Denitrification woodchip bioreactor treatment of wastewater from land-based recirculating aquaculture systems

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THE CONSERVATION FUND

Abstract

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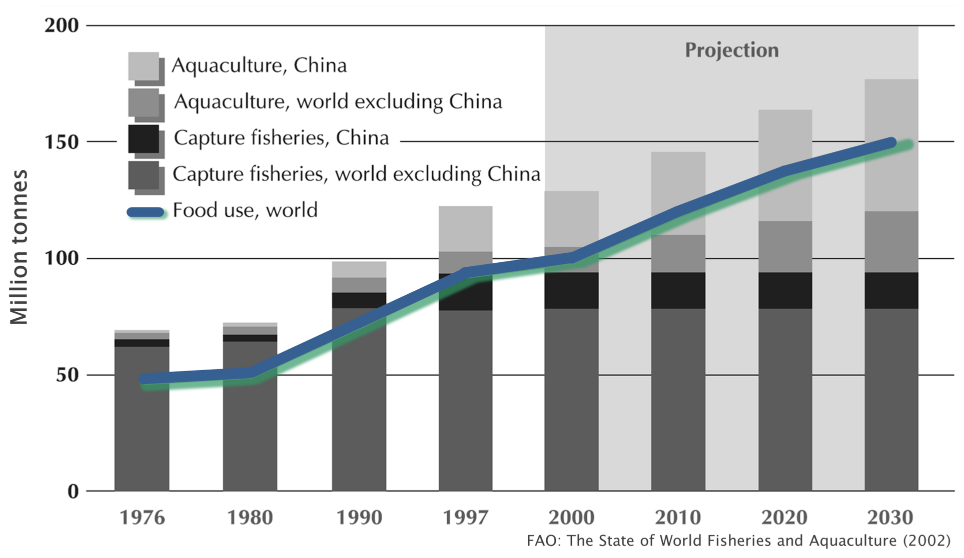
Denitrification "woodchip" bioreactors are a natural treatment technology ideally suited to mitigate point and non-point sources of nitrate from multiple types of agriculture and industry. A new application for "managed denitrification" practices is the treatment of the small, concentrated outflows from recirculating aquaculture systems (RAS). As aquaculture is the fastest growing segment of global animal agriculture production, land-based, closed-containment RAS are poised to significantly contribute to the market-driven demand for responsibly produced seafood. However, the "environmentally-friendly" marketability of these systems depends upon their ability to treat waste and mitigate negative point-source water quality impacts. Denitrification bioreactors are a potentially ideal treatment option for RAS wastewater as (1) nitrate-nitrogen is the primary effluent water-quality concern, (2) effluent water temperatures are fairly consistent (>10 ºC), and (3) controlled effluent flow rates allow for a consistent design hydraulic retention time. This poster describes The Conservation Fund Freshwater Institute's recent activities in the area of woodchip bioreactors for RAS wastewater nitrate mitigation. Six bioreactors, designed in triplicate, each receive wastewater from a closed-containment aquaculture system that produces 22 tonnes of fish annually. A design procedure for agricultural drainage bioreactors in Iowa was modified to design these bioreactors for a consistent retention time. This work-in-progress study will provide insight into woodchip bioreactor design criteria for treatment of RAS wastewater and an overall feasibility assessment of this novel treatment process for aquaculture production systems.

