POLLUTANT TRADING: ESTIMATING COSTS OF PHOSPHORUS REMOVAL IN WASTEWATER TREATMENT FACILITIES

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Abstract. Current interest in developing schemes of pollutant trading as a market-based approach to achieving the goals of the Total Maximum Daily Load (TMDL) approach to watershed management is considerable. In this paper, our specific concern is the prospect of lowering nutrient levels in rivers and lakes using an offset banking scheme for pollutant trading between point and nonpoint sources of pollution. A basic pre-requisite for any such scheme is a good understanding of the costs of constructing entirely new (point-source) wastewater treatment facilities, or upgrading existing facilities, in particular in Georgia, in order to reduce the discharge of phosphorus to streams and rivers. In most situations, we need to adapt the already existing facilities — operating at a level of x % removal of P, say — to a higher level of y % removal. An approach based on extensive simulation studies is reported in the paper. Simulation has an important advantage over pilot-scale experiments, since the influence of a very wide range of design features and operating conditions can be rapidly evaluated on a consistent basis. To be specific, our studies have been based on the WEST simulation platform (Hemmis,nv, Kortrijk, Belgium).The results indicate that activated sludge process with alum addition is more economical then A/O and A/A/O process under the effluent TP limit of 2 mg/l.

INTRODUCTION

Current interest in developing schemes of pollutant trading as a market-based approach to achieving the goals of the Total Maximum Daily Load (TMDL) approach to watershed management is considerable. One promising method is to lower nutrient levels in rivers and lakes by using an offset banking scheme for pollutant trading between point and nonpoint sources of pollution. A basic pre-requisite for any such scheme is a good understanding of the costs of constructing entirely new (point-source) wastewater treatment facilities, or upgrading existing facilities, in particular in Georgia, in order to reduce the discharge of phosphorus to streams and rivers. In most situations, we need to adapt the already existing facilities — operating at a level of x % removal of P, say — to a higher level of y % removal. In this sense, were it the case that an entirely new facility should be constructed, this would be tantamount to x being 0%. Since a number of paths of adaptation are possible, it is clear some will be more cost-effective than others. In particular, at the extremes, a path of adaptation based on *no* reconstruction and maximal adaptation of operational policies — a “0 percent reconstruction” policy — may have costs of a very different size and nature to a path based entirely on reconstruction with no operational innovations — a “100 percent reconstruction policy”. Within this broad setting, our current goal is to examine merely a small number of adaptations (all essentially under the policy of 100 percent reconstruction) that will transfer the performance of a given design of facility, for a variety of capacities, through a number of transitions from x % to y % removal rates and to generate the resulting various costs of such transitions.

In order to estimate these costs one might examine this problem using data available on some of the actual transformations (Scltulz et al, 2003) or possibly by scaling up from various pilot plant configurations (Guiss et al, 2003). An approach based on extensive simulation was chosen for this study (see also Alex et al, 1999). Simulation has important advantage over pilot-scale experiments, since the influence of a very wide range of design features and operating conditions can be rapidly evaluated on a constant basis (Hao et al, 2001). To be specific, we shall base our studies on the WEST simulation platform (Hemmis,nv, Kortrijk, Belgium).

Table 1 The flux-based average influent characterization in Athens No.2 WWTP

Parameters	Unit	Concentration
Total COD, COD_{TOT}	mgCOD/l	349
BOD_5	mgO_2/l	228
Total inert COD, C_I	mgCOD/l	59.5
Particulate COD, X_I	mgCOD/l	36.9
Soluble inert COD, S_I	mgCOD/l	22.6
Biodegrable COD, C_S	mgCOD/l	289.4
Fermentable COD, S_F	mgCOD/l	62
Acetate, S_A	mgCOD/l	56.4
Slowly biodegrable COD, X_S	mgCOD/l	171
Ortho-P, S_{PO4_P}	mgP/l	2.97
Total Phosphorus, TP	mgP/l	6.34
Ammonium, NH_4_N	mgN/l	16.1
TSS	mgSS/l	186

SIMULATION METHOD

From the several alternatives supported within WEST, Activated Sludge Model No. 2d (ASM 2d) (Henze et al, 1999) has been selected for our present purpose, because it simulates both biological phosphorus removal and removal of phosphate through precipitation by metal addition. The data used in the simulation were collected in Athens #2 Wastewater Treatment Plant (Liu, 2000). The characterization of influent wastewater, as required for the state variables, is performed according to the research conducted by Insel et al (2003) and Hao et al (2001) and is listed in Table 1. Values assigned to parameters of ASM 2d are derived from the research of Insel et al (2003). The behavior of clarifier is simulated with the double-exponential settling function in a 10-layer model (Takacs et al, 1991).

