Summary Performance Analysis of BANRT Field-Installed Systems

Field Evaluation of Total Nitrogen (TN) Performance in Innovative/Alternative (IA) Wastewater Treatment Technologies

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1. Introduction & Purpose

This data analysis was conducted to better understand Total Nitrogen (TN) levels across Innovative/Alternative (IA) technologies included on the Best Available Nitrogen Reducing Technologies (BANRT) list, produced by Massachusetts Department of Environmental Protection (MADEP). The goal is to clarify the various aspects of IA performance.

Total Nitrogen (TN), which represents the combined concentration of organic nitrogen, ammonia, nitrite, and nitrate, is an important parameter of interest in wastewater treatment. Nitrogen inputs from onsite wastewater treatment systems contribute to environmental degradation by causing algal blooms, reduced oxygen levels, and other long-term ecological impacts on surface waters as well as impairing groundwater resources used for drinking water.

Nitrogen is removed from wastewater through two biological processes. The first, nitrification, converts ammonia into nitrate in the presence of oxygen. The second, denitrification, occurs in low oxygen conditions and converts that nitrate into nitrogen gas, which is released harmlessly into the atmosphere. Systems on the BANRT list are designed to create the specific conditions needed for both processes so that the nitrogen in wastewater can be effectively transformed into nitrogen gas.

Updated regulatory frameworks, including recent changes related to MADEP's Title 5 regulations and watershed permitting on Cape Cod, have emphasized the need for communities to actively monitor and reduce nitrogen loading from onsite wastewater treatment systems. As a result, understanding treatment performance, specifically in technologies that claim to remove nitrogen, is critical for determining whether these systems can effectively support local nutrient-reduction goals.

The BANRT list identifies onsite wastewater treatment technologies that have demonstrated enhanced ability to reduce nitrogen beyond what is achievable with the range of treatment options and conventional Title 5 systems. These systems vary in design, operational requirements, treatment mechanisms, and approval status—such as General Use or Provisional Use—within the MADEP approval process. Each technology included on the BANRT list also has a corresponding TN Approval Limit. This limit is the highest TN concentration a system should discharge into the environment, at any given time, as determined by their demonstrated performance during their approval process

The purpose of this analysis is to assess the extent to which field-installed systems meet those limits. By examining real sampling data collected through Operation and Maintenance (O&M) programs, this review seeks to identify overall performance patterns, outliers, and areas where system function may depart from approval expectations.

The following report presents the field performance of six IA septic systems listed on the BANRT:

- Advantex Treatment System by Orenco Systems (General Use; TN Limit: 19 mg/L)
- Amphidrome Process by F.R. Mahony & Associates, Inc (Provisional Use; TN Limit: 19 mg/L)
- Fuji Clean CEN unit by Fuji Clean USA, LLC (Provisional Use; TN Limit: 19 mg/L)
- Nitrex Filter by Lombardo Associates, Inc (Provisional Use; TN Limit: 10 mg/L)
- NitROE Wastewater Treatment System by KleanTu LLC (Provisional Use; TN Limit: 11 mg/L)
- STAAR by SeptiTech/Bio-Microbics of Maine, Inc (General Use; TN Limit: 19 mg/L)

2. Dataset Overview

The data used in this analysis were sourced from the Barnstable County Department of Health and Environment Septic Management Program and represent field-installed systems located on Cape Cod, Martha's Vineyard, Nantucket, and six towns in Southeastern Massachusetts: Plymouth, Wareham, Marion, Sharon, Mansfield, and Westport. The dataset spans January 1, 2019, through January 1, 2026, and includes only single-family residential properties. In total, the dataset contains 259 Advantex systems, 23 Amphidrome systems, six Fuji Clean systems, five Nitrex systems, 134 NitROE systems, and 405 SeptiTech systems.

For the purposes of this analysis, only effluent samples were evaluated. Effluent represents the treated wastewater discharged from the IA system into the drainfield and therefore reflects the nitrogen load entering the subsurface environment. Influent samples, internal recirculation samples, or intermediate treatment stage data were not included.

Effluent samples were collected by licensed third-party service providers as part of routine Operation and Maintenance (O&M) inspections. These providers reported sampling results to the Barnstable County Septic Management Program, and all laboratory analyses were conducted by certified, third-party environmental testing laboratories.

From this dataset, systems with fewer than five sampling or inspection datapoints were excluded from the study. Both year-round and seasonal residences were included.

3. Methodology

Overview

Mean TN levels are used herein to assess system performance. Histograms and box-and-whisker plots are used to allow rapid visualization to compare mean total nitrogen levels in effluent samples for each site.

Visualizing the Data

Mean TN in Individual Systems

Histograms are used to compare mean Total Nitrogen (TN) values across field installed I/A systems. In this report, each bar represents an individual system. Bars are sorted in ascending order of mean TN, meaning shorter bars correspond to lower TN levels and taller bars indicate higher TN levels.

The histograms can be interpreted as follows:

- Shorter bars represent systems with lower mean TN concentrations;
- Taller bars represent systems with higher mean TN concentrations;
- A bar that is noticeably taller than the others may indicate an outlier with elevated TN.
- Two horizontal reference lines at 10 mg/L and 19 mg/L show the range of TN Approval Limits assigned to BANRT technologies. Bars that exceed the relevant limit indicate systems not meeting their approval standard.

These graphs highlight the distribution of performance within a technology and help identify both consistently strong systems and systems that may require further investigation.

Percentage of Systems Meeting Their TN Approval Limits

Bar charts are also used to summarize the proportion of systems operating below their technology-specific TN Approval Limit. Each bar represents one IA technology, and the height of the bar shows the percentage of systems whose mean effluent TN concentration meets the MADEP discharge standard.

Separate charts are used for technologies with 10–11 mg/L limits and those with the 19 mg/L limit. This grouping ensures that technologies are compared only against systems held to the same regulatory threshold.

These visualizations allow readers to:

- Compare how reliably each technology meets its approval limit;
- Identify technologies with consistently high compliance;
- Recognize technologies showing wider variability or lower compliance in field conditions.

Average TN Across Technologies

Another bar chart is used to compare the average effluent TN concentration across all systems within each BANRT technology. Instead of showing individual system results, this visualization presents a technology-level average, providing an overview of “typical” TN performance for each system type.

Reference lines at 10 mg/L and 19 mg/L again offer context for interpreting the average TN values relative to the range of approval limits.

This chart helps illustrate:

- How the six BANRT technologies compare in typical performance;
- Whether a technology generally trends above or below the approval threshold;
- Where technologies cluster in terms of overall nitrogen reduction effectiveness.

