ReCip for municipal and on-site wastewater treatment

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ABSTRACT: The Tennessee Valley Authority (TVA), has developed and patented a novel technology for aerating the root zone and rock substrates of subsurface flow constructed wetlands. The technology, referred to as recurrent reciprocation, was retrofitted to a municipal subsurface-flow wetland treatment system in November 1995. Prior to the retrofit, the municipal wastewater treatment system was failing with respect to several NPDES water quality parameters including fecal coliform bacteria counts. Within six months of retrofitting the reciprocating system, water quality and fecal bacteria populations were significantly improved and have continued to improve for the past four years. Data will be presented comparing water quality data prior to and after installation of the recurrent reciprocating technology.

INTRODUCTION

Constructed wetlands for treating domestic and municipal wastewater have been shown to be effective for removal of suspended solids (SS), carbonaceous biological oxygen demand (CBOD5), fecal coliform bacteria, and certain heavy metals. However, in organically enriched wastewater many of the aerobic treatment processes, such as nitrification, are rate limited due to chronically low dissolved oxygen concentrations. The passive wetland designs in use today, including both free water surface and subsurface-flow, rely on two limited sources of oxygen: 1) oxygen derived from aquatic plants and their associated root transport system (Armstrong et al. 1990 and Steinberg and Coonrod 1994) and 2) atmospheric oxygen diffusion at the air-water interface (Behrends et al. 1993). Both sources are meager at best, and are usually not sufficient to meet the high aerobic respiratory demands in wastewater treatment wetlands. At low D.O. concentrations (< 2.0 mg/L), nitrification is rate limited and thus total ammonia nitrogen (TAN) accumulates to unacceptably high concentrations, often exceeding 20-30 mg/l.

Such high effluent concentrations can be harmful to aquatic organisms during periods of high temperature and elevated pH.

Within the past decade, design criteria have been developed for passive surface-flow constructed wetlands (free water surface), to treat ammonia in domestic wastewater. However, to reduce ammonia to compliance levels requires a large wetland area, often 10-12 times larger than the area required for removal of CBOD5 and suspended solids (Knight and Iverson 1990). Thus, designing free-water-surface wetland systems for ammonia removal may dramatically increase capital costs bringing into question their cost-effectiveness.

This paper will present information on an experimental subsurface-flow constructed wetland system in which a novel reciprocation process vastly improved wastewater treatment. Recurrent reciprocation, is a patented process (January 1999), whereby adjacent wetland cells are alternately drained and filled on a defined and recurrent basis. This recurrent fill and drain technique provides environmental control for microbially mediated processes such as nitrification, denitrification, and biological phosphorus removal (Behrends et al. 1993, 1996). A continuum of redox-specific reactions can be controlled within and between treatment cells via system design and operation.

MATERIALS AND METHODS

Scientists at TVA's Environmental Research Center (ERC) in Muscle Shoals, AL. provided design modifications and monitoring of an experimental subsurface-flow constructed wetland. The wastewater system, located in Tennessee, was designed as an alternative decentralized system for treating municipal wastewater from the small community and the local high school. The original design consisted of a passive subsurface-flow system including 4 lined cells (30 mil plastic liner). Each lined-cell was back-filled with various grades of substrate.

Domestic wastewater was pretreated in a large (380 m3. capacity), above ground septic tank. Beginning in 1992, the four cells were operated as two independent pairs with each pair operated in series. Design hydraulic loading for the 4-cell system was equivalent to 190 m3 (50,000 gpd), although the actual hydraulic loading rate has averaged approximately 50% of the design value.

The system was designed to accommodate gravity flow of wastewater from the septic tank through the paired series of wetland cells.

Wastewater effluent from the septic tank was distributed via gravity to 6 " PVC header pipes with adjustable turn-down tees. The distribution headers were positioned across the length of each cell rather than across the width; thus cells were operated at a very low aspect ratio equal to 0.22. Water leaving the wetland cells was directed via gravity through an aeration system, a U.V light system and a v-notch weir prior to exiting to a small receiving stream.

