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NitROE™ Tank Technology for Enhanced Nitrogen Removal from Title 5 Septic Systems

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Introduction

This document provides background information on CES Clean Water's NitROE™ tank technology developed as a supplement to a Title 5 septic system for the purpose of enhanced total nitrogen reduction prior to groundwater discharge into a soil absorption system (SAS). For the past seven months, a NitROE™ tank demonstration unit has been successfully operating at the Massachusetts Alternative Septic System Test Center (MASSTC) in Barnstable, Massachusetts. Here, total nitrogen levels from the NitROE™ tank effluent have been consistently below 10 mg/l, with the last four months of operation achieving TN concentrations less than 5 mg/l.

Due in part to the significant total nitrogen reductions being achieved by the MASSTC NitROE™ tank demonstration unit, the Town of Tisbury on Martha's Vineyard applied for and was recently awarded a grant from the Massachusetts Clean Energy Center (MassCEC) for the design and installation of at least ten NitROE™ tanks within the Town of Tisbury. These installations will be carried out following Massachusetts Department of Environmental Protection (MADEP) guidelines and procedures cited in "310 CMR 15.00: The State Environmental Code Regulating Septic Systems ("Title 5")." Specifically, these demonstrations will be performed under MADEP's "Piloting Permit" process cited in 310 CMR 15.285, with the intent being to provide field testing and technical demonstration for this particular innovative supplemental addition to a Title 5 system; in this case, the NitROE™ tank technology.

The following sections of this document provide:

- An overview of the NitROE™ tank technology
- An operational and performance summary of the MASSTC NitROE™ tank demonstration unit
- Plans for installation and monitoring of at least ten (10) NitROE™ tanks per MADEP's "Piloting" program

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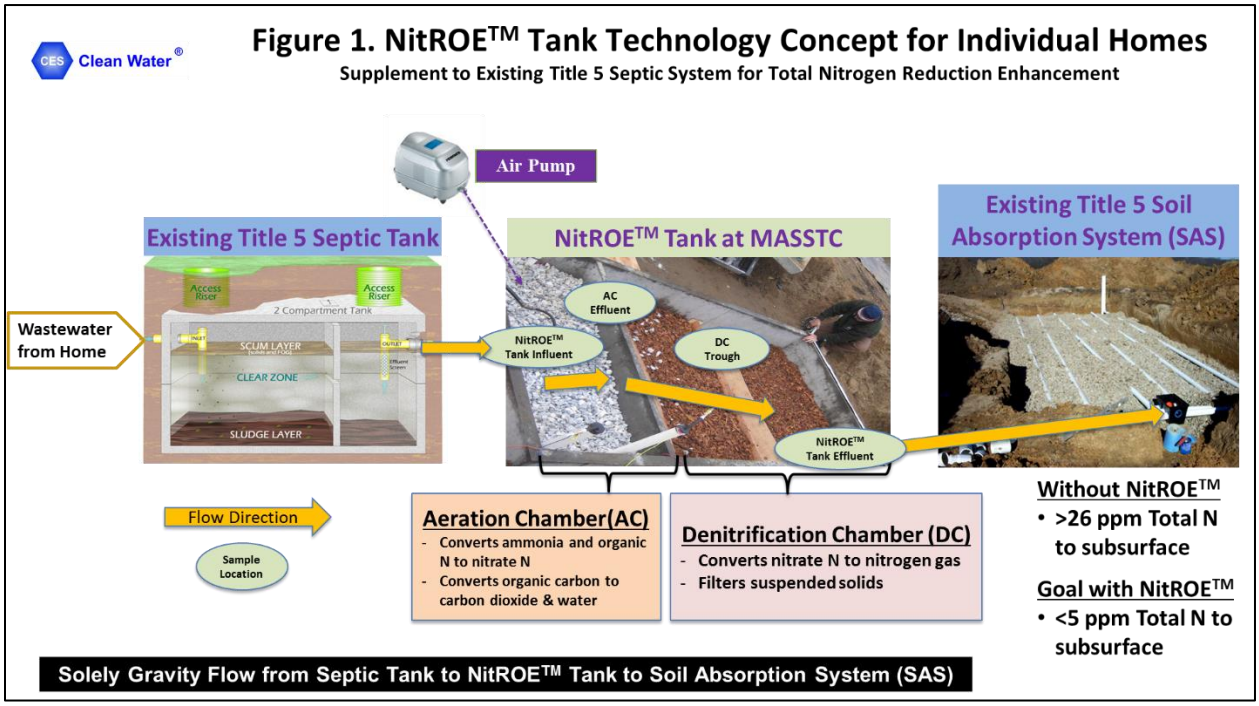
NitROE™ Tank Technology Overview

Conceptual Approach

CES Clean Water LLC (Clean Water) developed the NitROE™ tank technology as an "Innovative Alternative (I/A)" to supplement a Title 5 septic system aimed at enhanced total nitrogen removal prior to groundwater discharge into a soil absorption system (SAS).

Figure 1 illustrates that the NitROE™ tank is placed in the gravity-flow path between a Title 5 septic tank and a Title 5 soil absorption system (SAS) for the purpose of enhanced total nitrogen removal. This supplementary NitROE™ tank can be installed as part of a new or upgraded Title 5 system, or it can be installed to supplement an existing Title 5 system for enhanced total nitrogen reduction. For those site-specific situations where pumping is required within a Title 5 system due to site topography, the NitROE™ tank can be arranged to fit within that particular scenario as well. However, the main goal is to use gravity flow whenever possible. It is to be noted that the NitROE™ tank is not intended to be an alternative to or a substitute for any part of a Title 5 septic system, but rather it is a supplemental tank for enhanced total nitrogen reduction prior to Title 5 subsurface discharge.