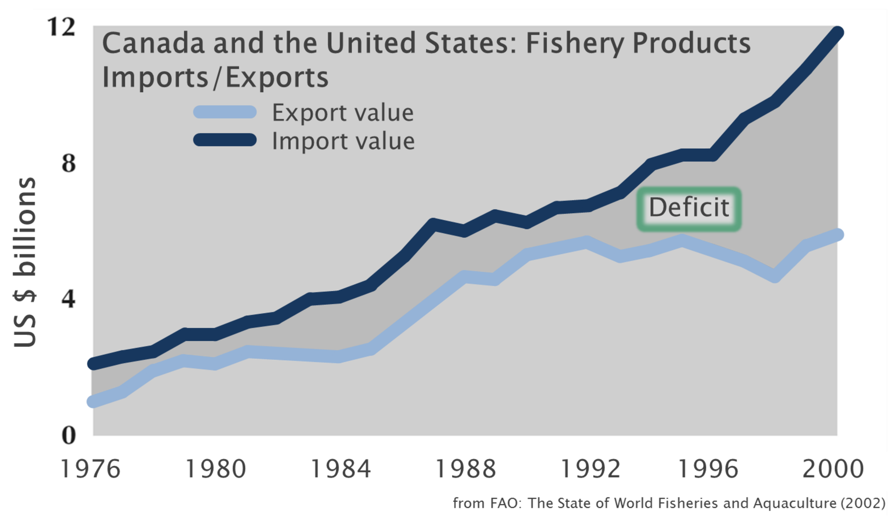
Background

The annual U.S. seafood trade deficit of several billion dollars provides a driving force for the expansion of the fisheries and aquaculture industries. Within this market growth exists a unique niche for land-based, recirculating aquaculture systems (RAS) capable of intensive fish production while minimizing water footprints and environmental concerns. In the design of such systems, removal of solids, total ammonium nitrogen (TAN), and nitrite (NO_2-) are critical to allow recirculation of water to fish culture tanks. Although nitrification unit processes transform fish-toxic TAN and NO_2- to nitrate (NO_3-), this nitrogenous waste, which is typically not considered a key contaminant within recirculated waters, presents concerns of its own. Nitrate-nitrogen is now being targeted as a primary water quality contaminant due to a growing number of nitrogen-induced marine hypoxic zones and other water quality problems.

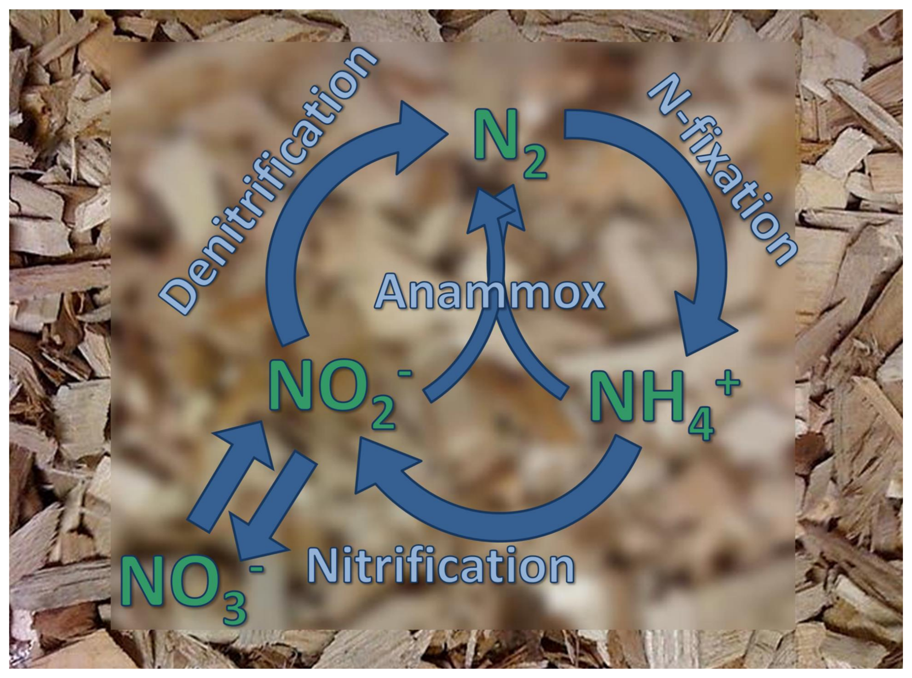
The ability to consistently and confidently reduce NO_3-loads from land-based RAS could provide a number of distinct economic and environmental benefits:

- Improved proximity to urban markets that have often already placed significant pressures upon their watersheds
- Increased reuse of effluent to even more fully close the RAS water-use cycle
- Furthering the public perception of this industry as a sustainable, environmentally friendly protein option





Biological denitrification, the microbially-mediated reduction of NO_3^- to various oxides of nitrogen and eventually nonreactive dinitrogen (N_2), is one of the most effective and cost efficient methods to remove NO_3^- from wastewater. The transformation of reactive forms of nitrogen to stable N_2, either via denitrification or the more recently described anammox process, is the only way to reduce environmental impacts of the "nitrogen cascade". The past decade has seen increasing interest in wood-based denitrification technologies that utilize solid carbon sources to supply the electron donor required to fuel heterotrophic denitrification. The earliest work in this field investigated nitrate removal in septic effluent and groundwater, with this body of research growing to now include treatment of storm water, agricultural drainage, and hydroponic waste waters, among others.



