Analysis of Nitrogen Sedimentation in the Advanced Integrated Wastewater Pond System (AIWPS) at Richmond Field Station, U.C. Berkeley

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Abstract

Wastewater systems are necessary for the reduction of limiting nutrients such as nitrogen. High levels of nitrogen flow into the wastewater system. After treatment, nitrogen is expected to flow out below limits set by government agencies. The nitrogen that is removed in the Advanced Integrated Wastewater Pond System (AIWPS) partially settles to the bottom of the various ponds after having been incorporated into algae. Currently, the AIWPS does not remove nitrogen below limits established by the EPA. The objective of this study is to determine the pathway in which nitrogen is removed so that future modifications to the AIWPS can be more effective in removing nitrogen. Once complete and fully operational, the AIWPS can be replicated in developing nations and remote locations in advanced countries as an effective, low-cost method of wastewater treatment. Anoxic conditions at the bottom of the ponds in the AIWPS rarely support nitrate and nitrite forms of nitrogen. Organic nitrogen appears to be the most abundant form of nitrogen present in the ponds. The amount of nitrogen measured in the sediment indicates that settling is not the primary method of nitrogen removal in the AIWPS. Total Kjeldahl Nitrogen analysis has revealed an average concentration of 49.5 mg TKN/g sediment in the advanced facultative pond (AFP), 40.4 mg TKN/g sediment in the high rate pond (HRP), and 34.7 mg TKN/g sediment in the settling basins (SB). Ammonia analysis has revealed a level of 9.27 mg NH_3/g sediment in the advanced facultative pond (AFP), 1.54 mg NH_3/g sediment in the high rate pond (HRP), and 4.30 mg NH_3/g sediment in the settling basins (SB). Depth measurements of sediment along with known dimensions of the ponds allowed quantification of N-compound pathways: 4% of inflow settles into the sediment, 79.6% of which is removed by the AFP, 16.2% by the HRP, and 4.2% by the SBs.

Introduction

Nitrogen is usually abundant in raw sewage that first enters a wastewater facility (Lundquist 1999, pers. com.). Once inside a pond, nitrogen in its various forms can go to a gaseous state, become trapped in solids and settle, or be suspended in the wastewater pond (Horne and Goldman 1994). During the summer, some nitrogen is lost to the atmosphere at a higher rate (Lundquist 1999, pers. com.). Various algae can also obtain and incorporate nitrogen flowing into the pond (Horne and Goldman 1994).

One purpose of wastewater systems is to remove potential limiting nutrients like nitrogen from the water to prevent eutrophication from occurring wherever treated wastewater flows. Nitrogen exists in various forms in water systems, including nitrate and nitrite, organic nitrogen (defined as "organically bound nitrogen in the trinegative oxidation state" (Standard Methods Committee 1994), and ammonia. Total oxidized nitrogen consists of nitrate and nitrite nitrogen. Of the specific forms of nitrogen, both nitrate and nitrite have been identified as growth-limiting nutrients, but have also been identified as toxic substances in high doses, known to cause methemoglobinemia in infants (SMC 1994). For these reasons, limits have been imposed on nitrate and nitrite concentrations in drinking water supplies. Limits have also been imposed on nitrogen levels from wastewater that flows back into the environment. Wastewater systems have been designed to reduce amounts of toxins, suspended solids, and potential limiting nutrients below limits set by local, state, and national governments (Frankenbach and Meyer 1999). Without wastewater management systems, excess nutrients can destabilize ecosystems, cause anoxia, and kill large populations of aquatic life (Horne and Goldman 1994). Also, lack of wastewater management systems can result in biological and chemical toxins entering drinking water sources such as groundwater (Palin 1950).

The system currently being studied is monitored for nitrogen inflow and outflow. Using data collected over a period of time, it is possible to determine how much nitrogen the wastewater treatment system removes. Data regarding nitrogen attenuation at this facility does not yet exist. The purpose of this study is to determine if nitrogen is settling into the sediment at the bottom of the wastewater ponds and if so, in what quantity. Knowledge of this information is important in understanding how the overall system works to remove nitrogen in wastewater. More specifically, the study can potentially determine which section of the system performs nitrogen removal most efficiently. This determination can recommend future studies into making other ponds in the wastewater treatment system more efficient in nitrogen removal for improvement. Alternative, low-technology treatment centers such as this study site could become sufficiently effective at nitrogen removal to benefit developing communities that cannot afford current standard wastewater facilities.