The NitROE™ tank thus serves to provide an even higher degree of environmental and public health protection beyond that of a conventional Title 5 by significantly reducing total nitrogen. The addition of a NitROE™ tank does not modify or replace a Title 5 septic system, but adds to it. Thus, the overall Title 5 treatment of sanitary wastewater per 310 CMR 15 regulations is maintained with the added benefit of total nitrogen removal. This approach provides for a much better final Title 5 effluent for discharge to the subsurface.

The ultimate goal of the NitROE™ tank is to reduce total nitrogen to below 5 mg/l on an average yearly basis. This goal is comparable to conventional municipal wastewater treatment systems requiring

nitrogen removal. The NitROE™ tank technology is based on applications of long-established wastewater treatment processes deployed for flowrates in the 100,000 to 1,000,000 gallons per day range. Clean Water has innovatively configured and scaled down these processes to fit within the NitROE™ tank, resulting in a successful nitrogen removal process for Title 5 system enhancement.

For the purpose of achieving construction and operational simplicity, the NitROE™ tank is designed to:

- Have a head loss no greater than 3 inches during maximum flow conditions
- Utilize the same shell and pipe materials as Title 5 systems
- Have a small air pump as its only mechanical equipment
- Require little maintenance (e.g., there are no recycle pumps or lines, no frequent routine sludge wasting, and no significant process control requirements)

The NitROE™ tank is configured such that should the NitROE™ tank ever encounter an operational difficulty, the Title 5 septic system will perform as originally designed and installed, thereby maintaining the overall environmental protection of a Title 5 system.

Process Description

Referring to previously cited Figure 1, the two main components of the NitROE™ tank are an **Aeration Chamber** (AC) and a **Denitrification Chamber** (DC). Wastewater first flows through the Aeration Chamber and then subsequently through the Denitrification Chamber to achieve the ultimate conversion of organic and ammonia nitrogen to nitrogen gas.

The **Aeration Chamber** is designed to provide the proper environmental conditions for the bacterial mediated conversion of organic nitrogen to ammonia and the subsequent conversion of ammonia to nitrate (i.e., biological nitrification) per equations (1) and (2) below:

(1) $NH_4^+ + 1.5O_2 \rightarrow 2H^+ + 2H_2O + NO_2^-$

(2) $NO_2^- + 0.5O_2 \rightarrow NO_3^-$

Equation (1) cites the conversion of ammonium ion (NH_4^+) to nitrite (NO_2^-) mediated by the bacterial species *Nitrosomonas*. Equation (2) cites the next step in the process where the bacteria *Nitrobacter* convert the nitrite (NO_2^-) to nitrate (NO_3^-). Equations (1) and (2) together cite that oxygen (O_2) is a critical component which is why a NitROE™ tank is equipped with a small air pump to continuously supply oxygen (O_2) to the aeration chamber. It is noteworthy that this small air pump is the only piece of mechanical equipment associated with the NitROE™ tank. In addition to the aeration chamber designed to achieve biologically nitrification, it is also designed to significantly reduce concentrations of biodegradable organic compounds present in the influent wastewater.

The **Denitrification Chamber** is designed to subsequently reduce the biologically produced nitrate to nitrogen gas which is ultimately discharged into the atmosphere. Equation (3) provides the reaction for the bacterial mediated conversion of nitrate to nitrogen gas (N_2). The conversion to nitrogen gas is an acceptable endpoint as nitrogen is an inert gas comprising approximately 78% of the atmosphere.

(3) $4NO_3^- + 5CH_2O \rightarrow 2N_2 + 5CO_2 + 3H_2O + 4OH^-$

This equation also cites that a carbon source (shown in the above equation as the generic carbohydrate CH_2O) is required for denitrification to occur. The Denitrification Chamber provides the carbon source in the form of wood chips. Here the slow release of wood sugars and juices serve to provide the necessary organic carbon over the course of many years.

The indicated biochemistry, taken in total, serves to reduce total nitrogen in the wastewater as it flows by gravity consecutively through the NitROE™ tank's Aeration and Denitrification Chambers. These sequential biologically mediated process steps result in significantly reduced total nitrogen prior to groundwater discharge, with total nitrogen defined as the sum of ammonia-, organic-, nitrite- and nitrate-nitrogen.

Construction and Installation

The NitROE™ tank technology is designed so that it operates by gravity flow and is supplemental to and compatible with a Title 5 septic tank and a soil absorption system.

From a construction standpoint, the NitROE™ tank can be either a concrete or plastic structure assembled to provide both the aeration and denitrification chambers. Both chambers are baffled to accomplish flow distribution through the tank. For the planned deployments on Martha's Vineyard, concrete septic tanks will be used as the NitROE™ tank shell. The NitROE™ tank will have a permanent top similar to that of a Title 5 septic tank, as well as strategically placed access ports to provide long-term operational flexibility.

