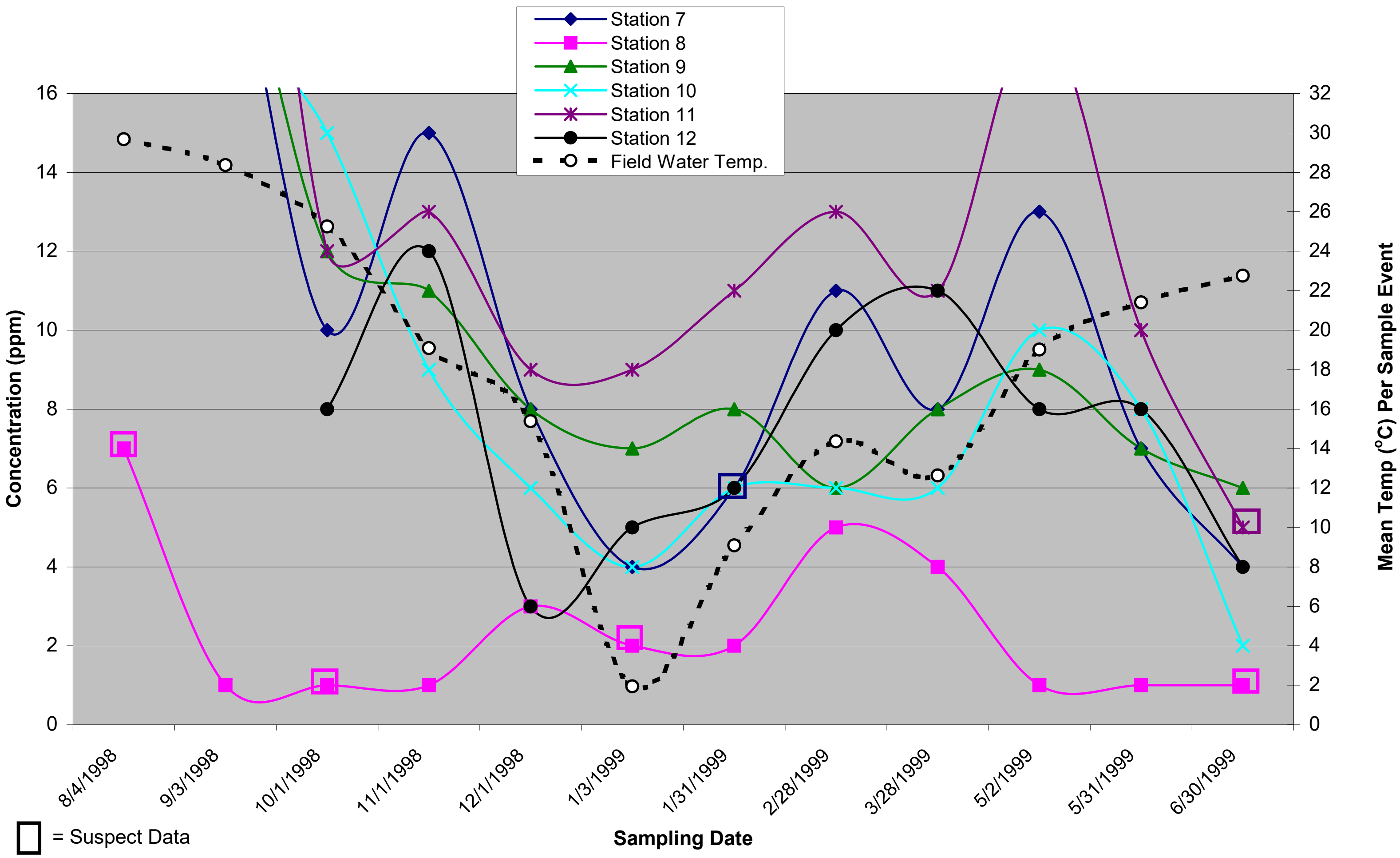


Figure 9 NO3-N Concentration for Sampling Stations #7-#12

From the Box and Whisker Plots in Figures 10 and 11, the sampling stations that depicted the highest NO3-N interquartile variability were Stations #3 (runoff into BD#15E), #6 (BD#26G), and #7 (runoff into BD#26G). Station #11 (Front Basin) had the highest average annual NO3-N concentration (13.80 ppm) and highest median concentration (11.50 ppm), followed by Station #7 (mean = 11.73 ppm and median = 10.00 ppm). Other stations that exhibited high NO3-N interquartile variability included Stations #9, #10, and #12 (see Figure 2). The station that depicted the lowest NO3-N interquartile variability was Station #34 (upgradient or inflow), followed by Stations #1 (Illinois River) and #8 (BD1H). A histogram of the NO3-N test results, exclusive of the suspect data, depicted a concentration of 5 mg/l as having the highest frequency (see Figure 12).

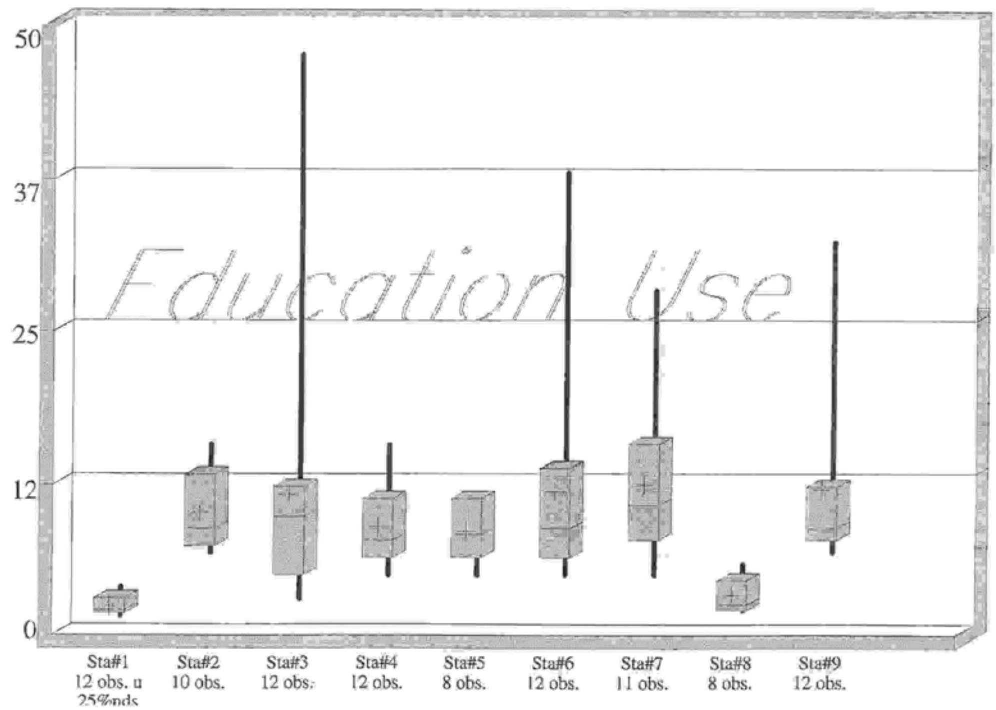


Figure 10. NO3-N Box and Whiskers Plots Station #1

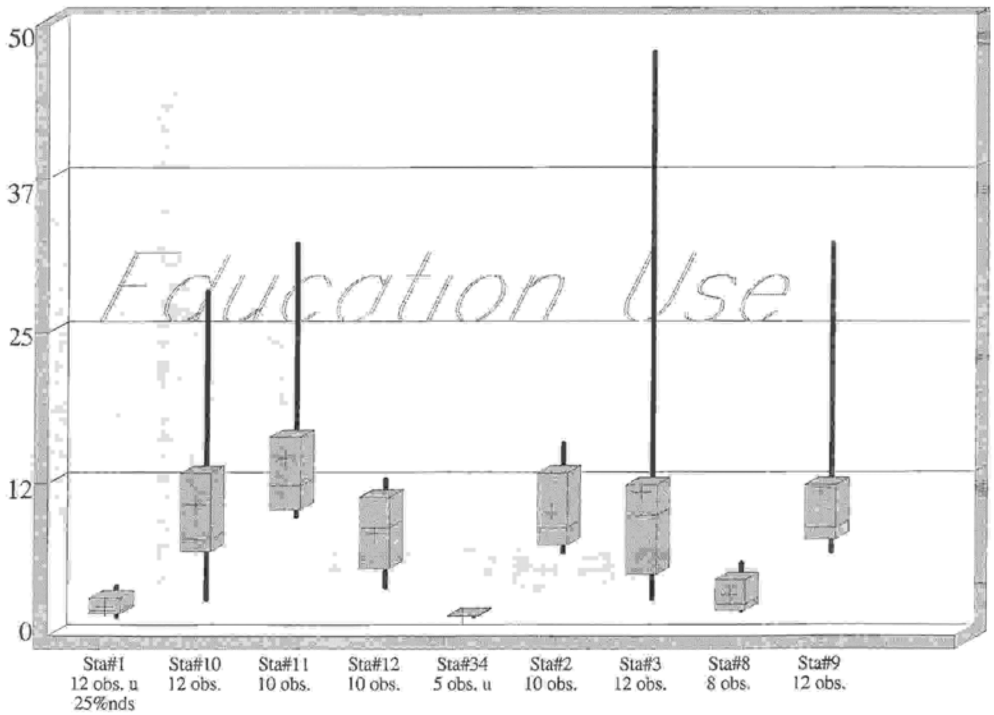


Figure 11. NO3-N Box and Whiskers Plots Other Sampling Stations.

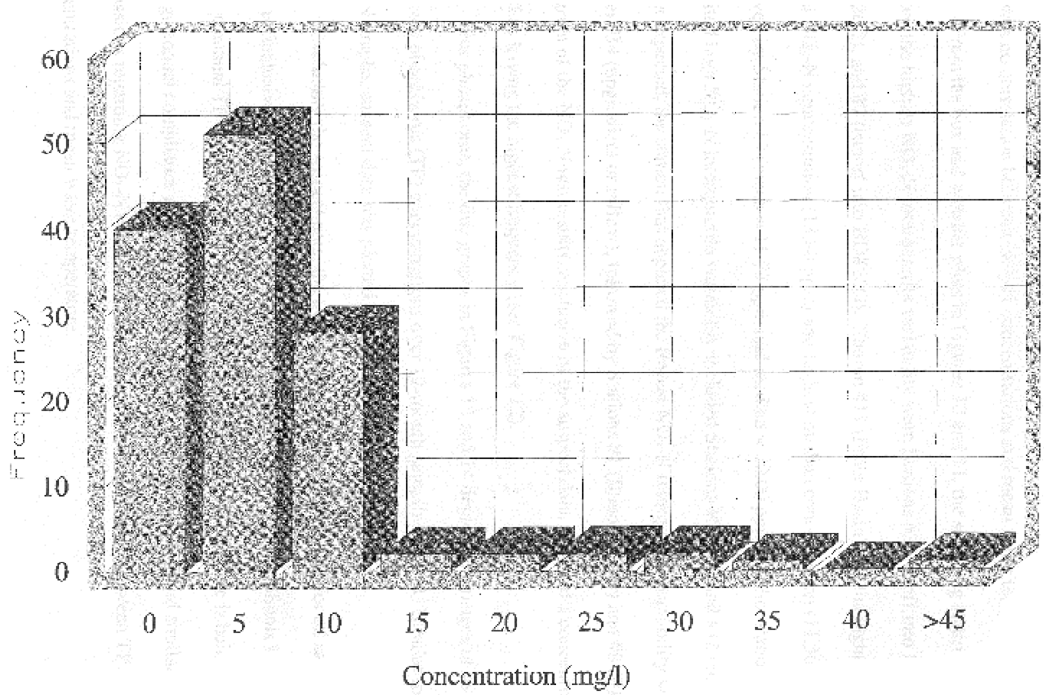


Figure 12. NO3-N Frequency Histogram (suspect data excluded)

Although there was a general decrease of NO3-N concentrations at many stations during the winter months (i.e. see December 1998 and January-February 1999), there was no correlation between NO3-N concentrations and mean water temperature.

For phosphorus, the line graphs in Figures 13 and 14 depict the changes of total dissolved phosphorus (TP) concentrations over 12-month sampling period. Similar to the NO3-N graphs, suspect data was plotted but noted on the graphs.

Excluding the suspect data, the average annual TP concentration for all sampling stations (inclusive of the Illinois River) was 0.56 ppm. Exclusive of the Illinois River, the average annual TP concentration for all stations was 0.60 ppm. This value is below OSDA's average annual compliance agreement of 1.0 ppm for TP. Similar to NO3-N, there was no correlation between TP concentrations and mean water temperature.

Based on a review of the Box and Whisker Plots in Figures 15 and 16, the sampling stations that depicted the highest TP interquartile variability were Stations #3 (runoff into BD#15E), #4 (BD#7A), #7 (runoff into BD#26G), and #12 (above weir in BD#15E). Station #4 (BD#7A) had the highest average annual TP concentration (0.885 ppm) and highest median concentration (0.745 ppm), followed closely by Station #7 (Runoff to BD#26G, with mean = 0.835 ppm and median = 0.740 ppm). Other stations that exhibited high interquartile variability included Stations #2, #5, #6, and #11 (see Figure 2). The station that depicted the lowest TP interquartile variability was Station #34 (upgradient or inflow), followed by Stations #1 (Illinois River) and #8 (BD1H). A histogram of the TP test results, exclusive of the suspect data, depicted a concentration of 0.36 mg/l as having the highest frequency (see Figure 17).

