Procedures Used in the Construction of a Denitrifying Border

by

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Introduction

Plants require a number of different nutrients to meet their metabolic needs. Some nutrients are required in large quantities such as; carbon, nitrogen, phosphorus, etc. and others in lesser quantities such as; manganese, copper, iron, etc. Nitrogen has been identified as the nutrient in limiting concentration for most coastal marine systems, i.e. plant growth and abundance is regulated by the availability of nitrogen in the water.

Since the 1950's housing development along the coast has increased sharply with many communities relying on Individual Septic Disposal Systems (ISDS) to process household effluent (Fig. 1). An ISDS system breaks down organic compounds to their elemental components and converts nitrogen from the more toxic form of ammonia (NH_4) to nitrate (NO_3). As nitrogen-rich household effluent passes through an ISDS system it percolates through the aerated soil under the leech field and becomes part of the groundwater in the water table. Once incorporated into groundwater, nitrogen moves freely in a plume along the surface of the water table and can be transported into nearby coastal waterways. Groundwater entering Ninigret Pond can be documented using infrared photography taken from a low flying aircraft in 1973 (Fig. 2).

This document describes the construction of an underground "woodchip border" that allows for unimpeded groundwater flow through a woodchip media while removing dissolved nitrogen in the form of nitrate (NO_3) and dissolved organic nitrogen (DON) (Figs 1,3,4,5,6, and 7). By placing a woodchip border parallel to the shoreline it is possible to remove virtually all of the nitrogen carried by the upper few meters of groundwater in the water table. Simply put, a "border" is created by excavating a trench deep enough to intrude several feet into the upper portion of the water table (Figs. 1, 6, and 7). The lower section of the trench that lies in water table, i.e. in hydrated or saturated soils, is backfilled with woodchips, then the upper portion of the trench that lies in aerated soils is backfilled with top soil and graded to the site's original elevation. We discuss the logistics and procedures used to construct proto-type nitrate removal borders at two sites along the shore of Greenhill Pond in Charlestown, RI (Ocean Ridge and Indigo Point). Each installation will face its own set of site specific considerations, however the information and experiences gained from our own installations provide a basic set of steps that can be followed or altered to accommodate a range of site conditions and applications.

Site Selection

Locating a site that maximizes nitrogen removal by the border is guided by a few basic considerations. In order for nitrogen removal to occur, groundwater must flow through the woodchip media. The amount of nitrogen removed from groundwater is then controlled by the "residence time" or amount of time that groundwater takes to pass through the woodchip layer. Woodchips provide the correct environment where bacteria that thrive in the anaerobic conditions (without oxygen) can convert nitrate to nitrogen gas (NO_3 to $N_2\uparrow$). The groundwater is made anaerobic within the border by the respiration of bacteria digesting the organic matter in the wood chips. The nitrogen gas that is released by the bacteria is colorless, odorless and constitutes 80% of the air we breathe.

The long axis of the trench should be positioned perpendicular to the direction of groundwater flow to ensure that water passes through the border. In shoreline areas the border would be located parallel to the shoreline and sufficiently landward to ensure that salt water does not intrude into the woodchips as it would prove detrimental to the desired anaerobic bacteria (Fig. 7). If salt water gets into the wood chips, a foul smelling hydrogen sulfide gas may be produced instead of nitrogen gas.

The time it takes groundwater to move through the woodchip media is primarily determined by two factors, groundwater flow rate (cm d^{-1}) and the width of the trench. Based on laboratory tests where we passed nitrate-rich water through woodchips at various flow rates we estimated the residence time required to denitrify the enriched water. Relying on these results along with a conservative estimate of groundwater flow for the area, we determined a trench 6 feet wide would ensure nearly complete nitrogen (NO_3) removal at our test sites. Groundwater can display a wide range of flow rates and a trench 2 meters wide should accommodate the majority of locations. However, in areas with particularly fast groundwater movement the trench width will need to be increased to ensure a sufficient residence time to ensure complete nitrogen removal.

After the borders were installed at our test sites, monitoring wells were placed "upstream", i.e. before groundwater entered the woodchips and "downstream" to capture groundwater after passing through the woodchips. The wells were monitored monthly for two years and without exception over 95% of the NO_3 and from 30% to 60% of the dissolved organic nitrogen (DON) were removed from groundwater as it moved through the woodchips (Table 1). The efficiency of nitrogen removal remained constant through seasonal changes in temperature, precipitation, and water table height.