Box-and-Whisker Plot

A box-and-whisker plot is used in this report to show the full distribution of Total Nitrogen (TN) sample results within each BANRT technology. The box-and-whisker plot illustrates how TN values vary across all samples collected from a given technology.

These plots can be interpreted as follows:

- The box represents the middle 50% of all TN sample values (the interquartile range). A taller box indicates greater variability in results, while a shorter box indicates more consistent performance.
- The dot inside the box represents the median TN concentration. The median is the midpoint of the dataset, meaning 50% of all samples fall above this value and 50% fall below it. This makes the median a stable indicator of typical performance because it is not influenced by unusually high or low values.
- The whiskers extend to show the range where most sample values fall. Longer whiskers indicate wider variation in TN results, while shorter whiskers indicate tighter clustering.
- Reference lines at 10 mg/L and 19 mg/L appear across the plots to provide context for interpreting TN distributions relative to the approval limits associated with the BANRT systems.

Box-and-whisker plots therefore allow for a more complete characterization of field performance by highlighting not only the central tendency of TN results, but also the variability and frequency of higher-than-expected concentrations across technologies.

Key Assumptions

The key assumptions for this review are;

- The analysis assumes that effluent data accurately represents system performance, without accounting for influent variability or operational anomalies.

- Systems with fewer than five samples were excluded, assuming that five samples provide a representative snapshot of overall performance.
- No differentiation in performance metrics was made between seasonal and year-round homes, assuming similar system stress and usage.

Limitations

The key limitations for this review are;

- Sampling frequency and timing vary across systems, affecting the comparability and accuracy of performance metrics.
- Differences in climate, season, or sampling conditions may influence system performance and are not accounted for in this review.
- System maintenance quality is not evaluated, despite its significant influence on performance outcomes.
- Only systems located in Massachusetts are included, which reduces geographic diversity and limits the representativeness of the dataset.
- Data depends on reporting from Operation and Maintenance (O&M) providers, with no quality-assurance oversight, creating potential for data gaps or recording errors.
- Using concentration alone as a performance indicator does not provide enough information about the mass load of nitrogen being disposed of at a particular site. To really understand how much nitrogen is being disposed of to the environment the concentration must be multiplied by the actual flow volume to calculate the mass load at each site.

4. Graphs & Visualizations

Advantex

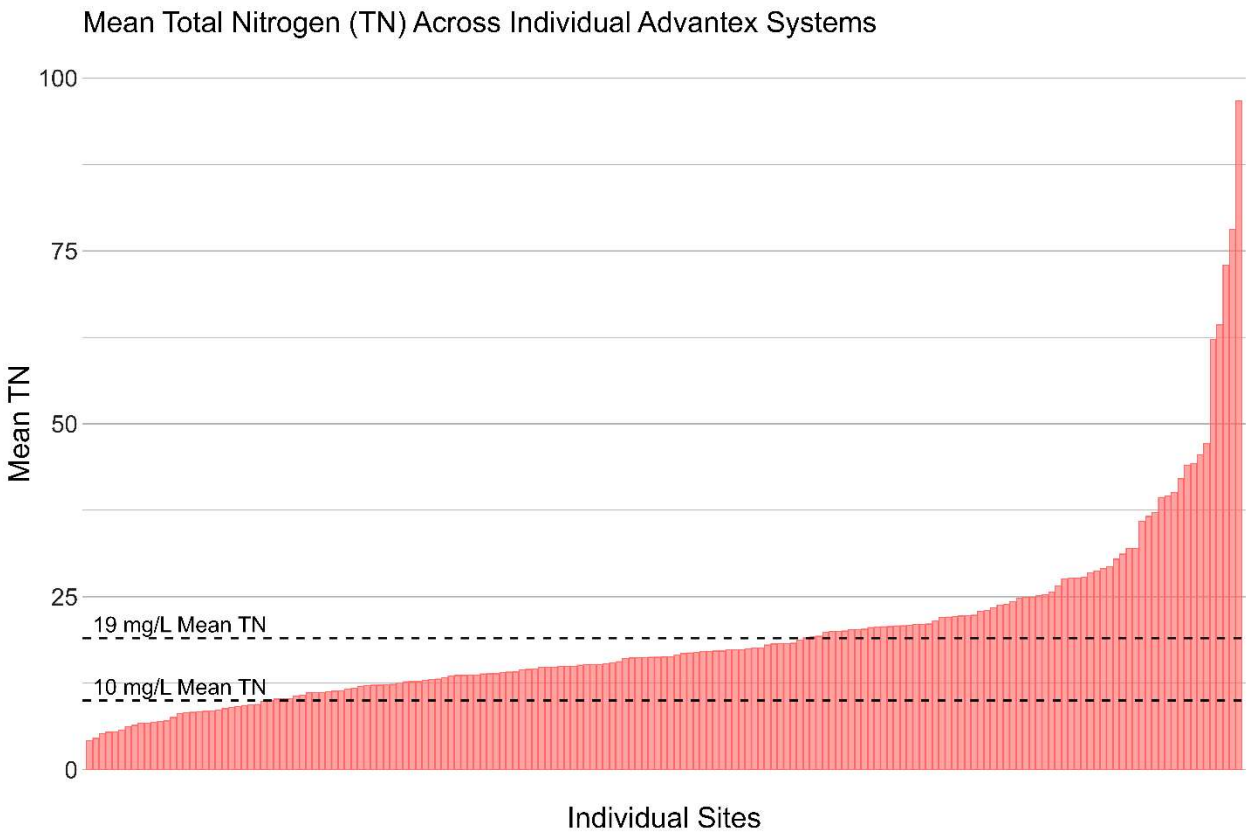

Figure 1. Mean Total Nitrogen (TN) across Advantex Systems

Figure 1 is a histogram representing the average TN among all Advantex systems in Barnstable County and Southeastern MA between January 1, 2019, and January 1, 2026. This graph represents 179 sites, each of which had data from at least five sampling events.

Advantex has a TN Approval limit of 19 mg/L. Of the 179 Advantex sites evaluated, 65 (36%) were found to have a mean TN level above the MADEP approval limit of 19 mg/L, and 114 sites (64%) were found to have a mean TN level below 19 mg/L. Of the 179 Advantex sites, 32 (18%) were found to have a TN mean under 10 mg/L.