The NitROE™ tank will be delivered to the site with internal aeration and flow distribution baffle type components already in place within the NitROE™ tank shell. This tank will then be installed in the same manner as a septic tank at the elevation necessary to insure gravity flow from the Title 5 septic tank through the NitROE™ tank and then to the Title 5 soil absorption system. The air pump to supply the aeration chamber will require a 115V/20-amp power outlet, which will be installed in compliance with the appropriate local code. The air pump will be placed in its housing and connected to the aeration apparatus in compliance with the appropriate local code. Access ports for sampling, inspection, etc., with risers to the surface, similar to those for septic tanks, will be installed before final soil cover is placed. In effect, the NitROE™ tank installation is the same as that of a standard Title 5 septic tank.

Operation and Maintenance (O&M)

As the NitROE™ tank is not a replacement or modification, but a supplemental addition to a Title 5 system for the purpose of total nitrogen reduction, relevant O&M standards and guidelines applicable to Title 5 systems will be followed as well as all those applicable to Innovative/Alternative (I/A) systems per 310 CMR 15.

During the first year of pilot operation, inspections will be done at least every three months by Clean Water personnel and/or its certified and trained designee with results documented on relevant MADEP standard forms. Thereafter, inspections will be done at six-month intervals.

The interior of the NitROE™ tank consists of stationary, non-mechanical internal components, with the only mechanical equipment being an external small air pump. Because of this straightforward design, there is little training needed beyond what is already provided to installers and inspectors of Title 5 systems. Additional items that would be addressed for training of the NitROE™ tank technology relate to

the overall functionality of the different NitROE™ processes addressing the relatively few critical components needed for efficient troubleshooting and corrective action. The training program will follow the same training guidelines applicable to Title 5 septic system installers and inspectors supplemented to cover the air pump and functionality of the different NitROE™ processes cited above.

From a longer term operational perspective, the NitROE™ tank design provides for maintenance-related change-out and replacement of critical components via access ports without having to remove the tank top.

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MASSTC NitROE™ Tank Demonstration Summary Results

The NitROE™ technology is currently being demonstrated, via a full-scale pilot demonstration unit, at the Massachusetts Alternative Septic System Test Center (MASSTC) in Barnstable, MA. Here, the NitROE™ tank shown in Figure 1 is the actual demonstration unit that was installed and operated at MASSTC.

Figure 2 shows seasonal pictures of the NitROE™ tank operated at MASSTC along with a timeline of the demo project, which began with its' installation in mid-December 2016. As a consequence of the winter start-up challenges, the MASSTC influent wastewater to the NitROE™ tank had a temperature range of 43-46°F (6-8°C), which is somewhat lower than that of household sewage flowing to a septic tank. This lower temperature retarded the normal establishment of a nitrifying bacterial population needed for conversion of ammonia to nitrate, the first step in total nitrogen reduction. For this reason, supplemental heat was temporarily added to the last chamber of the septic tank, which fed the NitROE™ tank. Within weeks of heat addition, significant total nitrogen reduction was achieved and sustained, with the temporary heating discontinued once a sufficient nitrifying bacterial population was established. Also noteworthy is that there will be no actual access ports for the Tisbury installations right at the surface as shown for the MASSTC demo, as any access ports will be 8 inches below the surface and with the number of access ports significantly reduced as well.

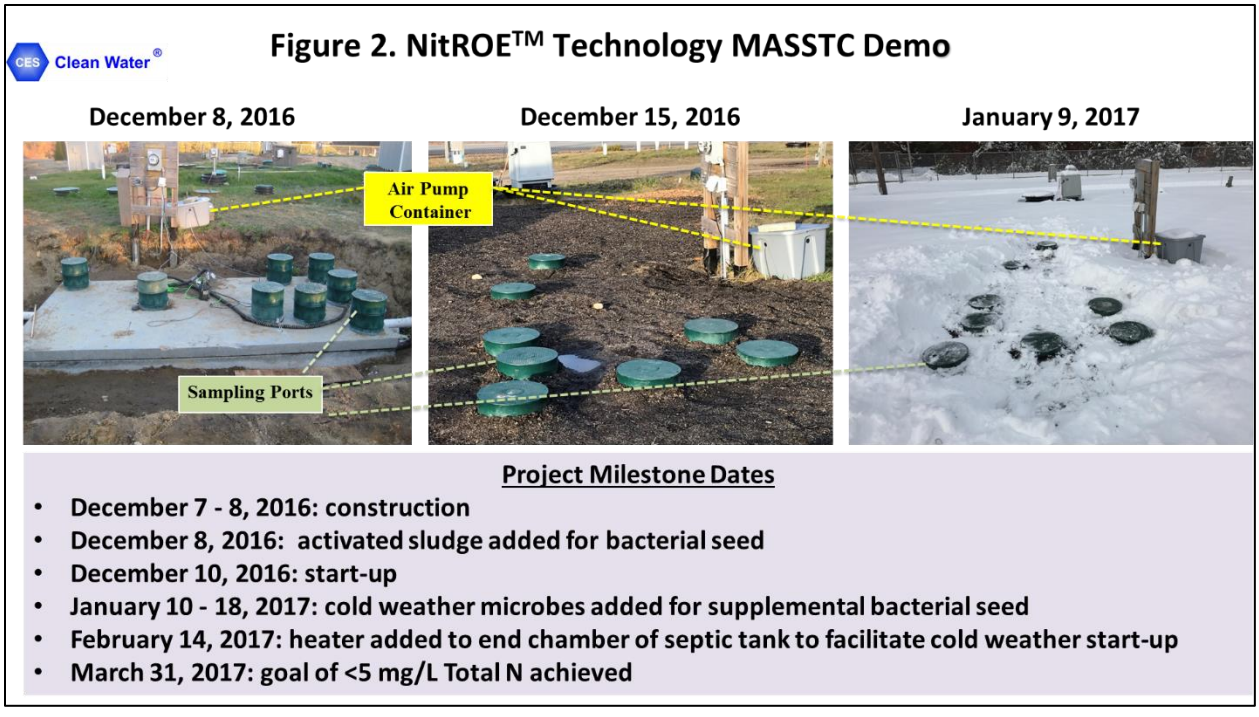


Figure 3 shows total nitrogen results of 24-hour composite samples collected over the last five months of operation. With an average influent total nitrogen concentration of 35 mg/l, significant total nitrogen reduction was established and consistently maintained. Referring to Figure 1, the denitrification chamber trough samples refer to a mid-point within the denitrification chamber, with results supporting that the