Study site. This study was located at the Richmond Field Station, under operation of the University of California at Berkeley. The study site contains a laboratory responsible for designing alternative wastewater systems that are cost-efficient and require little maintenance and advanced materials. These systems are intended for use in developing nations that have few resources to dedicate to wastewater management. The wastewater system known as the Advanced Integrated Wastewater Pond System (AIWPS) and the Algae Laboratory operate under Environmental Engineering and Health Sciences Laboratories (EEHSL) (Oswald, 1999).

The AIWPS consists of two large ponds and a set of three settling bins. Wastewater from the city of Richmond enters the digester pit located at the center of the advanced facultative pond (AFP). The digester pit is surrounded by an octagonal wooden platform that also extends to the edge of the pond. The pit provides an anaerobic environment for bacteria. These anaerobic bacteria break down sewage through fermentation, reducing biological oxygen demand (BOD) and releasing methane. Water overflows from the digester pit into the AFP. The AFP serves as an aerobic environment for algae processes. Algae take up nutrients such as nitrogen and phosphorus released by bacterial processes. This treated sewage flows from the AFP to the high rate pond (HRP), which is responsible for increasing and optimizing algal growth and cycling of nutrients. The HRP is actually two ponds with a shared water system and for the purpose of this study is treated as one pond. Most pathogens and toxins are also removed at the HRP. The sewage then flows to a set of settling basins (SB). Settling basins are responsible for removing algae through settling. There are two active rectangular settling basins of different widths. The SBs are named Settling Basin Wide (SBW) and Settling Basin Mid (SBM). Wastewater flowing out of the system from the settling basins should then be low in BOD, suspended solids, toxins, and potential limiting nutrients, including nitrogen. This wastewater can then be used for irrigation or be allowed to percolate into the ground since the system is supposed to reduce the above-mentioned contaminants to safe levels. The dimensions of the ponds are described in the Table 1 below. A simplified diagram of the AIWPS is provided below (Figure 1.).

Pond Unit	Volume (m^3)	Area (m^2)	Length (m)	Width (m)	Diam. (m)
AFP	1776	1072	N/A	N/A	37
HRP 1	467	1140	95	12	N/A
HRP 2	456	1140	95	12	N/A
SBW	26.9	25.1	10.9	2.30	N/A
SBM	18.0	16.8	10.9	1.54	N/A
SBN	9.4	8.8	10.9	0.81	N/A

Table 1. Volume, area, and dimensions in each element in the Richmond AIWPS.