Amphidrome

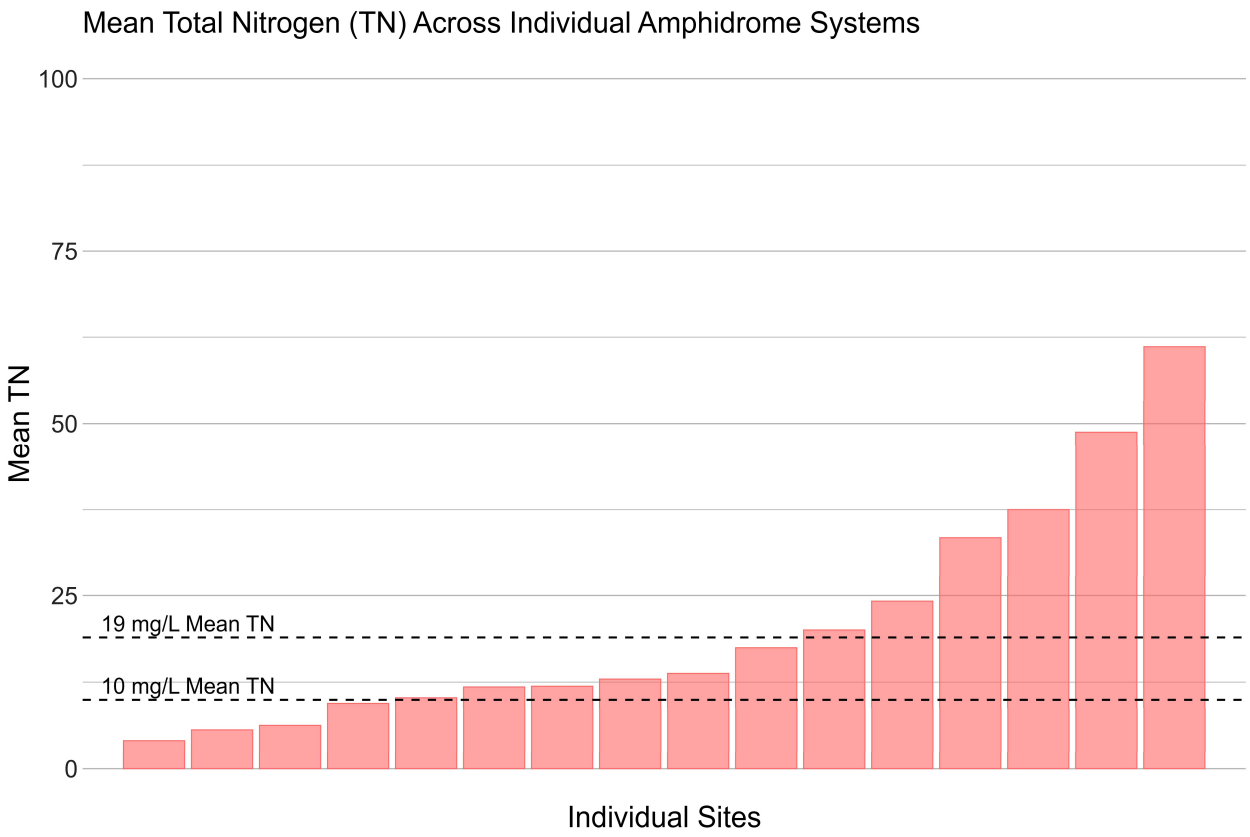

Figure 2. Mean Total Nitrogen (TN) across Amphidrome Systems

Figure 2 is a histogram representing the average TN among all Amphidrome systems in Barnstable County and Southeastern MA between January 1, 2019, and January 1, 2026. This graph represents 16 sites, each of which had data from at least five sampling events.

Amphidrome has a TN Approval limit of 19 mg/L. Of the 16 Amphidrome sites evaluated, six (37%) were found to have a mean TN level above the MADEP approval limit of 19 mg/L, and 10 sites (63%) were found to have a mean TN level below 19 mg/L. Of the 16 Amphidrome sites, five (32%) were found to have a TN mean under 10 mg/L.

Fuji Clean

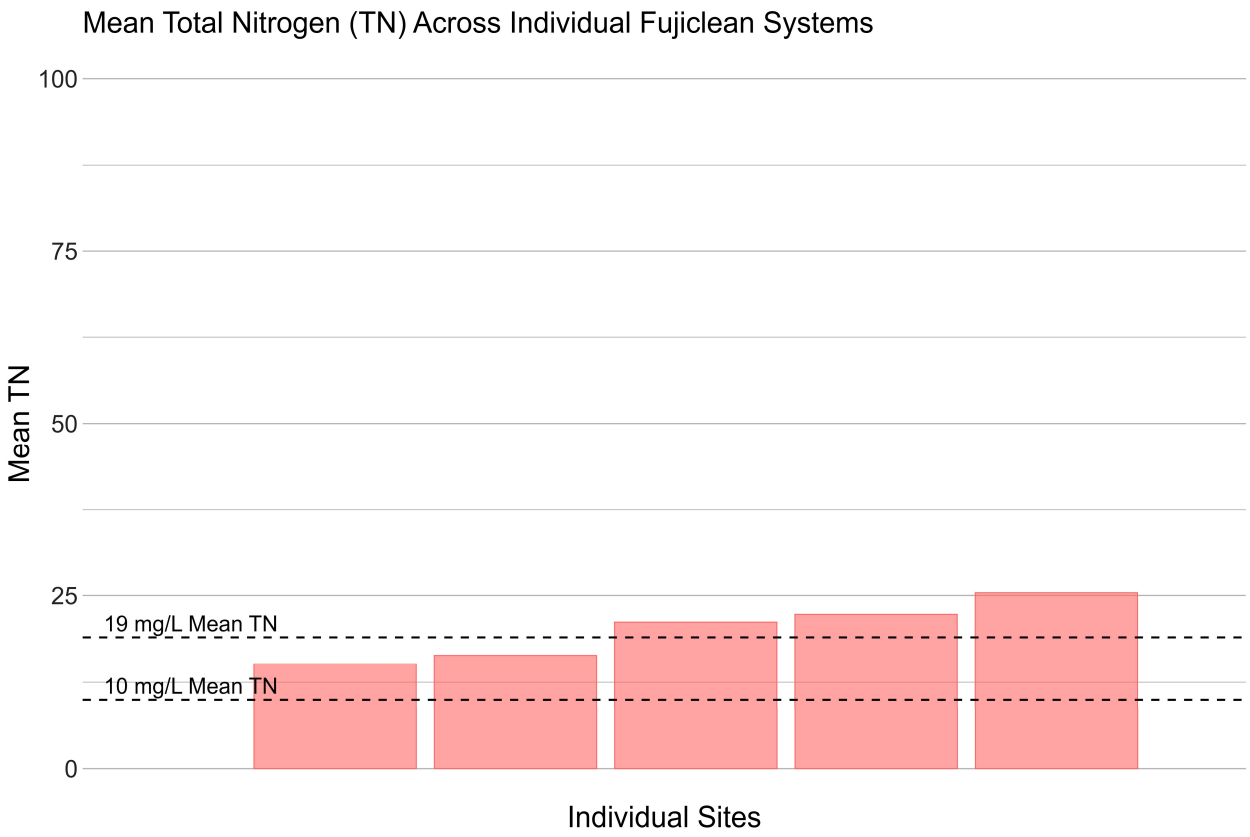

Figure 3. Mean Total Nitrogen (TN) across Fuji Clean Systems

Figure 3 is a histogram representing the average TN among all Fuji Clean systems in Barnstable County and Southeastern MA between January 1, 2019, and January 1, 2026. This graph represents five sites, each of which had data from at least five sampling events.