Accessibility

Excavation equipment such as a backhoe and dump truck require access to the trench and therefore the site must be located in such a way as to allow free access for the earth moving equipment. A Caterpillar 211 backhoe with a ¾ yd^3 bucket dug our two test trenches that measure 6 feet (width) by 16 feet (length) and are from 6 feet to 10 feet deep (Fig 3). The material removed from the trench as well as the woodchip media were transported in two 16 yd^3 dump trucks. While the installation can be completed using only one dump truck by making multiple trips to unload fill material or retrieve woodchips, we found that two trucks reduced waiting time and allowed us to continue work on the trench while one of the trucks was sent to load woodchips at a local sawmill.

Excavation of the Trench

The backhoe begins the construction process by removing surface soil over the trench site and storing it in a convenient location where it can be easily retrieved and used as backfill material. After the first 3 feet of surface soil is removed, a trench box is lowered into the trench (Fig. 3). Trench boxes of various sizes can be rented from Eastern Pipe Products located in Newington, CT. The trench box should be inserted before the excavator reaches the water table to prevent the trench from collapsing. We found that by removing one of the four jack posts on the trench box, i.e. the post that lies at the top of the box and is closest to the backhoe, the backhoe operator to could remove the subsoil more easily (Figs. 3 and 5).

As the excavator removes the soil and the trench deepens the operator uses the backhoe bucket to tap the top of the trench box and coax it deeper into the trench. We reached groundwater at depths of 3 feet and 6 feet at our test sites (Fig. 6), and continued excavating until reaching 3 feet below the water table. Groundwater will flow freely into the void created by the excavator, so before the wood chips can be added the trench must be drained (wood chips float). Using two portable gas driven pumps with flow rates of 150 gallons per minute and 2 inch discharges, we were able to keep the trenches clear of water. Discharge hoses can be emptied into an area surrounded by staked hay bales to remove suspended sediment. Once this is accomplished the backfilling operation can begin.

Backfill Operation

The material used to backfill the lower portion of the trench provides a source of carbon to the anaerobic bacteria and allows for the conversion of nitrate in groundwater to nitrogen gas. We used woodchips from Thompson’s sawmill in Hopkinton, Rhode Island as our media (Fig 4). The particle size of the woodchips will determine transmissivity (a measure of porosity) of the media and ultimately how easily groundwater will pass through the layer. Larger wood chips allow groundwater to flow freely through the woodchip border while smaller particles or heavily compressed chips may resist groundwater penetration and cause the water to flow around or under the trench. Once the wood chips have been dumped into the open trench the backhoe spreads the chips evenly. We continued backfilling the trenches with woodchips until reaching about 1 foot above the water table. Landscaper’s cloth is added to keep the woodchips separated from the surface soils (Figs. 4 and 5). Finally, the surface soil removed during the initial excavation is replaced and the site graded to the original elevation before construction. As we stated earlier, we have monitored our test sites for two years during which the natural vegetation has grown over the disturbed area and it is virtually impossible to determine the location of the border.

Summary

The construction of a permeable wood-chip border can provide a low-cost, effective method of removing nearly all of the dissolved nitrogen from groundwater by converting it into nitrogen gas which is not biologically available to plants. When a wood-chip border is correctly oriented to groundwater flow and properly constructed, groundwater flows freely through the wood-chip media providing an effective method of nitrogen removal that does not require the interruption or re-engineering of any existing ISDS systems. The location of the border is virtually impossible to determine after the disturbed site is allowed to develop covering vegetation. The wood-chip media continues to provide the proper bacterial environment for nitrogen removal for many years (estimated time for Ocean Ridge site exceeds fifty years) and does not require any maintenance or amendments (Fig 8.)

Note: The construction of permeable woodchip trenches within the coastal zone will most often require a permit from the RI Coastal Resources Management Council (CRMC). Any construction activity within the CRMC's jurisdiction (i.e., on a shoreline feature or its 200-foot contiguous area) requires review and approval by the agency. Please consult with a CRMC staff member for determination as to whether your project will require a permit, and guidance on the application process.

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Telephone: 401-783-3370

Suggested Reading

Robertson, W.D. and J. Cherry. 1995. In situ denitrification of septic-system nitrate using reactive porous media barriers: field trials. Ground Water 33:99-111.

Robertson, W.D., D. Blowes, C.Ptacek, and J. Cherry. 2000. Long-term performance of in-situ reactive barriers for nitrate remediation. Ground Water 38:689-695.