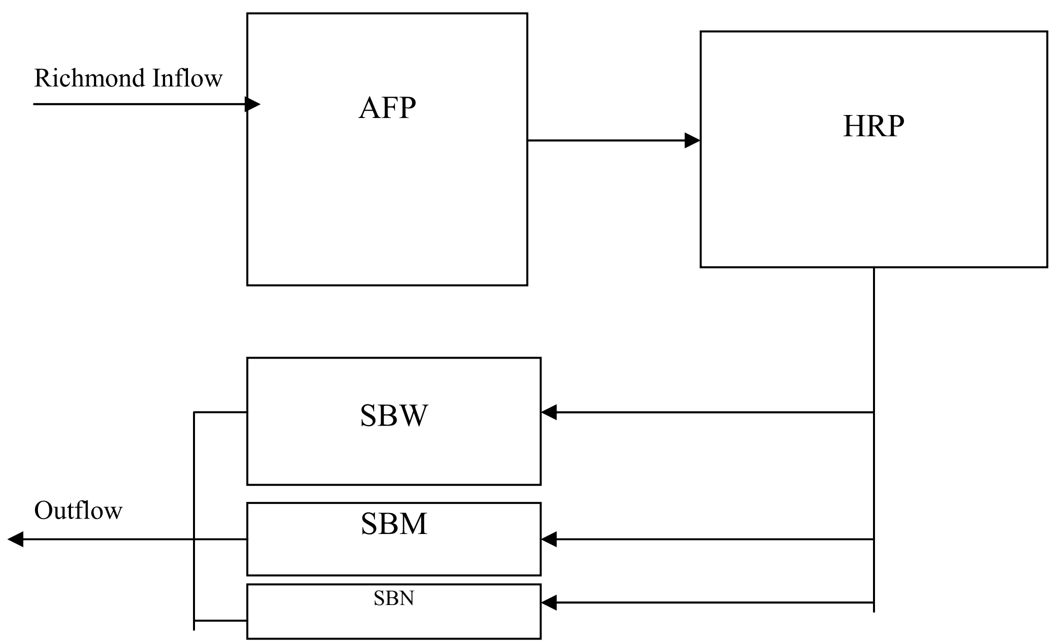

Figure 1. The AIWPS System. The AFP provides both an anoxic and an oxic environment for digestion and algal uptake. The HRP provides for increased nutrient cycling as well as a location to add biological or chemical catalysts. The SBs provides a region where algal biomass and dissolved solids can settle so that the sediment can be removed easily at a later date.

Methods

Sampling *EEHSL Sampling.* Liquid samples were collected on a weekly basis by EEHSL personnel with Nalgene sample jars at the primary inflow point, between the AFP and HRP, the HRP, and the settling basins. These sample measurements form an estimation of how much total nitrogen flows from pond to pond as well as overall flow into and out of the AIWPS. Any difference in nitrogen in these flows is assumed to have settled in the pond it was flowing through and is in the sediment to be sampled for the experiment. There was one sample taken at each point each week. The sample date was recorded at the time the sample was placed into jars.

Sediment Sampling. Sediment samples were collected with the use of a hollow plastic cylinder (1" dia.) attached to several linked tent poles. At the end of the tent pole furthest from the cylinder attachment, a string is attached and led through the cylinder to a rubber stopper. The cylinder is marked with measurement indicators in centimeters with the zero located where the tent pole and cylinder meet. The device is placed into the pond-cylinder first-until the tip strikes the bottom of the pond. The string is then pulled to cap the cylinder with the rubber stopper and the cylinder is brought back up. Excess water is emptied from the top of the cylinder and the rubber stopper is removed (Lundquist, 1999). The sludge sample is then placed into a Nalgene sample jar. The thickness of the sediment layer is measured by the markings on the side of the cylinder unit.

From the primary inflow, the sewage is channeled into a pipe that distributes the inflow into the digester pit, which is located in the center of the AFP. Water from the digester pit overflows into the AFP. Sediment samples will be collected from the platform on the AFP. There is a deck that surrounds the digester pit and leads to the edge of the pond. A set of 14 sediment samples was taken from the edge of the deck surrounding the digester pit.

Between the AFP and the HRP, there is another inflow unit. Flow samples taken by EEHSL personnel are taken from this unit. Two sediment samples were taken at random from the HRP. For the settling basin samples (SBW and SBM), sediment samples will be taken directly at random. Five sediment samples were taken from the SBW as well as the SBM. The volume of sediment in each pond will be estimated by multiplying the depth of sediment by the pond dimensions.

Lab Analyses *Nitrogen Analysis (Organic N).* Measurement of organic nitrogen was done with the Macro-Kjeldahl method (Kjeldahl 1883). Using an 800 ml Kjeldahl flask, the sample was placed inside, neutralized to pH 7 and dechlorinated. Selenized Hengar Granules were then added and 300 ml was boiled off. For digestion, 50 ml Kjeldahl digestion reagent was added to a cooled digestion flask. The flask was then heated until white fumes became visible. Once fumes were cleared by the fume hood, the flask was cooled. Once cooled, the contents of the flask was diluted to 300 ml with water and mixed. The flask was tilted away and 50 ml sodium hydroxide-thiosulfate reagent was added. The flask was then connected to steamed-out distillation equipment and swirled. The contents were distilled and 250 ml distillate was collected. The distillate was added with 50 ml boric acid or 0.04N H_2SO_4 depending on ammonia measurement method. The titrimetric method then proceeded with the addition of 0.02N HCl to the distillate flask until the distillate became purple. The amount of HCl needed to change the distillate purple was recorded and used in calculating Total Kjeldahl Nitrogen (TKN) for the sample. Organic nitrogen is defined as TKN minus NH_3.