Limited Ammonium (as N) Test Results

Due to historic test results and the OSDA Compliance Agreement, a greater emphasis was placed on NO3-N analysis over other nitrogen compounds. However, to determine the presence and significance of other nitrogen compounds at the study site, ammonium as nitrate (NH4-N) analysis was performed on water samples collected at all stations during the last three (3) sample events (#10, #11, and #12).

According to DeSimone (1998), nitrogen is one of the most common contaminants in ground water. Additionally, infiltration of nitrogen-enriched surface water and subsequent baseflow often provides a mechanism for contaminant loading of nitrogen compounds to a stream or river (Yadav et al, 1998).

As shown in Table 10, NH4-N concentrations averaged approximately 100% of the NO3-N concentrations on sample event #11. For the other two sample events (#10 and #12), NH4-N concentrations averaged approximately 10% of the NO3-N concentrations. This relationship was the same for water in the Illinois River (Station #1) as the onsite sampling stations.

According to Hounslow (1995), ammonification occurs when microorganisms decompose nitrogen compounds to inorganic ammonium salts. Cationic ammonium ($NH4^+$) compounds are strongly adsorbed on mineral surfaces (Hem, 1985). Hem further stated that above a pH of 9.2, the form of most dissolved ammonium ions will be $NH_4OH_{(aq)}$, which is an uncharged species. Feth (1966) stated that most of the nitrogen dissolved in rainwater occurs in the form of ammonium ($NH4^+$) ions. As seen in Figure 4 and other rainfall information presented in Appendix C, the highest 30-day rainfall amount (10.27 inches) occurred during May 1999 prior to sample event #11.

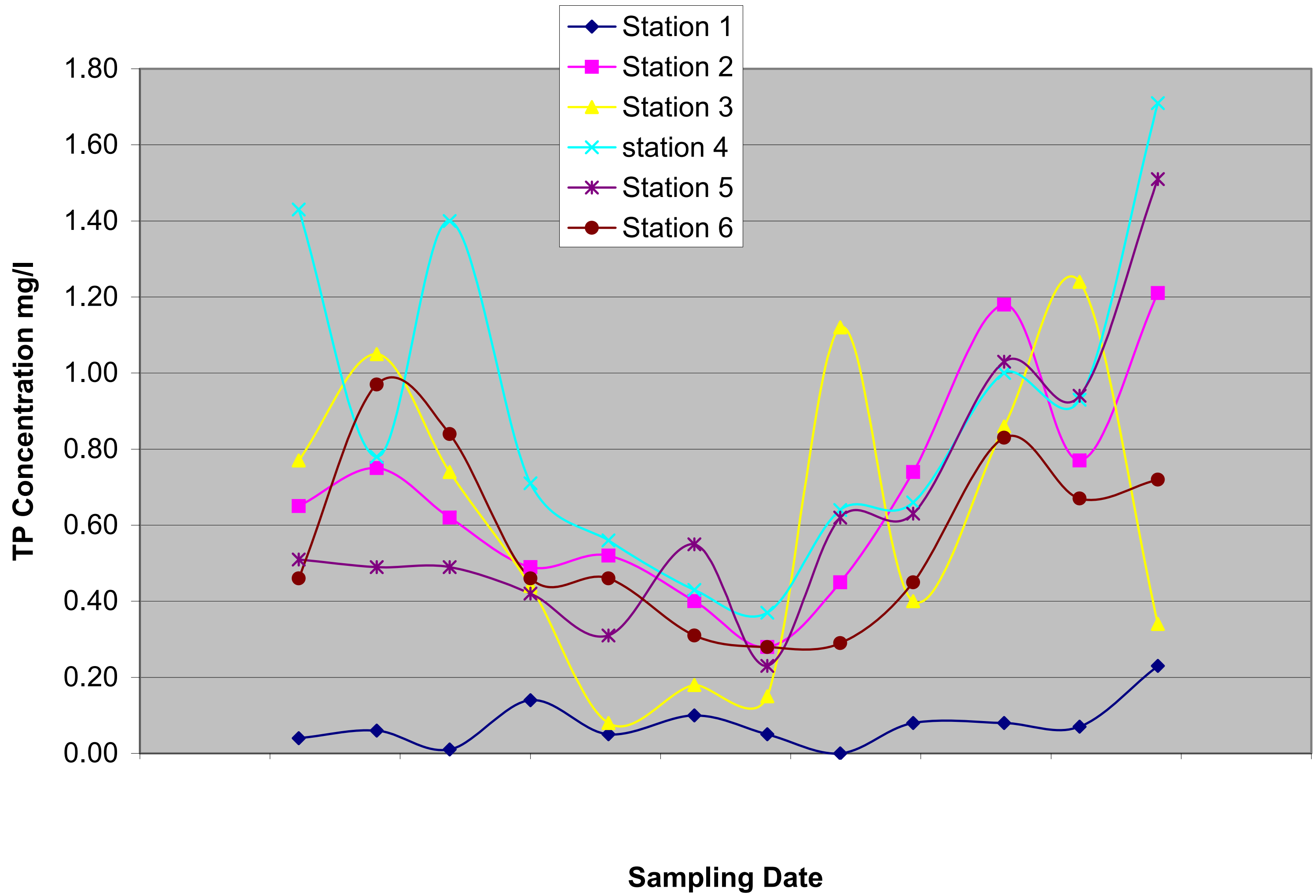


Figure 13. TP at stations 1 through 6 1

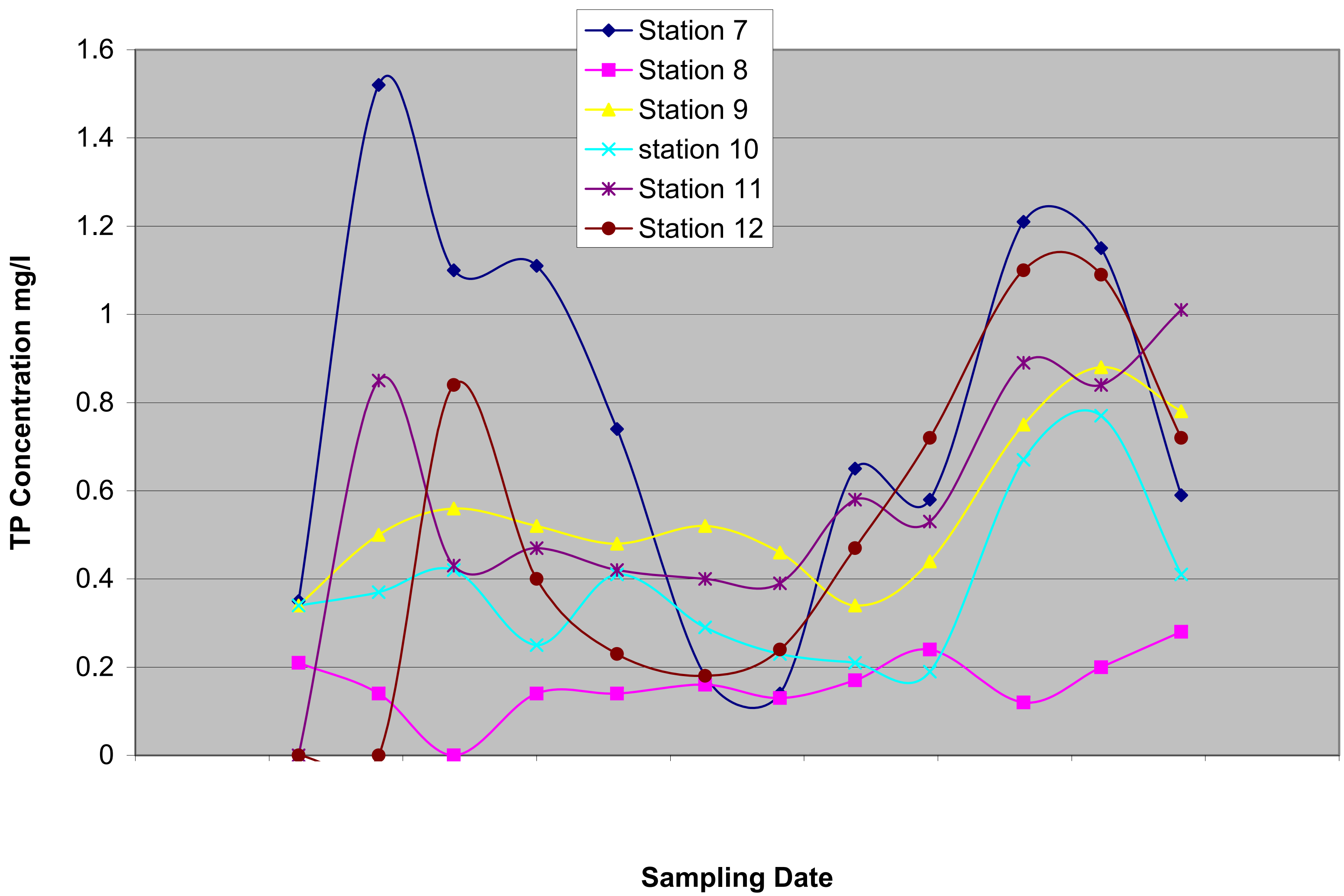


Figure 14. TP at Stations 7 through 12 1

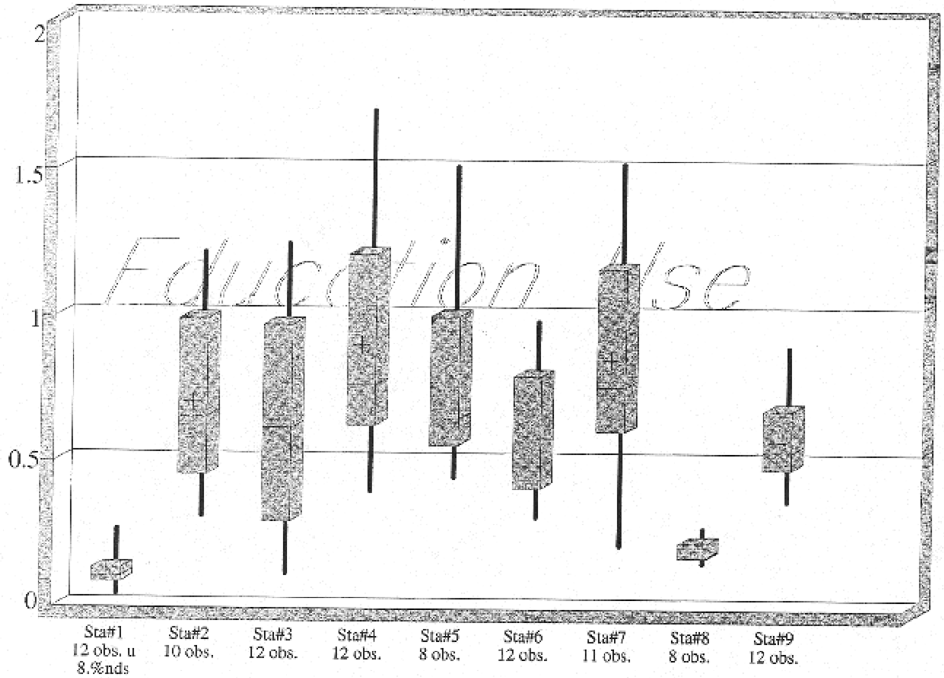


Figure 15. TP B ox and whiskers plots for Stations 1 through 9

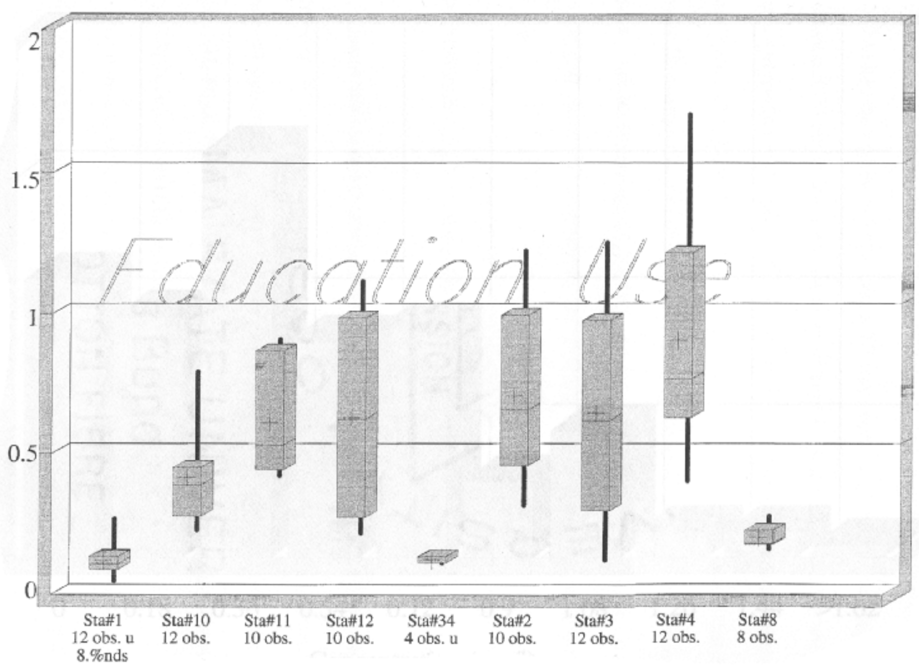


Figure 16. TP B ox and whiskers plots for other sampling stations

Throughout this study, a poor correlation was seen between the field pH and the lab pH, with some differences approaching 2.5 orders of magnitude (see Figures 18 and 19 for examples of field pH vs. lab pH for Stations #7 and #12). On sample event #11, the field pH "facility mean" of all samples including the Illinois River was 9.02, while it was 8.54 and 8.42 on sample events #10 and #12, respectively. For sample event #11, the laboratory pH facility mean of all samples including the Illinois River was 7.72. The lab pH value of 7.72 was the highest facility mean and it exhibited the lowest laboratory standard deviation (0.13) for lab pH values of all sample events in this study. Thus, the increase of pH of water secured during sample event #11 is the most plausible explanation for the one (1) order of magnitude increase (from 10% to 100%) of NH4-N concentrations relative to NO3-N concentrations.