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Schipper, L. and M. Vojvodic-Vukovic. 1998. Nitrate removal from groundwater using a denitrification wall amended with sawdust: field trial. J. Envr. Quality 27:664-668.

Schipper, L. 1999. Groundwater denitrification wall: an update. Water and Wastes in New Zealand 105:46-47.

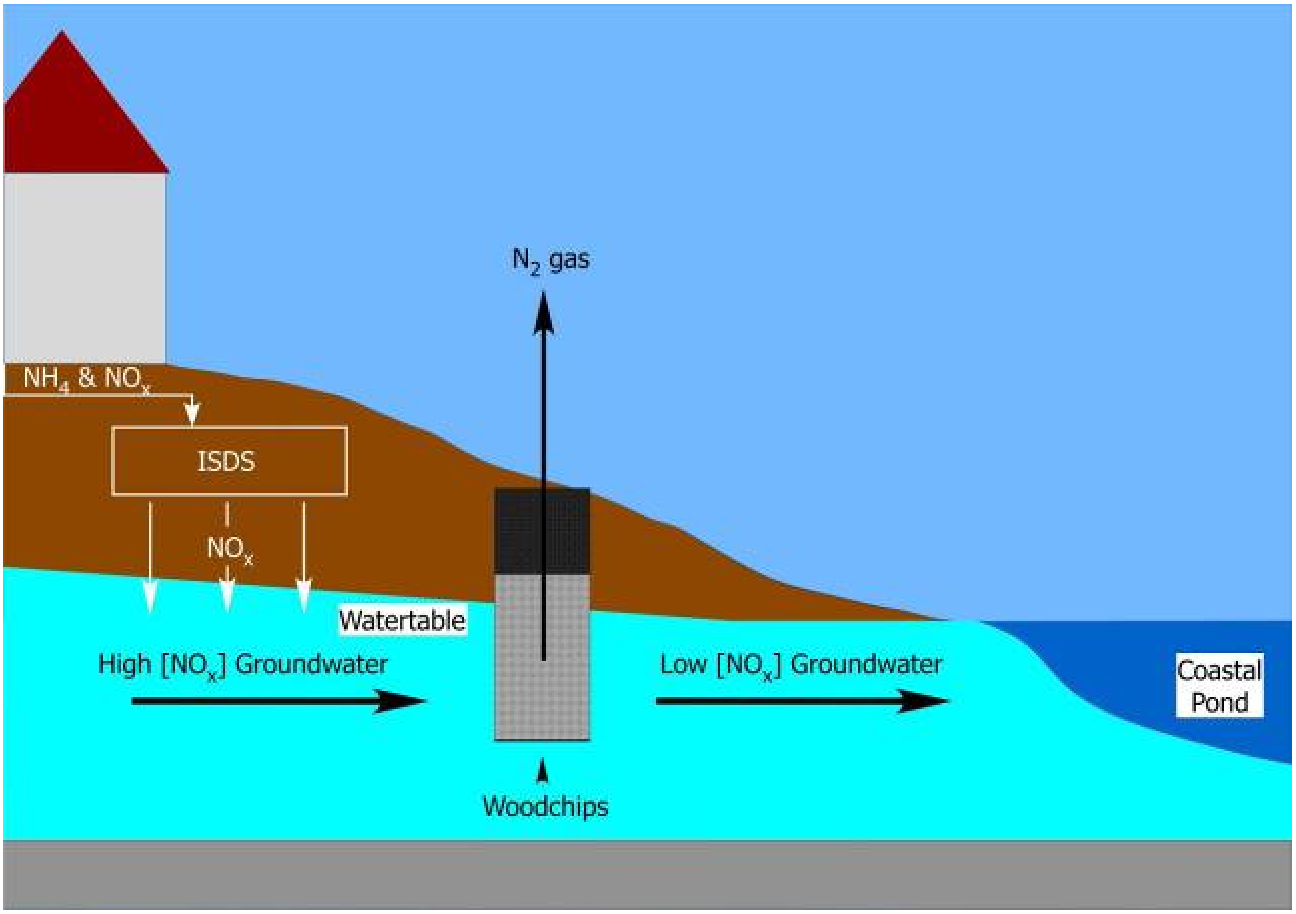


Fig. 1. Schematic of a woodchip border with the flow path of household nitrogen-rich effluent as it passes through the on-site treatment (ISDS) into the groundwater then moves through a woodchip nitrogen removal trench.