Nitrogen Analysis (Nitrate). To measure nitrate levels, the Ultraviolet Spectrophotometric Screening method was used (SMC 1994). A 50 ml clear sample is added to 1 ml HCl and mixed. Nitrate calibration standards are prepared in the range of 0 to 70 mg NO_3^{-}N/L. Using spectrophotometric measurement, the absorbance or transmittance was read against distilled water set at zero absorbance or 100% transmittance. The wavelength was set at 220 nm to obtain the nitrate reading and set at 275 nm to determine dissolved organic matter interference.

Nitrogen Analysis (Nitrite). To measure nitrite levels, the Colorimetric method was used (Boltz 1958). If sample pH was not between 5 and 9, HCl or NH_4OH was added until sample was within range. To a 50 ml sample, 2ml color reagent was added and mixed. After 10 minutes but before 2 hours have passed after adding the color reagent, absorbance was read at 543 nm.

Nitrogen Analysis (Ammonia). To measure ammonia levels, the ammonia-selective electrode method was used (Lee *et al.* 1999). This required the use of an electrometer, an ammonia-selective electrode, a magnetic stirrer, ammonia-free water, sodium hydroxide, NaOH/EDTA solution 10N, and standard ammonia solutions. A 100 ml sample was placed into a 150 ml flask. The stirrer was then inserted and the electrode inserted once stirring commenced. An amount of 1.5 ml NaOH was added to raise the pH above 11. The electrometer was set to measure mV and measurement was recorded when the mV reading stabilized. These laboratory methods were all necessary to measure inorganic and organic nitrogen within samples.

Dry Weight Conversion. All laboratory methods performed above were done with 1ml sediment dissolved into water. To convert concentrations into units of actual dry weight of sediment, equivalent amounts of dissolved samples were placed into pre-weighted aluminum trays and left to dry by evaporation in a fume hood for three days. After the three-day period, the tray and the dried sample were again weighed and the amount of sediment per ml sample was determined.

Data calculation and collection. The AIWPS was last cleaned out of all sediments eight years ago. Since then, data concerning nitrogen inflow and outflow has been recorded and archived. Analysis will consist of calculations with past data, measurement of new samples, and calculations concerning estimated nitrogen within sediments in the ponds.

Lab analysis results will be subject to respective data calculation. Data will be added to past work to determine long-term patterns. Long-term pattern study can also assist in understanding nitrogen peaks and final destinations.

Results

Early nitrate and nitrite analysis has revealed near zero levels. Kjeldahl analysis has resulted in significant levels of organic nitrogen. Calculations resulted in levels of approximately 49.5 mg TKN/g sediment in the AFP, 40.3 mg TKN/g sediment in the HRP, and 34.7 mg TKN/g sediment in the SBs. (See Figure 2.)