The need of land-based, closed-containment recirculating aquaculture systems (RAS) to mitigate nitrate in their effluent provides an interesting application for these low-energy, low-maintenance denitrification systems. Although land-based RAS are poised to significantly contribute to the rapidly-growing demand for responsibly produced seafood, the expansion of this industry may hinge upon the development of nutrient pollution-reduction technologies.

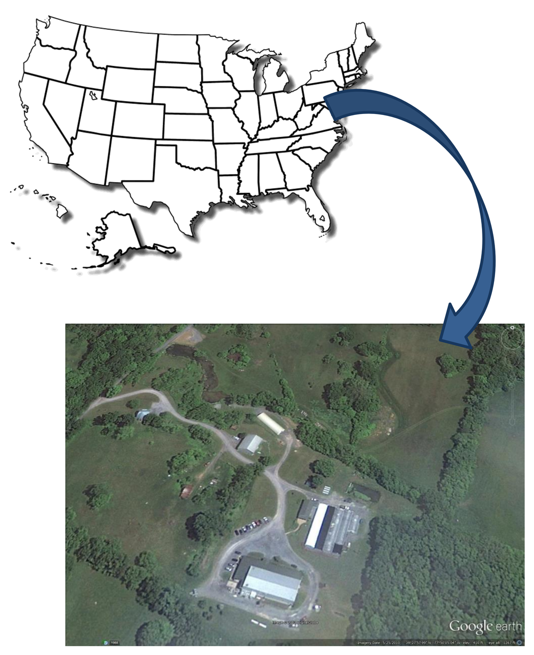
Methods: Site and Design Approaches

Much recent design work for wood-based denitrification technologies has focused on the design of these systems for treatment of subsurface agricultural drainage. More design optimization research is needed however, as there is no woodchip bioreactor design model specifically calibrated for the high NO_3^- concentrations and other water chemistry parameters associated with RAS effluent.

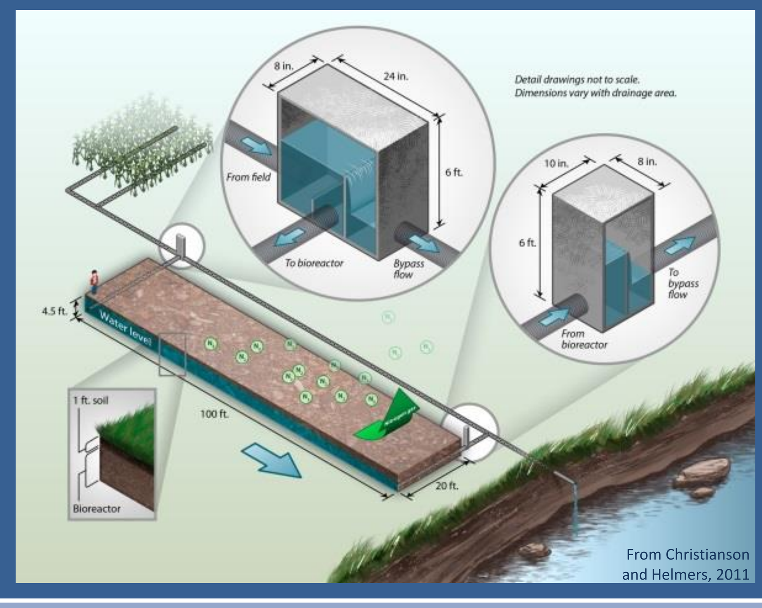
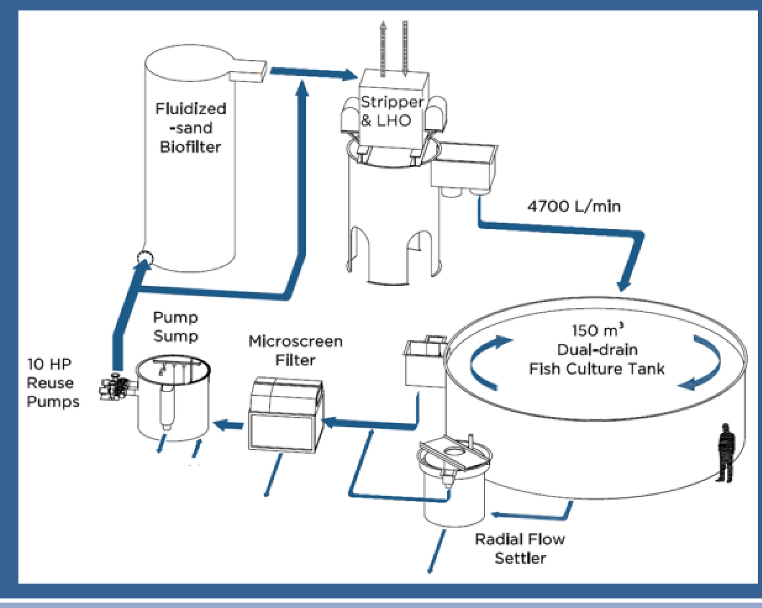
Objective: Design and install a woodchip bioreactor research system allowing empirical data collection across a range of flow rates and water quality criteria for calibration of a design model. Existing design approaches include:

- Volumetric Design Method: Use empirical removal rates to generate a required bioreactor volume for sites with known flow rates and water quality parameters; works best for effluent with a consistent flow rate
- Simultaneous Solution of Darcy's Law and Hydraulic Retention Time Model: Calibrate model with either a desired retention time at a given design flow rate or a given desired load reduction based on an empirical performance curve; requires empirical hydraulic conductivity and porosity information for the fill media

Additionally designs should consider reactor hydraulics (e.g., length to width ratio, flow routing, inlet/outlet position, design features) and site-specific calibrations for temperature, hydrology, watershed placement.



The Freshwater Institute (Shepherdstown, WV) is a research and engineering branch of the national nonprofit, The Conservation Fund. The 40 ha research farm produces 22 tonnes of fish annually including Atlantic salmon and rainbow trout, among others. The farm is permitted as a point source discharge (National Pollution Discharge Elimination System).

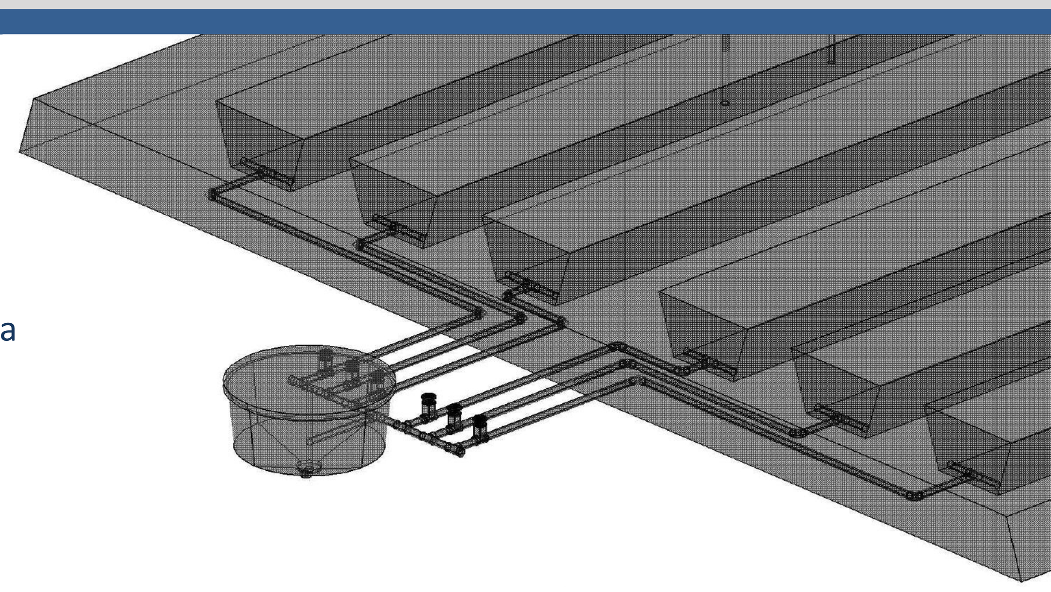
	Woodchip bioreactor design for typical agricultural tile drainage	Woodchip bioreactor design for typical Freshwater Institute aquaculture effluent
	 From Christianson and Helmers, 2011	
Influent Water Quality		
Nitrate-N	10-20 mg NO_3-N/L (average range)	1-5 mg NO_3-N/L (average range) * Typical RAS effluent will be 50 to >200 mg NO_3-N/L *
Temperature	<3°C (winter) to >15°C (summer)	11.6°C to 15.5°C
Dissolved oxygen	<3 (summer) to >8 (winter) mg DO/L	8.2 to 10.9 mg DO/L
Total susp. solids	<1 mg TSS/L	<1 to 10 mg TSS/L
Biological Oxygen Demand	2 mg BOD/L	1.4 to 8.2 mg BOD/L
Design Characteristics		
Flow rate (Design flow rate)	≈1360 lpm (10-35 ha) (Design: 230 lpm)	≈1140 lpm (Design: 230 lpm)
Design hydraulic retention time	4 to 8 hrs (minimum)	At least 6 hrs * Typical RAS effluent will likely require ≥ 24 hrs *