The original NPDES permit for the treatment wetlands included daily or monthly averages for the following parameters: CBOD5, not to exceed 25 mg/l; suspended solids not to exceed 30 mg/l, fecal coliform bacteria not to exceed 1000/100 ml grab sample on a daily basis or 200 /100 ml on a monthly average basis; and dissolved oxygen not to be less than 1 mg/l on a daily basis. Initially, TAN effluent concentrations were not limited by the NPDES permit, but the permit was subsequently amended to include TAN limits on a seasonal basis, with TAN concentrations not to exceed 5 mg/L in the summer (April -

September), and 10 mg/L in the winter (October - March).

Reciprocation Retrofit

In 1995, the State of Tennessee's Division of Water Pollution Control requested that the wetland-based treatment system be brought into compliance with respect to the NPDES permit limits. After evaluating historical water quality data and discussing options, it was mutually decided that an experimental recurrent reciprocating system should be installed in one of the paired wetland systems, with the other paired system operated as a control. The experimental retrofit system was installed and operational by November of 1995. The goal of the large scale experimental reciprocating system was to determine optimum operating conditions to remove odor, to improve removal of CBOD5, fecal coliform, and nutrients; specifically TAN.

From November of 1995 to April of 1996, cells A and B were operated in series as standard sub-surface flow wetlands and served as an appropriate control for cells C and D which were operated in the recurrent reciprocation mode. All four cells were operated in the reciprocating mode after April, 1996. The system has been successfully operated under various experimental guidelines since November 1995. A recurrent fill and drain cycle between contiguous cells allows atmospheric oxygen to contact the roots and bacterial biofilms on a semi-continuous basis.

RESULTS AND DISCUSSION

Within six months of start-up in 1992, the conventional subsurface flow wetland system became anoxic / anaerobic and began to emit noxious gases, i.e., hydrogen sulfide. Based on weekly and monthly samples, the facility was frequently out of compliance with respect to CBOD5, D.O., and fecal coliform bacteria (F.C.). During 1993, 1994, and 1995 non-compliance violations (N.C.V.) for CBOD5 were observed 25, 29, and 47 times respectively. Dissolved oxygen concentrations were chronically low and TAN levels were often in excess of 20 mg/l.

<u>However, within a week of beginning the operation of the experimental reciprocating system</u>, the strong smell of hydrogen sulfide was dramatically reduced. Results of weekly water quality monitoring also revealed continuous improvement in dissolved oxygen concentrations, water clarity and reductions in CBOD5, TAN and TP (Figures 2a, b and c). For example, during October of 1996, the reciprocating wetland system was in compliance with all NPDES permit limits. The monthly averages for October were: TAN, 4.6mg/l; CBOD5, 15.9 mg/l;, and fecal coliform bacteria, 7.2 colonies /100 ml. The significant removal of