Historic vs. Recent Test Results

In order to evaluate the change of NO3-N and TP concentrations over time at the study site, historic test results for inflow, the Illinois River, and outflow samples were retrieved from historic documents. As discussed in Chapter 3 of this report, there are five (5) sampling stations at the study site that have been consistently sampled and analyzed over time. Identifiable in studies by Houghton (1984), The Curtis Reports (1989-1996), and this study (1999), the stations that have been consistently sampled over time include:

- the Illinois River,
- the Waterfall Outfall (discharge)
- the creek near the front gate and/or discharge from the Front Basin,
- upgradient (inflow or background) samples from the south slope of Mahaney Mountain, and
- collective offsite discharges or outflows from the southeast portion of the property to the Illinois River.

Table 10 Comparison of NO3-N to NH4-N Concentrations of 12 Sampling Stations for 3 Sampling Events

Sample Station Description	Sample Sta. and Event Number	NO3-N Conc. (ppm)	NH4-N Conc. (ppm)	Summation of NO3 + NH4 as N (ppm)
	#1-10	1	0.3	1.3
Illinois River	#1-11	1	1.1	2.1
	#1-12	1	0.1	1.1
	#2-10	11	0.4	11.4
BD#15E	#2-11	7	6.4	13.4
	#2-12	6	0.7	6.7
	#3-10	8	0.0	8.0
Runoff into BD#15E	#3-11	11	10.6	21.6
	#3-12	3	0.4	3.4
BD#7A	#4-10	10	0.6	10.6
	#4-11	9	9.0	18.0
	#4-12	4	1.5	5.5
BD#5B	#5-10	10	0.5	10.5
	#5-11	6	5.3	11.3
	#5-12	4	0.8	4.8
BD#26G	#6-10	13	1.0	14.0
	#6-11	6	5.8	11.8
	#6-12	4	0.3	4.3
	#7-10	13	0.6	13.6
Runoff into BD#26G	#7-11	7	6.2	13.2
	#7-12	4	0.3	4.3
	#8-10	1	0.2	1.2
BD#1H	#8-11	1	0.9	1.9
	#8-12	1	0.3	1.3
BD#17D	#9-10	9	0.3	9.3
	#9-11	7	8.0	15.0
	#9-12	6	0.4	6.4
BD#9D	#10-10	10	0.5	10.5
	#10-11	8	6.8	14.8
	#10-12	2	0.3	2.3
BD#8C	#11-10	18	1.4	19.4
	#11-11	10	10.1	20.1
	#11-12	5	0.5	5.5
BD#15E	#12-10	8	0.0	8.0
(at Weir)	#12-11	8	7.4	15.4
	#12-12	4	0.5	4.5

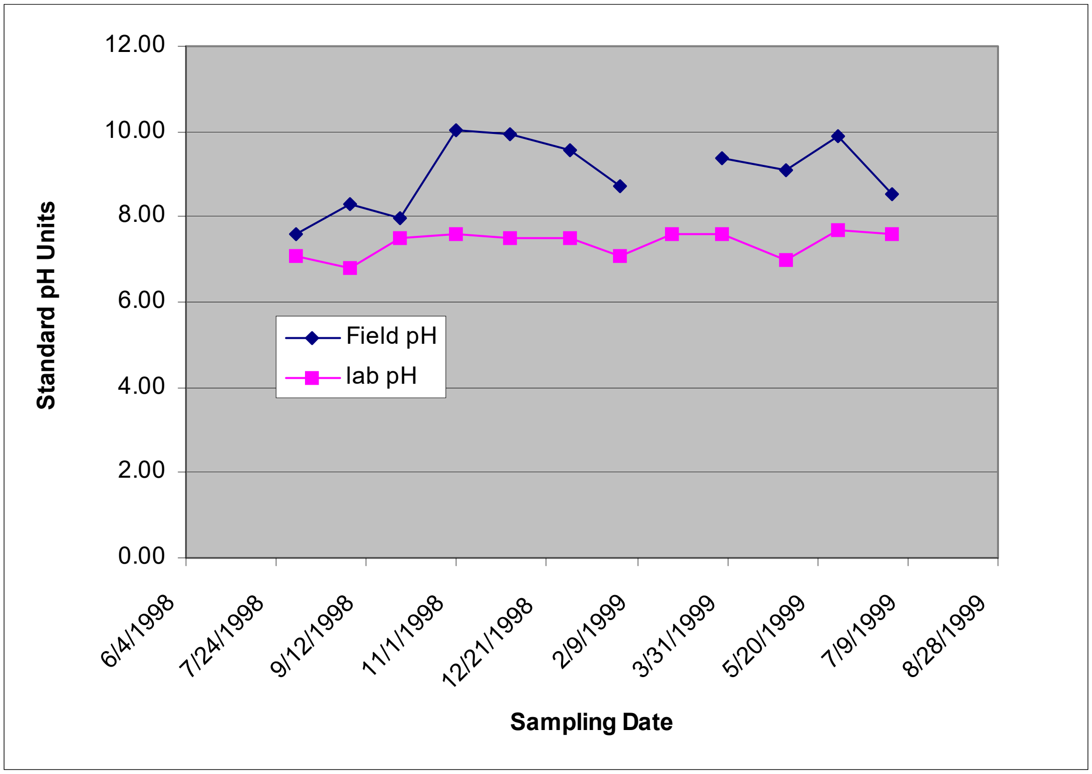


Figure 18. Field pH vs. lab pH, Station 7

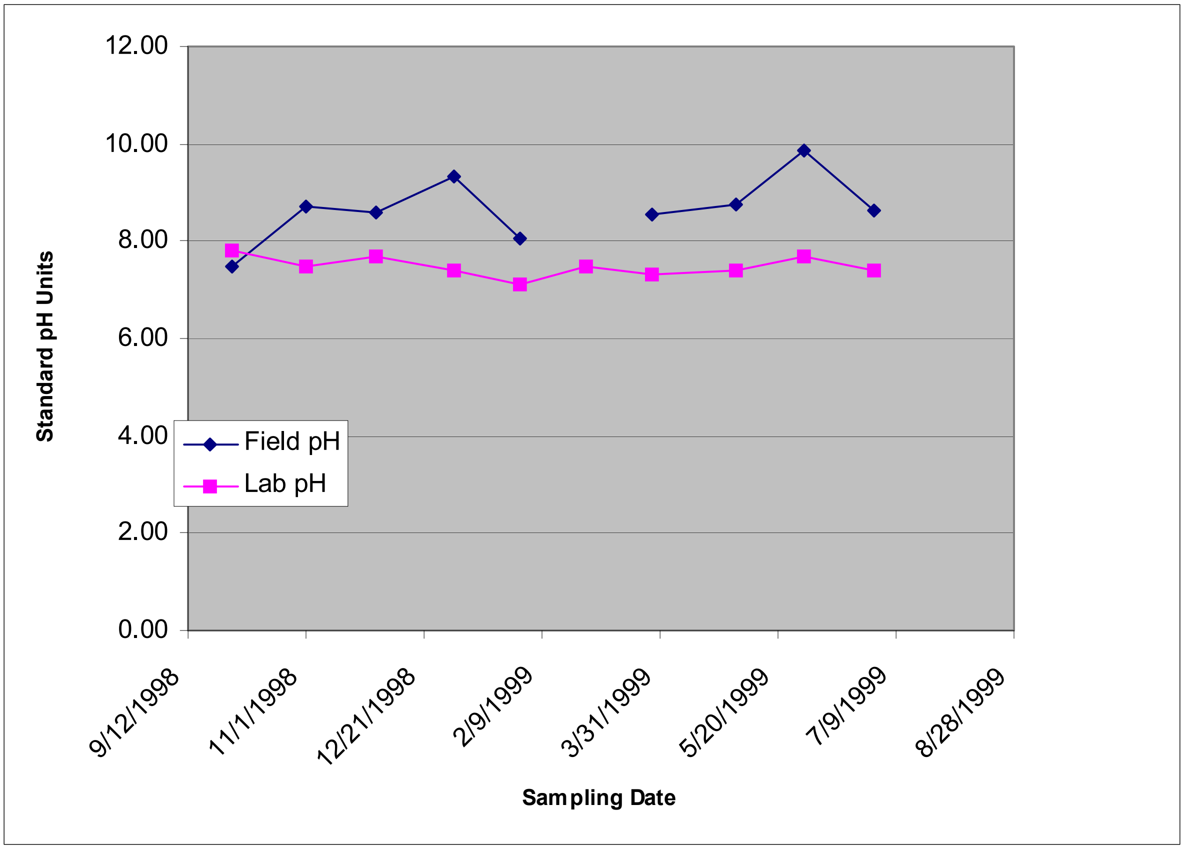


Figure 19. Field pH vs. Lab pH, Station 12.

Historic test results from Houghton (1984) and The Curtis Reports (1989-1996) of NO3-N and TP from the five (5) listed stations have been summarized in Table 11 and 12, respectively. For comparative purposes, test results provided in this study have also been included in the following tables.

Table 11Comparison: Average NO3-N concentrations (ppm) from historical studies

Date	Sample Station No.				
Houghton(OSDA)	1	4	3		2
Curtis Reports	IT-1	IT-2	IT-3a	IT-4 & 5	IT-6
Alexander	Ill. River	Waterfall	Discharge	#34	Discharges From
	#1	Outfall	From #8C	(Upgradient)	BD#15E, 26G, 5B
1975-1977	0.70	16.40	15.40		12.10
1989	1.84	30.22	18.08		44.75
1990	1.11	32.91	14.44		21.45
1991	1.29	12.05	18.31		24.94
1992	1.08	8.58	15.65		14.48
1993	1.11	6.24	11.85		9.30
1994	1.10	10.53	6.97		8.57
1995	0.81	10.13	6.56	0.07	4.27
1996	1.18	8.65	9.01	0.42	13.12
1998-1999	1.29	6.14	10.00	<1.00	7.92

Table 12 Comparison: Average Phosphate-P concentrations (ppm) from historical studies

Date	Sample Station No.				
Houghton(OSDA)	1	4	3		2
Curtis Reports	IT-1	IT-2	IT-3a	IT-4 & 5	IT-6
Alexander	Ill. River	Waterfall	Discharge	#34	Discharges From
	#1	Outfall	From #8C	(Upgradient)	BD#15E, 26G, 5B
1975-1977	0.10	0.27	0.31		0.28
1989	0.38	1.63	0.37		0.43
1990	0.08	1.11	0.55		0.47
1991	0.15	1.86	0.65		0.60
1992	0.10	1.13	0.46		0.44
1993	0.11	1.09	0.61		0.60
1994	0.16	1.37	0.43		0.44
1995	0.09	1.29	0.68	0.10	0.51
1996	0.12	0.80	0.51	0.07	0.41
1998-1999	0.08	0.79	0.78	0.08	0.68

Inflow

From Tables 11 and 12, upgradient or inflow samples in The Curtis Reports (see Sample Stations IT-4 & 5) depicted an average annual NO3-N concentration of 0.07 ppm in 1995 and 0.42 ppm in 1996 in an intermittent stream that flows onto the study site. Although Sample Station #34 identified in this study is in a different geographical location than those identified in The Curtis Reports, Station #34 was nonetheless an upgradient station to the subject property (see Figure 2). At Station #34, test results reported an average annual NO3-N concentration of <1.00 ppm (less than detection limits) from a total of eight (8) 'run-on' or inflow samples, five (5) of which were deemed reliable (see Appendix B). Based on these analyses, it appears that no significant changes in NO3-N concentrations has occurred in upgradient or background samples since 1995.

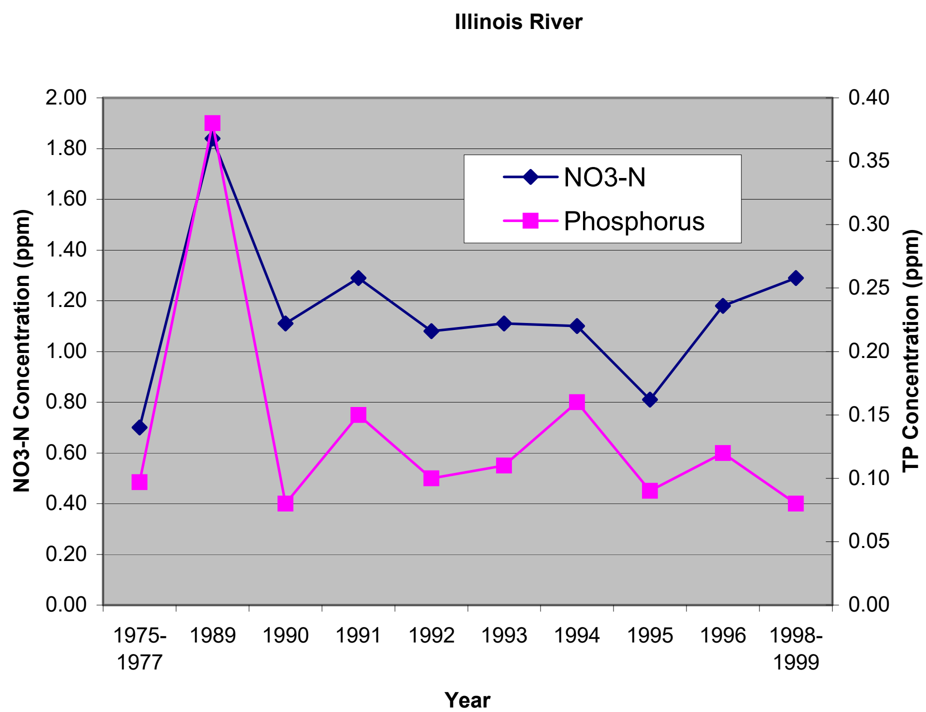
Regarding phosphorus, upgradient or inflow water samples in The Curtis Reports had an average annual TP concentration of 0.10 ppm and 0.07 ppm for the years 1995 and 1996, respectively (See Sampling Stations IT-4 & 5 in Table 12). For Sample Station #34 described in this study, the average annual TP concentration for 1998-1999 was 0.08 ppm. As expected, no apparent or significant change in TP concentrations has occurred in upgradient or background samples since upgradient sampling began in 1995.

