CONSTRUCTED WETLANDS AS AN ALTERNATIVE TECHNOLOGY FOR ADVANCED WASTEWATER TREATMENT

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INTRODUCTION

It is common knowledge among environmental engineers and scientists that wetlands can play a major role in improving water quality through natural processes. Over the past decade, constructed wetlands have been increasingly used as a natural, low cost, and energy-efficient alternative to more typical advanced wastewater technologies (AWT). The growing interest is exemplified by the Congressional hearing last year on the role of constructed wetlands and other alternative technologies.[1] Further indication is given by the rapid increase in the number of publications and conferences devoted to this topic.

Among the major problems currently confronting advanced wastewater treatment are the high costs of constructing, operating, and maintaining a conventional facility. At the same time, there is continuous damage to and destruction of wetlands stemming from the expansion of agriculture and construction projects into wetland areas. The growing interest in using natural and constructed wetlands can help to address both these issues by providing a low cost treatment alternative and by adding to the inventory of wetlands. A list of advantages and disadvantages of using constructed wetlands is provided in Table 1.

The transport and transformation of pollutants through the wetland ecosystem, known as biogeochemical cycling, involve a great number of interrelated physical, chemical, and biological processes. Typically, a constructed wetland mimics the behavior of natural wetlands in its design and functioning. Water entering the system experiences settling as the primary physical process. Chemical action takes place as water contaminants can be oxidized or bonded to the soil or other porous media selected as a base for the wetland. The principal action occurs biologically as wetland plants and soil, together with bacteria, further decompose and neutralize the contaminants.

This paper gives an introduction to the design of artificial wetland systems and provides the results of a research project undertaken on a large constructed wetland facilities in central Florida. The Experimental System, comprised of 120 ha of artificial and natural wetlands, was designed as a receiver for secondary treated wastewater. The facility is located in Orange County, Florida, on the periphery of Orlando.

DESIGN OF CONSTRUCTED WETLANDS

Constructed wetlands have been designed in a variety of sizes and shapes, but the broad categories of design are free water surface (FWS) wetlands and vegetated submerged bed (VBS) wetlands. The VBS system involves subsurface flow through a porous material, whereas the FWS has surface flow similar to natural wetland. Both systems used aquatic vegetation and depend upon basic microbiological reactions for water treatment.[3]

Of the many possible uses of constructed wetlands, the two primary functions are for treatment of stormwater runoff, and for tertiary treatment of municipal, and specific industrial wastewater. The FWS wetland, for example, is widely used as a low-cost method for treating acid mine drainage with over 20 such systems built in 1984-85 in four coal mining states.[4]

The principal components that have some influence in the wetlands treatment process include plants, soils, bacteria, and other organisms. The performance of the systems is affected by water temperature, depth, pH, and dissolved oxygen. Aquatic plants used in constructed wetlands vary widely, depending upon climate and soils, but the most common emergent plants are reeds, cattails, rushes, bulrushes, and sedges. Regardless of which plant type is selected, ultimately natural processes will cause certain plants to become dominant.[5] The emergent plants have the ability to absorb oxygen and other needed gases from the atmosphere through their leaves and stems above water and conduct those gases to the roots. Thus the soil zone in immediate contact with the roots can be aerobic in an anaerobic environment. The plants can uptake nutrients and other constituents. Perhaps the most important plant functions in FWS wetland are the submerged portions which serve as the substrate for attached microbial growth.

Constructed wetlands can reduce high levels of BOD, suspended solids, nitrogen, and phosphorus, as well as lower significantly the concentration of trace metals, organics, and pathogens.[6] The performance of wetlands is discussed below with respect to our experimental system.

ANALYSIS OF EFFECTIVENESS OF A CONSTRUCTED WETLAND

The particular example analyzed in this paper is the Phase III Experimental Wetlands Exemption System in Orange County, Florida, which has been monitored for five years (1988-1992). The paper presents results of a study of this system, which is a combination of created and natural wetlands designed for treatment and recycling of wastewater (Figure 1). The overland-flow type of constructed wetland, planted with selected herbaceous plants and trees, is integrated with a natural, forested wetland. The whole system is divided into two major halves. The primary function of the first part is treatment of discharged wastewater; the second part provides a final polishing of water and serves as a buffer zone. Recycled wastewater is ultimately released into a small creek. The construction of the system was completed in 1987, and the secondary treated wastewater flowed into wetlands for the first time in March 1988.