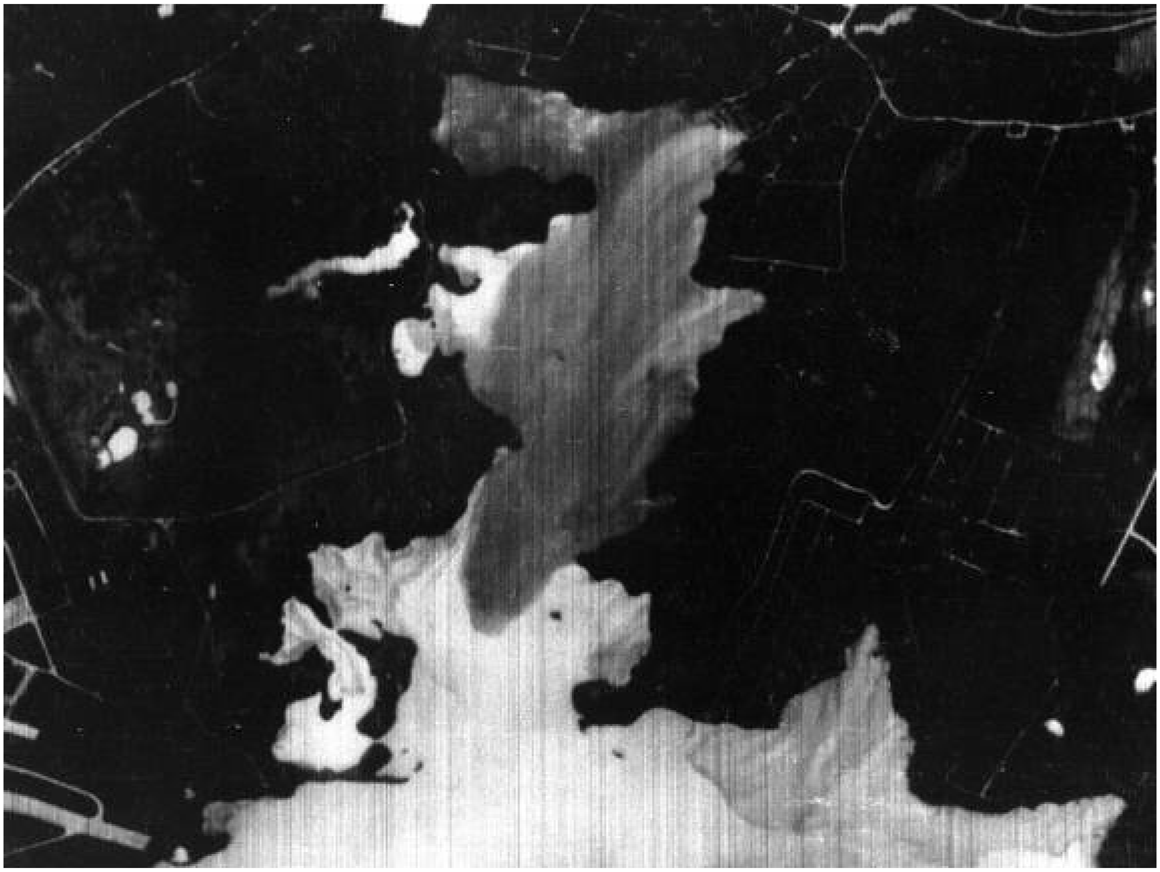


Fig 2. An infrared photograph taken in August 1973 of Fort Neck Cove, Ninigret Pond, Charlestown, R.I. Land appears in the image as black (or nearly black) area, while the water in Ninigret Pond is seen as the white or lighter areas. Groundwater entering the pond at the shoreline is cooler than pond water and appears as a wisps or plumes of darker colored water. A particularly large plume can be seen moving down the center of Fort Neck Cove from the upper pond toward the breachway.

Fig. 3. A trench box is used to stabilize the trench and prevent the sides from slumping. After digging to a depth 3 feet, we lowered a trench box into the trench. Just below a depth of three feet groundwater began seeping into the trench making the walls unstable. In this location we used two trench boxes placed end to end resulting in a woodchip border measuring 6 feet (wide) by 16 feet (long).