total nitrogen reduction levels are generally the same for both the denitrification chamber trough and NitROE™ tank effluent samples. These data support that total nitrogen levels below 10 mg/l were generally achieved and sustained for the past five months of operation, with a total nitrogen concentration below 5 mg/l achieved for the last four months of operation.

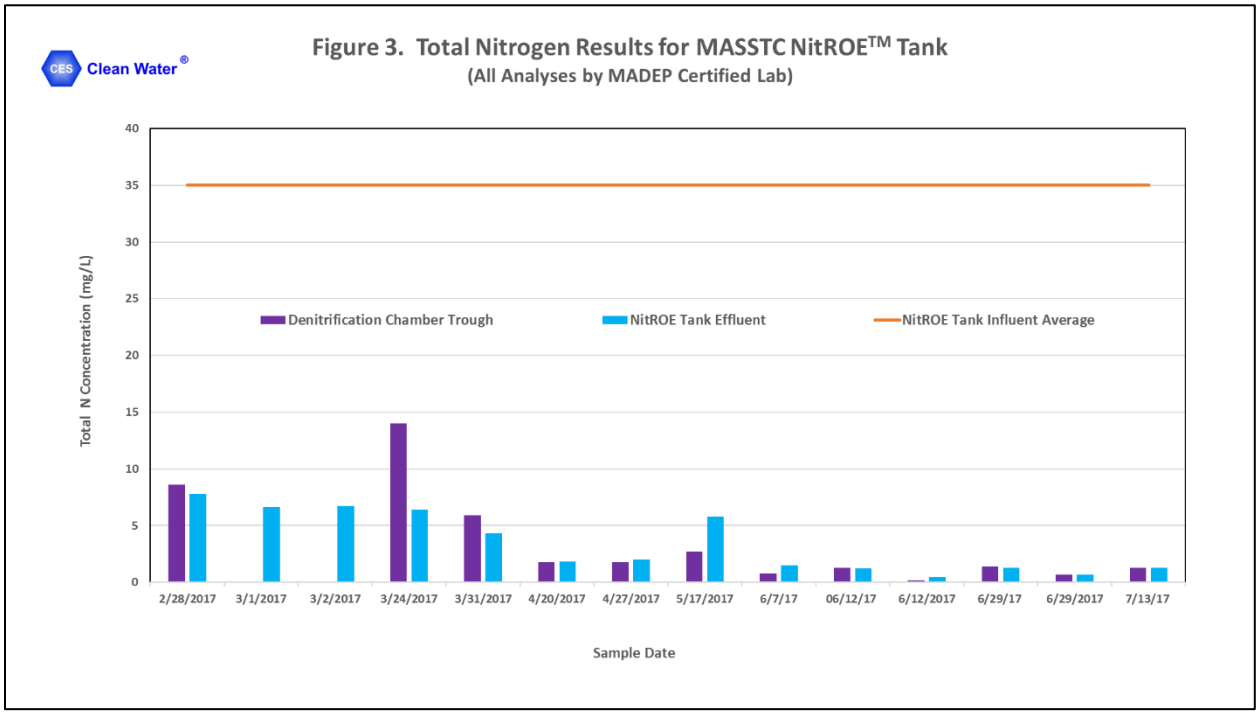
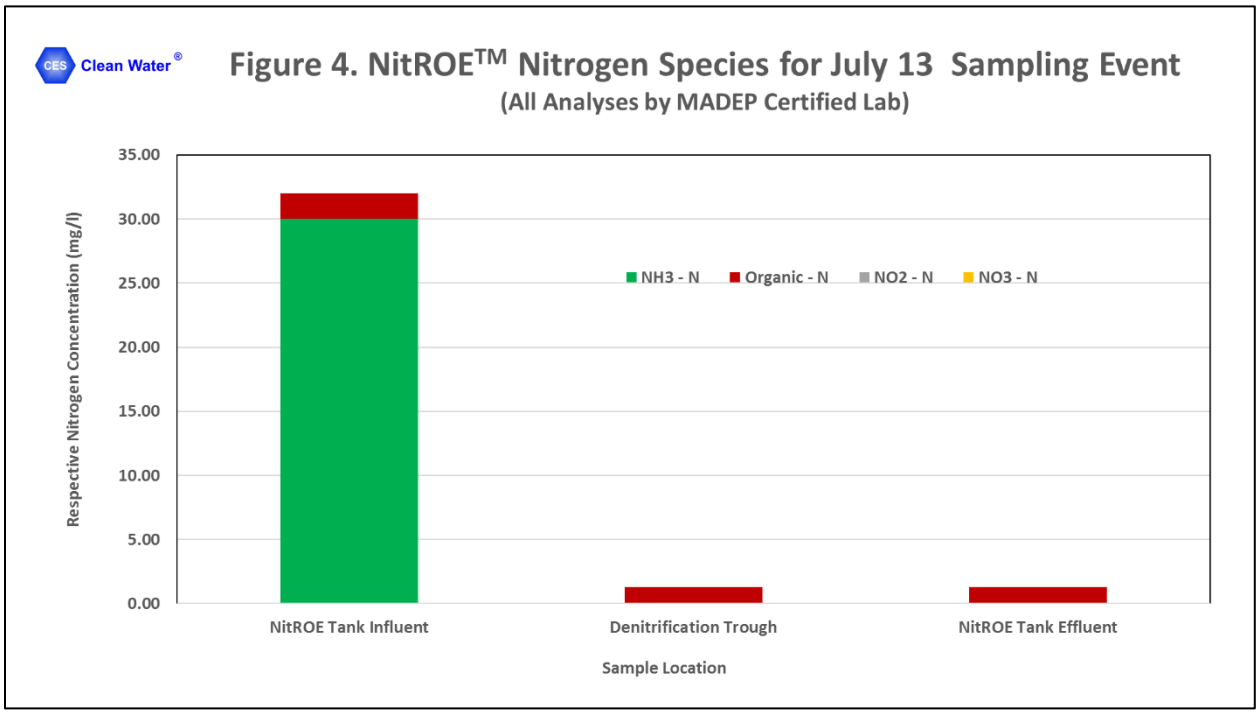
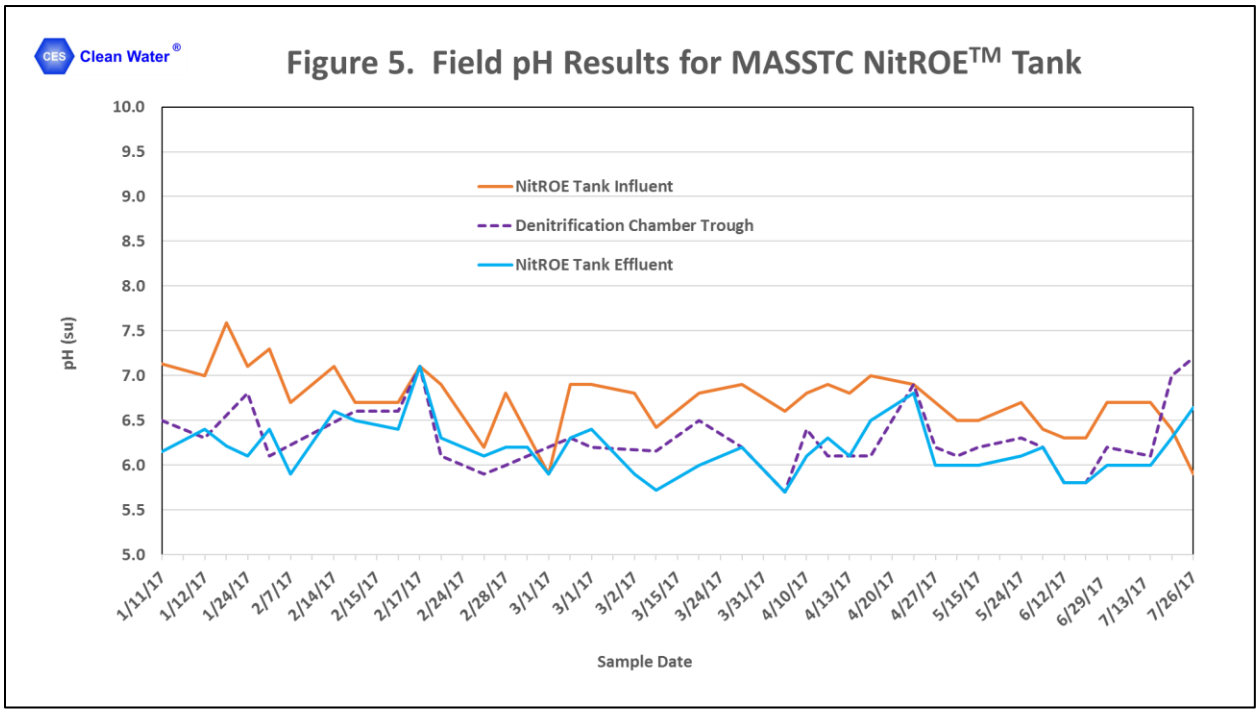
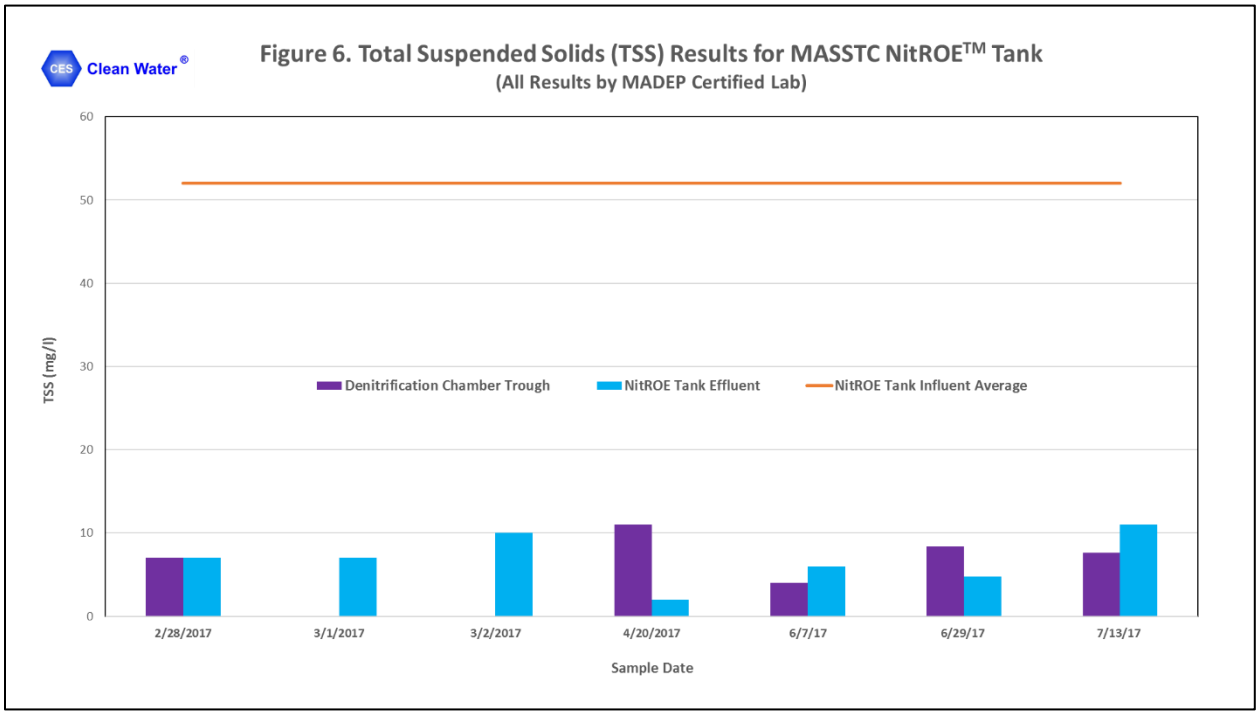