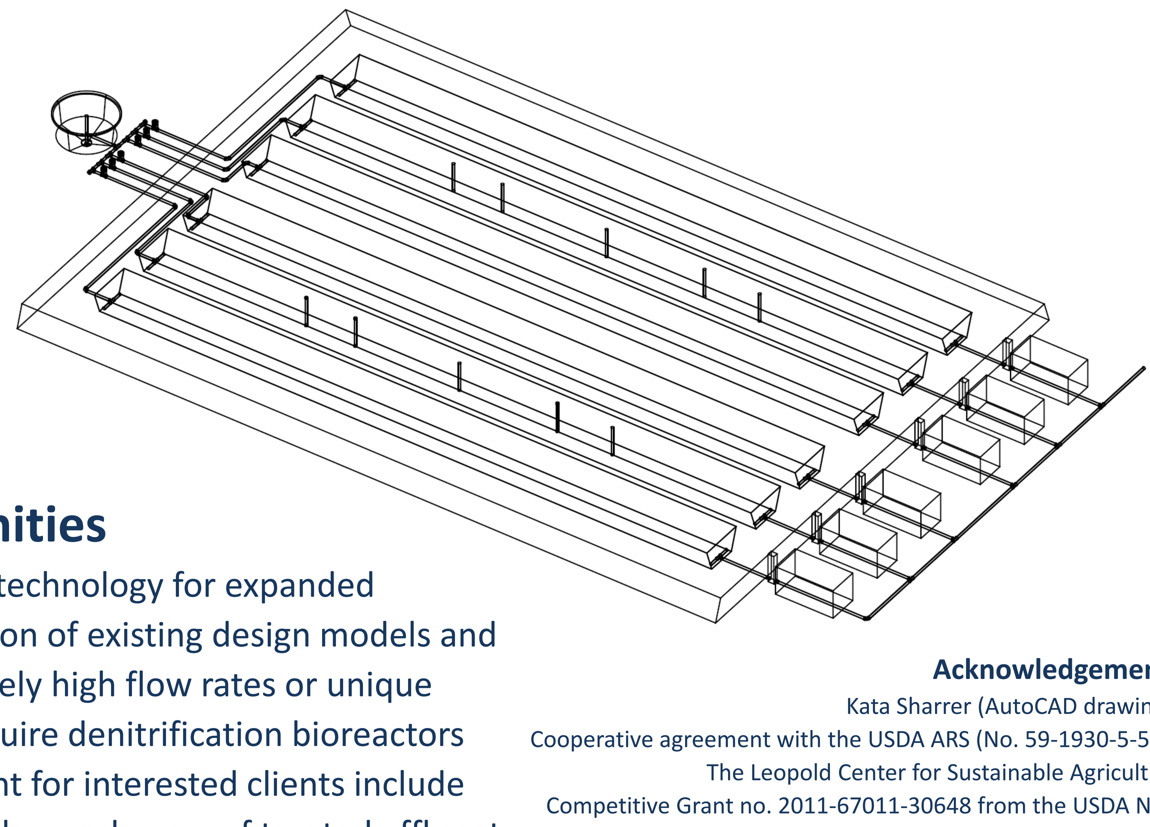
Results: Proposed Design (Installation Spring 2014)