Figure 1 shows a general view of the site, location of the stations, and flowing direction. Reclaimed wastewater is distributed to an overland flow system (IF), the major functions of which are dechlorinating of wastewater, increasing concentration of dissolved oxygen, and providing vegetative uptake of nutrients. This part is adjacent to the distribution (created) wetlands (DA, DB). The wastewater passes through this section into a natural pond of cypress dominated swamps (TW) and is then recollected and dispersed in the redistribution, created wetlands (RA, RB). Reclaimed water flows next to a natural, jurisdictional, mixed hardwood swamp wetland (JW), then to a natural, cypress dominated swamp (the exit wetlands - XW), and ultimately to the Little Econlockhatchee River. The control wetland (CW), similar to the monitored system but separated from it, provides background information about quality of water in this area and depends on the type of weather and wet/dry season during the study period.

Primary objectives for the research were: 1) the evaluation of the chemical and hydrological responses of the experimental system to increased hydraulic input; 2) the development of scientifically valid data to answer major questions regarding the future reduction of operational and capital cost; and 3) future minimization of the treatment level in the wastewater treatment plant to provide acceptable nutrient concentrations at the discharge from the wetland.

METHODOLOGY

The water and wastewater samples were collected on a monthly basis and analyzed to determine the concentration of nutrients (nitrite + nitrate, ammonia, Kjeldahl-N, total-P), minerals (conductivity), organic matter (BOD) and metals (Fe, Cu). Supplemental to this the field measurements of temperature and dissolved oxygen were performed at all sampling locations during each designated water collection at the three water levels: 1) top - just below the surface, 2) approximate middle of the water column, and 3) bottom, at the water-sediment interface. Measurements of pH and conductivity were performed in the field also. Additional analyses of the total residual chlorine, total and fecal coliform, and five metals (Pb, Zn, Cd, Ni, K) were made seasonally, three times during the year.

The methods used for the determination of physical and chemical water quality parameters were those approved by the Florida Department of Environmental Regulation (DER) or the US Environmental Protection Agency (EPA). As a part of the laboratory's overall Quality Assurance (QA) Program, various Quality Control (QC) actions were taken during the study to insure data validity. These actions included the analysis of standard and "unknown" EPA performance evaluation samples as well as the routine analysis of duplicates and "spikes" to determine accuracy and precision of performed analyses.[6,7]

The sampling stations (total 57) were located at the wastewater discharge to the wetland areas; the distribution, treatment, jurisdictional, and exit wetlands; at the area of outflow from the system; and at the control wetland side.

NUTRIENTS REMOVAL

Nitrogen

As is well known, one of the major focuses of tertiary wastewater treatment is removal of compounds that contain nitrogen (N) and phosphorus (P), which can cause eutrophication of lakes and streams and deterioration of water quality. Several studies have investigated possibilities, conditions, and efficiency in removal of N and P by various wetlands, located in different climate zones. Depending on the type of the wetland, climate, soil, and biota, one of the four general processes would dominate: 1) vascular plant uptake, 2) algal uptake, 3) bacterial and fungal uptake and transformation, and 4) sediment processes (sorption, ion exchange, precipitation, etc.).[9,10,11]

The reduction in nutrients concentration in the wastewater at various wetland treatment facilities in Florida varies widely from 6.9% to 96% for nitrogen and 6.4% to 94% for phosphorus.[12,13,14]

Generally, most wetlands have the natural possibility of generating a certain level of total nitrogen (TN) through nitrogen fixation in which specific plants and algae convert atmospheric nitrogen into the organic form. The average, natural background of TN concentrations recorded in a wetland's water are mainly in the range 0.5 to 3 mg/L,[15] with some fluctuations depending on the season and weather conditions.