FIGURE 1A. CBOD5 CONCENTRATION

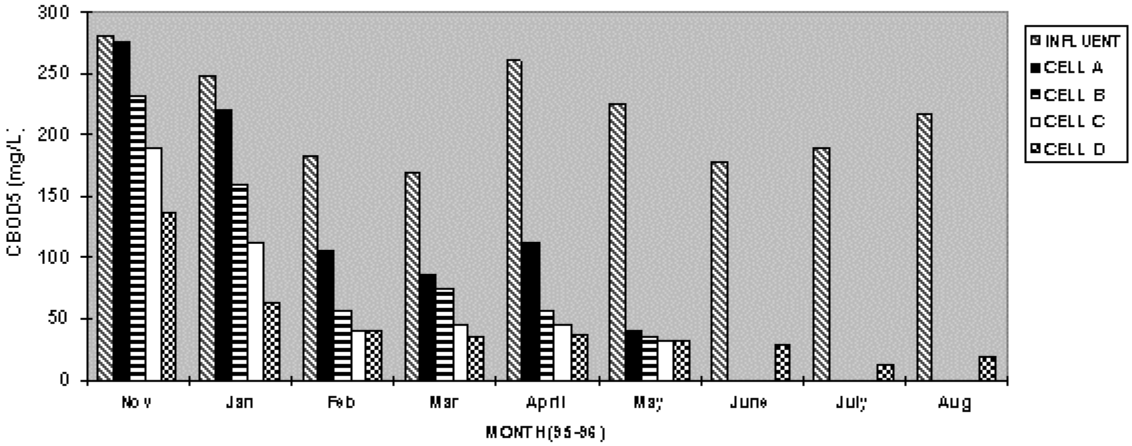
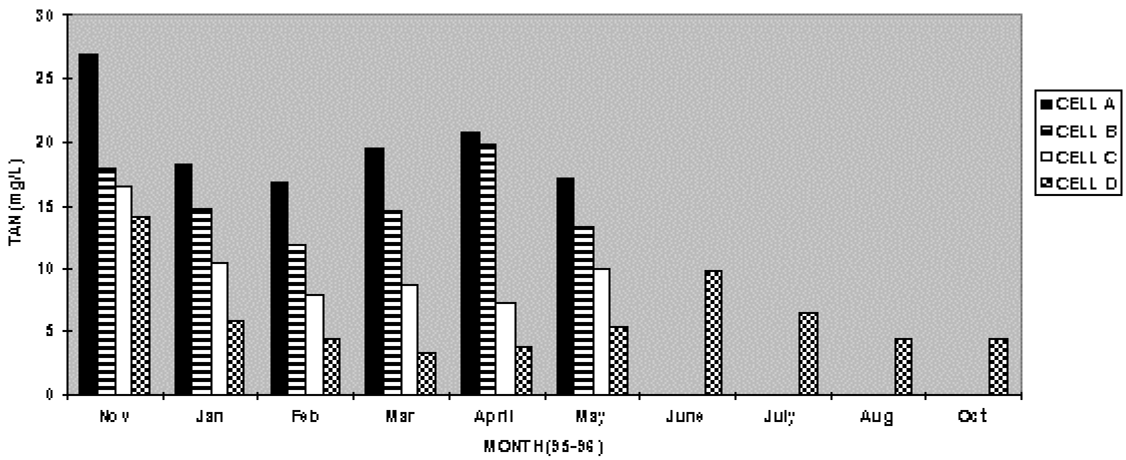
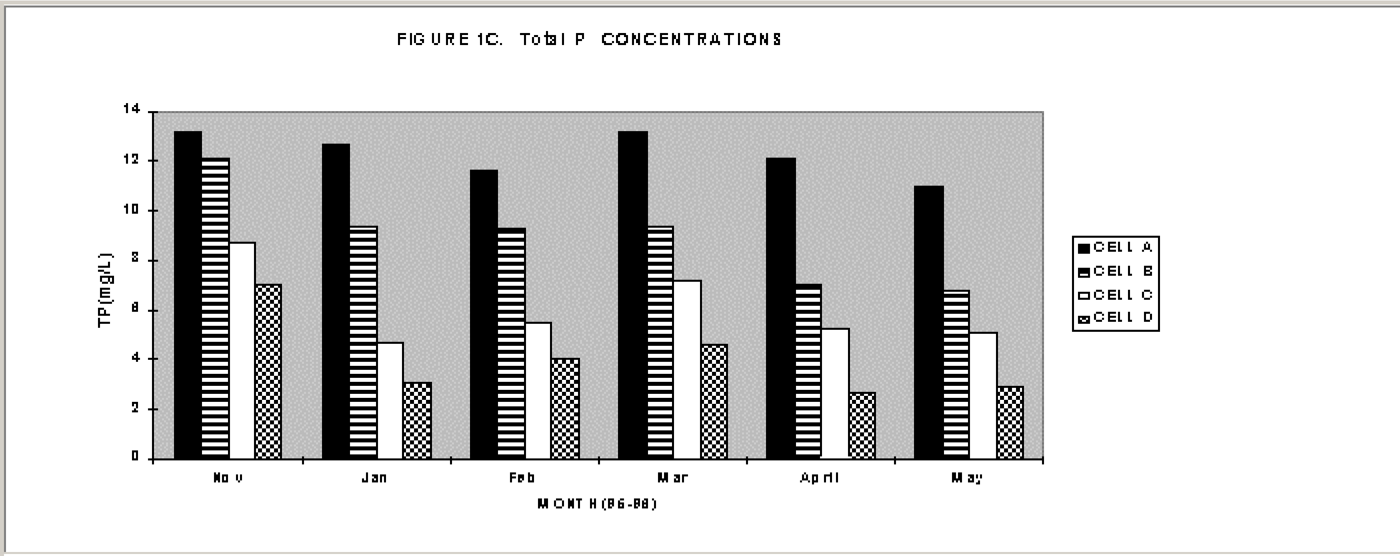


