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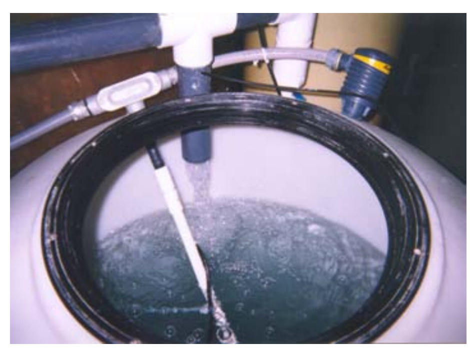
EcoMat Inc.'s Biological Denitrification Process

Innovative Technology Evaluation Report



SITE

SUPERFUND INNOVATIVE TECHNOLOGY EVALUATION

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Innovative Technology Evaluation Report

National Risk Management Research Laboratory
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Notice

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Foreword

The U.S. Environmental Protection Agency is charged by Congress with protecting the Nation's land, air, and water resources. Under a mandate of national environmental laws, the Agency strives to formulate and implement actions leading to a compatible balance between human activities and the ability of natural systems to support and nurture life. To meet this mandate, EPA's research program is providing data and technical support for solving environmental problems today and building a science knowledge base necessary to manage our ecological resources wisely, understand how pollutants affect our health, and prevent or reduce environmental risks in the future.

The National Risk Management Research Laboratory (NRMRL) is the Agency's center for investigation of technological and management approaches for preventing and reducing risks from pollution that threatens human health and the environment. The focus of the Laboratory's research program is on methods and their cost-effectiveness for prevention and control of pollution to air, land, water, and subsurface resources; protection of water quality in public water systems; remediation of contaminated sites, sediments and ground water; prevention and control of indoor air pollution; and restoration of ecosystems. NRMRL collaborates with both public and private sector partners to foster technologies that reduce the cost of compliance and to anticipate emerging problems. NRMRL's research provides solutions to environmental problems by: developing and promoting technologies that protect and improve the environment; advancing scientific and engineering information to support regulatory and policy decisions; and providing the technical support and information transfer to ensure implementation of environmental regulations and strategies at the national, state, and community levels.

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Hugh W. McKinnon, Director
National Risk Management Research Laboratory

Abstract

This report summarizes the findings of an evaluation of a biodenitrification (BDN) system developed by EcoMat Inc. of Hayward, California (EcoMat). This evaluation was conducted between May and December of 1999 under the U.S. Environmental Protection Agency Superfund Innovative Technology Evaluation (SITE) Program; it was conducted in cooperation with the Kansas Department of Health and Environment (KDHE). The demonstration site was the location of a former public water supply well in Bendena, Kansas. The well water is contaminated with high levels of nitrate. Based on historical data, nitrate concentrations in the water have ranged from approximately 20 to 130 ppm, well above the regulatory limit of 10 mg/l. Low concentrations of volatile organic compounds (VOCs), particularly carbon tetrachloride (CCl_4), have been a secondary problem. The overall goal of EcoMat was to demonstrate the ability of its process to reduce the levels of nitrate in the groundwater to an acceptable concentration, thus restoring the water supply well as a drinking water source.

EcoMat's process is a two component process consisting of 1) an *ex situ* anoxic biofilter BDN system, and 2) a post-treatment system. The BDN system utilizes specific biocarriers and bacteria to treat nitrate-contaminated water, and employs a patented reactor for mixing the suspended biocarriers and retaining biocarrier within the reactors to minimize solids carryover. Methanol is added to the system as a carbon source for cell growth and for inducing metabolic processes that remove free oxygen and encourages the bacteria to consume nitrate. EcoMat's post-treatment system can be subdivided into two primary treatment parts: one part for oxidation and a second part for filtration. The oxidation treatment is intended to oxidize residual nitrite back to nitrate, oxidize any residual methanol, and destroy bacterial matter exiting the BDN system. The oxidation treatment may consist of ozonation or ultraviolet (UV) treatment, or a combination of both. Filtration usually consists of a clarifying tank and one or more filters designed to remove suspended solids generated from the BDN process.

The demonstration consisted of four separate sampling events interspersed over a 7½ month period of time. During these events EcoMat operated its system to flow between three and eight gallons per minute. During this same time period nitrate levels in the well water varied from greater than 70 mg/l to approximately 30 mg/l. For Event 1, chlorination was the only post-treatment used. Post-treatment for Event 2 consisted of clarification; sand filtration; cartridge filtration using 20µm rough filters; and UV oxidation. Post-treatment for Event 3 consisted of ozone; UV oxidation; clarification; cartridge filtration using 20µm rough filters, 5µm high efficiency filters, carbon adsorption, and 1µm polishing filters. Post-treatment for Event 4 consisted of chlorination, clarification, 5µm high efficiency filtration, air stripping, and 1µm polishing filtration.

The primary objective of the study focused on three performance estimates. The first performance estimate was to determine if the BDN portion of the process was capable of reducing combined nitrate-N/nitrite-N (total-N) to less than 10.5 mg/l. The second performance estimate included evaluation of the post-treatment for its ability to produce treated groundwater that would meet applicable drinking water standards with respect to nitrate-N, nitrite-N, and total-N, using a level of significance of 0.10. This required reducing high levels of nitrate-N to less than 10.5 mg/l, maintaining nitrite-N levels to less than 1.5 mg/l, and achieving a total-N level of less than 10.5 mg/l. When rounded to whole numbers, these performance estimates would meet the regulatory maximum contaminant limits (MCLs) of 10, 1, and 10 mg/l for nitrate-N, nitrite-N, and total-N respectively. The

Abstract (Cont'd)

third performance estimate involved evaluating the final effluents for other parameters, such as turbidity, pH, residual methanol, suspended solids, and biological material.

Results for the final system outfall indicate that when the post BDN effluent contains nitrite-N levels in excess of the regulatory limit of 1 mg/l the EcoMat post-treatment components failed to adequately and reliably reduce the nitrite-N levels to below the 1 mg/l level. The post-treatment system was varied considerably throughout the demonstration. For Event 1, chlorination was the only post-treatment used. Post-treatment for Event 2 consisted of clarification; sand filtration; cartridge filtration using 20µm rough filters; and UV oxidation. Post-treatment for Event 3 consisted of ozone; UV oxidation; clarification; cartridge filtration using 20µm rough filters, 5µm high efficiency filters, carbon adsorption, and 1µm polishing filters. Post-treatment for Event 4 consisted of chlorination, clarification, 5µm high efficiency filtration, air stripping, and 1µm polishing filtration. Comparison of samples collected immediately upstream and immediately downstream of the post-treatment systems indicated that none of the combinations used were effective for removing residual methanol. In all instances methanol levels were virtually the same or higher in final effluent exiting the post-treatment systems.

Since the post-treatment system implemented by EcoMat varied for each of the four events, data from the four events was first analyzed separately. Formal statistical analyses were used to address the first two performance estimates discussed above, using a significance level of 0.10. The overall conclusion from these tests was that:

- Events 1 and 2 were found to be successful in meeting the first two performance goals for significantly reducing levels of nitrate-N and nitrite-N after BDN and after post treatment.
- Event 3 and 4 were not shown to be successful in significantly reducing levels of nitrate-N and nitrite-N after BDN and after post treatment.

Daily dissolved oxygen (DO) field measurements indicated that the de-oxygenating step of EcoMat's BDN process may not have been optimized throughout the demonstration, and especially during Events 3 and 4. The desired DO level of partially biodenitrified (partial BDN) water in the De-oxygenating Tank is $\leq$ 1 mg/l. However, DO values below 1 mg/l were measured only during the first two events.