For Experimental Wetland System, the effluent limitations on an annual average that were established by "Condition 4 of the Wetland Exemption" were 3 mg/L of total nitrogen.[16]

The yearly averages of the TN for each part of the System are displayed in Figure 2. The decrease of TN concentration with the distance is compared between background, the first, second, and fifth year of monitoring. The measurements obtained in February 1988 are treated as a background for Experimental Wetland. It was the last month before the first discharge of wastewater into the System, in March 1988. At this month, the level of TN was even lower than for Control Wetland (1.1 mg/L at the treatment area and 0.5 mg/L in XW). The total nitrogen concentration recorded at Control Wetland (CW) showed a great stability during those years because the level of TN remained similar, in the range 1.68 mg/L in the first year and 1.82 mg/L after 5 years. The comparison of the available data shows that after 5 years of receiving of wastewater, the concentration of total nitrogen in the water collected in the Exit Wetlands was comparable with the control site and below permitted limit. The characteristic pattern of decreasing initial concentration of TN shows that major removal occurs in the first artificial part of the System (DA and DB). However, the concentration of TN increases temporarily in the treatment area (TM), but comparison with the February '88 data and other parameters recorded at the time of monitoring (DO, BOD, higher concentration of ammonia, odor of H_2S) clearly indicates anaerobic processes dominated at this site.

Phosphorus

The other plant nutrient of interest to the presented study was phosphorus. This element behaves differently from nitrogen in wetland systems. Nitrogen, depending on conditions, can be transformed into nitrogen gas and released to the atmosphere or it can be absorbed from the atmosphere and converted to the organic forms. This possibility is not available in the phosphorus cycle, but dissolved inorganic forms of phosphorus can be readily converted into organic forms by plant uptake and, following plant death, may be transformed into inorganic form again and recycled to the water column or deposited into sediment.

The highest annual concentration of inorganic and organic compounds measured as Total Phosphorus (TP) in the effluent from Experimental System was limited by the wetland Exemption to 1 mg/L-P.[16] The only sites within the study area where soluble ortho-phosphate was evident at noticeable levels were at IF, DA, and DB. The annual average of TP at Control Wetland was almost the same for the first, second, and fifth year of monitoring (0.05, 0.03, and 0.06 mg/L-P, respectively) (Figure 3).

By comparison, the highest concentration of TP was seen in the wastewater discharged to the System (IF). Thereafter, the concentrations decreased rapidly through DA, DB, and TW, reaching to Control Wetland level at the second part of the System. The background data from February 1988 shows that in the natural wetlands (treatment - TW, jurisdictional - JW, and exit - XW), the concentration of TP has slightly increased compared with constructed parts. This anomaly was observed with the same pattern during the first, second, and after five years of discharging of wastewater and didn't depend on the initial concentration of TP found in wastewater influent (IF). This can be explained by the different type of mechanisms generated in different types of soil (mostly organic in the natural wetlands, against mineral at the constructed sites).

MINERALS REMOVAL

The total concentration of cations and anions from dissolved ionic composition can be measured as conductivity. As might be expected, the highest annual averages for conductivity were seen in the wastewater influent (Figure 4). The conductivity generally decreases through the wetlands system as the treated effluent is diluted with ambient waters, but the comparison of the five years data shows a dramatic increase of dissolved minerals in the whole System. The average annual conductivity recorded in February 1988, as well as in the Control Wetland during the five year period, remains at the narrow range of 99 to 122 _mhos/cm, and 86 to 102 _mhos/cm, respectively. The conductivity measured in the water collected from the Exit Wetland shows almost double value (comparing with the background) after the first year of discharging of wastewater, triple value after second year, and quadruple increase after five years. This situation can be explained by increasing ratio of wastewater flow to ambient waters, as well as by limited possibilities of precipitation of chloride and sulfate anions, which are mainly responsible for this increase.

CONCLUSIONS

The use of constructed wetlands for tertiary wastewater treatment may by a feasible and cost-effective alternative under certain design and loading constraints. At appropriate levels of pH, DO, conductivity, and other design parameters, constructed wetlands can reduce pollution level substantially.