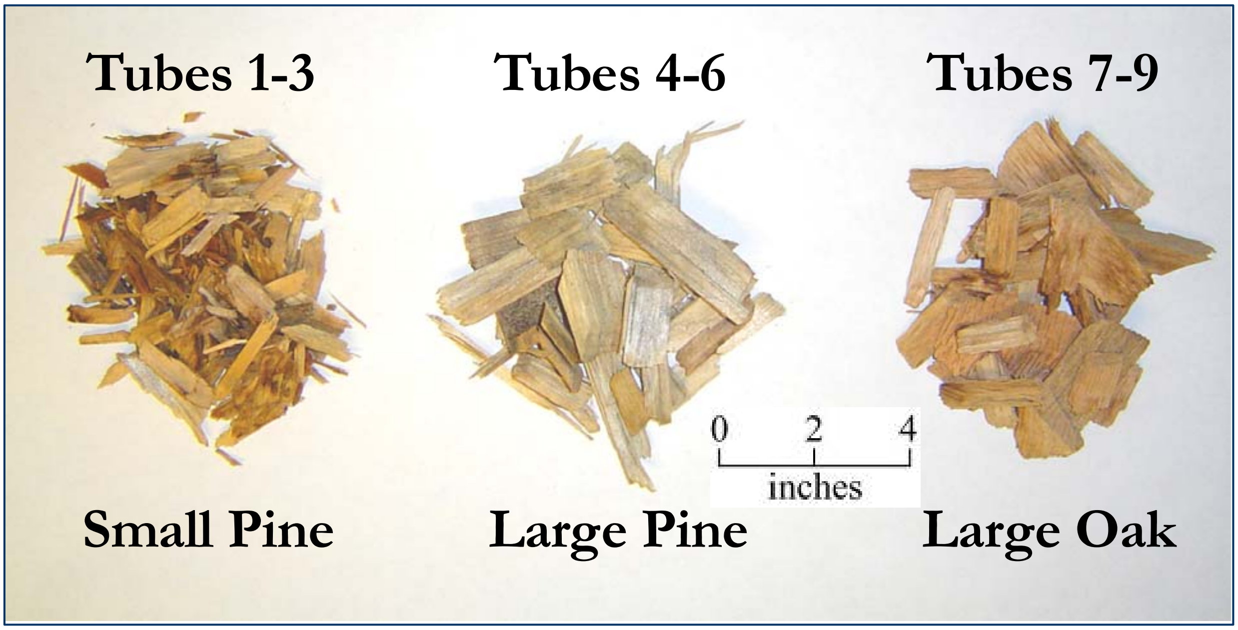
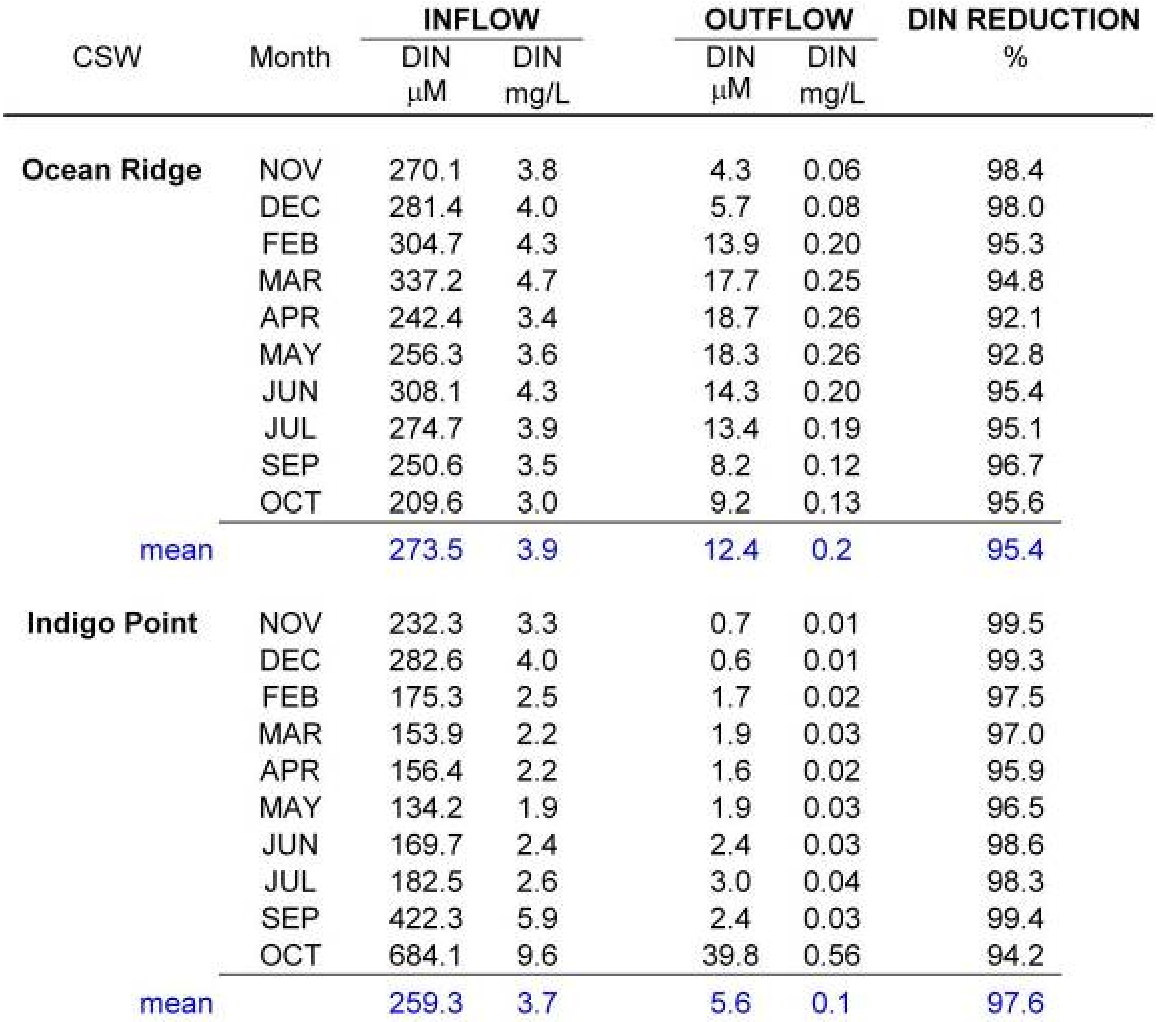