The effectiveness of the post-treatment systems were variable for different parameters. Comparison of samples collected immediately upstream and immediately downstream of the post-treatment systems indicated that none of the combinations used were effective for removing residual methanol to the demonstration objective of $\leq$ 1 mg/l. In all instances, downstream methanol levels were virtually the same or higher than upstream methanol levels. Methanol concentrations averages in final effluent were between 15 and 98 mg/l during the four events. the first two events appear to have had a substantial beneficial impact on solids carryover. Residual bacterial content in the final effluent, decreased significantly in Events 3 and 4, likely the result of adding "high efficiency" (5µm) and "polishing" (1µm) filters to the post-treatment system. Nevertheless, the levels of total heterotrophic and facultative anaerobe bacterial matter measured in the final effluent for all events was well above corresponding inlet water levels.

An economic analysis was also conducted for estimating the cost of implementing EcoMat's biological denitrification technology at full-scale. For a 100 gpm system, the estimated cost to treat nitrate-contaminated groundwater over a one year period is $490,000, or approximately $0.012/gal. The cost over 5, 10,or 15 years is estimated to increase to approximately$730,000 ($0.0034/gal.); $1,000,000 ($0.0024/gal.) and $1,300,000 ($0.002/gal.), respectively.

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Abbreviations and Acronyms

AQCR	Air Quality Control Regions
AQMD	Air Quality Management District
ATTIC	Alternative Treatment Technology Information Center
ARARs	Applicable or Relevant and Appropriate Requirements
BDN	Biodenitrification
cm^3	Cubic centimeter
CAA	Clean Air Act
CCl_4	Carbon tetrachloride
CERI	Center for Environmental Research Information
CERCLA	Comprehensive Environmental Response, Compensation, and Liability Act
CFR	Code of Federal Regulations
CSCT	Consortium for Site Characterization Technologies
cfu	Colony forming units
CWA	Clean Water Act
DI	Deionized
DO	Dissolved oxygen
EcoMat	EcoMat Inc. of Hayward, CA
EDA	Exploratory data analysis
FA	Facultative anaerobes
FC	Fecal coliform
FS	Feasibility study
FID	Flame Ionization Detector
ft^2	Square feet
gpm	Gallons per minute
GC/MS	Gas chromatography/mass spectroscopy
G&A	General and administrative
g/cm^3	Gram per cubic centimeter
HSWA	Hazardous and Solid Waste Amendments
ICP	Inductively coupled plasma spectroscopy
ITER	Innovative Technology Evaluation Report
KDHE	Kansas Department of Health and Environment
kW/Hr	Kilowatts per hour
LDR	Land disposal restriction
LOS	Level of significance
m^3	Cubic meter
MS/MSD	Matrix spike/matrix spike duplicate
MCLs	Maximum contaminant levels
MCLGs	Maximum contaminant level goals
MDL	Method detection limit
MeOH	Methanol or methyl alcohol
mg/l	Milligrams per liter

Abbreviations and Acronyms (Cont'd)

MPN	Most probable number
NAAQS	National Ambient Air Quality Standards
NCP	National Oil and Hazardous Substances Pollution Contingency Plan
NIST	National Institutes of Standards and Technology
NOAA	National Oceanographic and Aeronautic Administration
NPDES	National Pollutant Discharge Elimination System
NPL	National Priorities List
NRMRL	National Risk Management Research Laboratory (EPA)
NSCEP	National Service Center for Environmental Publications
Nitrate-N	A measure of nitrate in which each mg/l of nitrate-N equates to 4.4 mg/l of nitrate
Nitrite-N	A measure of nitrite in which each mg/l of nitrite-N equates to 3.2 mg/l of nitrite
ND	Non-detectable, not detected, less than detection limit
NPDWS	National primary drinking water standards
NTU	Normal turbidity unit
OSHA	Occupational Safety and Health Administration
ORD	Office of Research and Development (EPA)
OSWER	Office of Solid Waste and Emergency Response (EPA)
OSC	On-scene coordinator
PLFA	Phospholipid fatty acids
POTW	Publicly owned treatment works
PPE	Personal protective equipment
PQL	Practical quantitation limit
POA	Project Objective Agreement
PVC	Polyvinyl chloride
PWS	Public water supply
POTW	Publicly owned treatment works
QAPP	Quality assurance project plan
RPD	Relative percent difference
RI/FS	Remedial Investigation / Feasibility Study
RPM	Remedial project manager
RCRA	Resource Conservation and Recovery Act
SAIC	Science Applications International Corporation
SARA	Superfund Amendments and Reauthorization Act
SDWA	Safe Drinking Water Act
SOP	Standard operating procedure
SW-846	Test methods for evaluating solid waste, physical/chemical methods
SWDA	Solid Waste Disposal Act
SITE	Superfund Innovative Technology Evaluation
S.U.	Standard units
TER	Technology Evaluation Report
TCH	Total culturable heterotrophs
TOC	Total organic carbon
TSCA	Toxic Substances Control Act
TSD	Treatment, storage, and disposal
THM	Trihalomethanes
µg/l	Micrograms per liter
UV	Ultraviolet
US EPA	United States Environmental Protection Agency
VOC	Volatile organic compound
WSR	Wilcoxon signed rank

Acknowledgments

This report was prepared under the direction of Dr. Ronald Lewis (retired) and Mr. Randy Parker, the EPA Technical Project Managers for this SITE demonstration at the National Risk Management Research Laboratory (NRMRL) in Cincinnati, Ohio. EPA NRMRL peer review of this report was conducted by Mr. Vicente Gallardo. Mr. Andrew Matuson of Science Applications International Corporation (SAIC) served as the SITE work assignment manager for the implementation of demonstration field activities and completion of all associated reports.

The demonstration required the combined services of several individuals from EcoMat Inc., the Kansas Department of Health Services (KDHE), the town of Bendena, KS, and SAIC. Peter Hall and Jerry Shapiro of EcoMat, Inc. served as logistical and technical contacts for the developer. Rick Bean of the KDHE was instrumental for making provisions for the treatment shed and associated utilities, and for conducting additional sampling and analysis independent of the SITE Program. Iraj Pourmirza of the KDHE Bureau of Water - Water Supply Section provided technical support regarding drinking water issues. The cooperation and efforts of these organizations and individuals are gratefully acknowledged.

This report was prepared by Joseph Tillman, Susan Blackburn, Craig Chomiak, and John Nicklas, of SAIC. Mr. Nicklas also served as the SAIC QA coordinator for data review and validation. Joseph Evans (the SAIC QA Manager), Dr. Herbert Skovronek, and James Rawe, all of SAIC, internally reviewed the report. Field sampling and data acquisition was conducted by William Carrier, Dan Patel, Steve Stavrou, and Joseph Tillman.

Cover Photographs: Clockwise from top left are **1)** "EcoLink" - synthetic polyurethane cubes, 1 cm on a side, used as biocarrier medium; **2)** Gas detector tube monitoring above overflow tank (dark tank in background is the "EcoMat Reactor" , also known as "R2"); **3)** Concrete cap for 23 ft. ID Public Water Supply Well # 1 (vent pipe visible on right side of cap); **4)** Post-BDN effluent discharging to overflow tank; **5)** Overview of biodenitrification system - Overflow tank (front), 2 m^3 EcoMat Reactor (center), and De-oxygenating Tank (far right); **6)** Portion of post-treatment system (clarifying tank at left); and **7)** Shed for housing treatment system.

Executive Summary

This report summarizes the findings of an evaluation of the EcoMat Biodenitrification (BDN) treatment process. The process was tested for treating groundwater contaminated with high levels of nitrate at the location of a former public water supply well in Bendena, Kansas. This evaluation was conducted under the U.S. Environmental Protection Agency (EPA) Superfund Innovative Technology Evaluation (SITE) Program.

It should be noted that BDN processes have been used for some years for treatment of wastewater and groundwater. However, the technology has been known in the past to be applied to the treatment of groundwater for drinking water purposes. Thus, the SITE Program's interest was to evaluate such an application.

Overview of Site Demonstration

The EcoMat BDN process is a type of fixed film bioremediation that uses specific biocarriers and bacteria to treat nitrate-contaminated water. Fixed film treatment allows rapid and compact treatment of nitrate with minimal byproducts. Unique to the EcoMat system is a patented mixed reactor that retains the biocarrier within the system, thus minimizing solids carryover. Methanol is added to the system as a source of carbon for cell growth and for inducing metabolic processes that remove free oxygen and encourage the bacteria to consume nitrate. Methanol is also important to assure that the nitrate conversion results in the production of nitrogen gas rather than the intermediate nitrite, which is considered to be more toxic.