Illinois River

Water from the Illinois River adjacent to the study site has been sampled over time and analyzed for NO3-N, TP and other dissolved constituents. From the test results summarized in Table 11 and depicted in Figure 20, the lowest average annual NO3-N concentration of Illinois River water was 0.70 ppm in 1975-1977, and the highest average annual NO3-N concentration was 1.84 ppm in 1989. From Table 12 and Figure 20, the lowest average annual TP concentration in Illinois River water was 0.08 ppm in 1990 and in 1998-99, while the highest average

Figure 20. NO3-N and TP Concentrations in Illinois River

annual TP concentration was 0.38 ppm in 1989. Because phosphorus is known to be the limiting factor in aquatic systems and the primary cause for eutrophication, algal blooms, and other adverse affects, it was encouraging to discover the lowest TP concentrations occurred in 1998-1999. This finding suggests that the collective efforts to minimize discharges from Greenleaf and others located upgradient of the study site are having a favorable effect on the Illinois River.



For NO3-N and TP, the highest average annual concentrations in the Illinois River water occurred in 1989 (see Figure 20), which coincides with the initiation of significant efforts by the OSDA regarding point source and non-point source discharges to the river. The reduction of these nutrients in the Illinois River over time suggests that the regulatory efforts and oversight of discharges have been successful.

Outflow

There are three (3) separate outflow stations at the study site that appear to be consistent in both historic and recent studies, including:

- the Waterfall Outfall,
- the front creek or outflow from the front basin, and
- the collective discharges from various retention basins near the southeast portion of the facility.

Following is a discussion of the historic vs. recent NO3-N and TP test results for the previously identified stations.

Waterfall Outfall. At the Waterfall Outfall, the highest average annual NO3-N concentration of 32.91 ppm occurred in 1990 (see Table 11 and Figure 21). Although considered to be high by current (1999) standards, this value did not exceed, at that time, the average allowable discharge NO3-N concentration of 41.0 ppm per the OSDA Permit. The lowest average annual NO3-N concentration reported was 6.14 ppm in 1998-99, which was obtained in this study by averaging three (3) separate storm water discharges or outflows from the Waterfall Outfall. This suggests that the capture and recycling efforts by Greenleaf, perhaps combined with reduction in their use of liquid ammonium nitrate over the past decade (see Table 2), has had a favorable affect on minimizing nutrient discharges from this outflow.

Regarding phosphorus, the highest average annual TP concentration at the Waterfall Outfall was 1.86 ppm in 1991 (see Figure 21), and the lowest average annual TP concentration was 0.27 ppm in 1975-77 (Houghton, 1984). The second lowest average annual TP concentration was 0.79 ppm in 1998-99 as described in this report. Based on NO3-N and TP test results of historic vs. current Waterfall Outfall discharge samples, the designed curbing system that allows storm water to completely bypass BD#7A has been effective in its function and performance, resulting in minimizing NO3-N and TP concentrations in storm water discharges from the facility.

Front Creek. The front creek is located immediately east of and parallel to State Highway 82 near the front gate of study site. This creek historically and currently receives discharge from the Front Basin (BD#8C). As seen in Table 11 and Figure 22, the highest average annual NO3-N concentration in the front creek was 18.31 ppm in 1991. The lowest average annual NO3-N concentration was 6.56 ppm in 1995.

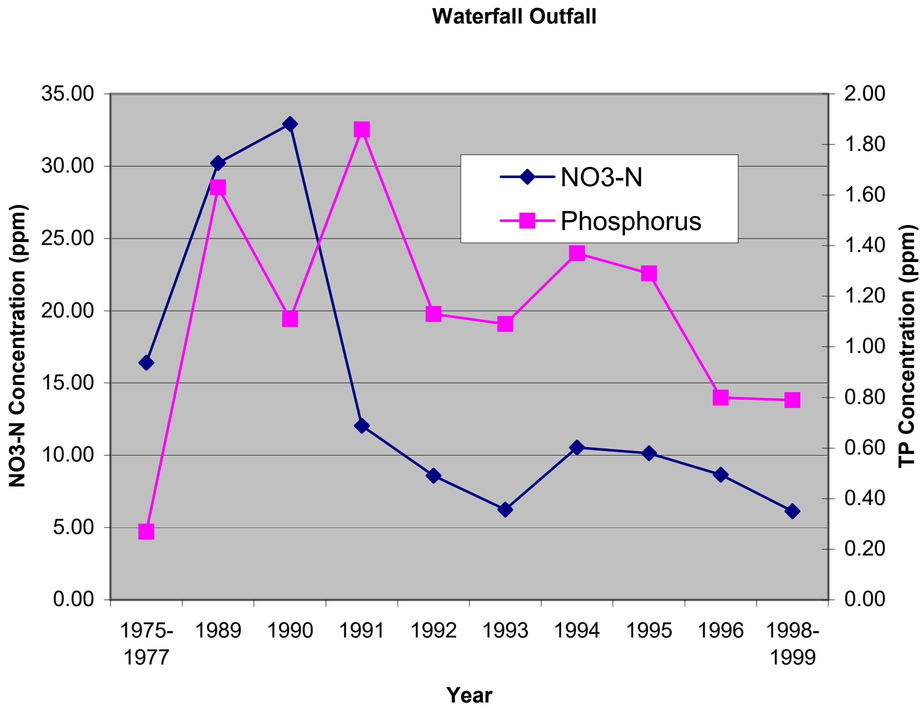


Figure 21. NO# and TP Concentration in Waterfall Outfall.

Based on one (1) storm water sampling event per this study, discharge from the Front Basin (BD#8C) was 10.0 ppm. Per the OSDA permit, 10.0 ppm is the average annual discharge allowable NO3-N concentration and 15.0 ppm is the maximum discharge allowable NO3-N concentration for a single event (see Table 6).

For phosphorus, the highest average annual TP concentration of 0.78 ppm was seen in 1998-1999 (see Table 12 and Figure 22), which is below the OSDA discharge permit allowable of 1.0 ppm.

In late 1997 and the first half of 1998, the Front Basin (BD#8C) was completely drained, redesigned, and reconstructed by Greenleaf personnel. Thus, the 1998-1999 increases in TP and NO3-N concentrations are most likely a result of dirt work and other construction activities in the area. It is expected that discharge concentrations of both NO3-N and TP constituents will decrease in the following years now that construction activities are completed and the basin is fully operational.

Collective Discharges from Various Retention Basins. Regarding offsite discharges, Houghton and OSDA established a sample station in the Corps of Engineer's buffer zone where several outflows from the study site converge near the edge of the Illinois River. This historic sample station was located immediately north of Sample Station #5 at BD#5B in this report (see Figure 2), and was identified as Station #2 in the Houghton (1984) Report and Station IT-6 in The Curtis Reports (1989-1996). For comparative purposes, all storm water discharges sampled in this study that outflow to the historic sample station were averaged.

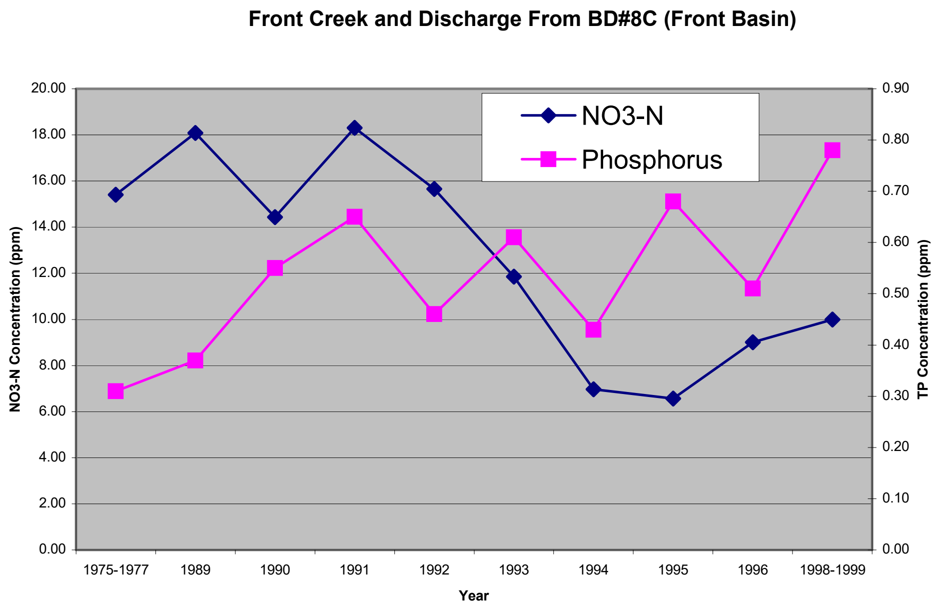


Figure 22. NO3-N and TP Concentration in Front Creek and Discharge from BD#8C

Based on a collective total of eight (8) outflows from BD#15E, BD#26G, and BD#5B, the average NO3-N concentration reported in this study was 7.92 ppm, the second lowest (see Table 11 and Figure 23). The lowest average annual NO3-N concentration was 4.27 ppm in 1995.

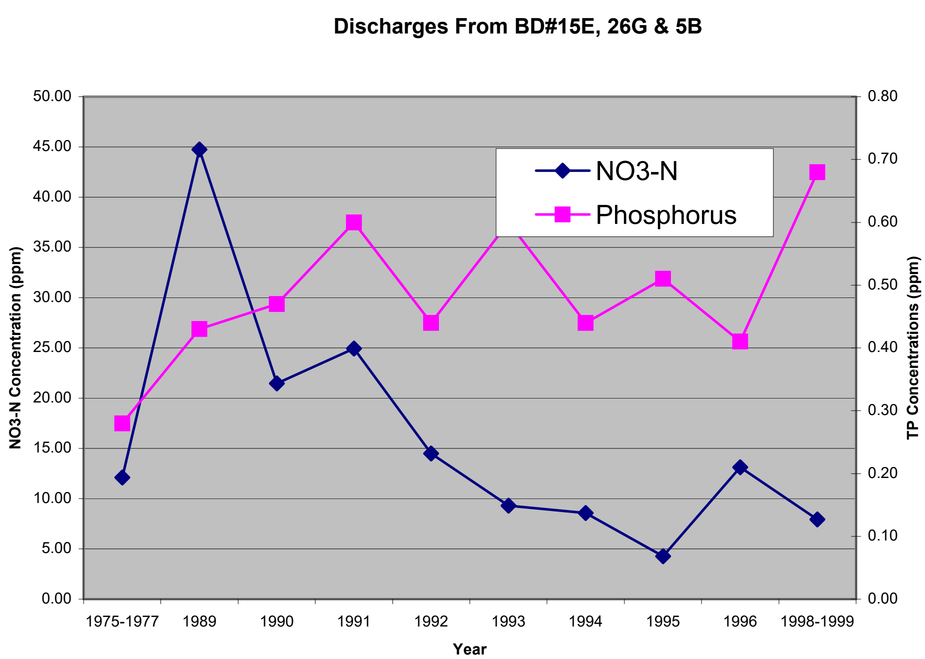


Figure 23. NO3-N and TP Concentrations from BD#15E, #26G, and #5B.

For phosphorus, the lowest TP concentration was 0.28 ppm in 1975-1977, and the second lowest TP concentration was 0.41 ppm in 1996 (see Table 12 and Figure 23). The average annual TP concentration per this study was 0.68 ppm, which is below the value of 1.0 ppm as stated in the OSDA permit. Although it is below the permit discharge compliance standards of 1.0 ppm for TP, the 1998-1999 concentration is the highest seen at this station. The difference may be a result of the methodology used in this study to determine an average concentration rather than securing samples directly at the historic location.

Spatial and Temporal Patterns

To evaluate the spatial and temporal patterns at the study site, a total of 28 different sets of samples were analytically "mixed" in this study. Analytical mixes were performed using the *WATEVAL* (Hounslow, 1995) 3-analyses mixing routine. The resulting mixes that had a correlation coefficient (R^2) greater than or equal to 0.960 are summarized in Appendix E.

General Discussion

The mathematical mixing and evaluation of all possible combinations (12^3 or 1728) at the site would have been impractical. Thus, the criteria for selecting which samples to mix were based on the logical expectation that a specific mix could occur at the study site from a topographical or hydrological perspective. When a 3-station combination was selected for further evaluation, all twelve (12) sample events for that set of stations were mixed, including those with suspect data.

For this study, there were 28 sets of 3-station combinations that were analyzed using the selection criteria described above. This resulted in the mixing of 336 (28 sets x 12 analyses per set) individual mixtures. Of the 336 individual mixtures attempted, 188 or 56.0% (188/336 x 100) meet the strict acceptance criteria of $R^2 \geq 0.960$.