Fig. 4. Woodchips used in our laboratory tests to determine the proper volume needed to remove elevated nitrogen concentrations typically found in groundwater. We used large pine and large oak chips in our field tests to ensure that the media did not resist groundwater flow. The different types of woodchips did not alter the efficiency of nitrogen removal.

Fig. 5. A woodchip border during the backfill operation. The trench boxes have been removed, the trench pumped dry and backfilled with woodchips to about one foot above the water table. Landscaper cloth was used to prevent soil from penetrating into the woodchip media.

Table 1. Results from monthly monitoring of woodchip borders. Concentrations for DIN include NO_3 = nitrate, NO_2 = nitrite, NH_4= ammonia and are expressed in units of micromoles per liter (μM /liter) and milligrams per liter (mg/liter).



CSW	Month	INFLOW		OUTFLOW		DIN REDUCTION
		DIN μM	DIN mg/L	DIN μM	DIN mg/L	%
Ocean Ridge	NOV	270.1	3.8	4.3	0.06	98.4
	DEC	281.4	4.0	5.7	0.08	98.0
	FEB	304.7	4.3	13.9	0.20	95.3
	MAR	337.2	4.7	17.7	0.25	94.8
	APR	242.4	3.4	18.7	0.26	92.1
	MAY	256.3	3.6	18.3	0.26	92.8
	JUN	308.1	4.3	14.3	0.20	95.4
	JUL	274.7	3.9	13.4	0.19	95.1
	SEP	250.6	3.5	8.2	0.12	96.7
	OCT	209.6	3.0	9.2	0.13	95.6
mean		273.5	3.9	12.4	0.2	95.4
Indigo Point	NOV	232.3	3.3	0.7	0.01	99.5
	DEC	282.6	4.0	0.6	0.01	99.3
	FEB	175.3	2.5	1.7	0.02	97.5
	MAR	153.9	2.2	1.9	0.03	97.0
	APR	156.4	2.2	1.6	0.02	95.9
	MAY	134.2	1.9	1.9	0.03	96.5
	JUN	169.7	2.4	2.4	0.03	98.6
	JUL	182.5	2.6	3.0	0.04	98.3
	SEP	422.3	5.9	2.4	0.03	99.4
	OCT	684.1	9.6	39.8	0.56	94.2
mean		259.3	3.7	5.6	0.1	97.6