EcoMat's BDN system was evaluated under the SITE Program at the location of a former public water supply well #1 (PWS) in Bendena, Kansas. The primary contaminant in the well water was nitrate. Based on historical data, nitrate concentrations in the water ranged from approximately 20 to 130 ppm, well above the regulatory limit of 10 mg/l. Low concentrations of VOCs, particularly carbon tetrachloride (CCl_4), were a secondary problem. The overall goal of EcoMat was to demonstrate the ability of its process to reduce the levels of nitrate in the extracted groundwater and restore the public water supply well as a drinking water source.

The central goal of EcoMat was to demonstrate that its system could produce groundwater from PWS Well # 1 that would be in compliance with the drinking water MCLs for nitrate-N, nitrite-N, and total-N, while at the same time meeting requirements for other parameters such as turbidity, pH, residual methanol, suspended solids, and biological material. With respect to both the BDN and post-treatment components of the system, EcoMat proposed the following three performance estimates:

- With incoming groundwater having nitrate-N of 20 mg/l or greater, and operating at a flow through rate of 3-15 gpm, the BDN unit would reduce the combined nitrate-N and nitrite-N level (total-N) in PWS Well #1 groundwater to at or below a combined concentration of 10 mg/l.
- The post treatment or polishing unit would produce treated groundwater meeting applicable drinking water standards with respect to nitrate-N (10 mg/l), nitrite-N (1 mg/l), and total-N (10 mg/l).
- Coupled with the planned or alternative post-treatment, the product water would consistently meet drinking water requirements, except for residual chlorine. Specifically it would not contain turbidity of greater than 1 NTU, detectable levels of methanol (1 mg/l), or increased levels of biological material or suspended solids, and would have a pH in the acceptable 6.5-8.5 range.

For the purposes of these evaluations, demonstration criteria were chosen that, when rounded to the nearest whole number, they would be consistent with the Kansas Department of Health and Environment (KDHE) MCL values. The KDHE MCL values for nitrate-N, nitrite-N, and total-N were 10, 1, and 10 mg/l, respectively. Thus, values less than the nitrite-N demonstration criterion of 1.5 mg/l (i.e., $\leq$ 1.49 mg/l) would reduce to 1 mg/l. Values less than the nitrate-N and total-N demonstration criterion of 10.5 mg/l (i.e., $\leq$ 10.49 mg/l) would reduce to 10 mg/l.

Conclusions from this SITE Demonstration

Since the post-treatment system implemented by EcoMat varied for each of the four events, data from the four events were first analyzed separately. Formal statistical analyses were used to address the first two performance estimates previously discussed (i.e., total-N level less than 10 mg/l, and nitrate-N and nitrite-N levels less than 10 mg/l and 1 mg/l, respectively), using a significance level of 0.10. The overall conclusion from these tests was that:

- Events 1 and 2 were determined successful in meeting the 1st and 2nd performance goals. Concentrations of total-N, nitrate-N, and nitrite-N were significantly reduced to below MCLs immediately following BDN treatment and after post treatment.
- Event 3 and 4 were determined not successful in meeting the 1st and 2nd performance goals for significantly reducing levels of total-N, nitrate-N, and nitrite-N after BDN and after post treatment.

A number of additional conclusions may be drawn from the evaluation of the EcoMat BDN and post-treatment processes as a whole, based on extensive analytical data supplemented by field measurements. These include:

- The filtration systems incorporated following the first event appear to have had a substantial beneficial impact on solids carryover. Based on laboratory and field measurements, the 5µm high efficiency and 1µm polishing filters used during the last two events produced better results for reduction of biological material, total suspended solids, and turbidity in the final effluent.
- Specific to turbidity, which has a secondary drinking water criterion of 1 Normal Turbidity Unit (NTU), average field measurement results for Events 3 and 4 final effluents were 1.2 and 0.96 NTU, respectively. These results were improved in comparison to the 1.8 NTU average value for Event 2 final effluent, in which “sand filtration” and “rough filtration” (20µm) were used; and where greatly improved in comparison to the 4.4 NTU average value for Event 1 final effluent, in which no filtration was used.
- Total suspended solids (TSS) laboratory results were similar to the turbidity field measurements. The demonstration criterion for TSS in final effluent was to be less than or equal to that of the inlet water, in which TSS was consistently measured to be below the detection limit of 5 mg/l for all four events. TSS results for Event 1 were consistently above this 5 mg/l threshold and averaged 10 mg/l. During Events 2, 3, and 4 TSS was measured above 5 mg/l in 3 of 9, 7of 9, and 7 of 8 of the final effluent samples collected, respectively. However, the average TSS value for these events was below the detection limit of 5 mg/l.
- The demonstration criterion for residual bacterial content in the final effluent was also to be less than or equal to that of the inlet water. The highest bacterial counts in final effluent occurred for Event 2. This was likely due to the fact that no disinfection (i.e., chlorine, ozone, etc.) was used and that “rough” filtration (20 µm) was the smallest filtration size used during Event 2. Residual bacterial content in the final effluent, decreased significantly in Events 3 and 4, likely the result of adding “high efficiency” (5µm) and “polishing” (1µm) filters to the post-treatment system. Nevertheless, the levels of total heterotrophic and facultative anaerobe bacterial matter measured in the final effluent for all events was well above corresponding inlet water levels.
- None of the post treatment system combinations used during the demonstration was effective in removing residual methanol to the demonstration objective of $\leq$ 1 mg/l. Methanol concentration averages in final effluent were between 15 and 98 mg/l during the four events. Methanol was actually measured on average to be higher in the final effluent samples than in post BDN samples (collected upstream of the post-treatment system) for three of the four events. This may be an anomaly attributable to ongoing methanol degradation in the post BDN samples prior to analysis. The final effluent samples were disinfected (preserved) so that further reaction was halted.
- There appears to be an inverse correlation between flow rate and nitrate removal (i.e., higher flow rate correlating to less effective nitrate removal), based on a per sample round comparison of system flow rate and Total-N concentration in final effluent. However, it was not possible to confirm that this was a cause/effect relationship because of (a) the narrow range of flows actually investigated and (b) variations in performance that occurred or became necessary due to upsets, and other operational problems.

- pH was not altered by the EcoMat BDN or post-treatment systems. For Events 1 and 2 there was a very slight increase in pH from the inlet water to the post BDN effluent. No discernable change in pH between inlet water and final effluent was measured for Event 3. For Event 4, the pH values for inlet water ranged from 8.3 - 9.2 (outside of the acceptable drinking water limits of 6.5-8.5). Final effluent pH values were slightly lower and ranged from 6.8 - 8.9.

- Daily dissolved oxygen (DO) field measurements indicated that the de-oxygenating step of EcoMat's BDN process may not have been optimized. The desired DO level of partially biodenitrified (partial BDN) water in the de-oxygenating tank is $\leq$ 1 mg/l. However, DO values below 1 mg/l were measured only during the first two events. Average DO during Events 1 and 2 were 1.1 and 1.0 mg/l, respectively. DO in partial BDN effluent during Event 3 were consistently measured above 1 mg/l and averaged 2.1 mg/l. DO in partial BDN effluent during Event 4 was also consistently measured above 1 mg/l and averaged 2.8 mg/l. Because Events 3 and 4 had poorer nitrate removal than Event 1 and 2, the inability to optimize the de-oxygenating step of the BDN process during the last two events could have negatively impacted results.

- The quality assurance analyses of critical sample data indicated adequate data quality was achieved for evaluating the EcoMat technology. With respect to data accuracy, the overall demonstration recovery average for 44 nitrate-N MS/MSD sample sets was approximately 95%. The overall demonstration recovery average for 44 nitrite-N MS/MSD sample sets was approximately 96%. With respect to data precision, the overall demonstration average relevant percent difference for those MS/MSD sets for nitrate-N and nitrite-N were 2.7 and 2.1, respectively.