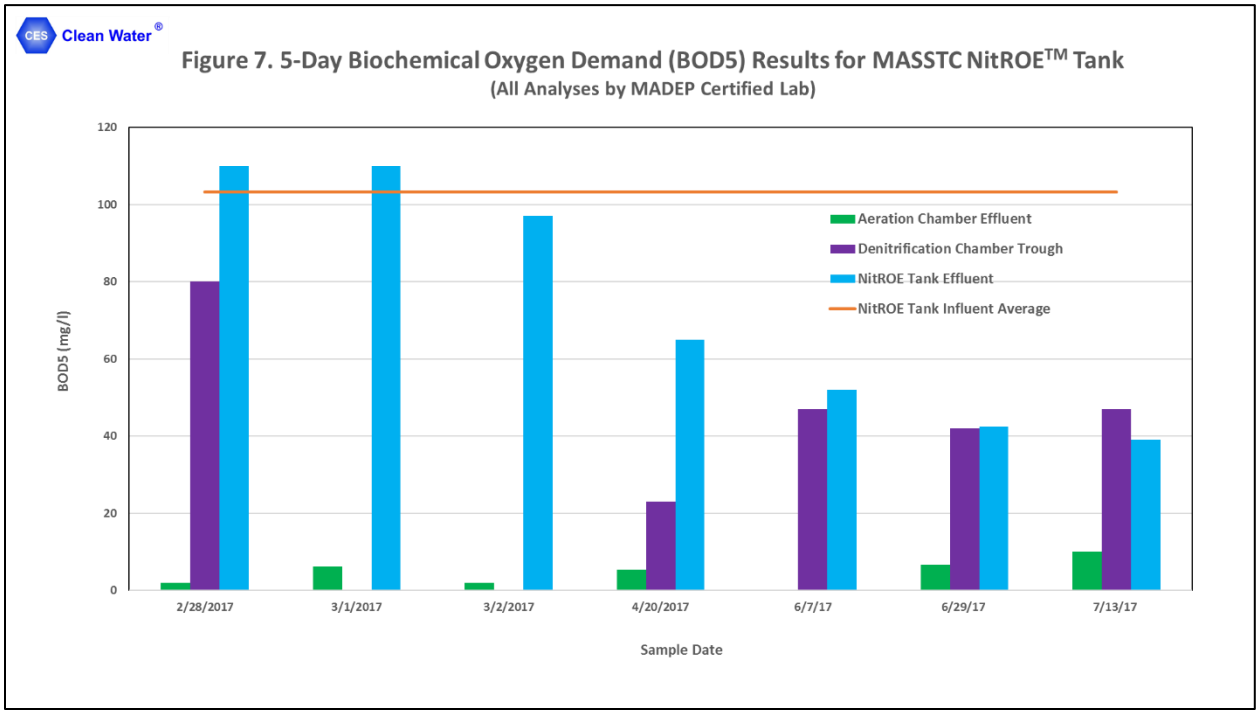
Figure 4 supports that nearly all of the influent ammonia concentration was converted to nitrogen gas by the fact that no ammonia, nor nitrate, could be detected in both the denitrification chamber trough and the NitROE™ tank effluent. All remaining nitrogen was present as more recalcitrant organic nitrogen in the 1-2 mg/l range, which is typical of sanitary wastewaters. These data serve to support that the NitROE™ tank consistently performed as designed.