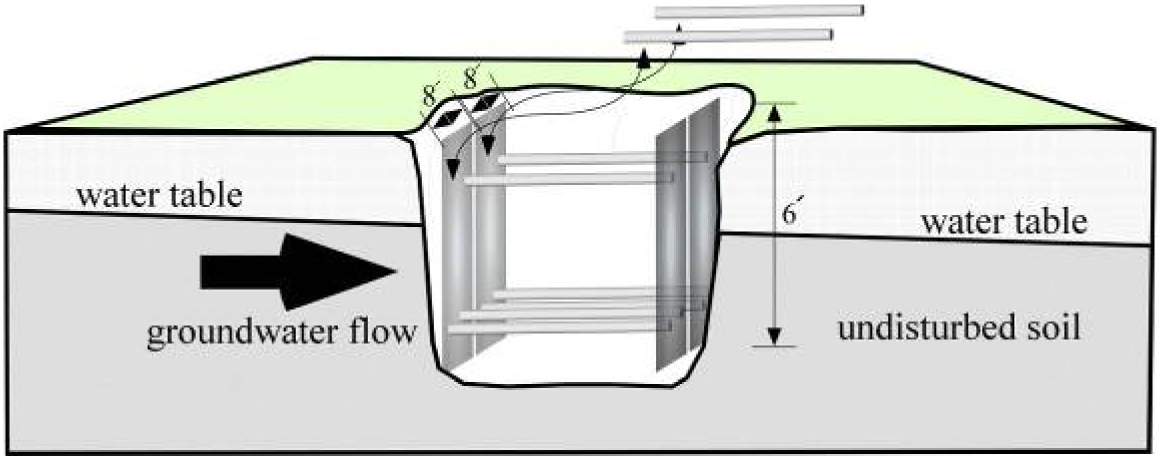


Fig. 6. A cross-sectional view of an excavated trench with two trench boxes measuring 8 feet (length) by 6 feet (width) by 6 feet (depth). Note: each of the trench boxes has a single support pole removed to facilitate soil removal by a backhoe.