- Carbon tetrachloride, which had been historically detected in PWS Well #1 water, was not detected in inlet water or final effluent samples. Thus, the effectiveness of any of the post-treatment combinations for treating this compound could not be evaluated.

- For a 100 gpm system, the estimated cost to treat nitrate-contaminated groundwater over a one year period is $490,000, or approximately $0.012/gal. The cost over 5, 10,or 15 years is estimated to increase to approximately$730,000 ($0.0034/gal.); $1,000,000 ($0.0024/gal.) and $1,300,000 ($0.002/gal.), respectively.

Section 1.0
Introduction

This section provides background information about the Superfund Innovative Technology Evaluation (SITE) Program, discusses the purpose of this Innovative Technology Evaluation Report (ITER), and describes EcoMat Inc.'s Biological Denitrification (BDN) process. Key contacts are listed at the end of this section for inquiries regarding additional information about the SITE Program, this technology, and the demonstration site.

1.1 Background

The EcoMat Inc. BDN process was demonstrated under the Superfund Innovative Technology Evaluation (SITE) Program at a former public water supply (PWS) well in Bendena, Kansas. The demonstration project, which occurred in cooperation with the Kansas Department of Health and Environment (KDHE), evaluated an ex situ anoxic BDN technology developed by EcoMat Inc. of Hayward, California. The technology is a type of fixed-film biofilter that uses specific biocarriers and naturally occurring anoxic bacteria to treat nitrate contaminated water. During this demonstration the technology was part of an overall system that included four different combinations of post-treatment systems. Each of the four post-treatment systems included an oxidation component to convert residual nitrite back to nitrate. A filtration component was included in three of the four post-treatment systems to remove suspended solids. Both the biological denitrification process and post-treatment technology were evaluated during this demonstration.

The well of concern, the Bendena Rural Water District #2 Public Water Supply (PWS) Well #1, and surrounding monitoring wells have been the subject of numerous groundwater investigations since 1985. Historical data from these investigations revealed elevated concentrations of nitrate and carbon tetrachloride (CCl_4). The data show that nitrate concentrations in the groundwater range from approximately 20 to 130 ppm, which is well above the National Primary Drinking Water Standards (NPDWS) limit of 10 mg/l. The historical data show a history of CCl_4 concentrations between 2 µg/l and 31 µg/l (the current MCL for CCl_4 is 5 µg/l).

Numerous sampling investigations at PWS Well #1 have been unsuccessful in identifying the specific source of contamination for both nitrate and CCl_4. Since the land surrounding the city is primarily agricultural, non-point runoff of contaminated surface water from agricultural land was considered as a possible contamination source for nitrate. This explanation was not supported by the low concentrations of ammonia (< 0.8 mg/l) found in groundwater samples. There was also reason to suspect an industrial leak upgradient of the well as the source of nitrate, but this has not been confirmed.

The demonstration project, which occurred between May and December 1999, consisted of four separate sampling events. During these events, EcoMat operated its system with a flow rate between approximately three and eight gallons per minute. During this time period, nitrate levels in the well water varied from greater than 70 mg/l to approximately 30 mg/l.

The overall goal of EcoMat was to demonstrate the ability of its process to reduce the levels of nitrate in the extracted groundwater and restore the public water supply well as a drinking water source. Specifically, the Primary Objectives for this SITE demonstration included the following:

- demonstrate, that with an incoming groundwater nitrate-N concentration of 20 mg/l or greater, and operating at a flow rate of 3 to 15 gpm, the BDN unit will reduce the combined nitrate-N and nitrite-N (i.e., total-N) level in the PWS Well #1groundwater to less than 10.5 (which would reduce to less than or equal to the MCL of 10 mg/l when rounded to a whole number).
- demonstrate that the post-treatment unit will produce treated groundwater that will meet applicable drinking water standards with respect to nitrate-N (i.e., to less than 10.5 mg/l), nitrite-N (i.e., to less than 1.5 mg/l) and combined nitrate-N and

nitrite-N (i.e., to less than 10.5 mg/l). These demonstration criteria would reduce to less than or equal to the MCLs of 10, 1, and 10 mg/l when rounded to whole numbers).

1.2 Brief Description of the SITE Program

The SITE Program is a formal program established by the EPA's Office of Solid Waste and Emergency Response (OSWER) and Office of Research and Development (ORD) in response to the Superfund Amendments and Reauthorization Act of 1986 (SARA). The SITE Program promotes the development, demonstration, and use of new or innovative technologies to clean up Superfund sites across the country.

The SITE Program's primary purpose is to maximize the use of alternatives in cleaning hazardous waste sites by encouraging the development and demonstration of new, innovative treatment and monitoring technologies. It consists of three major elements:

- the Demonstration Program,
- the Consortium for Site Characterization Technologies (CSCT), and
- the Technology Transfer Program.

The objective of the Demonstration Program is to develop reliable performance and cost data on innovative technologies so that potential users can assess the technology's site-specific applicability. Technologies evaluated are either available commercially or close to being available for full-scale remediation of Superfund sites. SITE demonstrations usually are conducted at hazardous waste sites under conditions that closely simulate full-scale remediation conditions, thus assuring the usefulness and reliability of the information collected. Data collected are used to assess: (1) the performance of the technology; (2) the potential need for pre- and post-treatment of wastes; (3) potential operating problems; and (4) the approximate costs. The demonstration also provides opportunities to evaluate the long term risks and limitations of a technology.

Existing and new technologies and test procedures that improve field monitoring and site characterizations are explored in the CSCT Program. New monitoring technologies, or analytical methods that provide faster, more cost-effective contamination and site assessment data are supported by this program. The CSCT Program also formulates the protocols and standard operating procedures for demonstration methods and equipment.

The Technology Transfer Program disseminates technical information on innovative technologies in the Demonstration and CSCT Programs through various activities. These activities increase awareness and promote the use of innovative technologies for assessment and remediation at Superfund sites. The goal of technology transfer activities is to develop interactive communication among individuals requiring up-to-date technical information.

1.3 The SITE Demonstration Program and Reports

In the past technologies have been selected for the SITE Demonstration Program through annual requests for proposal (RFP). EPA reviewed proposals to determine the technologies with promise for use at hazardous waste sites. Several technologies also entered the program from current Superfund projects, in which innovative techniques of broad interest were identified for evaluation under the program.

Once the EPA has accepted a proposal, cooperative arrangements are established among EPA, the developer, and the stakeholders. Developers are responsible for operating their innovative systems at a selected site, and are expected to pay the costs to transport equipment to the site, operate the equipment on-site during the demonstration, and remove the equipment from the site. EPA is responsible for project planning, sampling and analysis, quality assurance and quality control, preparing reports, and disseminating information. Usually, results of Demonstration Programs are published in three documents: the SITE Demonstration Bulletin, the Technology Capsule, and the Innovative Technology Evaluation Report (ITER). The Bulletin describes the technology and provides preliminary results of the field demonstration. The Technology Capsule provides more detailed information about the technology, and emphasizes key results of the SITE field demonstration.

The ITER provides detailed information on the technology investigated, a categorical cost estimate, and all pertinent results of the SITE field demonstration. An additional report, the Technology Evaluation Report (TER), is available by request only. The TER contains a comprehensive presentation of the data collected during the demonstration and provides a detailed quality assurance review of the data.

For the EcoMat Inc. Biological Denitrification process demonstration, there is a SITE Technology Bulletin, Capsule, and ITER; all of which are intended for use by remedial managers for making a detailed evaluation of the technology for a specific site and waste. A TER is also submitted for this demonstration to serve as verification documentation.