Of the 28 different sets of stations that were mixed, only 2 sets or 7.1% (2/28 x 100) reported the same final mixture in the mixes that met the acceptance criteria (see Stations 1, 6, 7 and Stations 1, 7, 11 in Appendix E). Five (5) sets reported the same final mixture with one (1) exception (see Stations 2, 3, 8, Stations 2, 3, 34, Stations 3, 12, 34, Stations 6, 9, 34 and Stations 7, 8, 10). The remaining 21 sets of stations that were evaluated using the 3-analyses mixing routine reported various and inconsistent final mixtures, with a final mixture that did not necessarily represent the most logical or expected result.

As seen in Appendix E, there were 188 individual mixing calculations that met the stringent acceptance criteria. Of this, 119 or 63.3% (118/188 x 100) occurred during the sampling events that represented storm conditions (see discussion in following subsection). The remaining 36.7% (69/188 x 100) individual mixing calculations represent non-storm conditions.

As expected, and based on the findings discussed above, it appears that a significant amount of surface water mixing has occurred at the site. The significant degree of mixing and unpredictability of final mixtures is further expected to mask many spatial and temporal patterns at the site that would otherwise be obvious or apparent.

Spatial and Temporal Patterns For Storm Conditions

One objective of this study was to determine the spatial and temporal patterns of NO3-N and TP at the facility during storm conditions. Two (2) different methods were used to accomplish that objective. First, the acceptable calculations in Appendix E of those stations mixed during storm conditions were reviewed for spatial and temporal patterns. Second, water samples were collected and analyzed during storm conditions from an upgradient station, the retention basins, and outflows of storm water discharges.

On several occasions, rainfall and storm water discharges occurred during regular sampling events. The regular sampling events and their corresponding dates that represented storm conditions at the study site included the following:

- Sample Event #3 on 10/1/98,
- Sample Event #4 on 11/1/98,
- Sample Event #5 on 12/1/98,
- Sample Event #6 on 1/3/99,
- Sample Event #7 on 1/31/99,
- Sample Event #11 on 5/31/99, and
- Sample Event #12 on 6/30/99.

Storm water discharge samples were collected from one or more retention basins on each date listed above except for sampling event #12. Thus, 7 out of 12 regular sampling events, or 58.3%, represented storm conditions at the study site. In addition to those identified above, storm conditions prevailed and storm water discharge samples were collected for analyses on April 3, 1999.

As discussed, there were five (5) other dates when the author made a trip to the facility for the expressed purpose to collect storm water discharge samples, only to discover that discharges from the facility were not occurring. These dates include August 10, 1998, September 13, 1998, September 23, 1998, March 7, 1999, and April 24, 1999. On the referenced dates, weather reports indicated an approaching frontal system or other favorable conditions for storm conditions. However, upon arrival at the facility, water elevations in the retention basins were below their respective spill points and no discharges or overflows occurred, resulting in a "dry run". Although it is an indirect measurement, this information is an indicator of the efficiency regarding the retention basins and capture and recycle technology in minimizing offsite discharges.

Inflow

An upgradient sample station was established to provide information on background water quality concentrations. Identified as Station #34 and located near the northwest corner of the facility, the station receives overland flow from the upgradient property. Except for the Del Ranch Restaurant and Highway 82, the upgradient property consists of steep, undeveloped forestland.

Over a 12-month period, Station #34 was sampled on eight (8) separate occasions. As summarized in Appendix A and B, the first three analyses are suspect due to excessive cation-to-anion ratios. However, based on five (5) acceptable analyses, the average NO3-N concentration was less than analytical detection limits (<1.00 ppm) and the average TP concentration was 0.08 ppm.

Onsite

A review of acceptable 3-analyses mixes summarized in Appendix E depict the following onsite patterns during storm conditions:

Based on an average of four (4) acceptable mixes, the water contained in BD#17D (Sta. #9) mathematically consisted of ~82% water pumped into it from BD#26G (Sta. #6) and ~19% of storm water runoff originating from upgradient properties (Sta. #34).

Based on an average of three (3) acceptable mixes, the water contained in BD#26G (Sta. #6) mathematically consisted of ~87% runoff water that flows into it (Sta. #7) and 13% Illinois River water (Sta. #1).

Based on an average of four (4) acceptable mixes, water contained above the weir in BD#15E (Sta. #12) mathematically consisted of ~64% creek runoff water that flows into it (Sta. #3) and ~36% of water contained in the larger body of water at BD#15E (Sta. #2).

Based on an average of four (4) acceptable mixes, water contained in BD#9D (Sta. #10) mathematically consisted of ~83% creek runoff (Sta. #3) and ~17% of water contained in BD1H (Sta. #8).

Another method used to evaluate the change in NO3-N and TP concentrations in the retention basins over time was a review of the actual test results, rather than reliance upon mathematical calculations, on those dates that storm conditions were present.

Figure 24 depicts the overall annual average of NO3-N concentrations at all sampling stations, exclusive of the suspect data (see Appendix B). It also depicts the average NO3-N concentrations of those regular sample stations that were sampled during storm conditions, including sample events 3, 4, 5, 6, 7, 11, and 12. Figure 24 further depicts the average NO3-N concentrations for those regular stations that were sampled during non-storm conditions, including sample events 1, 2, 8, 9, and 10. From Figure 24, the NO3-N concentration at all sampling stations decreased during storm conditions. Based on the high solubility of NO3-N in water and its dilution in rainwater and runoff water, this finding was expected.

Figure 25 depicts the overall annual average of TP concentrations at all sampling stations, exclusive of the suspect data (see Appendix B). It also depicts the average TP concentrations for those regular sample stations that were sampled during storm conditions, including sample events 3, 4, 5, 6, 7, 11, and 12. It further depicts the average TP concentrations for those regular sample stations that were sampled during non-storm conditions, including sample events 1, 2, 8, 9, and 10.

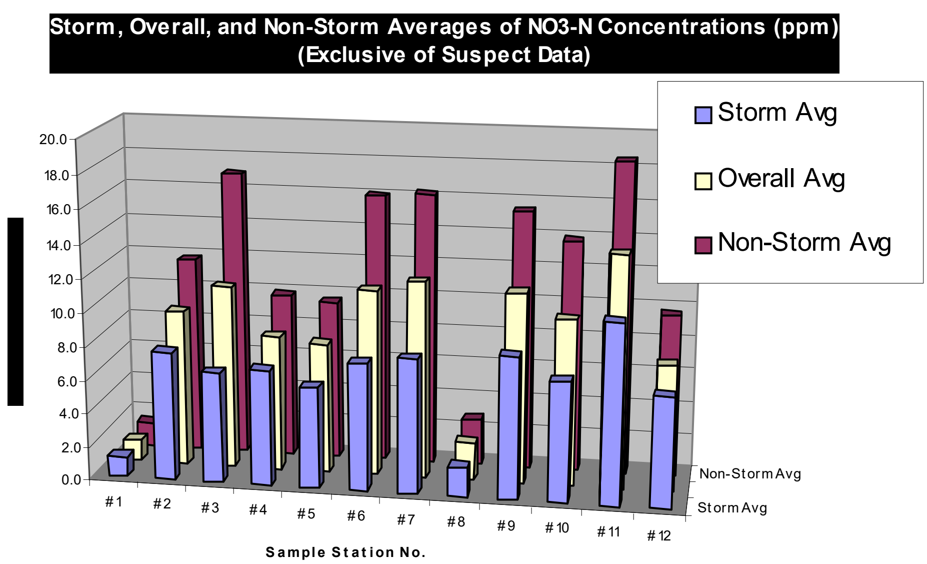


Figure 24. Storm, Overall, and Non-storm Average NO3-N Concentation for all Sampling Events.

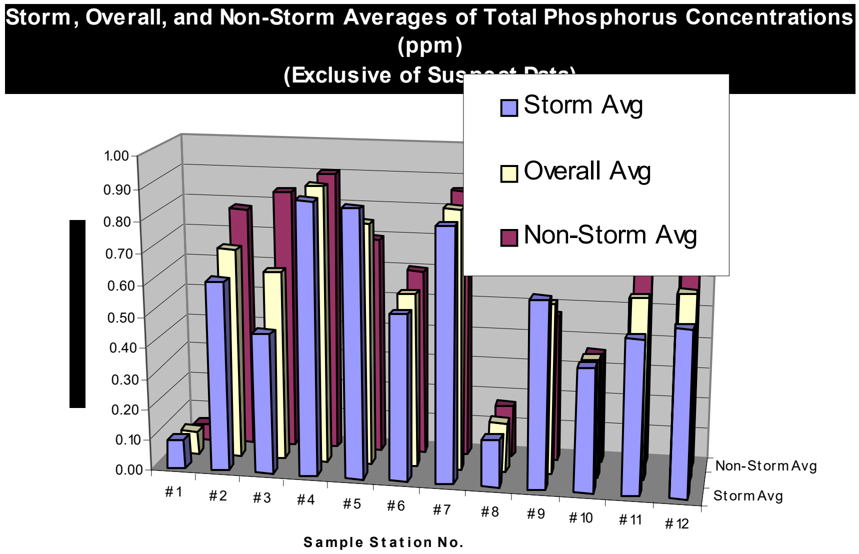


Figure 25. Storm, Overall, and Non-storm Average TP Concentation for all Sampling Events.

Contrary to the findings depicted in Figure 24 for NO3-N, Figure 25 depicts several sampling stations that exhibited higher TP concentrations during storm conditions. These stations include Station #1 (Illinois River), Station #5 (BD#5A), Station #9 (BD#17D), and Station #10 (BD#9D). Of these, Stations #5 (BD#5A) and #9 (BD#17D) exhibited the greatest impact of phosphorus loading during storm events. Due to the tendency for phosphorus to adsorb and chemically bind with solid particles, this finding suggests that BD#5B and BD#17D may be more susceptible to total dissolved phosphorus and sediment loading rates during storm events relative to the other basins.

Outflow

A review of acceptable 3-analyses mixes summarized in Appendix E depicted the following outflow pattern during storm conditions:

Based on one (1) acceptable mix, water in the Illinois River (Sta. #1) mathematically consisted of ~81% of water contained in BD#17D (Sta. 9) and ~19% of storm water originating from upgradient properties (Sta. #34).

Although a total of eight (8) sets of mixes were performed using test results from Station #1, no other spatial or temporal patterns were established for the Illinois River during storm conditions using the 3-analyses mixing method.

Another method used to evaluate the change in NO3-N and TP concentrations in discharges from outflows over time was a review of the actual test results, rather than reliance upon mathematical calculations, on those dates that storm events occurred. A total of twelve (12) outflow or storm water discharge samples were collected for this study. Although an emphasis was placed on discharges from BD#15E and BD#26G, at least one discharge sample was collected and analyzed from each of the five (5) outfalls present at the study site.

The first storm water discharge sample was collected from BD#15E on October 1, 1998. As depicted in Figure 26, NO3-N concentrations onsite were greater than 10.0 ppm, but reduced in concentration as rainfall runoff exceeded the basin's holding capacity and offsite discharge began. A complete set of graphs of storm water discharges is presented in Appendix D in this report.

As seen by the storm water graphs in Appendix D, most storm water discharge events were below the acceptable limits for NO3-N and TP set by OSDA in the Compliance Agreement. However, one storm water discharge that exceeded the maximum limits was from BD#5B (see Figure 27 dated 4-3-99). In this discharge event, the highest NO3-N and TP concentrations were 29.0 ppm and 2.36 ppm, respectively. Prior to the initiation of rainfall on that day, BD#5B was at or near total capacity and was unable to hold the first flush of the storm event. However, within 15 minutes of the first discharge, NO3-N and TP concentrations dropped to ~11.0 ppm and ~1.2 ppm, respectively.

By comparing the monthly test results of BD#7A (Station #4) to two (2) separate discharges from the Waterfall Outfall (Storm Water Graphs #6 and #10), it is apparent that the curbing system used to bypass BD#7A during runoff of storm water has been successful. The curbing system is designed to reroute and capture a storm event's initial flush. However, as the surface water elevation rises with increased rainfall and runoff, surface water runoff flows over the elevated curb and discharges through the Waterfall Outfall.