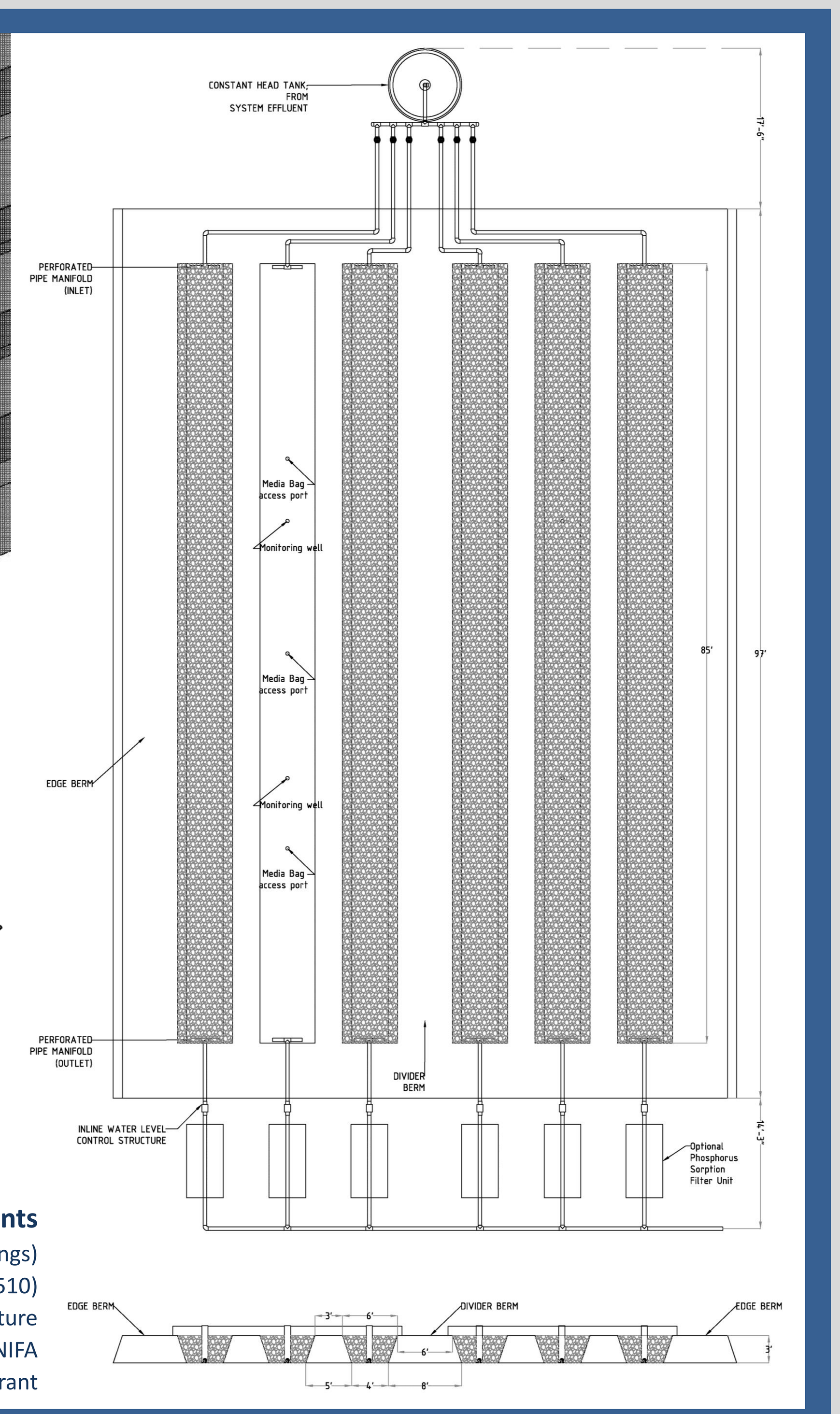
Six full-scale bioreactors (26 x 1.8 (top) x 0.91 m) allowing simultaneous comparison across replicated treatments will be installed to generate key design data to further refine woodchip bioreactor design models.

Features include:
- Constant head inlet tank
- Outlet control structures
- Lined with plastic
- Monitoring wells and media bags

The design will facilitate testing on:
- Nitrate removal at varying:
  - Hydraulic retention times
  - Influent water chemistries
- Media longevity
- Start-up organic flushing losses
- Coliform transport and fate
- Phosphorus removal design options







Future Challenges and Opportunities

Advancing woodchip denitrification bioreactor technology for expanded application of proven designs requires revisitation of existing design models and calibration with new data. Effluents with relatively high flow rates or unique water chemistries, such as RAS waters, may require denitrification bioreactors with novel design features. Ideas at the forefront for interested clients include use of circuitous flow routing, removable modules, and reuse of treated effluent.

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