Analysis of data from five years of measurement in a newly constructed experimental wetlands adjacent to the existed, natural wetland led us to the following conclusions.

The constructed wetland works well in reducing levels of phosphorus and nitrogen. Compared with control wetland, concentrations of phosphorus are comparable or slightly higher in the experimental system and nitrogen concentration generally lower in the experimental system. Both of these results occur in spite of a much higher concentration in the influent (IF) of the experimental system.

A major difference between constructed and control wetlands is especially apparent with conductivity and pH. As seen in Figure 4, conductivity increases over time and after five years there is only a 25% decrease between inflow and outflow. There is essentially no reduction in the initial created wetland (from IF to DA to DB), but it takes a large drop in the natural wetland (TW,TM). Conductivity increases in the constructed wetland (RA, RB) then improves again in the natural, jurisdictional, and exit wetland (JW, XW). This pattern cannot be explained by dilution with ambient water; if dilution occurred, we would show only decreases. We can conclude that the organic soil in the natural parts may provide sorption of those ions, but the amount is small because the second and fifth year shows almost the same conductivity of effluent, and it decreases from year two to year five in the remainder of the system.

We can reasonably conclude that constructed wetlands are effective for tertiary treatment of wastewater. They can provide substantial reductions in concentration of nitrogen, phosphorus, and minerals.

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Table 1
Advantages and Disadvantages in Operating of Constructed Wetlands[2]

Advantages	**Disadvantages**
- cheaper to built and operate	- needs a larger area
- can be built almost everywhere	- potential mosquito habitat
- energy efficient	- no optimal design factors
- consistent and reliable	- unfamiliarity of technology
- simple operation	- pulsed released may cause phosphorus problems
- advanced technology	- poor operation may produce undesirable odors
- accepts load variations	- some areas may be temperature and season dependent
- may eliminate sludge handling	- poor operation may produce undesirable odors
- eliminate chemical handling	- may spread pathogens
- attractive to wildlife	
- aesthetically pleasing	