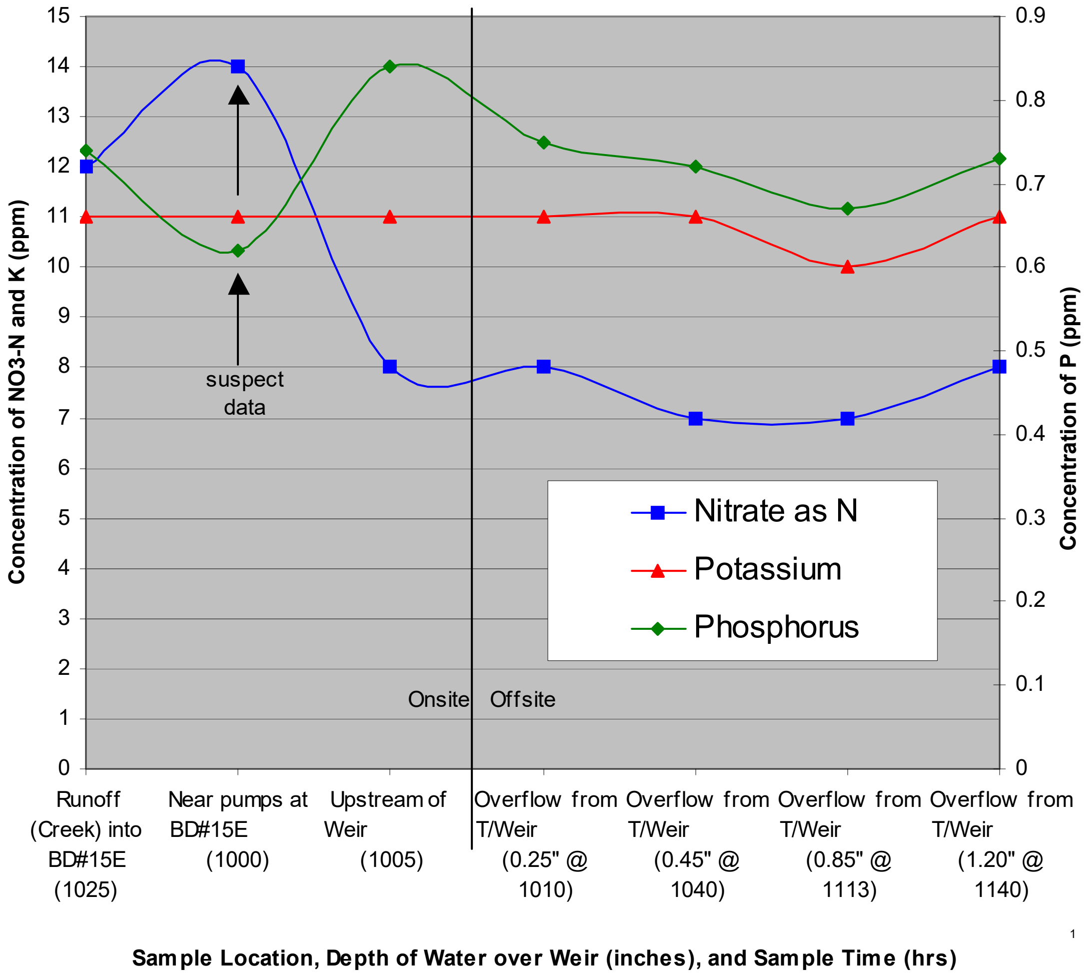


Figure 26. Storm Water discharge from BD#15E (10-1-98)

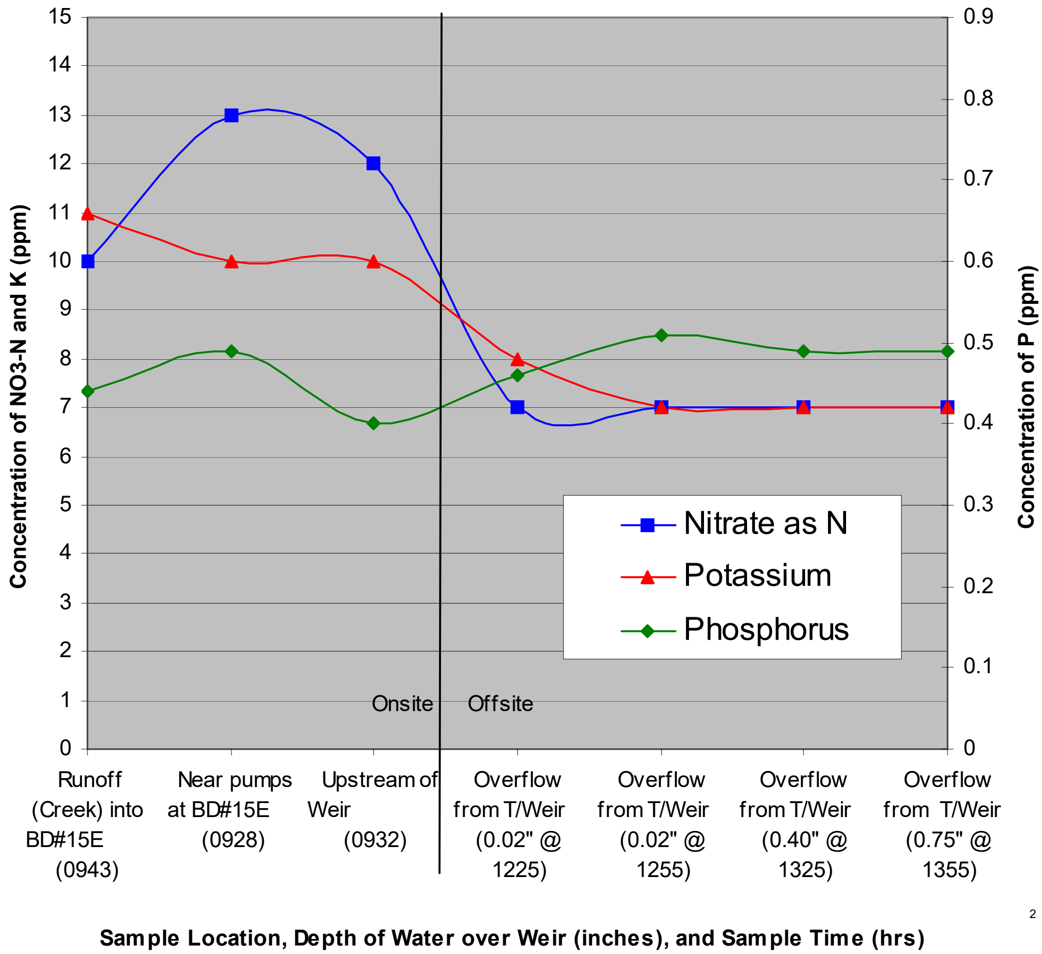


Figure 27. Storm WaterDischarge from BD#5B (4-3-99)

The 3-sample analysis subroutine in the *WATEVAL* program (Hounslow, 1995) was used to determine the percent concentrate (C), percent dilute (D), and final mixture (M) of all storm water discharges. Acceptance criteria for the mixing routine included the following: (1) storm water mixtures of the 3 samples selected for analyses must be in the correct geographic or hydrologic order, and (2) the correlation coefficient (R^2) must be equal to or greater than 0.96.

As previously discussed, a correlation coefficient equal to or greater than 0.960 is considered to be stringent, but was necessary at the study site due to pumping and recycling activities that result in the continuous mixing of surface waters. The following table (Table 13) summarizes only that data that met or exceeded the acceptance criteria.

Table 13.

Storm Water Mixing Using *WATEVAL's* 3-Sample Analysis Routine

Storm Wtr Graph No.	Sample Location	Sta. No. & Round	C, D, or M	Percent of Component	R^2	Sample Time	Sample Date
Graph #1	Upstream of Weir at BD15E	12-3	C	36.883		1005	10/1/98
	Creek Runoff into BD15E	3-3	D	63.117		1025	10/1/98
	Near pumps of BD15E	2-3	M	100.000	0.994	1000	10/1/98
	Upstream of Weir at BD15E	12-3	C	74.165		1005	10/1/98
	Creek Runoff into BD15E	3-3	D	25.835		1025	10/1/98
	Overflow from T/Weir	30-3	M	100.000	0.999	1010	10/1/98
	Upstream of Weir at BD15E	12-3	C	36.434		1005	10/1/98
	Creek Runoff into BD15E	3-3	D	63.566		1025	10/1/98
	Overflow from T/Weir	31-3	M	100.000	0.978	1040	10/1/98
	Upstream of Weir at BD15E	12-3	C	50.424		1005	10/1/98
	Creek Runoff into BD15E	3-3	D	49.576		1025	10/1/98
	Overflow from T/Weir	32-3	M	100.000	0.961	1113	10/1/98
	Upstream of Weir at BD15E	12-3	C	53.466		1005	10/1/98
	Creek Runoff into BD15E	3-3	D	46.534		1025	10/1/98
	Overflow from T/Weir	33-3	M	100.000	0.995	1140	10/1/98
Graph #3	Creek Runoff into BD15E	3-5	C	18.693		1020	12/1/98
	Upstream of Weir at BD15E	12-5	D	81.307		1000	12/1/98
	Underflow from B/Weir	30-5	M	100.000	1.000	1010	12/1/98
Graph #6	In BD7A	4-7	C	76.695		1155	1/31/99
	Run-on from DelRancho	34-7	D	23.305		1134	1/31/99
	Overflow at Waterfall	60-7 (C)	M	100.000	0.981	-	1/31/99
Graph #7	In BD5B	4/4-3-99	C	88.926		1117	4/3/99
	Run-on from DelRancho	34-9	D	11.074		1130	3/28/99
	Overflow from BD5B	6/4-3-99	M	100.000	0.979	1200	4/3/99
	In BD5B	4/4-3-99	C	56.241		1117	4/3/99
	Run-on from DelRancho	34-9	D	43.759		1130	3/28/99
	Overflow from BD5B	7/4-3-99	M	100.000	0.960	1215	4/3/99
Graph #8	Near pumps at BD15E	1/4-3-99	C	46.050		1058	4/3/99
	Creek runoff into BD15E	2/4-3-99	D	53.950		1100	4/3/99
	Overflow from T/Weir	20/4-3-99	M	100.000	0.996	1053	4/3/99
	Near pumps at BD15E	1/4-3/99	C	41.881		1058	4/3/99
	Creek runoff into BD15E	3/4-3-99	D	58.119		1100	4/3/99
	Overflow from T/Weir	23/4-3-99	M	100.000	0.999	1255	4/3/99
Graph #10	In BD7A	11/4-3-99	C	63.739		1154	4/3/99
	Run-on from DelRancho	34-9	D	36.261		1130	3/28/99
	Overflow from Waterfall	13/4-3-99	M	100.000	0.966	1109	4/3/99
	In BD7A	11/4-3-99	C	51.642		1154	4/3/99
	Runon from Del Rancho	34-9	D	48.358		1130	3/28/99
	Overflow from Waterfall	15/4-3-99	M	100.000	0.974	1307	4/3/99
Graph #11	In BD8C	11-11	C	93.179		0816	5/31/99
	Run-on from DelRancho	34-11	D	6.821		1150	5/31/99
	Overflow at BD8C	B-11	M	100.000	0.995	0916	5/31/99

Table 14.

Summary of Total Mixtures Attempted vs. Acceptable Mixtures (Storm Water Graphs Only)			
Storm Water Graph No.	Total Number of Mixtures Attempted	No. of Mixtures and % of Total that met acceptance criteria	BD No.
Graph #1	5	5 (100%)	BD#15E
Graph #2	5	0 (0%)	BD#15E
Graph #3	2	1 (50%)	BD#15E
Graph #4	2	0 (0%)	BD#15E
Graph #5	1	0 (0%)	BD#26G
Graph #6	2	1 (50%)	BD#7A
Graph #7	6	2 (33%)	BD#5B
Graph #8	6	2 (33%)	BD#15E
Graph #9	0	0 (0%)	BD#26G
Graph #10	4	2 (50%)	BD#7A
Graph #11	2	1 (50%)	BD#8C
Graph #12	2	0 (0%)	BD#7A
Total:	37	14 (37.8%)	

Regarding the results of Graph #1 in Table 13, during a storm event on October1, 1998 and based on an average of five (5) analyses, creek runoff was a dilute (D) responsible for ~50% of the offsite discharge over the top of the weir at BD#15E. The remaining 50% that comprised the concentrate (C) was captured surface water in BD#15E above the weir. The creek runoff that discharged over the weir at BD#15E exhibited slightly higher percentages (81%, 54%, and 58%) in subsequent runoff events that met the acceptance criteria.

Another interesting relationship from the mathematical mixing of discharge samples in Table 13 was that the concentration of the background water (Station #34, run-on from Del Rancho) averaged ~28% of the total discharge in lower retention basins based on six (6) storm water mixes. Compare the ~28% to its ~19% contribution to BD#17D in other storm events as previously discussed. It was expected that the concentration of upgradient water would increase over distance and time of travel to the lower retention basins.

From data provided in Table 14, there were a total of 37 storm water mixtures attempted using the *WATEVAL* 3-Sample Mixing Routine. Of those attempted, 14 mixtures or 37.8% met the acceptance criteria.

Evaluations of the study site's spatial and temporal patterns for storm events were difficult to characterize due to many site-specific variables. Such variables include the recycling and continuous mixing of captured water, differences in basin shapes, sizes, bypass or flow-through types, specific site operations, stormflow characteristics, unknown system losses, and many others. These and other variables have an adverse affect on the evaluation of system performance and management strategies for a recycling system designed for pollution control.

Spatial and Temporal Patterns for Non-Storm Conditions

One objective of this study was to determine the spatial and temporal patterns of NO3-N and TP at the facility during non-storm conditions. To accomplish this objective, water samples were regularly collected and analyzed from the source of fresh water (Illinois River), two (2) onsite flowing creeks, and eight (8) retention basins. The test results were then subjected to statistical analyses and evaluation using the *WATEVAL* 3-Analyses Mixing Routine (Hounslow, 1995).

Based on criteria previously discussed, the test results that reflect non-storm conditions consist of sample events 1, 2, 8, 9, and 10.

Inflow

For non-storm conditions, the inflow of surface water from topographically upgradient properties did not occur and overland samples were not obtained from Station #34.

Onsite

A review of acceptable 3-analyses mixes summarized in Appendix E depict the following onsite patterns during non-storm conditions:

- Based on an average of three (3) acceptable mixes, the water contained in BD#26G (Sta. #6) mathematically consisted of ~80% irrigation water in the creek that flows into it (Sta. #7) and ~20% Illinois River water (Sta. #1).
- Based on an average of two (2) acceptable mixes, the water contained in BD#8C (Sta. #11) mathematically consisted of ~83% irrigation water in the creek that flows into it (Sta. #7) and ~17% of Illinois River water (Sta. #1).
- Based on an average of two (2) acceptable mixes, the water contained in BD#15E (Sta. #2, by pumps) mathematically consisted of ~44% irrigation water in the creek that flows into it (Sta. #3) and ~56% water contained above the weir in BD#15E (Sta. #12).
- Based on an average of five (5) acceptable mixes, the water contained in BD#26G (Sta. #6) mathematically consisted of ~48% irrigation water in the creek that flows into it (Sta. #7) and ~52% water in BD#17D (Sta. #9).
- Based on an average of two (2) acceptable mixes, the water contained in BD#26G (Sta. #6) mathematically consisted of ~88% irrigation water in the creek that flows into it and ~12% upgradient or background water (Sta. #34).
- Based on an average of two (2) acceptable mixes, the water contained in BD#17D (Sta. #9) mathematically consisted of ~83% water contained in and pumped from BD#26G (Sta. #6) and ~17% upgradient or background water (Sta. #34).
- Based on an average of two (2) acceptable mixes, the water contained in BD#9D (Sta. #10) mathematically consisted of ~58% irrigation water in the creek that flows into it (Sta. #7) and ~42% water that contained in BD#1H (Sta. #8).
- Based on an average of two (2) acceptable mixes, the water contained in BD#8C (Sta. #11) mathematically consisted of ~87% irrigation water in the creek that flows into it (Sta. #7) and ~13% of upgradient or background water (Sta. #34).