Fuji Clean has a TN Approval limit of 19 mg/L. Of the five Fuji Clean sites evaluated, three (60%) were found to have a mean TN level above the MADEP approval limit of 19 mg/L, and two sites (40%) were found to have a mean TN level below 19 mg/L. Of the five Fuji Clean sites, none were found to have a mean TN level below 10 mg/L.

Nitrex

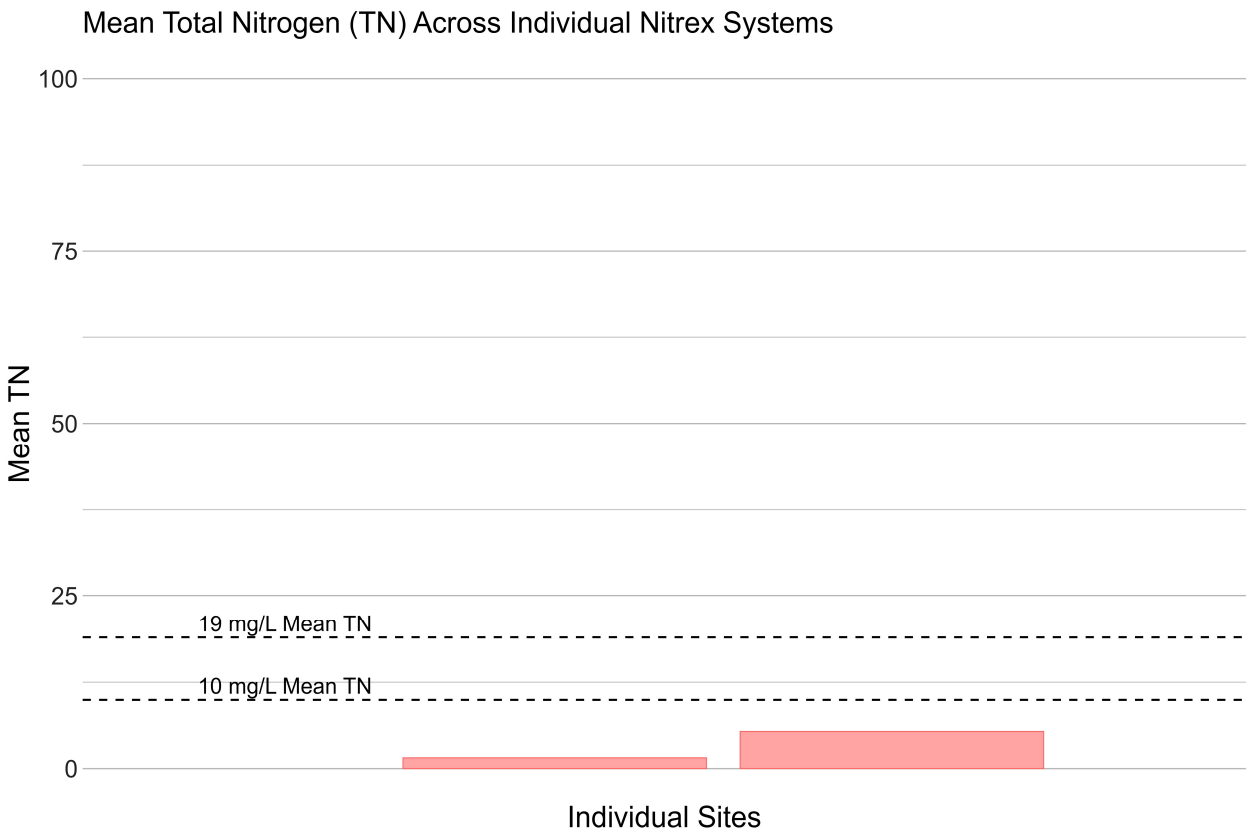

Figure 4. Mean Total Nitrogen (TN) across Nitrex Systems

Figure 4 is a histogram representing the average TN among all Nitrex systems in Barnstable County and Southeastern MA between January 1, 2019, and January 1, 2026. This graph represents two sites, each of which had data from at least five sampling events.

Nitrex has a TN Approval limit of 10 mg/L. Of the two Nitrex sites evaluated, both (100%) were also found to have a mean TN level below the MADEP approval limit of 10 mg/L. Of the two Nitrex sites evaluated, both (100%) were found to have a mean TN level below the MADEP approval limit of 19 mg/L.

It's important to note that the Nitrex systems are a polishing unit and are reliant on a separate I/A system to provide pretreatment and nitrification. The denitrification performance of the Nitrex will not perform if the pretreatment system does not provide adequate nitrification first.