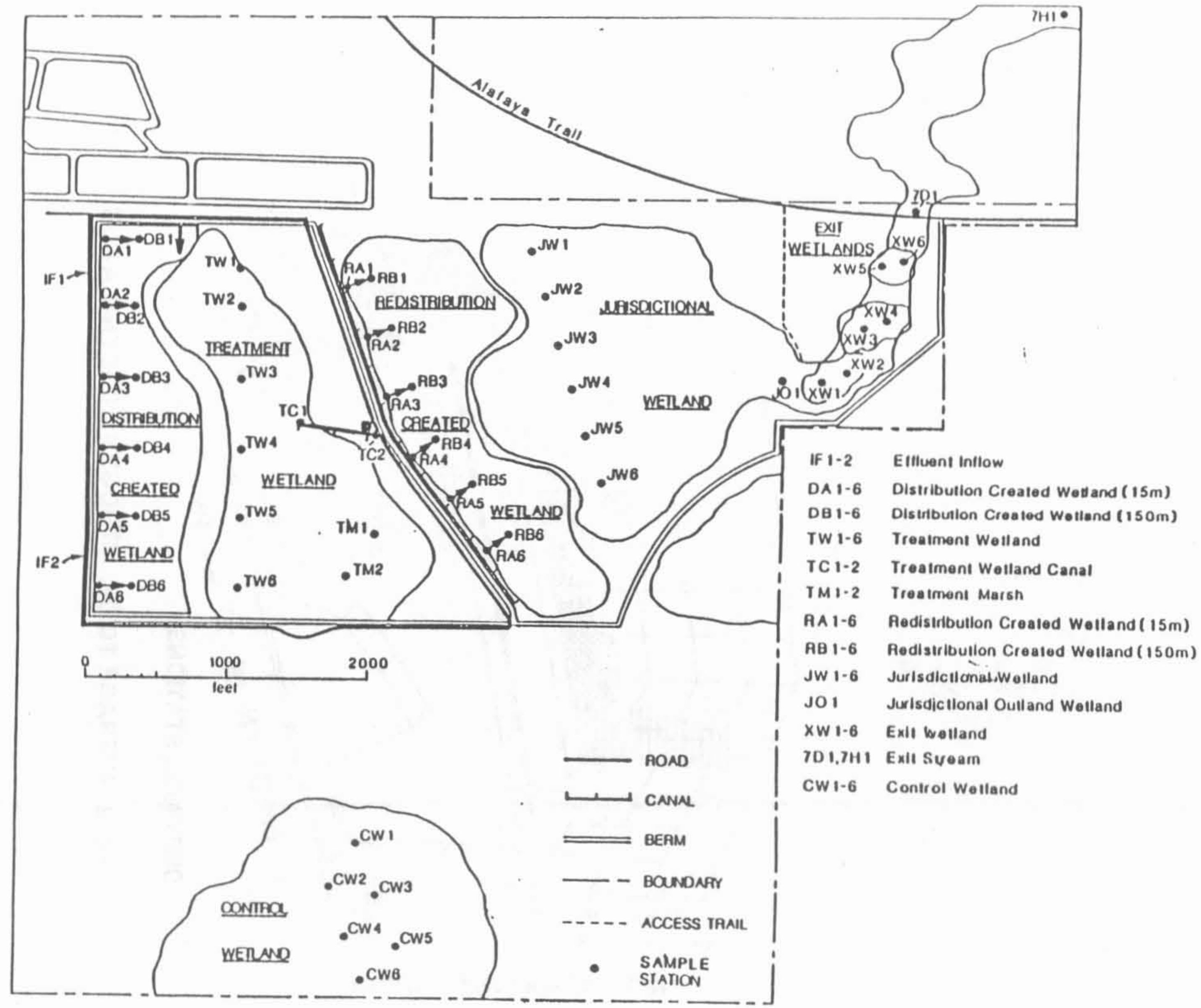

FIG 1. The Experimental Wetlands System, Orange County, Florida.