Another method used to evaluate the change in NO3-N and TP concentrations in the retention basins was a review of the actual test results, rather than mathematical calculations, on those dates that non-storm conditions were present.

Figure 24 depicts the overall annual average of NO3-N concentrations at all sampling stations, exclusive of the suspect data (see Appendix B). It also depicts the average NO3-N concentrations of those regular stations that were sampled during non-storm conditions, including sample events 1, 2, 8, 9, and 10. For non-storm conditions, BD#8C (Front Basin, Station #11) exhibited the highest average NO3-N concentration of 18.5 ppm. Other retention basins that exhibited high NO3-N concentrations during non-storm conditions include irrigation runoff into BD#15E (Station #3), irrigation runoff into BD#26G (Station #6), and BD#26G (Station #7).

Figure 25 depicts the overall annual average of TP concentrations at all sampling stations, exclusive of the suspect data (see Appendix B). It also depicts the average TP concentrations for those regular sample stations that were sampled during non-storm conditions, including sample events 1, 2, 8, 9, and 10. For non-storm conditions, BD#7A (Station #4) exhibited the highest average TP concentration of ~0.90 ppm. However, this retention basin has an effective storm flow by-pass system as previously discussed and therefore was not of concern. Irrigation returns in the two creeks (Stations #3 and #7) both exhibited average TP concentrations >0.85 ppm. However, since the basins are not prone to offsite discharges during non-storm conditions, this does not represent a threat to the Illinois River.

Outflow

During this study, the retention basins at the study site performed as designed and, with one exception, no offsite discharges were observed during non-storm conditions. The exception was the discovery on December 1, 1998 that the weir at BD#15E had inadvertently been left opened, resulting in offsite discharge from below the weir in BD#15E. Based on NO3-N results of 3.0 ppm and TP results of 0.23 ppm, this discharge from BD#15E did not exceed allowable permit limits (see Storm Water Graph #3 in Appendix D).

Effectiveness of Retention Basins

As used to describe the retention basins at the study site, the term "effectiveness" actually has a dual and overlapping meaning. The <u>hydrological</u> meaning of effectiveness relates to a retention pond's ability to capture and retain surface water, including both storm runoff water and irrigation tailwater water, for the expressed purpose of minimizing offsite discharges. The <u>chemical</u> meaning of effectiveness relates to a retention basin's ability to capture nutrient-rich irrigation tailwater for the expressed purpose of recycling.

The facility's system of retention basins was designed to capture both irrigation and control storm water runoff. Control is accomplished by pumping capture water from one basin that is at or near its holding capacity to another basin that has sufficient freeboard (i.e. less opportunity to overflow) and/or to potted plants as recycled irrigation. Thus, the hydrological and chemical objectives regarding the term "effectiveness" are interrelated.

From strictly a hydrologic perspective, a retention basin is 100% effective if it never overflows. However, according to the United States Department of Agriculture (1982), it is impractical to design a retention basin that can accommodate the peak rate of runoff from the most intense rainstorm ever known or anticipated. Calculations by the author for a 24-hour, 2-year and 10-year return period storm at the study site support that claim. Zero discharge at the study site is an unrealistic goal due to high annual rates precipitation, near constant saturation of the surface soils due to irrigation practices, steep surface slopes, concrete ditches to route surface flows to retention basins, and other site-specific conditions.

The determination of the 'hydrologic' effectiveness of a retention basin, without regard to chemical or other interrelated subjects, could be determined by observing how often a given basin overflows or discharges. This, of course, would be dependent upon other factors, such as the amount of pumping that occurred at the basin and its resulting surface water elevation. Rainfall-runoff relations could be examined and stream hydrographs could be prepared to determine what type of storm (i.e. duration and frequency) has the greatest effect on each specific basin. This, however, exceeded the scope of this study as it would require stream flow gauges, constant recording equipment, and additional engineering analysis on the size, depth, and geometric shape on each basin.

Knowledgeable personnel at Greenleaf have estimated that the retention basins have been 90 to 99% effective in capturing and controlling runoff at the facility, including both irrigation water and storm water, since their design and construction (Morrison, personal communication, 1999). Although not quantifiable, the author believes this is reasonable estimate based on 12 months of personal observations and numerous trips to the site during storm conditions, only to discover that overflows or offsite discharges were not occurring.

Although many facility documents lack the inclusion of water quality and N-P-K analyses (i.e. Circular E-951, Oklahoma Cooperative Extension Service, 1998), two studies were available that reported past test results of the facility (Houghton, 1985, and The Curtis Reports, various dates). A comparison between the historic versus recent test results of storm water discharges showed a decrease in NO3-N and TP concentrations. Additionally, there has been a noted decrease in the use of liquid ammonium nitrate at the facility (see Table 2).

As a retention basin fills with tailwater and/or storm water runoff, the new water entering a basin displaces some percentage (up to 100%) of the water contained in the basin. This displacement can occur as plug flow, which is known to minimize mixing of new water with existing water in a basin. However, it is more often than not that new water entering a basin mixes with water contained in the permanent pool, and the mixing process is more likely to occur when water, especially storm water, enters the basin in a rapid fashion (Urbonas et al, 1993).

Urbonas et al (1993) also states that it cannot always be assumed that the relatively clean water in the permanent retention basin will be discharged first. In support of this statement, there were several storm water discharges collected and analyzed in this study that depicted a reduction in NO3-N and TP concentrations as discharge first occurred (see discharge graphs of BD#15E in Figure 26 and other storm water graphs in Appendix D). Alternatively, there were a few storm water discharges that depicted higher NO3-N and TP concentrations after mixing and discharge initiated (see discharge graphs of BD#7A in Figure 27).

Hartigan (1989) states that properly designed retention basins should remove 30% to 40% of total dissolved nitrogen and 40% to 60% of total dissolved phosphorus. Using the data collected in this study, one method to determine a basin's effectiveness or ability to remove inorganic constituents is to compare NO3-N and TP concentrations in the creek runoff water to water contained in the receiving basin.

Regular monthly samples were collected and analyzed at Station #3, which flows into BD#15E (Stations #2 [by pumps] and #12 [above weir]), and at Station #7, which flows into BD#26G (Station #6). The pollutant removal efficiency was calculated as the NO3-N and TP concentration reported in the creek water runoff divided by NO3-N and TP concentration reported in the receiving retention basin. A basin's pollutant removal efficiency is the inverse of its difference in concentration (i.e. a 90% difference in NO3-N concentration in a given basin is equivalent to 11.11% pollutant removal efficiency for that station or basin). Since BD#15E has two (2) sampling stations, the pollutant removal efficiencies for both sample station #2 (at the pumps in the larger body of water) and sample station #12 (in small receiving arm of the basin above the weir) were calculated. The following table (Table 15) summarizes the NO3-N and TP removal efficiencies of BD#15E (for both stations) and BD#26G.

Based on the information provided in Table 15, the NO3-N removal efficiency is consistently higher for the smaller receiving arm above in the weir (Station #12) in BD#15E than it is for the larger but hydraulically connect body of water (Station #2).

On an annual average, there is a 45.6% efficiency for NO3-N removal with the smaller arm of BD#15E, with a high of 75.8% efficiency for non-storm and 0% efficiency for storm conditions. The 0% efficiency during storm conditions reflects the occurrence of plug flow of creek runoff water through the smaller arm (above the weir) of BD#15E.

Except for storm conditions, BD#26G appears to be less efficient in its ability to remove NO3-N than BD#15E. However, the calculations do not reflect the fact that BD#26G receives runoff from the soil mixing area, a variable not addressed in this study and one that may have a significant impact on a comparative analyses between the two basins. During storm conditions, BD#26G exhibited a calculated efficiency for NO3-N of 5.7% compared to 0.0% efficiency with BD#15E.

Table 15. NO_3-N and TP Removal Efficiencies for Two (2) Retention Basins

For Nitrate as N (ppm)							
Basin	Sta. No.	Annual Average	Percent Efficiency	Storm flow	Percent Efficiency	Non-Storm Conditions	Percent Efficiency
15E	#3	10.92	-	6.57	-	17.00	-
	#12	7.50	31.3%	6.57	0.0%	9.67	43.1%
	#2	9.30	14.8%	7.67	-16.7%	11.75	30.9%
26G	#7	11.73	-	8.00	-	16.20	-
	#6	11.08	5.5%	7.57	5.4%	16.00	1.2%
For Total Phosphorus (ppm)							
Basin	Sta. No.	Annual Average	Percent Efficiency	Storm flow	Percent Efficiency	Non-Storm Conditions	Percent Efficiency
15E	#3	0.61	-	0.45	-	0.84	-
	#12	0.60	1.6%	0.53	-17.8%	0.76	9.5%
	#2	0.68	-11.5%	0.61	-35.6%	0.78	7.1%
26G	#7	0.84	-	0.81	-	0.86	-
	#6	0.56	33.3%	0.53	34.6%	0.60	30.2%

For phosphorus, BD#26G exhibited a significantly higher percent of efficiency than BD#15E. The impact of the soil mixing area on BD#15E is not known. However, one favorable scenario is that substrate, bark, soilless media, and other solid materials that wash into BD#26G from the soil mixing area may provide opportunities for the chemical adsorption of dissolved phosphorus that was not present in BD#15E.

Performance and Management for Pollution Control

One objective of this study was to prepare an interactive model capable of evaluating the system performance and management strategies, during both storm and non-storm events, of the retention basins. In order to accomplish this objective, there were many site-specific variables that needed to be addressed. The variables included but were not limited to inflow from upgradient properties during storm conditions, various N-P-K concentrations in the captured water and irrigation tailwater, changes in the volume of water pumped from basin to basin, and rainfall/runoff amounts.

Based on a review of the literature and available computer programs on the modeling of surface water, there were no existing models that met the objectives or demand requirements for this study. Thus, in Microsoft Excel, the author prepared an analytical and interactive model to evaluate N-P-K mixing and dilution in BD#17D, BD#26G, and BD#15E for both storm and non-storm conditions. These basins were selected because they are considered to be the study site's main retention basins.

The Interactive Model

The models, entitled "Interactive Model of Three Greenleaf Basins", are capable of evaluating the effects of various flow (Q) and concentration (C) scenarios. The design of the models used a quantitative approach. For example, when an outside source of water is added to a specific basin with a known volume and N-P-K concentration, a change of N-P-K concentrations occurs in that basin. According to Hounslow (1995), loading rates can be calculated by the following equation:

$$\text{Loading Rates} = Q \times C \tag{12}$$

Where: Q = flow

C = concentrations of a particular constituent

Hounslow (1995) further stated that a mixing fraction can be calculated with any three input concentrations. A final mixture containing a given concentration with a known volume will change based on loading rates (C x Q) from outside sources. Changes to the final mixture ("m") from different sources (ie. pumped water, runoff water, etc.) are additive as shown in the following equation:

$$Cm \times Qm = C1 \times Q1 + C2 \times Q2 \tag{13}$$

Where: Cm = concentration of mixture

Qm = flow of mixture

C1 = the concentrated solution

Q1 = flow of C1

C2 = the dilute solution

Q2 = flow of C2

Because the models are both quantitative and interactive, changing one input parameter will affect other linked cells. If no water is introduced into a given basin from an outside source (i.e. tailwater, watershed runoff, pumping from another basin, etc), using a zero ("0") as a volume input results in no net change in N-P-K concentrations to that basin. Although the models are relatively simple and use logical, straightforward equations, they are nonetheless capable of quantifying the effects of stormwater runoff, irrigation returns, pumping and other scenarios associated with the facility's main basins.

By design, analytical data and current volume information are placed in a default summary (see Tables 16 and 17). This information is transferred to each specific basin represented by a box with a heavy border. Concentration and volume inputs from the various sources are then added, resulting in the calculation of a "Final Mix" for that basin.

The models are not capable of determining unexplainable system losses. Such losses can occur from intra-basin pumping, infiltration of NO3-N, adsorption of TP, nitrification-denitrification processes, precipitation of inorganic salts, and others. To incorporate these variables, however, would improve the model but increase its complexity and possibly limit its use by Greenleaf personnel.