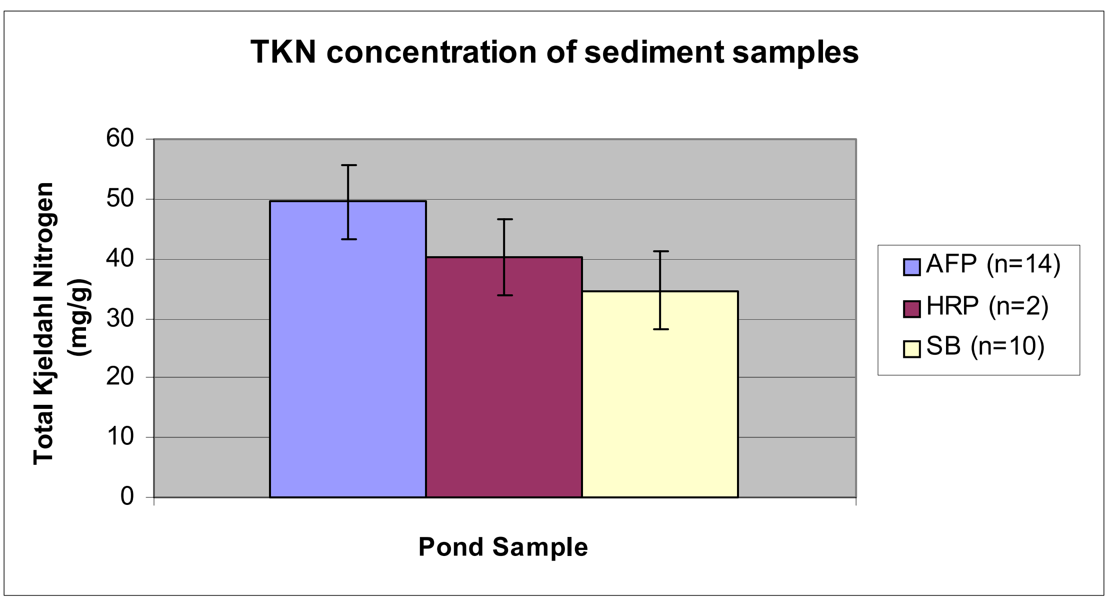

Figure 2. Total Kjeldahl Nitrogen concentrations in pond samples collected.

Ammonia analysis performed at the AFP has resulted in approximately 9.2 mg NH_3/g sediment. Ammonia analysis of samples collected at the HRP has resulted in approximately 1.5 mg NH_3/g sediment. Ammonia analysis of samples collected at the SBs resulted in approximately 4.3 mg NH_3/g sediment. (See Figure 3.)

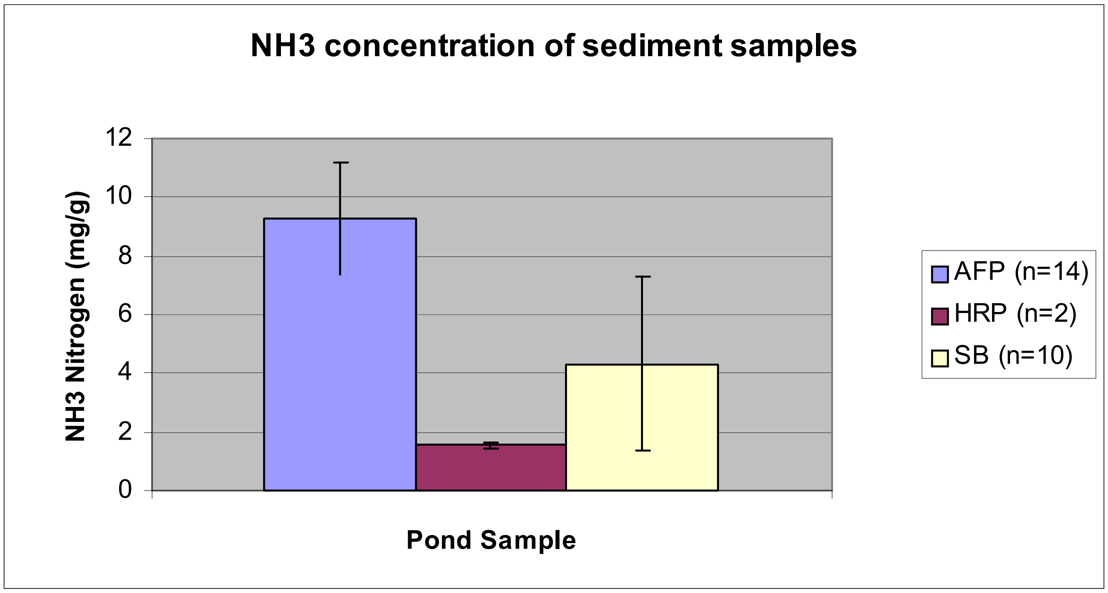

Figure 3. NH3 concentrations in pond samples collected.