In addition to the summary data supporting significant total nitrogen reduction (which was the main objective of the NitROE™ tank design), the data in Figures 5 through 7 serve to support that the NitROE™ tank treats sanitary wastewater while maintaining a pH between 6-9 (see Figure 5), while reducing total suspended solids levels (see Figure 6) and while significantly reducing organic carbon compounds indicated by 5-day biochemical oxygen demand (BOD_5) data (see Figure 7).







Referring to Figure 6, total suspended solids levels were consistently maintained near 10 mg/l and lower with an average influent level slightly above 50 mg/l. Figure 7 shows significant BOD_5 reduction as evidenced with aeration chamber effluent concentrations less than 10 mg/l with an influent average slightly more than 100 mg/l. The cited BOD_5 increases measured in the denitrification chamber trough

and the NitROE™ tank effluent represent readily biodegradable carbohydrates from the fresh wood chips that were used. Even though the initial levels were near the average influent concentrations, the later BOD_5 levels came down into the 40 mg/l range. The NitROE™ tank effluent BOD_5 will be subsequently treated in the soil absorption bed.

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NitROE™ Pilot Demonstrations in Partnership with Town of Tisbury, MA

Due in part to the significant total nitrogen reductions achieved by the MASSTC NitROE™ tank demonstration unit, The Town of Tisbury (Town) has received a grant from the Massachusetts Clean Energy Center (MassCEC) for the design and installation of at least ten (10) NitROE™ tanks for enhanced total nitrogen reduction as part of a pilot program. The attached two links provide further background regarding the awarding of this grant as recently published in both the Vineyard Gazette and the Vineyard Times:

- https://vineyardgazette.com/news/2017/04/28/tisbury-lands-grant-pilot-wastewater-study
- http://www.mvtimes.com/2017/05/03/test-program-trim-nitrogen-tisbury-watersheds-start-summer/.

The Town, in partnership with Clean Water, will be installing and monitoring a minimum of ten (10) NitROE™ tank systems at homes within the Lake Tashmoo and Lagoon Pond watersheds. Each NitROE™ tank installation will be either a retrofit to an existing Title 5 system with the NitROE™ tank placed between an existing septic tank and an existing soil absorption system, or it will be done as part of a new or upgraded Title 5 septic system. For these respective installations, Figure 8 provides a NitROE™ tank plan view and profile view for a 3- and 4-bedroom home where a 1,500-gallon tank will be used (Model T-330/440). Correspondingly, Figure 9 provides a NitROE™ tank plan- and profile-view for a 5- and 6-bedroom home where a 2,000-gallon tank will be used (Model T-550/660).