1.4 Purpose of the Innovative Technology Evaluation Report (ITER)

This ITER provides information on both 1) EcoMat Inc.'s Biological Denitrification process for treatment of nitrate in water and on 2) the post-treatment system for treatment of organics (e.g., VOCs, methanol), solids and microbes in water. This report includes a comprehensive description of this demonstration and its results. The ITER is intended for use by EPA remedial project managers, EPA on-scene coordinators (OSCs), contractors, and other decision-makers carrying out specific remedial actions. The ITER is designed to aid decision-makers in evaluating specific technologies for further consideration as applicable options in a particular cleanup operation. This report represents a critical step in the development and commercialization of a treatment technology.

To encourage the general use of demonstrated technologies, the EPA provides information regarding the applicability of each technology to specific sites and wastes. The ITER includes information on cost and desirable site-specific characteristics. It also discusses advantages, disadvantages, and limitations of the technology.

Each SITE demonstration evaluates the performance of a technology in treating a specific waste matrix. The characteristics of other wastes and other sites may differ from the characteristics of the treated waste. Therefore, a successful field demonstration of a technology at one site does not necessarily ensure that it will be applicable at other sites. Data from the field demonstration may require extrapolation for estimating the operating ranges in which the technology will perform satisfactorily. Only limited conclusions can be drawn from a single field demonstration.

1.5 Technology Description

Fixed film bioremediation using a biocarrier is the treatment of contaminated groundwater using bacteria appropriate to the contaminants of concern attached to some form of supporting substrate. Using EcoMat's patented mixed reactor, the biocarrier is designed to be retained in the system, thereby minimizing solids carryover. In the case of the Bendena water well, elevated nitrate in the groundwater is the primary problem; low concentrations of volatile organic compounds (VOCs) (particularly CCl_4) are a secondary problem. Fixed film treatment allows rapid and compact treatment of nitrate with minimal byproducts. Methanol is added as a source of carbon for the metabolic processes and cell growth of the bacteria that convert the nitrate to nitrogen gas.

The mechanism for anoxic biodegradation of nitrate consists of initial removal of excess oxygen followed by two sequential reactions as shown in the following equations.

Oxygen Removal:

$$CH_3OH + 1.5O_2 \text{ -------> } CO_2 + 2H_2O \qquad (1)$$

Denitrification Step 1:

$$CH_3OH + 3NO_3^- \text{ -------> } 3NO_2^- + CO_2 + 2H_2O \qquad (2)$$

Denitrification Step 2:

$$CH_3OH + 2NO_2^- \text{ -------> } N_2 + CO_2 + 2OH^- + H_2O \qquad (3)$$

Overall Denitrification Reaction:

$$5CH_3OH + 6NO_3 \text{ -------> } 3N_2 + 5CO_2 + 6OH^- + 7H_2O \qquad (4)$$

Note: The subsequent discussion refers to nitrate- and nitrite-nitrogen values (nitrate-N and nitrite-N, respectively), in which each mg/l of nitrate-N is equivalent to 4.4 mg/l of nitrate and each mg/l of nitrite-N is equivalent to 3.2 mg/l of nitrite.

Available oxygen must first be consumed to a dissolved oxygen concentration of < 1 mg/l so that the bacteria are forced to substitute the nitrate as the electron acceptor (Equation 1). The nitrate is then reduced to nitrite (Equation 2). In Equation 3, the nitrite is further reduced to nitrogen gas. The overall denitrification reaction is presented in Equation 4.

Nitrite production is an intermediate step and there is no *a priori* reason to assume that the second reaction is at least as fast and/or favored as the first reaction in the presence of a specific bacterial population. Consequently, any evaluation scheme must establish that there is no buildup of nitrite, particularly since the nitrite-nitrogen MCL is 1 mg/l, one-tenth that of nitrate. High concentrations of nitrate and high nitrate/methanol ratios may also affect the concentration of residual nitrite.

The effluent from the denitrification system will contain small amounts of bacteria and suspended solids which must be removed by a post-treatment system, and also may contain some concentration of nitrite. EcoMat can incorporate an oxidation component (ozonation and/or ultraviolet (UV) disinfection) into its post-treatment system to accomplish some degree of chlorinated hydrocarbon destruction as well as oxidation of remaining nitrite back to nitrate, oxidation of any residual methanol, and destruction of bacterial matter. A filtration component can also be incorporated into the post-treatment system to remove suspended solids. Although ozonation and UV oxidation may also result in disinfection of treated water, additional chlorination would also be required before the treated water could be used as a drinking water supply in Kansas.

Although this demonstration is being carried out on drinking water, anoxic BDN using a biocarrier should be applicable to industrial waste waters as well as leachate from commercial, industrial, and hazardous waste sites containing various levels of nitrate. The presence of other contaminants could play a significant role in the effectiveness and viability of the overall treatment system. The post treatment system components selected for the Bendena site were intended to produce final effluent that met drinking water standards for nitrate and nitrite and to also provide some removal of methanol. If the planned ozonation system proved to be inadequate for VOC removal, EcoMat had planned to reactivate an inactive air stripper at the site. With more complex waste waters, the post-treatment system may play a larger role in the overall effectiveness of the total system.

Design of the treatment process/system for a particular site requires the characterization of the contaminant types, concentrations, and variability in the water source that will become the feed to the system. This information is used to properly size the BDN unit and the post-treatment system. For the Bendena site, it was also necessary to assure that discharge of the treated water to a septic system did not unintentionally recharge the aquifer in such a way as to significantly alter (decrease) the nitrate (or chlorinated hydrocarbon) content of the aquifer feeding PWS Well #1.

1.6 Key Contacts

Additional information regarding EcoMat Inc.'s Biological Denitrification process, the company's other treatment processes, and the SITE Program can be obtained from the following sources:

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The SITE Program

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Information on the SITE Program is available through the following on-line information clearinghouses:

- The SITE Home page (**www.epa.gov/ORD/SITE**) provides general program information, current project status, technology documents, and access to other remediation home pages.
- The OSWER CLU-In electronic bulletin board (**http://www.clu-in.org**) contains information on the status of SITE technology demonstrations. The system operator can be reached at (301) 585-8368.

Technical reports may be obtained by writing to USEPA/NSCEP, P.O. Box 42419, Cincinnati, OH 45242-2419, or by calling 800-490-9198.

Section 2.0
Technology Applications Analysis

This section addresses the general applicability of the EcoMat Inc. BDN Technology to sites containing groundwater contaminated with nitrate. The analysis is based on results from and observations made during the SITE Program demonstration and from additional information received from EcoMat Inc. SITE demonstration results are presented in Section 4 of this report. The vendor had the opportunity to discuss the applicability, other studies and performance of the technology in **Appendix A**.

2.1 Key Features of the BDN and Post-Treatment Processes

The EcoMat Inc. BDN Technology is designed to quickly and effectively treat nitrate-contaminated groundwater while generating minimal byproducts. This system is appropriate for treating potential drinking water supplies and may also be effective in treating industrial wastewater or leachate from commercial, industrial, and hazardous waste sites. The system may be most suitable for treating water supplies in agricultural regions that are subject to increased nitrate concentrations due to seasonal fertilizer application. The system can also treat inorganic pollutants, other than nitrate, through cultivation of different types of microbes.

The EcoMat Inc. BDN Technology is a fixed-film bioremendiation process using a biocarrier and bacteria appropriate to the contaminant of concern. In the case of the Bendena water well, the contaminant of concern is nitrate. EcoMat's patented mixed reactor retains the biocarrier in the system, thereby minimizing solids carryover. In addition, the fixed film treatment allows rapid and compact treatment of nitrate with minimal byproducts. Overall, the denitrification process is intended to convert nitrates in the groundwater to nitrogen gas. In addition to demonstrating EcoMat's BDN Technology, the project also included demonstration of a post-treatment system designed to destroy or remove any intermediate compounds potentially generated during the biological breakdown of the nitrate (e.g., nitrite), and also remove small amounts of bacteria and suspended solids that are not attached to the biocarrier. Treatment of VOCs present in the influent can also be accomplished by the post-treatment system by incorporating traditional treatment methods, such as ozonation and air stripping.