Depth measurements combined with known dimensions of the ponds in the AIWPS resulted in the calculation of overall sludge/sediment settled. The AFP contains approximately 124 m^3 of sludge at the bottom of the pond. The HRP contains 15.96 m^3 of sludge. The SBW contains 5.21 m^3 of sludge settled at the bottom of the basin. The SBM contains 1.77 m^3 of sludge at the bottom of the pond. Using average dry sludge data, the amount of dry sediment in the AFP is calculated to be at 4327 kg. The amount of dry sediment in the HRP is calculated to be at 1078 kg. The amount of dry sediment in the SBW is calculated to be at 265 kg. The amount of dry sediment in the SBM is calculated to be at 62.5 kg. Depth measurements of sediment along with known dimensions of the ponds allowed quantification of N-compound pathways: 4% of inflow settles into the sediment, 79.6% of which is removed by the AFP, 16.2% by the HRP, and 4.2% by the SBs.

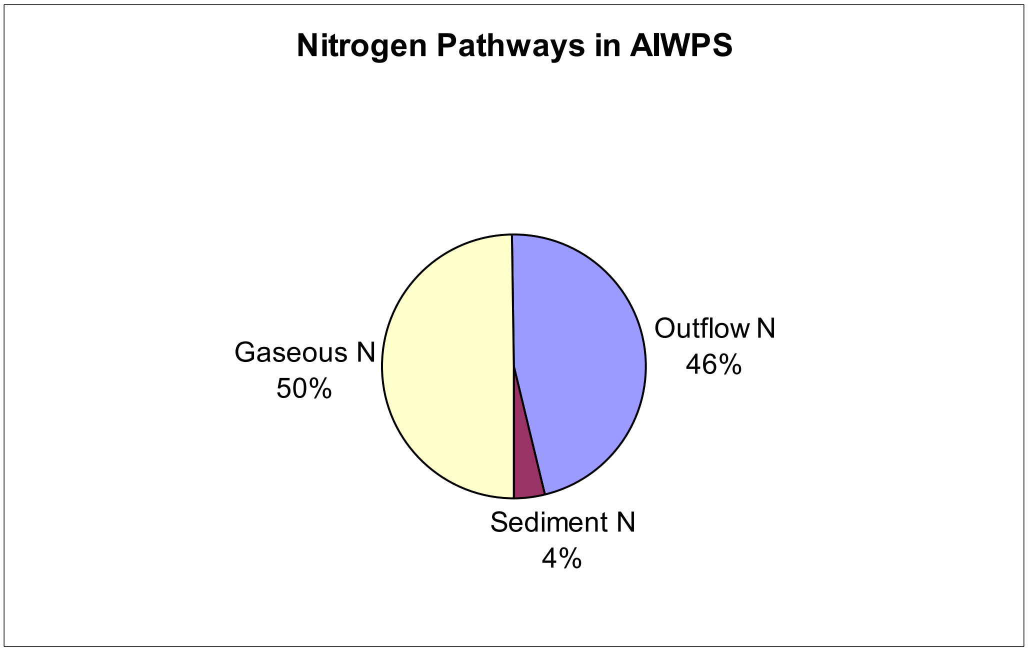

Figure 4. Nitrogen inflow distribution amongst possible exit pathways of the AIWPS.