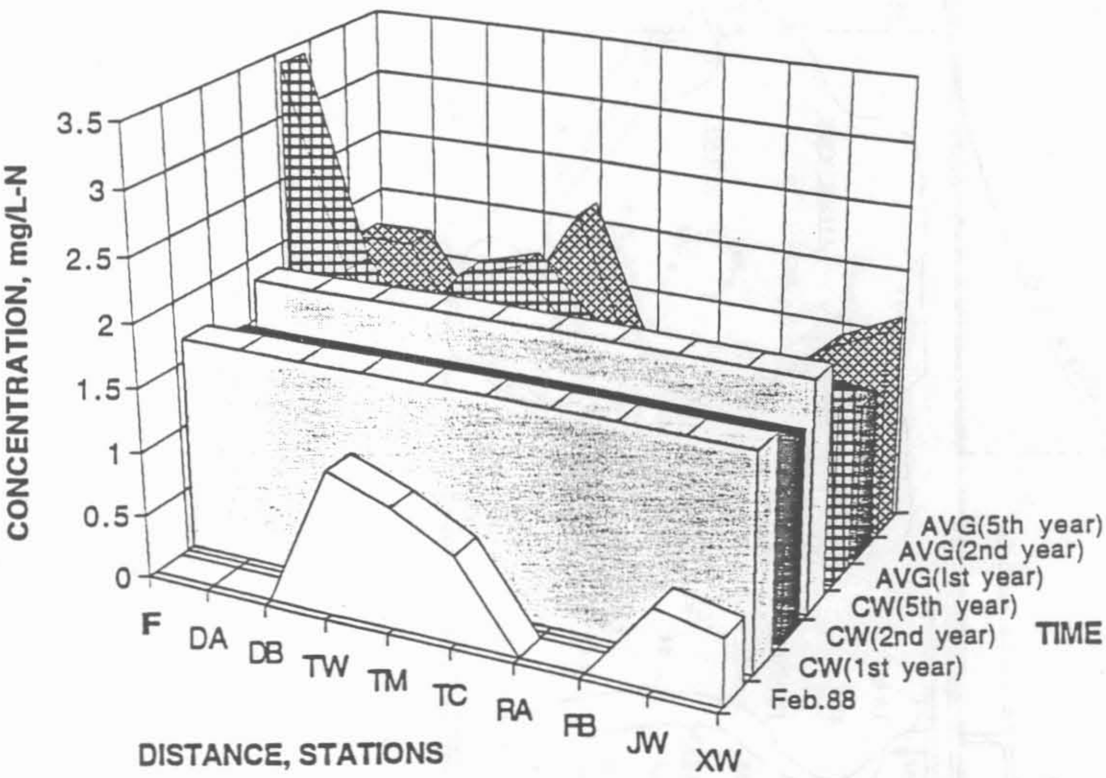

Fig. 2 AVERAGE TOTAL NITROGEN CONCENTRATION (1988 - 1992)

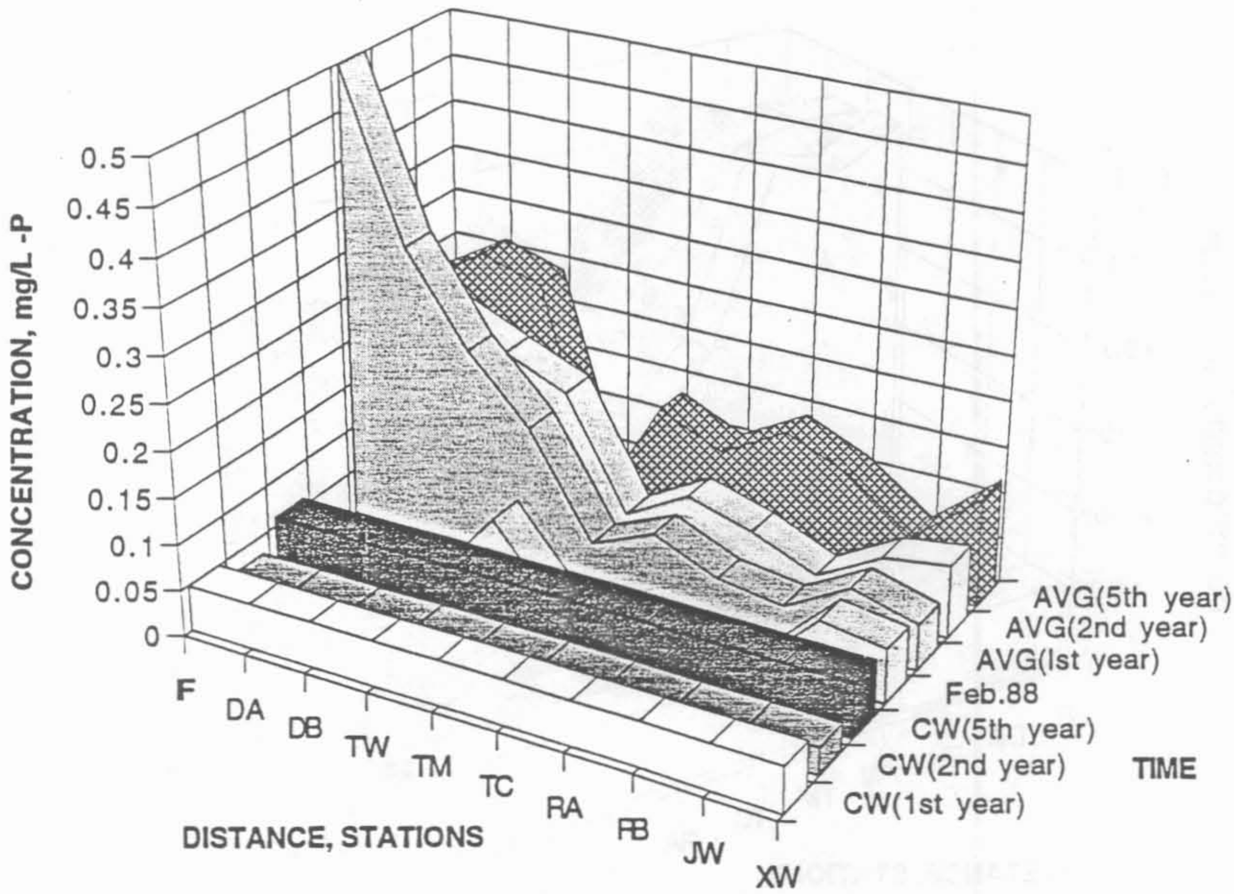

Fig.3. Average Total Phosphorus Concentration (1988 -1992)