The activated sludge (AS) process is a basic process of municipal wastewater treatment and is accordingly selected herein as the base-case process from which upgrading of performance and adaptation will take place. The costs estimated in this research are the costs involved in that adaptation, which excludes all the costs of the basic AS system. To enhance phosphorus removal, and to generate estimates of the costs of adaptation, two configurations of biological phosphorus removal, namely Anoxic/Oxic (A/O) and Anaerobic/Anoxic/Oxic (A/A/O) process, and one kind of chemical addition, are employed. Furthermore, additional unit processes, such as sandfilter and/or ultra-filter, can also be incorporated, to remove particulate matter from effluent and hence remove the attaching phosphorus. However, results of only three configurations are presented here because of limited space.

COST ESTIMATION METHOD

The costs of upgrading facility performance include both a capital cost and operations and maintenance (O & M) cost. Procedures for generating the former are derived from *Construction Costs for Municipal Wastewater Treatment Plants* (USEPA, 1980) and *Estimating Treatment Costs* (USEPA, 1979), and updated according to the method of Qasin et al (1993). The O & M cost is decomposed into energy, chemicals, sludge disposal, labor, maintenance, and insurance. The amounts of energy, chemicals, sludge disposal are directly derived from the simulation according to the procedure of Alex et al (1999). The amount of labor is estimated form *Estimating Water Treatment Costs* (USEPA, 1979), while the wage for skilled labor is derived from the Engineering News Record (ENR) indexes. Maintenance and insurance are estimated according to *Detailed Costing Document for the Centralized Wastewater Treatment Industry* (USEPA, 1998).

RESULTS AND DISCUSSIONS

Here we present the results of three configurations with effluent TP limit of 2 mg/l. The implementation of the three configurations in WEST is shown in Figure 1, Figure 2, and Figure 3 respectively. The simplest configuration is to augment the basic AS design with an alum feed system (Figure 1), which includes an alum storage tank, a metering pump, and related pipes, fittings, and valves. A second alternative configuration for adaptation is the A/O process, in which an anoxic tank is added in front of the aerobic tank, together with a recirculation pump between the two tanks (Figure 2). A more complicated configuration is shown in Figure 3, in which an anaerobic tank is added in front of the anoxic tank.

The effluent TP pattern of these configurations is shown in Figure 4. It is demonstrated that the removal of TP in A/A/O process is more stable than the other two options. This may be because in A/O process, the fermentation needed by TP removal occurs simultaneously with denitrification in the same tank (anoxic tank), where the fermentation is adversely affected by nitrate (Barnard et al, 1978). In contrast, in the A/A/O process, the fermentation and denitrification happens respectively in anaerobic tank and anoxic tank, so they don't interfere with each other. It is also noted that the effluent TP concentration of AS + Al process remains high in the last three days, whereas that of A/O and A/A/O process remains their diurnal cycles. The reasons may be that for AS + Al process, the addition of Al is adjusted according to phosphate concentration in the aerobic tank, so the effluent TP concentration is dominated by the influent TP concentration. However, in A/O and A/A/O process, besides influent concentration, the amount of Phosphorus Accumulating Organisms (PAOs) also affects the effluent TP concentration. Increase in influent TP concentration always induces rapid growth of PAOs, and then mitigate the effluent TP concentrations; thus, the effluent TP concentration cannot stay high for several days.