FIGURE 1B. TAN CONCENTRATIONS





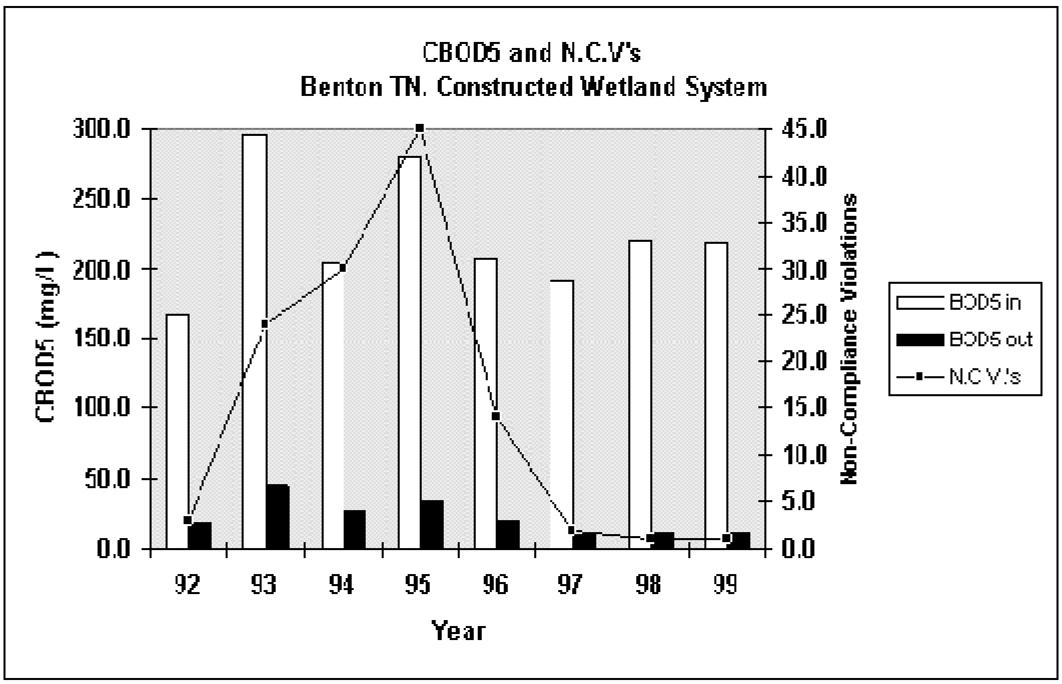
Figures 1a-c illustrate the significant improvement in water quality for reciprocating cells C and D with respect to CBOD5, TAN and TP. The means are based on weekly monitoring data of effluent from each of the respective cells (n = 4-5). During the period Nov. 95 to April 96, cells A and B were operated as controls, i.e., no recurrent reciprocation, while cells C and D were operated as reciprocating units. Starting in April of 1996, all units were operated as recurrent reciprocating units and effluent values for cell D represented values for the combined effluent of all four cells (see Figure a and b).

