Floating Wetland Solutions
Cleaning Water Nature's Way

FWS Project: Young Life Camp Rural Waste Water

Summary: Saranac Young Life Camp's wastewater treatment facility was not meeting discharge requirements for nitrate and FWS was hired to correct the problem. An innovative Floating Treatment Wetland (FTW) system was installed in August, 2015 to remove nitrate from nitrified wastewater by regulating the environmental factors controlling denitrification.

The essential elements for nitrate reduction are nitrate, the absence of oxygen, carbon, and for systems with high nitrate loads, sufficient microbial habitat. Submerged and non-submerged floating wetland modules were installed in a newly constructed, 5600 ft2 lined lagoon. In 2016, the first year of operation, nitrates were reduced by 50% at loads of 12 lb N per day. Several design modifications were made, and in the second year of operation in 2017, nitrates were consistently reduced to <0.1 mg/l, essentially a 100% reduction, at nitrate loads of 12 lb/day. In 2017, the 5600 ft2 lagoon had an areal nitrate removal rate of 4361 mg/m2/day without carbon supplement and over 10,000 mg/m2/day with carbon supplement, an order of magnitude higher than rates reported in the literature for both natural and constructed wetlands, and amongst the highest ever reported.

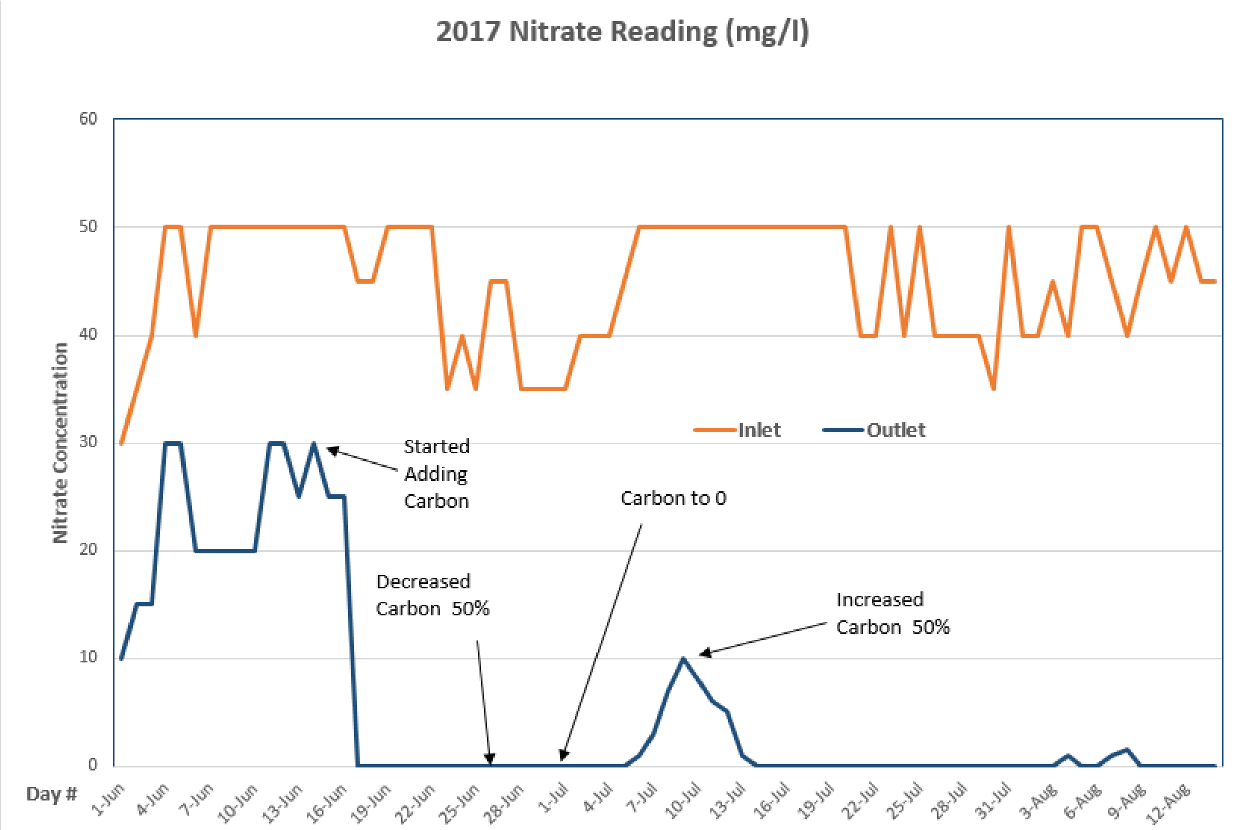
Introduction: The Saranac Village Young Life Camp is located in Santa Clara, New York. The camp's waste water treatment system consists of a 30,000-gallon septic tank which gravity discharges into a 7,000-gallon dual dosing siphon tank that alternates discharge into one of two open sand filters. Filter effluent is collected and gravity discharged into a sampling basin, before being discharged into the first of three lagoons. Lagoon 1 contains the floating treatment wetland system for reducing nitrates, lagoon 2 acts as a polishing basin, and a third lagoon serves as an infiltration basin.