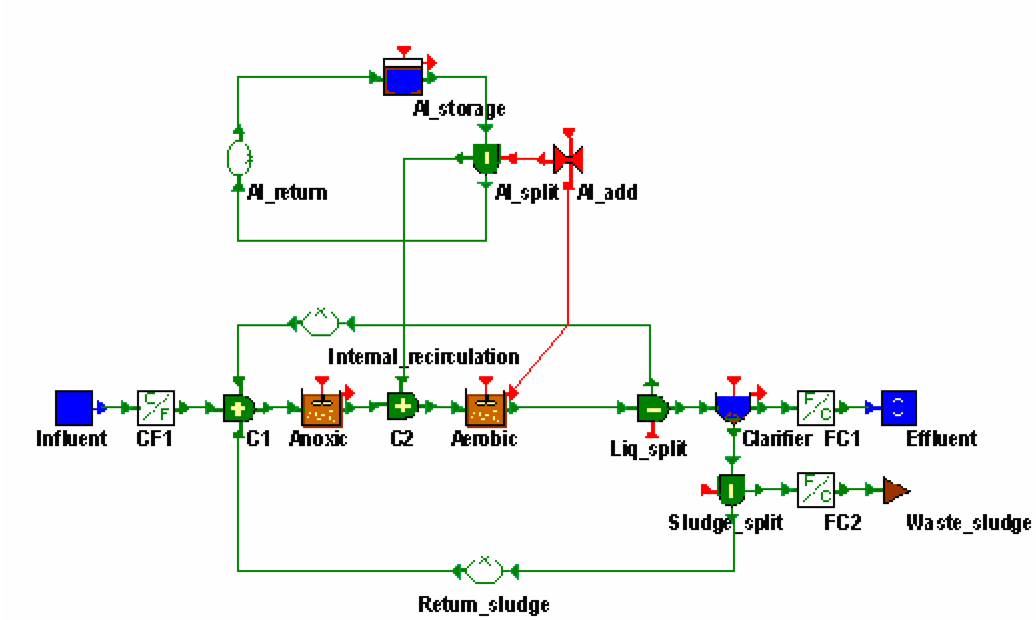

Figure 1. Implementation of AS with Al addition (AS + Al) in WEST

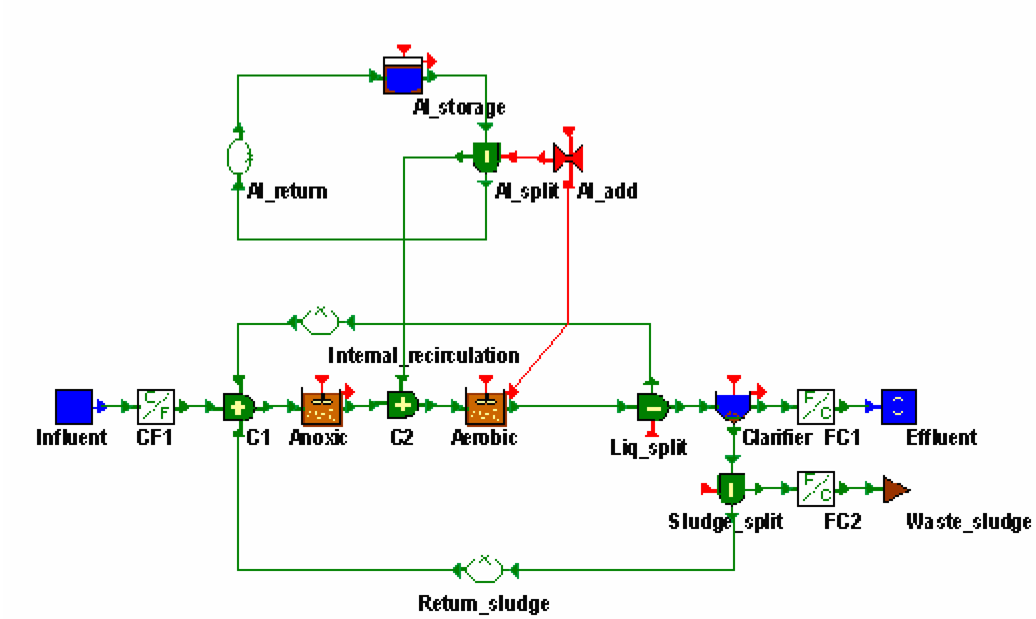

Figure 2. Implementation of A/O process in WEST

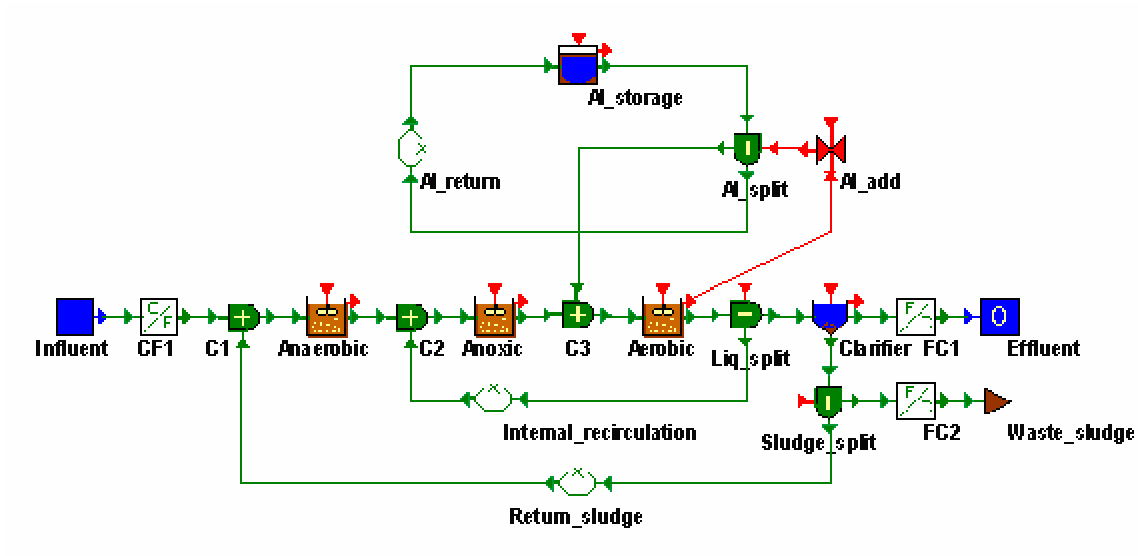

Figure 3. Implementation of A/A/O process in WEST

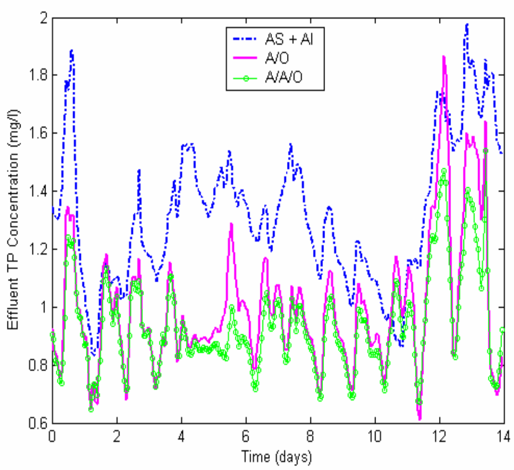

Figure 4. The simulated effluent TP concentration of the three configurations

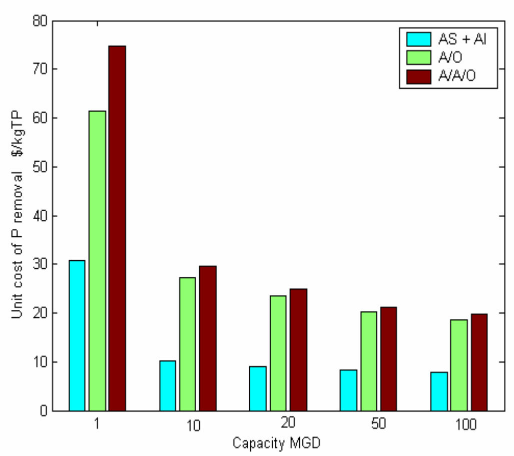

Figure 5. The unit cost of TP removal for the three adaptation configurations

The estimated costs of these configurations are expressed as the unit cost the TP removal, and shown in Figure 5. Compared with the A/O and A/A/O process, the AS + Al process seems more economical, as the unit cost in the AS + Al process is only 30 to 50 percent that of the other two alternatives. As expected, the unit cost falls with the capacity of the plant, as a result of an economy of scale. It is also demonstrated that the unit cost in the A/A/O process is a little higher than that of the A/O process, which may be due to the fact that the A/A/O process has a larger capital cost and higher energy consumption. Also, the sludge production is higher in A/A/O process than in A/O process.

CONCLUSION

In this research, the costs of adapting existing wastewater treatment facilities to various higher levels of performance have been compared on the basis of simulation exercises. For these exercises we have employed the WEST software platform, and industry standard models of related unit processes of wastewater treatment. The results showed the AS + Al process is the most economical for achieving an effluent TP limit under 2 mg/l.

The simulation procedure has been applied to estimate the costs of processes with more strict TP limits and more complicated configurations. Further work will focus on the control and optimization of these configurations.

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