Figure 8

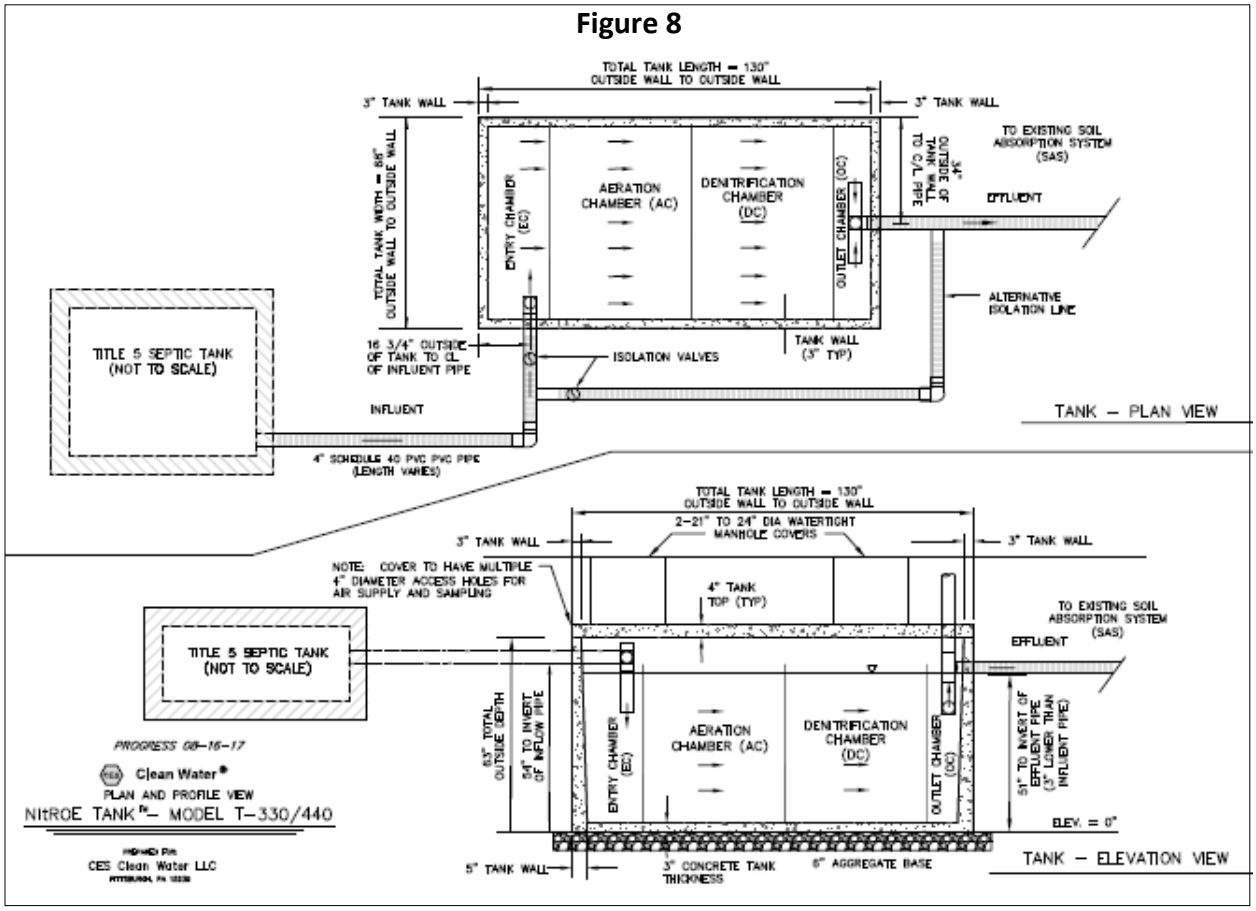
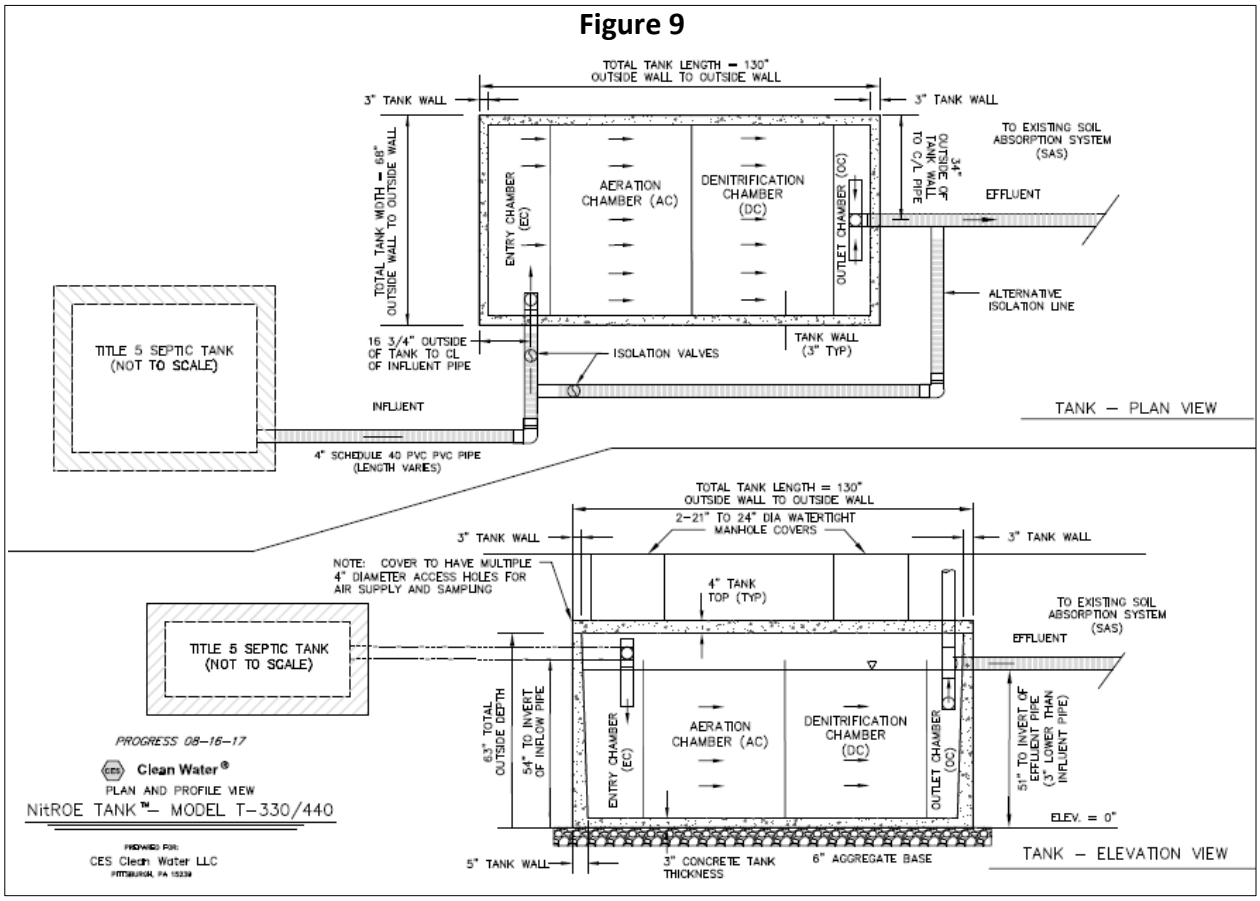


Figure 9



The Massachusetts Department of Environmental Protection (MADEP) has specified regulations for a Title 5 septic system and the components of a pilot program for the testing and evaluation of innovative/alternative (I/A) or enhanced systems. For this reason, the planed NitROE™ tank installations will be done under MADEP's pilot program for I/A technologies per guidelines and requirements cited in 310 CMR 15.285. Here, individual NitROE™ pilot installation approvals (per 310 CMR 15.287) will need to be obtained. Completing MADEP Form BRP WP64b will first be done, followed by approval by the Tisbury Board of Health, and then submission to the MADEP for final approval. In this regard, the selected engineering designer will provide site-specific information to be submitted as part of this application process. This includes site-specific drawings with a Massachusetts professional engineer's stamp. At a minimum, the drawings will include a plan view and cross-section of the Title 5septic tank, the NitROE™ tank, and the Title 5 soil absorption system.

NitROE™ Tank Contact Information

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