NitROE

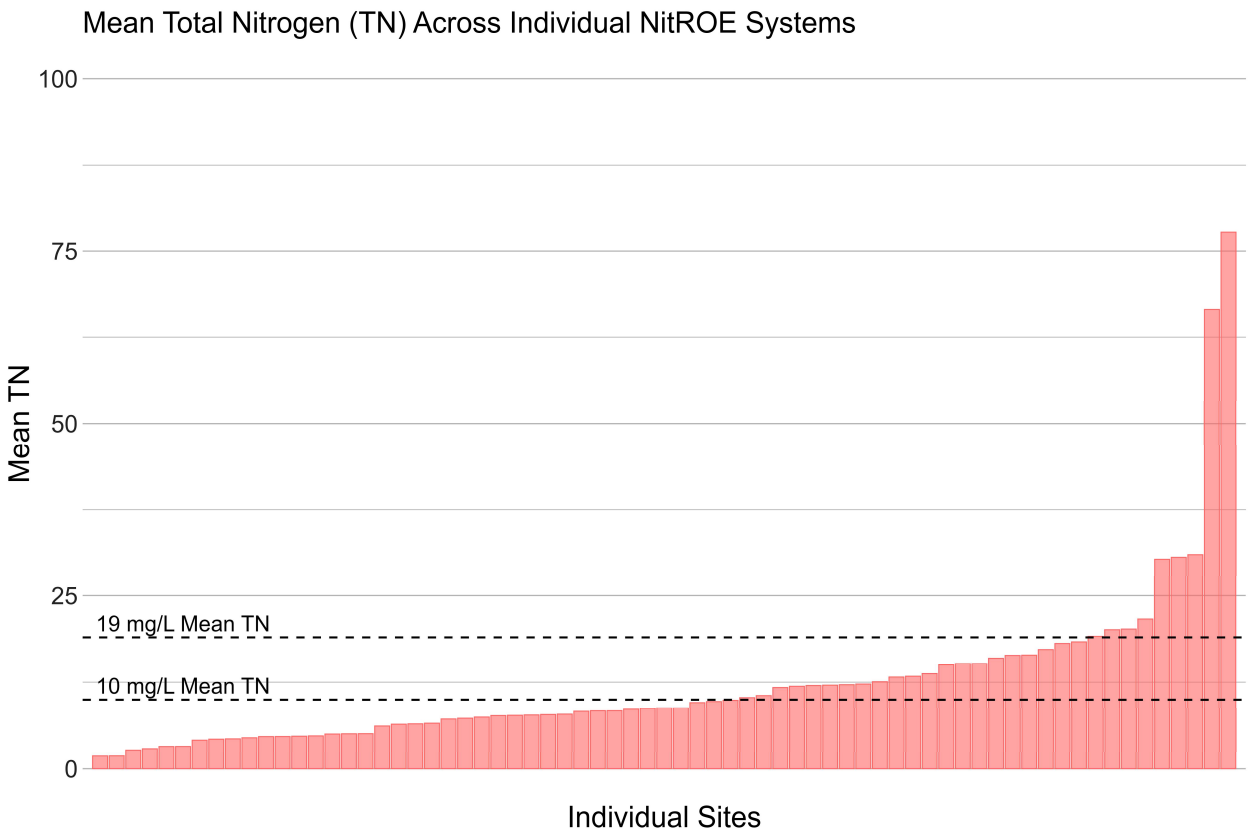

Figure 5. Mean Total Nitrogen (TN) across NitROE Systems

Figure 5 is a histogram representing the average TN among all NitROE systems in Barnstable County and Southeastern MA between January 1, 2019, and January 1, 2026. This graph represents 69 sites, each of which had data from at least five sampling events.

NitROE has a TN Approval limit of 11 mg/L. Of the 69 NitROE sites evaluated, 28 (41%) were found to have a mean TN level above the MADEP approval limit of 11 mg/L, and 41 sites (59%) were found to have a mean TN level below 11 mg/L. Of the 69 NitROE sites evaluated, eight (12%) were found to have a mean TN level above the MADEP approval limit of 19 mg/L, and 61 sites (88%) were found to have a mean TN level below 19 mg/L. Of the 69 NitROE sites, 40 (58%) were found to have a TN mean under 10 mg/L.

SeptiTech

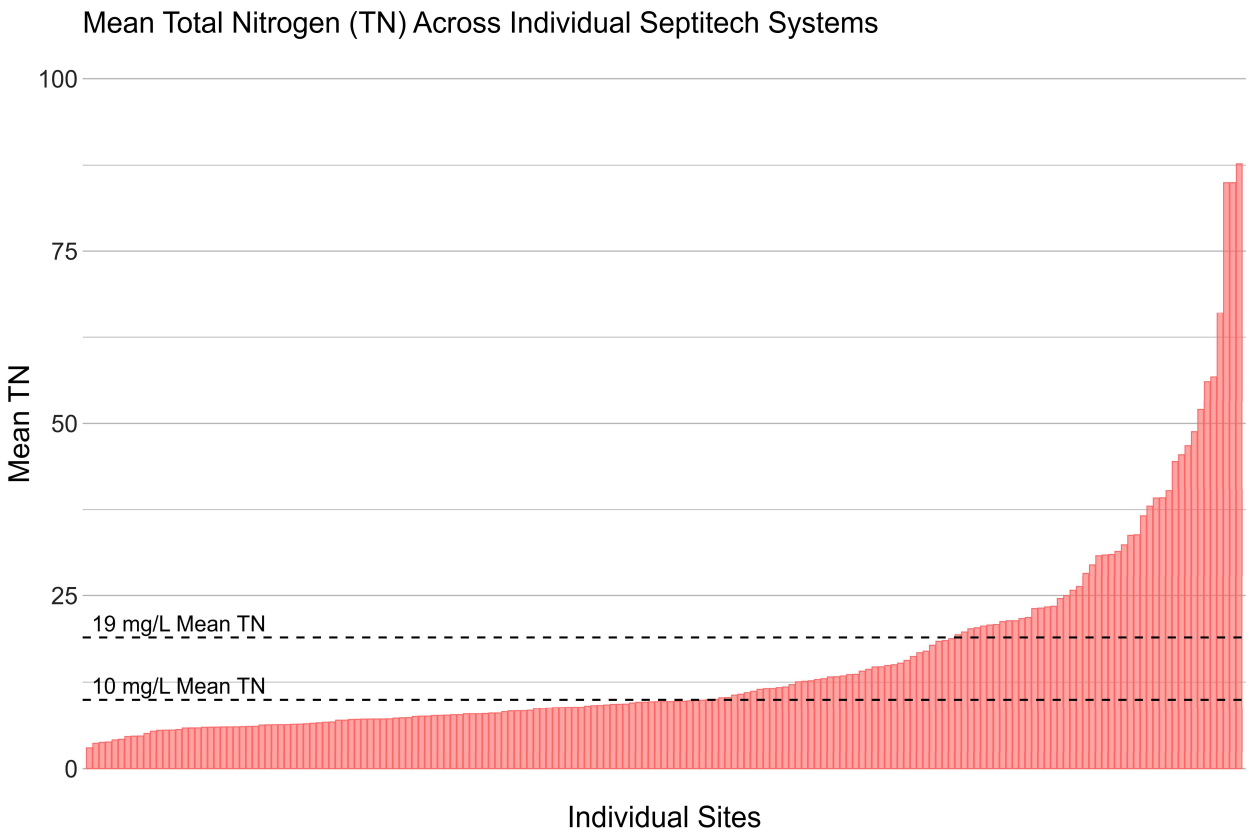

Figure 6. Mean Total Nitrogen (TN) across SeptiTech Systems

Figure 6 is a histogram representing the average TN among all SeptiTech systems in Barnstable County and Southeastern MA between January 1, 2019, and January 1, 2026. This graph represents 181 sites, each of which had data from at least five sampling events.

SeptiTech has a TN Approval limit of 19 mg/L. Of the 181 SeptiTech sites evaluated, 44 (24%) were found to have a mean TN level above the MADEP approval limit of 19 mg/L, and 137 sites (76%) were found to have a mean TN level below 19 mg/L. Of the 181 SeptiTech sites, 101 (55.8%) were found to have a TN mean under 10 mg/L.