The denitrification process is accomplished in two reactors. Reactor 1 (R1), referred to as the "De-oxygenating Tank," includes bioballs loaded with denitrifying bacteria. These bacteria are fed a 50 percent aqueous methanol solution to act as a carbon source for the metabolic processes that remove free oxygen and to act as a carbon source for cell growth. The second reactor (R2), which receives the de-oxygenated water from Reactor 1, is packed with 1-cubic centimeter (cm^3) cubes of a synthetic sponge-like polyurethane biocarrier called "EcoLink." The Ecolink medium hosts the colonies of bacteria cultured for degrading nitrate. An important feature to this medium is that small contiguous holes are incorporated into the medium to maximize surface area for the active bacteria colony and to permit the exit of the nitrogen gas formed during the denitrification process.

Reactor 2 also includes a specially designed mixing apparatus to direct the incoming de-oxygenated water into a circular motion, thus keeping the media in constant circulation and maximizing contact between the water and media. Methanol is also fed to this reactor to encourage nitrate consumption and to act as a carbon source for the anaerobic bacteria degrading the nitrate to nitrogen gas. The effluent from R2 received additional treatment, referred to here as post-treatment. During the course of the demonstration, four different combinations of post-treatment were incorporated into the overall treatment system. Each of the four systems utilized during the demonstration incorporated one or more oxidation components, such as chlorination, ultraviolet (UV) light, or ozonation. In addition to destroying any active bacteria exiting the BDN system, the oxidation component was designed to oxidize: 1) residual nitrite back to nitrate 2) residual methanol, and 3) VOCs in the water (e.g., CCl_4).

During the majority of the demonstration, the post-treatment system also incorporated a filtration component designed to remove suspended solids generated from the BDN process. In addition to using a clarifying tank, a variety of filter combinations were used, including a sand filter, a carbon filter, and different sized cartridge filters (i.e., rough, high efficiency, and polishing filters).

The developer believes that the denitrification technology is capable of effectively converting nitrate and methanol to nitrogen gas and carbon dioxide. This aspect was of primary interest for this demonstration. The developer also claims that the post-treatment or polishing step can 1) oxidize any residual nitrite to nitrate, 2) oxidize residual methanol, 3) destroy bacterial matter exiting the EcoMat reactor, and 4) remove suspended solids. No claim was made concerning the removal of VOC's.

2.2 Operability of the Technology

The prime factor in determining the effectiveness of the EcoMat Inc. BDN Technology is the growth of a healthy population of naturally-occurring anoxic bacteria (denitrifiers) to reduce nitrate to nitrogen gas and carbon dioxide in the presence of methanol. The growth of these denitrifiers is dependant upon a number of factors including nitrate-N concentration, pH, temperature, and carbon concentration. In addition, continuous operation with minimal process disruptions, including shutdowns, is critical to maintaining a healthy microbial population. Overall, the EcoMat technology is designed to provide optimum conditions for growing and sustaining an active bacteria colony.

The EcoMat technology is an ex situ process consisting of a BDN and a post-treatment system. The BDN system includes two reactors in series, followed by an overflow tank. Each reactor is two cubic meters in size with a water capacity of approximately 1,100 gallons. The first reactor (R1), referred to as the "Deoxygenating Tank" is equipped with ports for both the tank's influent and effluent, and a methanol feed. The second reactor (R2), referred to as the "EcoMat Reactor," is also equipped with ports for the influent, effluent. and methanol feed. The final component of the BDN system is a small overflow tank capable of holding approximately 200 gallons.

Prior to system start-up, a shakedown period is required to begin BDN by developing the necessary biological growth on the "biocarrier" in the bioreactor chamber under full recycle. The shakedown period normally takes approximately six weeks. This 6-week period gives the system operators an opportunity to adjust water flow and methanol feed rates based on observed nitrate and nitrite concentrations and other factors.

Since each of the reactors maintains large populations of sensitive microbes, continuous operation of the system is critical. The growth of denitrifying bacteria on the biocarrier in the Deoxygenating Tank is dependent upon achieving both a relatively low dissolved oxygen concentration (e.g., ~1 mg/l) and an environment rich in carbon. As a result, methanol is routinely fed to the De-oxygenating Tank to act as the source of carbon. To ensure that a healthy population of denitrifiers is maintained, routine monitoring of the methanol concentration is performed.

The Deoxygenating Tank requires little attention and maintenance. The groundwater simply enters the top of the reactor, flows through the bioballs and exits the bottom of the reactor. Level switches near the top of the tank control flow into the tank; these do require routine service.

Continuous operation of the EcoMat Reactor is also critical. Specialized bacteria for degrading nitrate are cultured in this reactor. Since an anaerobic environment is necessary to accomplish denitrification, dissolved oxygen levels are routinely monitored to ensure a concentration of less than 1.0 mg/l.

The EcoMat Reactor is equipped with a patented mixer that is designed to circulate the water within the reactor without the aid of moving parts. This reactor contains EcoLink media which also are circulated by the mixing apparatus. Like the de-oxygenating tank, the EcoMat Reactor also requires minimal operational attention and maintenance. The most common maintenance activity would be periodic replacement of the EcoLink biocarrier, which occasionally becomes overloaded and falls out of suspension.

Specific to the demonstration, delivery of the groundwater to the treatment system was accomplished by a submersible pump installed within PWS Well #1. The submersible pump was originally controlled by a float switch in Reactor #1. To prevent potential burn-out of the submersible pump, the float switch was replaced first with a pressure switch and finally with a "flapper." The line delivering the groundwater to the treatment system was equipped with a totalizer to monitor flow rate. Totalizers were also installed at the treatment system discharge point and on the recycle line for the SITE evaluation.

The post-treatment system included different treatment components during each of the four demonstration events. The four post-treatment scenarios are presented below.

Event 1 -	Chlorination
Event 2 -	Clarification, Sand & Rough (20μm) Filtration, and UV Oxidation
Event 3 -	Ozone, UV Oxidation, Clarification, Rough (20μm) & High Efficiency

(5µm) Filtration, Carbon Adsorption, & Polishing (1µm) Filtration

Event 4 - Chlorination, Clarification, High Efficiency (5µm filter) Filtration, Air Stripping, and Polishing (20µm) Filtration

Each component used in the post-treatment system was purchased "off the shelf" from equipment suppliers. Operation of the equipment was learned in the field during the demonstration period and appropriate adjustments to feed and flow rates were made to maximize the effectiveness of treatment. General maintenance of the post-treatment system during the demonstration included flushing out the entire post-treatment system, back washing of the sand filter, drainage of the clarifier, and replacement of the cartridge filters.

Both the BDN and post-treatment systems were installed inside a storage building that was twelve feet wide, twenty feet long, and twelve feet high. The shed was equipped with 1) electricity to operate pumps and provide heat, 2) a potable water supply for cleanup and decontamination activities, and 3) a telephone and facsimile machine hookup. The shed also provided sufficient work space and room for storage of equipment and reagents.

The process, including both the BDN and the post-treatment system, was designed to operate unattended; however, during the four sampling events seven system shutdown periods required the presence of on-site personnel to address the operational problems and bring the system back online. Shutdowns were caused by a combination of mechanical problems and electrical storms causing power outages. Numerous shutdowns during sampling Event 2 resulted in a decision to abort the event and restart when mechanical problems were corrected. It should be noted that additional shakedown periods were required after some of the shutdowns to reestablish microbial populations in the reactors.

2.3 Applicable Wastes

The EcoMat BDN technology is an ex situ fixed- film BDN system designed to destroy or remove nitrates in water. In addition to using the technology on a potential drinking water source during this demonstration, the technology should be applicable to industrial wastewaters and leachate from commercial, industrial, and hazardous waste sites containing elevated nitrate concentrations.

During the demonstration, a post-treatment system designed to remove chlorinated hydrocarbons from water was also evaluated. The developer also claims that the technology is suitable for treating other types of inorganic pollutants since the EcoMat reactor can effectively cultivate microbes that can degrade different contaminants.