The camp wastewater system runs a summer operation when the camp is occupied with up to 475 Campers plus staff from June through mid-August, and a rest of the year winter operation when the camp is occupied by staff only.

Lagoon 1 is EPDM lined, measures roughly 70' x 80', with total surface area of 5600 square feet and a 5.3-day retention period at the maximum Permitted flow rate (30,000 GPD). Lagoon 1 was constructed in 2015 and went operational in August 2015 with the installation of the FTW system. The sand filter discharge into Lagoon 1 contains low BOD (< 4 mg/l), low ammonia concentration (0-4 mg/l), and high nitrate concentration (70's mg/l), with flows generally ranging from 17,000 to 25,000 gallons per day in summer operation.

August 2015

Data: At the beginning of the camp's summer operation in June 2017, inlet nitrate levels were approximately 50 mg/l and outlet concentrations in the 20-30 mg/l range, with average flows of 17,000 GPD. During the first two weeks of June, a number of design modifications were made, including measures to provide an expanded treatment zone capable of maintaining a constant anoxic state and to improve organic carbon management and hydraulics related to the treatment zone. Beginning on June 12th a carbon supplement was added to each discharge from the 7000 gallon dosing tanks into Lagoon 1. By June 18 Lagoon 1 outlet nitrate concentration had been reduced to <0.1 mg/l. The system consistently reduced nitrates to concentrations <0.1 mg/l throughout the summer operation, with the exception of the period between June 26 and July 10, during which time the supplemental carbon was reduced by half, and then to zero, and then increased back up to half the original dose in order to calibrate the carbon supplement dose (graph below).



The daily nitrate data presented in the graph above was recorded by camp personnel using HACH nitrate test strips with a range of 0-50 ppm. Additionally, samples were collected on 6/26, 7/10, 7/31, and 8/14 for analysis by Life Science Laboratories, Inc. in Syracuse, NY (Table 1). The lab results confirmed the test strip data at the low end, however the test strips only measure up to 50 ppm, and lab results show that high end concentrations were up to 72 mg/l nitrate, thus inlet nitrate concentrations and loads may be higher than indicated by the nitrate test strips on days the strips measured 50 mg/l.

Table 1 2017 LAB RESULTS LAGOON 1

DATE	**INLET NITRATE** mg/l	**OUTLET NITRATE** mg/l	**INLET BOD** mg/l	**OUTLET BOD** mg/l
6/26/2017	54	<0.5	<6	150
7/10/2017	63	5.5	<4	16
7/31/2017	63	< 0.1	<4	54
8/14/2017	72	<0.1	<40	<40

* BOD lab results for 8/14/17 stated that BOD is estimate only due to high oxygen depletion