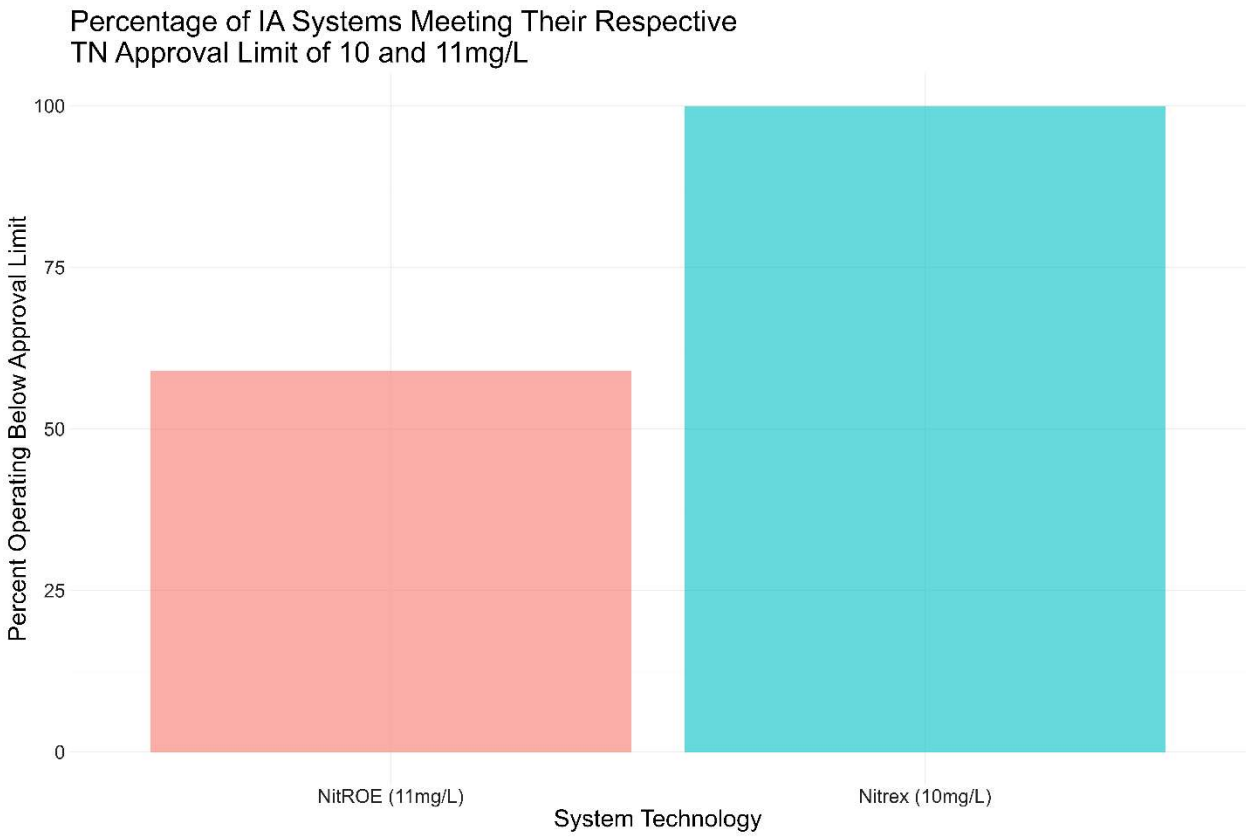

Figure 7. Percentage of IA Systems Meeting Their TN Approval Limits of 10 mg/L and 11 mg/L

Figure 7 is a bar chart showing percentage of IA systems with TN Approval Limits of 10 mg/L (Nitrex) and 11 mg/L (NitROE) that are operating below their respective thresholds. Separating these technologies from those with 19 mg/L limits allows for a more meaningful comparison among systems held to similar performance expectations.

Among the 69 NitROE systems included in this analysis, approximately 59% are performing within their 11 mg/L limit, indicating that a substantial portion of systems are achieving the level of nitrogen reduction required by MADEP. In contrast, both Nitrex systems in the dataset are operating below the 10 mg/L limit; however, the very small sample size limits the strength of any conclusions that can be drawn about overall performance.