An EcoMat biological reactor is currently being used at a Department of Defense facility in Southern California to treat perchlorate. Also, there are EcoMat systems installed at aquariums for removing nitrate from saltwater.

2.4 Availability and Transportability of Equipment

The EcoMat Biological Denitrification and Post-Treatment Process requires a level pad, ideally concrete, and a heated building. The size of the pad and building is dependent on the size of the process installed at a particular site. EcoMat has indicated that it is feasible to install a treatment system outside, which may be necessary for very large systems. In such instances, heat tracing would be installed to provide temperature control.

At the Bendena site, the process consisted of a Deoxygenating Tank, the EcoMat Reactor, an overflow tank, and the post-treatment system (ozone unit, UV treatment, clarifier, sand filter, cartridge filters, air stripper, and carbon filters). This entire process (except for the existing air stripper) and necessary support equipment fit inside a shed that was twelve feet wide, twenty feet long, and twelve feet high. Since this system is designed to be unattended, a trailer or additional office space in the building housing the process should not be necessary.

Equipment and supplies associated with the process were transported to the site by one truck. Each two cubic meter (m^3) reactor tank was delivered to the site in halves to permit for easy handling and assembly. The remainder of the treatment units and associated equipment can be handled and installed by one person.

Depending on well availability at sites intending to use this technology, a drill rig with associated drilling equipment might be necessary. Fortunately, during this demonstration a former railroad well constructed in the early 1900's served as the source for the nitrate-contaminated groundwater. The total well depth is 73.4 feet below ground surface (bgs) and the static water level is approximately 45 bgs; the inside well diameter is approximately 23 feet.

During the demonstration the EcoMat BDN and Post-Treatment systems required periodic maintenance of a number of process units and replacement was necessary for a number of units. Some of the equipment changes necessary during system operation included new pressure switches for controlling tank levels, new PVC piping and hoses to rectify leaks, and new filters to prevent filter microbial buildup. All replacement equipment was either purchased locally or delivered to the site via courier.

Treated water from the system was discharged to a 1,000 gallon septic system specifically purchased and installed for the demonstration. Heavy equipment such as a backhoe may be required for septic system installation.

If the application for septic system installation had been denied due to reasons such as a percolation, slope, depth to groundwater, etc., other discharge options would have been investigated. During this demonstration numerous options were available including discharge to 1) a down slope drainage network, 2) a return line back to the PWS Well #1, or 3) the ground up gradient of PWS Well #1. Ultimately, the intent of this system is to treat the water to meet drinking water standards. Therefore, in an actual installation treated water would be routed directly into the distribution system for delivery to customers in the community. Therefore, the availability and transportability of equipment related to delivery of water into a specific distribution system would need to be investigated.

2.5 Materials Handling Requirements

The major materials handling requirement for the EcoMat BDN and Post-Treatment systems was installation of the individual process units which make-up the treatment system. The KDHE provided a shed and a pumped line from PWS Well #1 to the shed. The shed included all necessary services such as potable water, electricity, heat and a phone line.

The entire system was delivered to the site on one truck. Installation of the system required the support of one person over a period of approximately one week. All process units and associated equipment are small and light enough to permit this one person to unload and install the equipment.

Prior to beginning the demonstration, a variety of activities were necessary to prepare the BDN and Post-Treatment systems for start-up, including a shake down of the equipment. The materials handling requirements for bringing water from the well were minimal since a pumping and groundwater delivery system had already been installed within the PWS well.

The shakedown period simply involved developing the necessary biological growth on the “biocarrier” in the bioreactor chamber. With the exception of more frequent sampling and adjustments to water flow and methanol feed rates, the activities performed during the shakedown period were no different from those that would be performed during routine operation of the system under normal conditions.

If the BDN and Post-Treatment systems are utilized to treat groundwater, installation of one or more wells may be necessary. Drilling services are generally subcontracted to a company which has both the required equipment (drill rigs, augers, samplers) and personnel trained in drilling operations and well construction. If work is to be performed on a hazardous waste site, drilling personnel must have the OSHA-required 40-hour health and safety training. Once the well(s) are drilled each must be equipped with a pump to deliver the groundwater to the treatment system. An equalization tank may be necessary to store the feed water rather than pumping directly to the system. All pumps chosen must be able to perform under a variety of conditions.

Depending on the characteristics of the source water, installation of a pretreatment system may be required. Parameters in the source water that may cause inhibition of the BDN system include pH, dissolved oxygen, temperature, and heavy metals.

The BDN system does not generate any hazardous residuals; however, extremely small quantities of non-hazardous residuals are generated by various units in the post-treatment system. Sludge is generated by the clarifying tank and the cartridge filters periodically become clogged and need to be flushed or replaced. Residuals generated during the demonstration included spent filter cartridges and biocarrier media; these were placed in plastic trash bags and discarded in an on-site dumpster.

2.6 Range of Suitable Site Characteristics

Locations suitable for on-site treatment using the EcoMat Denitrification and Post-Treatment System must be able to provide relatively uninterrupted electrical power and potable water for cleanup activities. Electrical power was required for a control panel equipped with high level alarms and reset buttons, and for operation of several electrically driven pumps throughout the system, including a submersible pump to draw water from the well. Power was also required to provide heat to the shed via an electrical heater. Heat was necessary to maintain a minimum water temperature of 60°F in the treatment system and to protect equipment and personnel during cold temperatures. Overall, the EcoMat Biological Denitrification System requires a 115-volt, 3-phase electrical service. During the four demonstration sampling events the average and maximum energy usage for the overall system were 8.2 kW-hr and 12.6 kW-hr, respectively.

There were minimal storage space requirements for process chemicals. Process chemicals required for the demonstration included 50% methanol aqueous solution and a liquid chlorine solution. The methanol solution was stored in a 100-gallon plastic tank near the de-oxygenating and EcoMat reactors. The chlorine solution was stored in a 5-gallon pail beside the post- treatment system. Any reagents required for system monitoring (e.g., Nitrate-N, Nitrite-N, DO, pH, etc.) were stored in small Styrofoam shipping containers on shelving inside the shed. All process residuals (spent filters and biocarriers, clarifier sludge) were placed in plastic trash bags and stored in the shed until final disposal as domestic trash.

2.7 Limitations of the Technology

The EcoMat BDN technology is a treatment system designed to remove excess nitrate and, with appropriate post-treatment may also remove chlorinated hydrocarbons (e.g., CCl_4), methanol, and microorganisms. The maximum removal of nitrates was achieved during the demonstration when the flow through the system was in the 3.0 - 5.0 gpm range. At this flow rate it is obvious that the system would not be appropriate for supplying large residential communities with adequate supplies of treated water. The system may be more applicable to reducing or eliminating nitrate in small community water supplies, in industrial wastewaters, or in the leachate from commercial, industrial, or hazardous waste sites.

The growth of healthy microbial populations within each of the system's reactors is the key factor in determining the effectiveness of the technology. The growth of these organisms is dependant upon factors such as a sufficient source of carbon, a continuous low dissolved oxygen concentration (< 1.0 mg/l), an acceptable steady pH and temperature range, and intimate contact between the biocarrier and contaminated water. Also, like most biological systems, the system can be inhibited by toxics (e.g., heavy metals) in the source water. Many of these factors are dependent upon a system that has minimal operational/mechanical problems and system shutdowns.

During the course of the demonstration project, the EcoMat Biological Denitrification System, which is designed to operate unattended, had numerous operational/mechanical problems that required immediate attention from on-site demonstration staff. System shutdowns occurred on approximately seven occasions; two of which occurred due to electrical storms and five occurring from system mechanical problems. A number of other operational problems occurred, impacting effluent quality but not causing system shutdown.

The majority of operational/mechanical problems encountered during the demonstration were remedied quickly; normally within minutes to a couple hours of learning of the problem. However, during the second sampling event, a faulty compressor switch in the de-oxygenating tank caused a chain-reaction of other problems downstream of the tank, thereby forcing the demonstration team to abort the event.