Table 16. Interactive Model of 3 Greenleaf Basins: STORM CONDITIONS

DEFAULT SUMMARY						
Sta. & Round No.	#9-2	#6-2	#2-2			
Variables	BD#17D "35MG"	BD#26G "Hub"	BD#15E 'SnakePit'	17D-SW 35MG-SW	26G-SW Hub-SW	15E-SW SP-SW
NO3-N (mg/l)	22.00	13.00	15.00	0.1	1.0	4.0
P (mg/l)	0.50	0.97	0.75	0.43	0.65	0.94
K (mg/l)	12.00	13.00	14.00	0.3	3.0	6.0
Current Vol (mgal)	10000	3000	7000			
Max. Volume (mgal)	11440	3752	7662			
Watershed Area (sq. ft)				8,000,000	7,000,000	13,000,000
Precipitation (inches)				1	1	1
Runoff Coefficient				0.75	0.70	0.75
Storm Water Runoff (mgals)				3740	3054	6078

SW = Storm Water

MIXING SCENARIOS

BD #17D ("35 MG")			
Add (mgal)	1000	10%	
from 35MG-SW	Orig	Add	Mix
N (mg/l)	22.0	0.1	20.0
P (mg/l)	0.50	0.43	0.49
K (mg/l)	12.0	0.3	10.9
Add (mgal)	500	5%	
from Hub (default)	Orig	Add	Mix
N (mg/l)	22.0	13.0	21.6
P (mg/l)	0.50	0.97	0.52
K (mg/l)	12.0	13.0	12.0
Add (mgal)	500	5%	
from Hub (Mixed SP)	Orig	Add	Mix
N (mg/l)	22.0	14.9	21.7
P (mg/l)	0.50	0.75	0.51
K (mg/l)	12.0	13.9	12.1

BD# 15E ("SnakePit")			
Add (mgal)	10	0%	
from Hub	Orig	Add	Mix
N (mg/l)	15.0	13.0	15.0
P (mg/l)	0.75	0.97	0.75
K (mg/l)	14.0	13.0	14.0
Add (mgal)	100	1%	
from SP-SW	Orig	Add	Mix
N (mg/l)	15.0	4.0	14.8
P (mg/l)	0.75	0.94	0.75
K (mg/l)	14.0	6.0	13.9
Mixed SP (Hub + SnakePit Stormwater)			
	HUB	SP-SW	Mix
N (mg/l)	15.0	14.8	14.9
P (mg/l)	0.75	0.75	0.75
K (mg/l)	14.0	13.9	13.9

BD#26G ("Hub")			
Add (mgal)	300	10%	
from 35 MG	Orig	Add	Mix
N (mg/l)	13.0	22.0	13.8
P (mg/l)	0.97	0.50	0.93
K (mg/l)	13.0	12.0	12.0
Add (mgal)	300	10%	
from Hub-SW	Orig	Add	Mix
N (mg/l)	13.0	1.0	11.9
P (mg/l)	0.97	0.65	0.94
K (mg/l)	13.0	3.0	12.1
Add (mgal)	30	1%	
from Mixed SP	Orig	Add	Mix
N (mg/l)	13.0	14.9	13.0
P (mg/l)	0.97	0.75	0.97
K (mg/l)	13.0	13.9	13.0

The model for Non-Storm Conditions (see Table 17) is capable of calculating a final N-P-K mix in the basin of choice from any combination of irrigation return flow and pumped water from the other basins. Unlike the model for Storm Conditions, the model for Non-Storm Conditions does not use an estimated watershed area or coefficient of runoff. Data input includes flow and concentration values for irrigation flow or tailwater. The resulting change of N-P-K concentrations in a basin from the inflow of irrigation return is then calculated. Additionally, because the pumping of water from basin to basin can occur simultaneously with the inflow of irrigation returns, any volume of water from one basin (with its specific N-P-K ratio) can be added to the water in another basin, and the resulting N-P-K final mixture is calculated.

Other improvements to the models would be the addition of all retention basins. Due to the number of basin pipe interconnections (see Figure 3), this addition would increase the complexity of the model. However, it would be prove useful in the evaluation of each specific basin.

Table 17. Interactive Model of 3 Greenleaf Basins: NON-STORM CONDITIONS

DEFAULT SUMMARY

Sta. & Round No.	#9-2	#6-2	#2-2			
Variables	BD#17D "35MG"	BD#26G "Hub"	BD#15E 'SnakePit'	17D-IR 35MG-IR	26G-IR Hub-IR	15E-IR SP-IR
NO3-N (mg/l)	22.00	13.00	15.00	44.0	1.0	4.0
P (mg/l)	0.50	0.97	0.75	2.0	0.44	0.67
K (mg/l)	12.00	13.00	14.00	6.0	3.0	6.0
Current Volume (mgal)	10000	3000	7000			
Max. Volume (mgal)	11440	3752	7662			

IR = Irrigation Return (or tailwater)

MIXING SCENARIOS

BD #17D ("35 MG")

Add (mgal)	1000	10%	
from 35MG-IR	Orig	Add	Mix
N (mg/l)	22.0	44.0	24.0
P (mg/l)	0.5	2.00	0.64
K (mg/l)	12.0	6.0	11.5
Add (mgal)	1000	10%	
from Hub (default)	Orig	Add	Mix
N (mg/l)	22.0	13.0	21.2
P (mg/l)	0.50	0.97	0.54
K (mg/l)	12.0	13.0	12.1
Add (mgal)	1000	10%	
from Hub (Mixed SP)	Orig	Add	Mix
N (mg/l)	22.0	14.5	21.3
P (mg/l)	0.50	0.75	0.52
K (mg/l)	12.0	13.7	12.2

BD# 15E ("SnakePit" or "SP")

Add (mgal)	60	1%	
from Hub	Orig	Add	Mix
N (mg/l)	15.0	13.0	15.0
P (mg/l)	0.75	0.97	0.75
K (mg/l)	14.0	13.0	14.0
Add (mgal)	600	9%	
from SP-IR	Orig	Add	Mix
N (mg/l)	15.0	4.0	14.1
P (mg/l)	0.75	0.67	0.74
K (mg/l)	14.0	6.0	13.4
Mixed SP (Hub + SnakePit Irrigation Returns)			
	Hub	SP-IR	Mix
N (mg/l)	15.0	14.1	14.5
P (mg/l)	0.75	0.74	0.75
K (mg/l)	14.0	13.4	13.7

BD#26G ("Hub")

Add (mgal)	300	10%	
from 35MG	Orig	Add	Mix
N (mg/l)	13.0	22.0	13.8
P (mg/l)	0.97	0.50	0.93
K (mg/l)	13.0	12.0	12.0
Add (mgal)	300	10%	
from Hub-IR (only)	Orig	Add	Mix
N (mg/l)	13.0	1.0	11.9
P (mg/l)	0.97	0.44	0.92
K (mg/l)	13.0	3.0	12.1
Add (mgal)	30	1%	
from Mixed SP	Orig	Add	Mix
N (mg/l)	13.0	14.5	13.0
P (mg/l)	0.97	0.75	0.97
K (mg/l)	13.0	13.7	13.0

Based on several runs using actual test data, with estimated pumping volumes, rainfall-runoff coefficients, and irrigation return volumes, the models provided very favorable results. With knowledge of actual pumping volumes and runoff coefficients, it is anticipated that the models will be capable, even beneficial, in evaluating various onsite management scenarios.

Due to the lack of information regarding pumped volumes, the overall performance and validation process of the models could not be specifically determined. However, because Greenleaf determines NO3-N and TP concentrations on a daily basis in many basins, it is anticipated that the models can be used during both storm and non-storm conditions to easily evaluate various water strategies. This may be particularly important during springtime months when plant production, fertilization requirements, and rainfall-runoff events are all at a maximum.

Storm Condition Model

The model for Storm Conditions (see Table 16) is capable of calculating a final N-P-K mix in any of the 3 basins from any combination of storm water runoff and pumped water added from the other two basins. Using an estimated watershed area (in sq. ft) for each basin, input for precipitation (in inches), and an input coefficient for runoff, the total volume of storm water runoff (in thousands of gallons or "mgals") for each basin's specific watershed has been calculated and is shown in the default summary.

The resulting change of nutrient N-P-K concentrations from the inflow of storm water runoff is calculated for each basin. Additionally, because the pumping of water between from basin to basin can occur simultaneously with the inflow of storm water runoff, any pumped volume of water from one basin with its N-P-K concentration can be added to another basin, and the resulting N-P-K mixture is calculated in the final mix. The storm water model has additional management value as it is capable of determining the amount of freeboard needed to contain the runoff from an individual rainfall event. Knowledge of freeboard will ensure that the first flush of a rainfall event is captured and retained by the basin, thereby minimizing offsite discharges.

CONCLUSIONS AND RECOMMENDATIONS

The construction of the retention basins and recycling of captured waters is an effective pollution prevention technology and best management practice (BMP) for the nursery industry. Recycling surface water captured in retention basins at the study site has reduced the concentration of N-P-K constituents over time and minimized offsite discharges to adjacent bodies of water during both storm and non-storm conditions.

Although a few excessive cation-to-anion ratios were discovered from mathematical analyses of the inorganic test results, the test results associated with this study exceeded the minimum standards of quality assurance and are therefore considered to be reliable. Generally, NO3-N and TP in the water behaved as expected based on a literature review of their partitioning coefficients.

A comparison of the facility's historic test results to the test results generated in this study indicated that the highest annual total phosphorus concentration of 1.84 ppm in the Illinois River occurred in 1989, while the lowest annual TP concentration of 0.08 ppm occurred in this study (1998-99). This suggests that oversight by the OSDA, EPA, and other regulatory authorities, combined with the collective efforts of Greenleaf and other industries to implement pollution controls and best management practices, have had a favorable affect on the Illinois River.

Based on final or end mixtures of numerous 3-analyses mixing routines, a significant amount of recycling and mixing has occurred at the site. The near-continuous mixing of water that occurs at the site has masked many of the spatial and temporal patterns and conditions at the site. Additionally, there are many other site-specific variables that made it difficult to evaluate system performance and water management strategies. Such variables but are not limited to differences in basin shapes, sizes, by-pass or flow-through types, specific site operations, use and methods of application of various types of fertilizers, stormflow characteristics, and many others.

Regarding spatial and temporal patterns that were recognizable, water contained in BD#26G (Hub) consisted, on an annual average, of 16.5% Illinois River water and 83.5 creek runoff water from its receiving stream. The water contained in BD#8C (Front Basin) was a mixture of near similar proportions. Also on an annual average, the water contained in BD#17D was a mixture of 18% inflow from Station #34 (upgradient or inflow) added to 82% of water pumped from BD#26G. Finally, water in BD#9D consisted of an average annual mixture of 27% water from BD1H added to 73% creek runoff water.

The concrete curbing and complete storm water bypass system at BD#7A appears to be functioning as expected. However, BD#5B (Station #5), the other concrete basin at the site, offers little if any protection to offsite properties during storm events, especially when storm water runoff enters the basin in a rapid fashion. Based on the collection and analyses of twelve (12) monthly samples and twelve (12) storm water discharges that included all five (5) facility outfalls, the data indicates that BD#5B presents the greatest potential for offsite adverse impacts of excessive NO3-N and TP concentrations. It is recommended that BD#5B be enlarged to contain additional water volumes and incorporate a by-pass system with sedimentation basin.

Although all retention basins and storm water outfalls at the facility were evaluated, an emphasized was placed on the three (3) largest basins, included BD#17D, BD#26G (Hub) and BD#15E (Snake Pit). Following are additional spatial and temporal patterns regarding these basins, especially as they are related to pollution control and watershed management strategies. Except during storm conditions, BD#15E appears to be more efficient than BD#26G in removing NO3-N in the water, although water contained in BD#26G typically exhibits slightly higher NO3-N concentrations than water in BD#15E. The data suggests that BD#26G is more capable of reducing NO3-N concentrations during storm conditions, while the smaller receiving arm of BD#15E appears to simply transfer its load via plug flow with little mixing to offsite areas. For both storm and non-storm conditions, BD#26G exhibited higher removal efficiencies for total phosphorus than BD#15E.

Higher NO3-N and TP concentrations were generally seen in the larger body of water of BD#15E (Station #12) relative to the hydraulically connected but smaller arm of the basin (Station #2). Thus, BD#15E appears to be performing during both storm and non-storm conditions as expected. However, since phosphorus is a limiting factor in aquatic systems and has lower discharge limits relative to NO3-N, it is recommended that water contained in BD#15E be pumped to BD#26G whenever possible, which will minimize the opportunity of discharge over the top of the weir during storm conditions.

In addition to the spatial and temporal patterns observed at the site, a simple interactive model was prepared to evaluate different flow (Q) and concentration (C) scenarios as they specifically relate to three (3) major basins at the study site. The analytical model is capable of predicting system performance and evaluating different management strategies at the nursery for both storm and non-storm conditions.

Although it was designed to be user-friendly, the usefulness of the models is somewhat limited by the lack of flow meters and accurate volume estimates in the basins. Thus, company personnel will have to use their best professional judgment in their use of the models.

RECOMMENDATIONS FOR FUTURE RESEARCH

Recommendations for future research at Greenleaf Nursery include the following:

Study the potential for pesticide and herbicide accumulation at the study site and ascertain their potential for offsite discharge. Include in the study analyses of degradation products. Although pesticides and herbicides are included in the OSDA Compliance Agreement for the facility, there appears to be limited historic and current information regarding this subject.Research the potential for nutrient migration through the ground water. Knowledge of nutrients in the ground water is one of several components needed to determine the mass balance of NO3-N and TP at the site. This research is expected to be especially relevant for nitrate or other constituents that preferentially partition to the aqueous phase rather than adsorb to soil particles. Although there are a few water wells on the facility, additional observation wells could be drilled and installed. Samples could then be collected and analyzed to determine if the ground water has been adversely affected from nursery activities. Included in the research should be an analysis of Illinois River hydrographs to determine the base flow, which is an important factor when determining contaminant loading rates.

Perform research on the rates and affects of sedimentation accumulation. This is expected to be particularly important for phosphorus and other constituents that preferentially partition to solid particles.

Perform additional research on the hydrological and surface water aspects at the facility. Information needed to assess the site and perform accurate hydrologic and mass balance calculations could be obtained with constant recording stream flow gauges at all outfalls, constant recording pressure transducers in the basins that are capable of offsite discharge, and other similar equipment. It is expected that the data generated from the study could be used to determine the hydrologic equation (Inflow = Outflow ± Changes in Storage) at the site.

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