Noteworthy is the nitrate reduction response to carbon supplement manipulation, indicating that at higher loads the capacity of the system to reduce nitrates is limited by carbon availability. The addition of a proprietary, glycerin-based carbon supplement that provides carbon sufficient to reduce 0.87 lb of nitrate per 1 gallon of supplement was initiated on 6-12-17, at a dose of 6 gallons added to each 7000 gallon batch of influent. At this carbon dose nitrates were reduced to <0.5 mg/l and 150 mg/l BOD was exported. On 6-26-17 the carbon supplement was reduced to 3 gallons per 7000 gallons of influent and nitrate outlet concentrations remained at essentially zero. Carbon supplement was eliminated on 7-1-17, and outlet nitrate started to rise after several days, reaching 5.5 mg/l on 7-10-17, at which time BOD had fallen to 16 mg/l. Carbon additions were reinstated on 7-10-17 at a dose of 3 gallons per 7000 gallons of influent, and on 7-15-17 outlet nitrate concentrations had fallen to <0.1 mg/l and outlet BOD had risen to 54 mg/l being exported. At nitrate concentration of 72 mg/l, each 7000 gallons of influent contains 4.2 lb of nitrate. The addition of 3 gallons carbon supplement with a yield of 0.87 lb nitrate reduction per gallon of supplement to each 7000 gallons of influent would say that carbon supplement is sufficient for reduction of 2.6 lb of nitrate out of the each 4.2 lb of total nitrate reduction, suggesting that 40 % of nitrate reduction can be attributed to endogenous carbon sources. Taking into account exported BOD, a rough mass balance suggests that endogenous carbon is currently sufficient for reduction of 5-6 lb/day of nitrate. The FTW plants and plants around the perimeter of the lagoon are young, 60 % of FTW plants in second season and 40% of FTW plants 2" plugs in June 2017, and endogenous carbon contribution is expected to increase for another 4 to 5 years, reducing need for supplemental carbon over time, potentially meeting the system's carbon requirements. Lagoon 1 2017 lab data in Table 2 show an average increase in pH of 1.4 (std units), with inlet pH averaging 4.6 and outlet pH averaging 6.0. The availability of nitrate, the absence of oxygen, sufficient organic carbon, and sufficient denitrifiers are the main factors controlling denitrification. However, pH and temperature also influence denitrifier growth and metabolism, thus having the ability influence denitrification rates . The average inlet pH of 4.6 is below the pH range (6-8) generally considered as most effective for denitrification, and while nitrate reduction was 100%, no data is available on N2O to N2 ratios.

Table 2 2017 Data

DATE	INLET NITRATE mg/l	OUTLET NITRATE mg/l	AVERAGE MONTHLY FLOW GPD	NITRATE LOAD LB/DAY	pH INLET	pH OUTLET
6/26/17	54	<0.5	23699	10.7	4.7	5.8
7/10/17	63	5.5	22241	11.7	4.6	5.9
7/31/17	63	<0.1	22241	11.7	4.9	6.2
8/14/17	72	<0.1	19216	11.5	4.2	6.2

A summary of data for 2016 operation is shown below in Table 3. Carbon was not added in May when the system reduced 100% of the nitrate load of 2.5 lb/day. Carbon supplement was added in June, July and August at 10 gallons per day. BOD for Lagoon 1 outlet was not measured in 2016.

Table 3 2016 Data

MONTH	NITRATES IN mg/l	NITRATES OUT mg/l	NITRATE LOAD LB/DAY	NITRATE REDUCED LB/DAY	REDUCTION % OF TOTAL
MAY 2016	19	0.1	2.5	2.5	100
JUNE 2016	64	34	10.34	4.9	46
JULY 2016	44	26	8.67	3.6	41
AUG 2016	70	32	10.46	5.7	54

Areal Nitrate Removal Rates: Experimental and field-scale studies typically report wetland nitrate removal rates in the range of from the teens to a few hundred mg/m2/day. Messer reported nitrate removal rates ranging 59 to 603 mg/m2/day and noted that the rates were comparable to rates found in the literature. In all types of wetlands reported by Vymazal the removal of total nitrogen varied between 40 and 55% with removed load ranging between 684 and 1726 mg N m^{-2} day^{-1} depending on constructed wetlands type and inflow loading. In reports of exceptionally high rates, Bachand reported nitrate removal rates of 2800 mg/m2/day in research at six 1300 m2 free-water surface macrocosm wetlands constructed in California's Prado Basin. The author noted that the rates were very high, being exceeded only by rates of 700-4000 mg/m2/day recorded at the Iowa State University Experimental Wetland Mesocosms and the Advanced Integrated Pond System in Richmond, Ca.