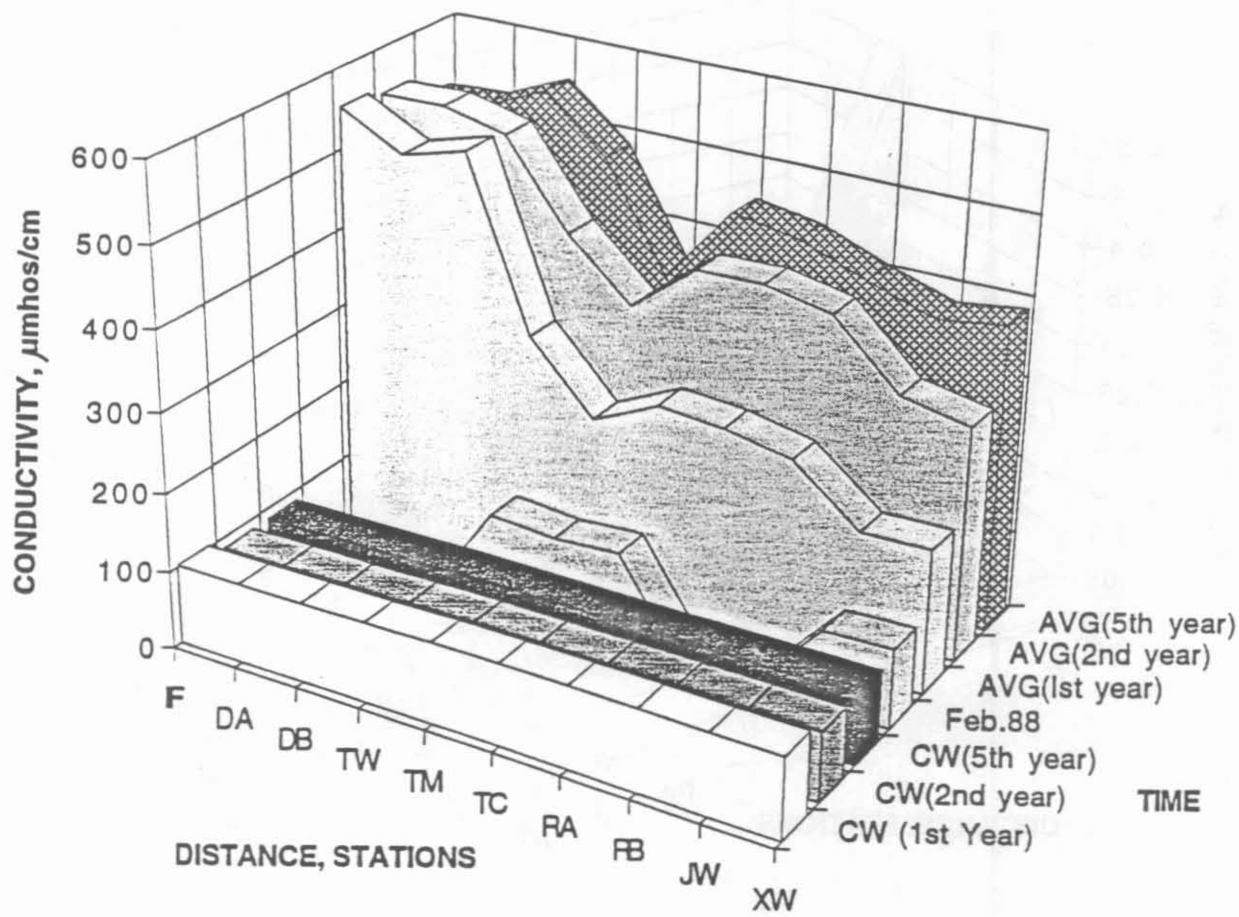

Fig.4. Average Conductivity Data (1988 -1992)