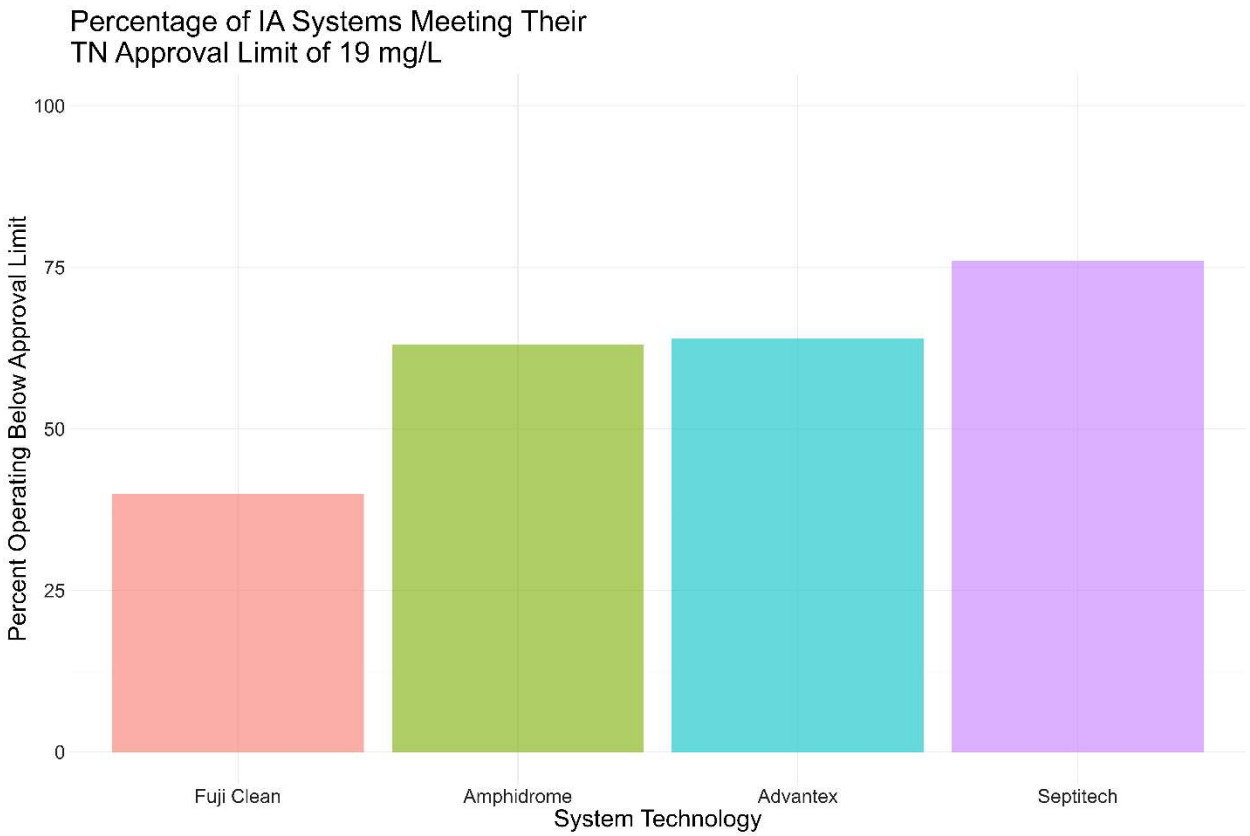

Figure 8. Percentage of IA Systems Meeting Their TN Approval Limit of 19 mg/L

Figure 8 is a bar chart showing the percentage of IA systems subject to the 19 mg/L TN Approval Limit that are operating below this threshold. Across the four technologies in this group—Advantex, Amphidrome, Fuji Clean, and SeptiTech, there is considerable variation in the proportion of systems meeting their approval standard. Advantex and Amphidrome show nearly identical performance, with 64% and 63% of systems, respectively, operating below 19 mg/L. SeptiTech exhibits the highest compliance rate, with 76% of systems falling within the limit. In contrast, Fuji Clean has the lowest proportion of compliant systems, with only 40% meeting the approval requirement. Overall, compliance among these technologies' ranges from 40% to 76%, illustrating substantial variability in field performance despite identical nitrogen-reduction expectations.

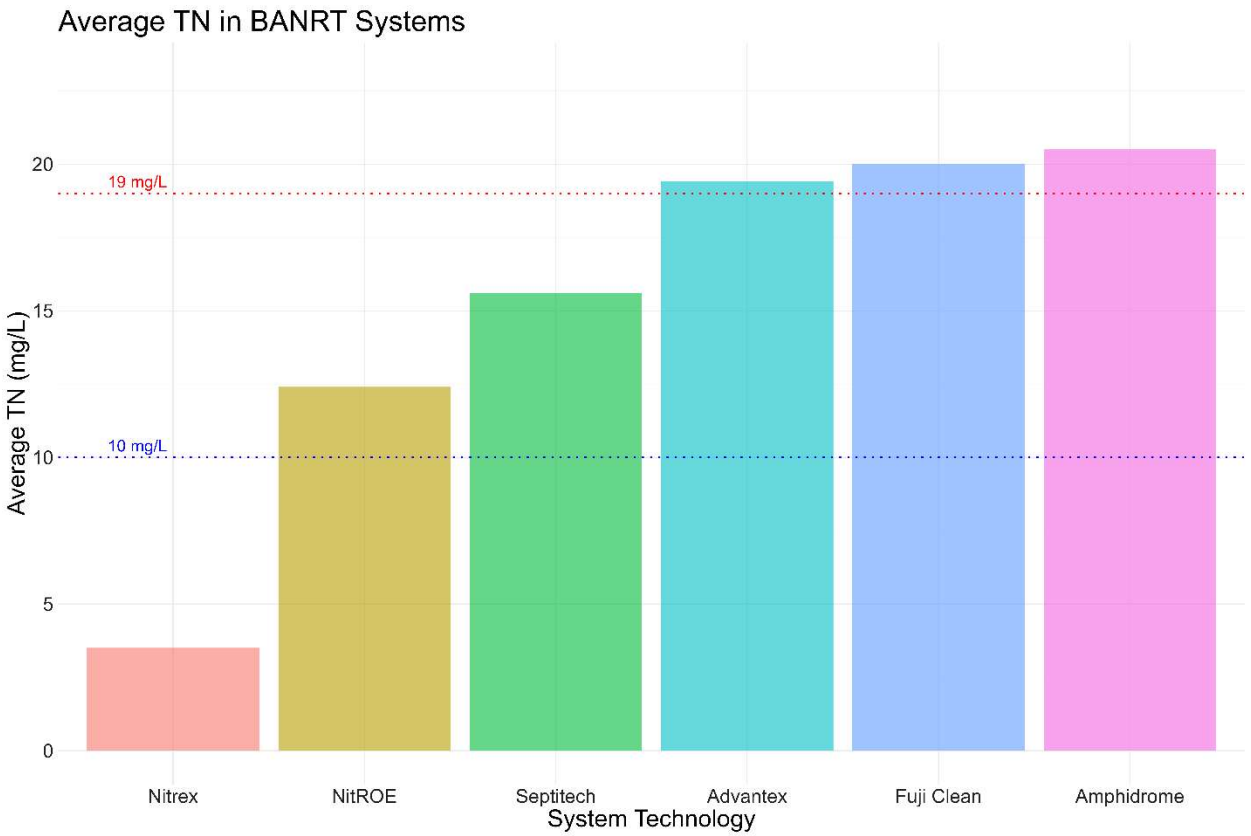

Figure 9. Average Total Nitrogen (TN) Across BANRT Technologies

Figure 9 is a bar chart presenting the average effluent Total Nitrogen (TN) concentration for each of the six BANRT technologies included in this analysis, highlighting broad performance patterns across systems. Nitrex exhibits the lowest mean TN concentration at approximately 3.5 mg/L, a value well below both the 10 mg/L and 19 mg/L reference lines shown on the graph. NitROE shows the next lowest mean TN concentration at roughly 12.4 mg/L—above the 10 mg/L reference line but below 19 mg/L—and is positioned close to its own 11 mg/L approval limit.

The remaining four technologies, SeptiTech, Advantex, Fuji Clean, and Amphidrome—form a cluster with mean TN values ranging from approximately 15.6 to 20.5 mg/L. Amphidrome has the highest mean concentration, slightly exceeding the 19 mg/L reference line. Overall, the figure demonstrates a wide range in mean TN concentrations across BANRT technologies, with averages spanning from about 3.5 mg/L to 20.5 mg/L.