The nitrate removal rate for the Young Life 5600 ft2 lagoon is first calculated based on the 5 lb of nitrate reduction attributed to endogenous carbon in order to be on a consistent basis with wetlands not receiving a carbon supplement. Converting the units (5 lb = 2,268,000 mg and 5600 ft2 = 520 m2) results in a nitrate removal rate of 4361 mg/m2/day. The nitrate removal rate with carbon supplement (12 lb nitrate removed per day in 5600 ft2 basin) is 10,467 mg/m2/day.

Denitrification Design: The Young Life design eschewed the conventional FTW design method of relating nutrient removal data from prior studies on a lb of nutrient removed per ft2 of FTW planted surface area basis. Alternatively, the Young Life FTW system was designed to achieve optimum reaction rates by regulating the environmental factors controlling denitrification. Of all the biological processes in nature, denitrification may well be the most sensitive to environmental regulation. The essential elements for nitrate reduction are the nitrate, the absence of oxygen, and organic carbon. For systems with high nitrate loads, sufficient microbial habitat is added to the list.
The 2017 Young Life FTW design included approximately 2100 ft2 of floating modules planted with Iris versicolor, representing a 37% coverage of the total 5600 ft2 water surface.

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Additionally, wetland modules providing high density microbial habitat were deployed vertically below the water surface.

Oxygen depletion; In habitats exposed to the atmosphere, oxygen is the main factor in limiting denitrification, thus the primary design concern is creating and maintaining an oxygen free treatment zone. FTWs regulate DO by blocking photosynthesis, blocking oxygen diffusion from the atmosphere into the water, and increasing oxygen consumption due to biological activity associated with the FTW plant roots. The design strategy for the oxygen free treatment zone utilized: 1) relationships between FTW size and percent surface coverage and the degree to which dissolved oxygen is depleted below the FTW physical footprint, and in adjacent open waters (Borne), and 2) distributed areas of respiration driven oxygen consumption.
The camp's 2016 FTW surface footprint was 1200 ft2 and a 50% nitrate removal rate was achieved, a removal of 5-6 lb per day. One of the modifications made prior to 2017 operation was the addition of 900 ft2 of FTW, deployed as fourteen individual floating wetlands, strategically positioned to divide the open water into smaller units such that the 1200 ft2 main wetland became more dominant relative to any one area of open water and that the main 1200 ft2 wetland's anoxic zone could be projected beyond its own footprint and extend across small strips of open water, expanding the treatment zone, potentially to the entire 5600 ft2 wetland.

Blocking photosynthesis and blocking diffusion from the atmosphere involve preventing oxygen from being added to the water column. The respiratory activity associated with the habitat is the major mechanism that removes oxygen, both the FTW plant roots and the submerged wetland modules provide distributed areas of oxygen consumption.

Organic Carbon: The FTW plants provide organic carbon via plant detritus and root exudates. As noted previously, the FTW plants and plants around the perimeter of the lagoon are young, 60 % of FTW plants in their second season and 40% of FTW plants were newly planted 2" plugs in June 2017. It was anticipated that supplemental carbon would be required initially, and then tapered down yearly until the system matured in 4 to 5 years. In addition to the FTW plants, cat tails are grown around the perimeter as another source of carbon.

Microbial habitat: The plant roots and wetland module surfaces provide microbial habitat to support biological processes. The data indicate that adequate habitat is available at current loads. As noted previously, the plants are young, and the root systems should expand significantly over the next 4 to 5 years, thus increasing microbial habitat, and support higher nitrate loads.

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P.O. Box 1589, North Augusta SC 29860 **Phone: (888) 660-3473**