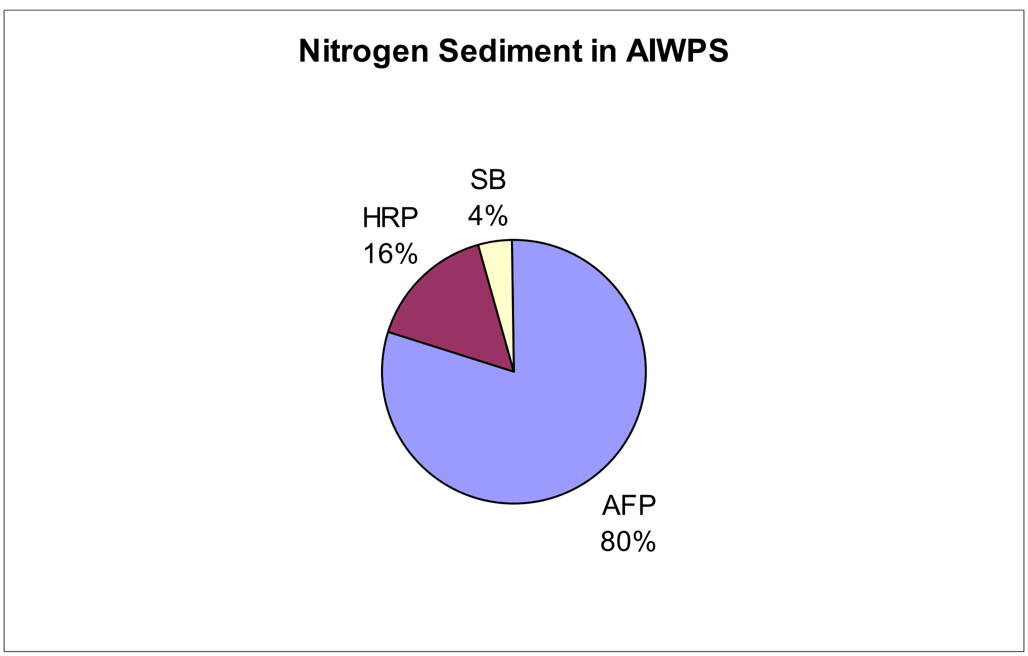

Figure 5. Nitrogen distribution in 4% sediment pathway within the AIWPS ponds.

Discussion

There are only three possible exit pathways nitrogen can leave the AIWPS. These include outflow, sediment deposits, and volatilization. It is suspected that the nitrogen that is missing between inflow and outflow measurements will be found in the sediment; and, all other nitrogen unaccounted for must have volatilized.

The lack of nitrate and nitrite in lab analysis confirms the anoxic conditions that exist where sediment samples were obtained. The sediment also seems to contain nitrogen in organic form, indicating that nitrogen was probably taken in by algae and other organisms that later died and settled to the bottom of the ponds.

Ammonia levels measured in the AFP were consistently higher than ammonia levels measured in samples taken from the SBs. Also, based on depth readings and known dimensions of the ponds, there is substantially more sediment in the AFP than in the HRP and SBs.

The accuracy of the overall study is subject to serious error due to uncontrollable factors. Measurements of nitrogen performed in the past spanned over several years. During this time-span, several events that may have had a severe effect on the nitrogen study. The AIWPS is an outdoor, exposed system that can be interfered with by anyone with access to the RFS. This can include regional pest control agencies to trespassers that breech the outer fences. In addition to direct interference, the inflow of Richmond wastewater is also potentially instable. Refineries in the Richmond area suffer from chemical spills and toxic gas release. Spills can flow into wastewater systems, causing severe fluctuations in sediment content for that time period. Such spikes in chemical concentrations would appear as a thin, high-concentration layer in the sediment at the bottom of the ponds. If a lab sample were to have come from a high-concentration layer, the lab result would be extremely high, not reflecting the overall performance of the AIWPS.

Another consideration in the analysis of past data includes mechanical failure. Several times in the past few years, various components of the AIWPS have failed, rendering some ponds in the system ineffective. A paddlewheel system in the HRP is currently offline as well as the SBN. Due to these types of failures, pond samples would not have been collected from disabled ponds. It is impossible to speculate exactly what nitrogen levels in the ponds during these times could be. These gaps in past collection of data introduce a large margin of error concerning past data analysis.

The study also may be in error due to different amounts of samples collected at the different ponds. Higher sample numbers usually result in greater accuracy. The HRP was only sampled twice successfully. The two samples also demonstrate severe differences in lab measurements.

Overall, the study shows that sedimentation is not the major pathway out of the AIWPS system for nitrogen. Future research should involve adjustments or additions to the system in hopes that nitrogen levels can further be reduced.

Conclusions

The results of lab experiments performed to date (Lundquist et al.) indicate a lack of nitrate and nitrite presence in sediment samples. Based on this information, attention will focus more on organic nitrogen and ammonia analysis. Also, results seem to indicate that large amounts of nitrogen did indeed settle into the sediment. Therefore, sediment that is cleaned out of the system could be of use as a potential fertilizer due to its nitrogen content. Levels of nitrogen are higher in the AFP than in any other pond. This indicates the greater effectiveness of the AFP to remove nitrogen. It is also apparent that larger settling basins have the potential of removing larger quantities of nitrogen through sedimentation.

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