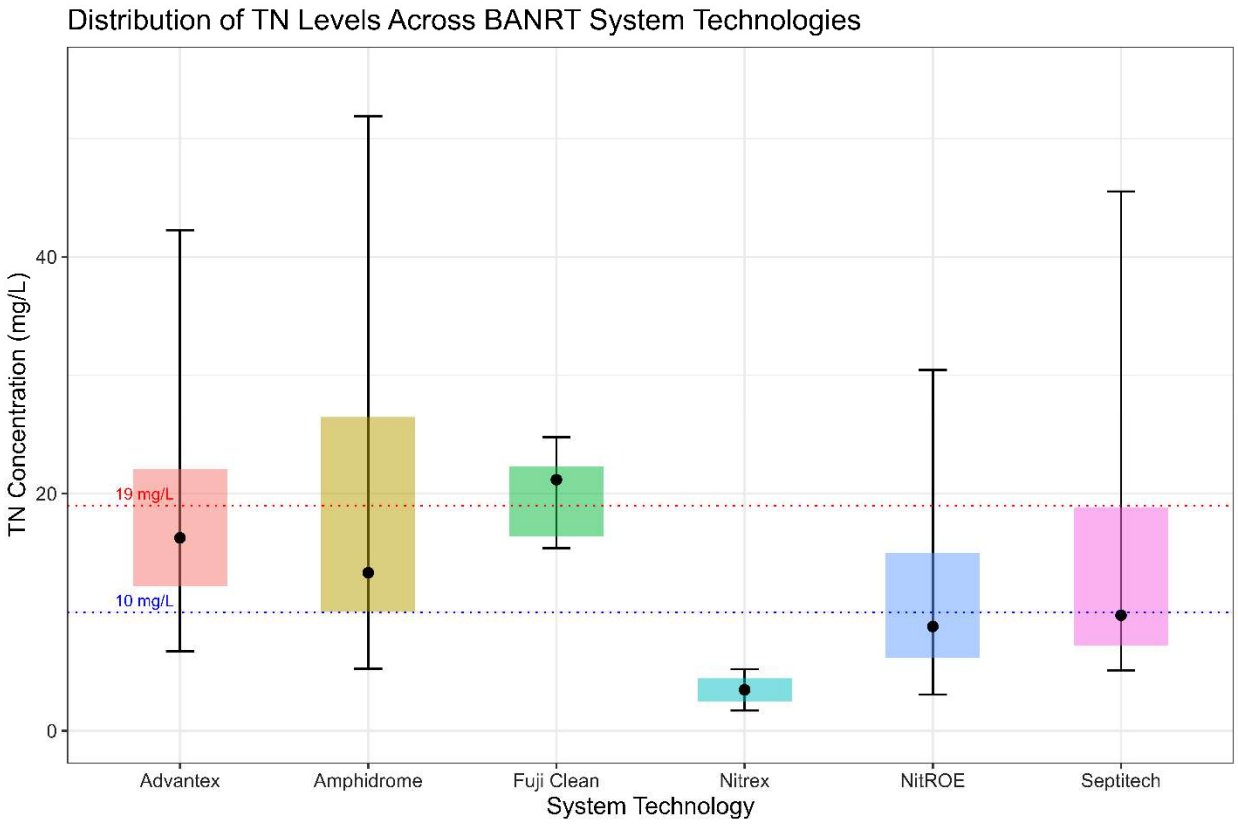

Figure 10. Distribution of TN Levels Across BANRT Technologies

Figure 10 presents the distribution of effluent Total Nitrogen (TN) concentrations for each BANRT technology using box-and-whisker plots. This visualization allows for direct comparison of both the central tendency and the variability of TN values across systems. Reference lines at 10 mg/L and 19 mg/L provide context for interpreting the distributions relative to the approval limits associated with the BANRT systems.

Across the technologies, the distributions demonstrate substantial variability in sample-level TN concentrations. Nitrex shows the tightest distribution. NitROE exhibits moderate variability, while SeptiTech, Advantex, Fuji Clean, and Amphidrome show wider spreads, indicating a broader range of field performance outcomes across their installed systems.

5. Conclusions & Recommendations

Most IA technologies on the BANRT list show moderate, but variable, success in meeting their respective TN Approval Limits. General-use systems such as Advantex and SeptiTech demonstrate relatively strong and consistent nitrogen-removal performance, with many systems operating below the 19 mg/L threshold. SeptiTech exhibits the highest proportion of compliant systems, while Advantex and Amphidrome show similar mid-range compliance rates. Fuji Clean displays lower compliance, although interpretation is limited by the small number of installations represented in the dataset. Among the technologies with more stringent limits, NitROE shows moderate compliance with its 11 mg/L limit, while Nitrex is the only technology with all systems meeting the stricter 10 mg/L limit; however, the very small sample size for Nitrex limits broader generalization.

The box-and-whisker plots reveal substantial variability within several technologies, particularly Advantex and Amphidrome, which exhibit the widest range of TN sample values. In contrast, Nitrex displays the tightest clustering of TN results, while NitROE, SeptiTech, and Fuji Clean fall between these extremes. These distributional differences highlight how real-world system loading, maintenance practices, site characteristics, and operational variability influence field performance beyond what is captured by mean TN values alone.

Technology-level average TN comparisons further reinforce these patterns. Nitrex exhibits the lowest mean TN concentration, followed by NitROE. SeptiTech, Advantex, Fuji Clean, and Amphidrome form a distinct group with higher mean TN values ranging from approximately 15.6 to 20.5 mg/L, with Amphidrome showing the highest average, slightly exceeding the 19 mg/L reference line. This spread in average values demonstrates that while several technologies can achieve compliance on a system-by-system basis, their overall field performance varies.

The compliance analyses also show that technologies sharing identical approval limits do not exhibit uniform field performance. For example, among technologies with the 19 mg/L limit, compliance ranges from 40% to 76%, indicating differences in installation environments, influent characteristics, homeowner usage patterns, and system operation and maintenance. Similarly, Nitrex and NitROE, though held to tighter limits, show very different compliance outcomes, again underscoring the importance of considering both system design and real-world conditions when evaluating performance.

Given these findings, the following recommendations can be made to strengthen future analyses and improve field performance outcomes:

- Expand the dataset both in terms of number of sites and samples, especially for underrepresented technologies like Nitrex and Fuji Clean, to strengthen the basis for regulatory or programmatic decisions.

- Increase both the consistency and frequency of sampling to improve reliability and comparability of system performance across technologies.
- Investigate outlier systems to determine whether elevated TN levels are linked to maintenance issues, design or installation factors, weather impacts, or specific site conditions.
- Expand data collection to include influent characteristics, maintenance records, and system loading to provide better context for interpreting performance variability.
- Evaluate seasonal usage patterns in future analyses, as differing conditions between year-round and seasonal homes may influence treatment outcomes.
- Collect flow volume data and multiply by measured concentration values to calculate mass load of nitrogen discharged at each site.

Overall, the updated analyses highlight that while the BANRT technologies generally provide enhanced nitrogen removal relative to conventional systems, their performance in the field is influenced by a wide range of real-world conditions. Understanding both the typical and the variable aspects of system behavior is essential for informing regulatory decisions, guiding technology selection, and improving water-quality outcomes across Cape Cod and Southeastern Massachusetts.

6. References & Sources

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