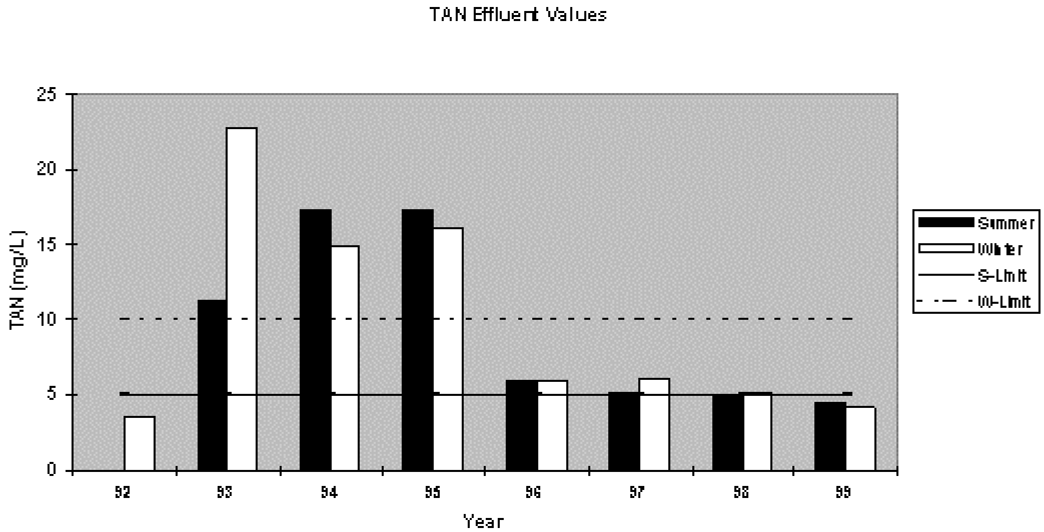
Fecal coliforms was thought to be due to both reciprocation (direct impact of alternating aerobic and anaerobic environments), and the improved clarity of the water passing the UV light system. Prior to reciprocation, the water had a dirty-gray coloration, and fecal coliform numbers were “to numerous to count”. Following reciprocation, water clarity was significantly improved due to the enhanced removal of particulate and dissolved organic matter. Although removal of fecal coliforms was noticeably enhanced with reciprocation, the populations tended to vacillate from week to week. It was observed that the quartz sleeve protecting the U.V. light was rapidly coated with a calcium carbonate film which reduced U.V. light transmittance. Acid washing of the sleeve on a weekly basis removed the coating temporarily, and subsequently enhanced bacterial kill rates. Figure 2 illustrates the typical and relatively high variance of fecal bacteria populations from week to week during several months in 1996.

Figure 2. Population dynamics of fecal coliform bacteria. Low numbers during summer months were based on optimum reciprocation and proper maintenance of U.V. light system. High populations during November and December were

correlated with pump failures which resulted in less than optimum reciprocation of wastewater.

Recurrent reciprocation enhanced removal of noxious odors via oxidation of reduced gases, improved water clarity, enhanced UV pathogen kill, and significantly improved effluent water quality, as expressed by the lower BOD5 and TAN effluent values for the period 1996 through 1999 (Figures 3a and b). From the onset of reciprocation in November of 1995, the annual averages have improved each year. Wastewater treatment efficiency did not seem to be significantly influenced by annual temperature variation. Benton, TN is located in the mid-south and has a mild temperate climate. However, the region is subject to





Figures 3 a and b illustrate average annual effluent values for CBOD5 and TAN respectively. Means are based on 20 to 48 weekly observations. Initiation of reciprocation in November of 1995 led to dramatic and steady improvements in water quality. Notice the significant reduction in non-compliance violations (N.C.V.'s), for CBOD5 and the small but steady improvements in TAN effluent values during the period 1996 to 1999.

freezing temperatures during winter months, and ice formation on the surface of the wetland was observed for brief periods during January and February of most years. The thin surface ice formations did not appear to impact the reciprocation process, and did not appear to impact wastewater treatment functions (See TAN results, Figure 3B). Table 1 summarizes three years of temperature data from a meteorological station near Cleveland, TN, which is within 50 miles of Benton, TN.

Table 1. Summary data of mean air temperatures for Cleveland, TN for the years 1996 through 1998.

Month	96-98 Mean Air Temperature OF	Standard Deviation Air temperature OF	Coefficient of Variation (CV)
January	39.9	3.96	9.9
February	43.3	3.20	7.4

March	49.5	5.11	10.3
April	55.6	1.38	2.5
May	67.0	4.16	6.2
June	73.6	2.05	2.8
July	77.7	0.75	1.0
August	75.7	1.04	1.4
September	71.0	3.10	4.4
October	59.6	1.80	3.0
November	46.4	3.64	7.8
December	42.5	2.95	6.9

CONCLUSIONS

Recurrent reciprocation proved to be a simple, economical, and powerful technology for significantly improving wastewater treatment in subsurface flow wetlands. The application of the technology as a retrofit to an existing wetland system was successful, but also pointed out deficiencies in the design of the conventional subsurface-flow wetland. TVA has conducted additional research related to improving design and operation of reciprocating subsurface-flow wetlands. Optimization of parameters such as backfill substrate (depth, composition and particle size), and reciprocation cycle times have led to significant improvements in wastewater treatment functions (see Behrends et al 1999, this volume). TVA is currently marketing the patented technology through exclusive and non-exclusive licenses to regional, national and international A&E firms and other small businesses.

AKNOWLEDGEMENTS

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