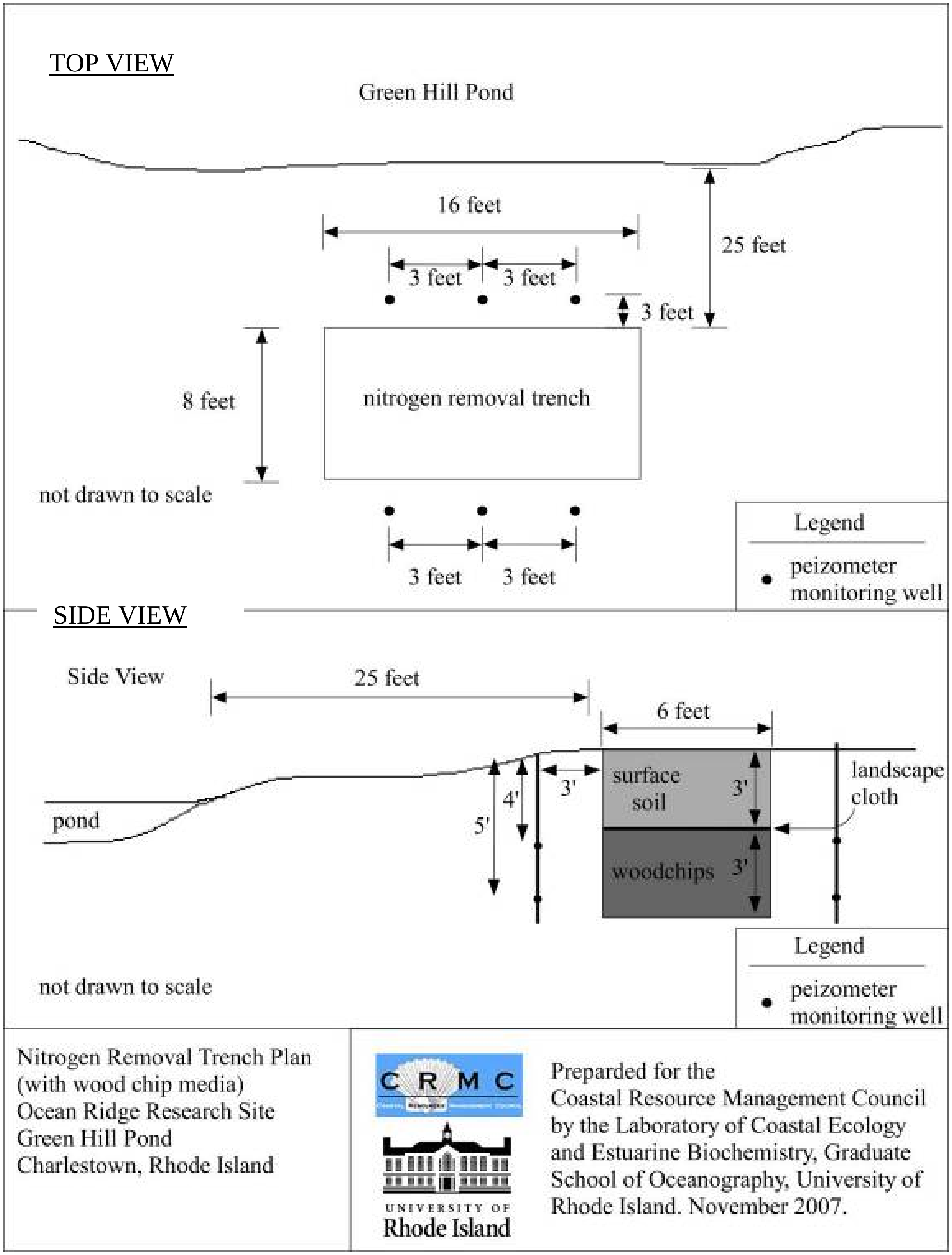


Fig 7. Site plan for a nitrogen removal trench using wood chips as a bacterial media. The plan was developed for a field test site located in Charlestown, Rhode Island.

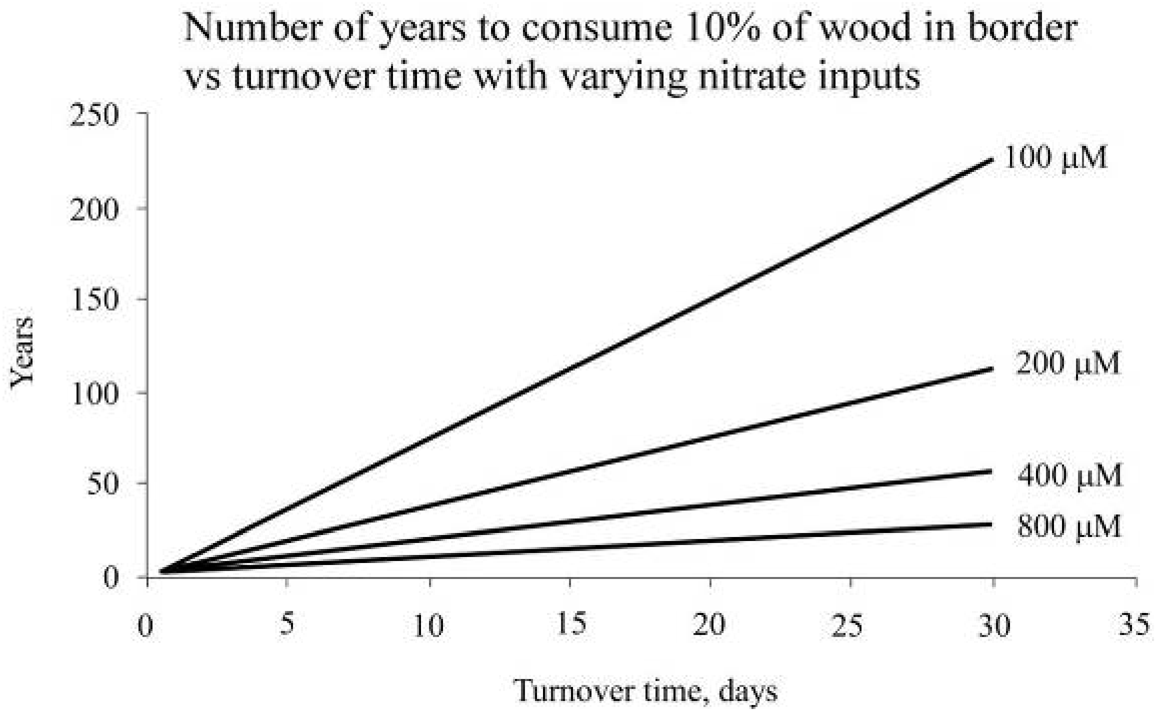


Fig. 8. Life expectancy of nitrogen removal by woodchips used in construction of a border. Bacteria that remove nitrogen from groundwater rely on wood-chips as a source of carbon to meet their metabolic needs. The length of time that the wood chips will remain effective in removing nitrogen is dependent on the concentration of nitrogen in groundwater and the time it takes to pass through the border. Higher concentrations of nitrogen and faster turnover times shorten time that the border will remove nitrogen.