It should be noted that the SITE team was not present during periods between the four events to monitor system perturbations (if they occurred). System shutdowns occurring during demonstration events that were not caused by an electrical storm are summarized below:

- Just prior to starting Event 2 (in July 1999) compressor switches in the de-oxygenating tank failed to monitor the water level in the tank. This prevented the switch from controlling the submersible pump delivering water from the well to the system. The malfunctioning switches were replaced with a "flapper" to control flow to the tank. This delayed the start of Event 2.
- Replacement of the compressor switch in the de-oxygenating tank required system shutdown and drainage of the tank. This maintenance activity caused the biocarrier to settle in the EcoMat reactor and clog the lower perforated screen used to separate the biocarrier mixing zone from the lower portion of the reactor. EcoMat drained the water level in the tank to allow pressure washing of the screen. The draining disrupted the microbe colonies and further delayed the start of Event 2.
- Activation of the high level alarm occurred on four separate occasions while no high levels were observed. The high level alarm shuts off the pump routing water to the EcoMat reactor. The shutdowns occurred twice during the aborted Event 2 in early July 1999, and twice again during Event 3 in October 1999.
- Towards the end of Event 3, a high level alarm was activated and the system was shut down due to excessive biological growth occurring on one of the post-treatment system filters. The filters were bypassed to complete the sampling event.

As stated earlier, other problems encountered during the demonstration affected the concentrations of parameters that are critical to treatment effectiveness and compliance with federal drinking water standards. These problems are summarized below.

- During Event 4 EcoMat discovered air entering the de-oxygenating reactor via the reactor feed pump. This increased the dissolved oxygen concentration in the reactor and disrupted the anoxic environment inhabited by the denitrifiers. EcoMat switched pumps to mitigate the problem.
- An ozone leak was found in the post-treatment system at the start of Event 3. This leak reduced the system's ability to oxidize residual nitrite to nitrate, oxidize residual methanol, and destroy bacteria. EcoMat replaced a leaking hose soon after the leak was discovered via gas detector tube monitoring.
- The pump feeding methanol either malfunctioned or was inadvertently turned off during Event 4. With no methanol being fed into the system, there was no carbon source for bacterial cell growth and nitrate consumption was reduced.

- Significant solids carryover from the BDN system to the post-treatment system caused unexpected frequent maintenance on the filters and clarifier. This occurred routinely during Event 2, when filters were first incorporated into the post-treatment system. Maintenance activities included replacing filters, back washing filters, and draining the clarifier. Also, large concentrations of heterotrophic bacteria and high turbidity readings in the system's final effluent made the water unacceptable for drinking purposes.
- High methanol concentrations (range: 14.6 - 98 mg/l) in the final effluent also made this water unacceptable for drinking purposes. These high methanol concentrations were caused by excessive feed rates, or by the failure of the post-treatment systems to oxidize residual methanol.

2.8 ARARS for the EcoMat BDN Technology

This subsection discusses specific federal environmental regulations pertinent to the operation of the EcoMat Biological Denitrification and Post-Treatment processes including the transport, treatment, storage, and disposal of wastes and treatment residuals. These regulations are reviewed with respect to the demonstration results. State and local regulatory requirements, which may be more stringent, must also be addressed by remedial managers. Applicable or relevant and appropriate requirements (ARARs) include the following: (1) the Comprehensive Environmental Response, Compensation, and Liability Act; (2) the Resource Conservation and Recovery Act; (3) the Clean Air Act; (4) the Clean Water Act; (5) the Safe Drinking Water Act, and (6) the Occupational Safety and Health Administration regulations. These six general ARARs are discussed below; specific ARARs that may be applicable to the EcoMat BDN and Post-Treatment Process are identified in **Table 2-1**.

2.8.1 *Comprehensive Environmental Response, Compensation, and Liability Act (CERCLA)*

The CERCLA of 1980 as amended by the Superfund Amendments and Reauthorization Act (SARA) of 1986 provides for federal funding to respond to releases or potential releases of any hazardous substance into the environment, as well as to releases of pollutants or contaminants that may present an imminent or significant danger to public health and welfare or to the environment. As part of the requirements of CERCLA, the EPA has prepared the National Oil and Hazardous Substances Pollution Contingency Plan (NCP) for hazardous substance response. The NCP is codified in Title 40 Code of Federal Regulations (CFR) Part 300, and delineates the methods and criteria used to determine the appropriate extent of removal and cleanup for hazardous waste contamination.

SARA states a strong statutory preference for remedies that are highly reliable and provide long-term protection. It directs EPA to do the following:

- use remedial alternatives that permanently and significantly reduce the volume, toxicity, or the mobility of hazardous substances, pollutants, or contaminants;
- select remedial actions that protect human health and the environment, are cost-effective, and involve permanent solutions and alternative treatment or resource recovery technologies to the maximum extent possible; and
- avoid off-site transport and disposal of untreated hazardous substances or contaminated materials when practicable treatment technologies exist [Section 121(b)].

In general, two types of responses are possible under CERCLA: removal and remedial action. Superfund removal actions are conducted in response to an immediate threat caused by a release of a hazardous substance. Many removals involve small quantities of waste of immediate threat requiring quick action to alleviate the hazard. Remedial actions are governed by the SARA amendments to CERCLA. As stated above, these amendments promote remedies that permanently reduce the volume, toxicity, and mobility of hazardous substances or pollutants. The EcoMat BDN and post-treatment systems are likely to be part of a CERCLA remedial action since the toxicity of the contaminants of concern is reduced by either denitrification or oxidation. Remedial actions are governed by the SARA amendments to CERCLA. On-site remedial actions must comply with federal and more stringent state ARARs. ARARs are determined on a site-by-site basis and may be waived under six conditions: (1) the action is an interim measure, and the ARAR will be met at completion; (2) compliance with the ARAR would pose a greater risk to health and the environment than noncompliance; (3) it is technically impracticable to meet the ARAR; (4) the standard of performance of an ARAR can be met by an equivalent method; (5) a state ARAR has not been consistently applied elsewhere; and (6) ARAR compliance would not provide a balance between the protection achieved at a particular site and demands on the Superfund RPM for other sites. These waiver options apply only to Superfund actions taken on-site, and justification for the waiver must be clearly demonstrated.

Table 2-1. Federal and State ARARs for the EcoMat BDN Process.

Process Activity	ARAR	Description	Basis	Response
Characterization of untreated waste	RCRA: 40 CFR Part 261 (or state equivalent)	Standards that apply to identification and characterization of wastes.	Chemical and physical properties of waste determine its suitability for treatment by the EcoMat BDN Process.	Chemical and physical analyses must be performed to determine if waste is a hazardous waste.
Waste Processing	RCRA: 40 CFR Part 264 (or state equivalent)	Standards apply to treatment of wastes in a treatment facility.	Applicable or appropriate for the EcoMat BDN Process.	When hazardous wastes are treated, there are requirements for operations, record keeping, and contingency planning.
	CAA: 40 CFR Part 50 (or state equivalent)	Regulations govern toxic pollutants, visible emissions and particulate matter.	During process operations, any off-gases (i.e., from ozonation, air stripping, etc.) must not exceed limits set for the air district of operation. Standards for monitoring and record keeping apply.	Off-gases may contain volatile organic compounds or other regulated substances; although, levels are likely to be very low.
Storage of auxiliary wastes	RCRA: 40 CFR Part 264 Sub-part J (or state equivalent)	Regulation governs standards for tanks at treatment facilities.	Storage tanks for liquid wastes (e.g., decontamination waste) must be placarded appropriately, have secondary containment and be inspected daily.	If storing non-RCRA wastes, RCRA requirements may still be relevant and appropriate.
	RCRA: 40 CFR Part 264 Subpart I (or state equivalent)	Regulation covers storage of waste materials generated.	Potential hazardous wastes remaining after treatment (i.e., spent biocarrier, etc.) must be labeled as hazardous waste and stored in containers in good condition. Containers should be stored in a designated storage area and storage should not exceed 90 days unless a storage permit is obtained.	Applicable for RCRA wastes; relevant and appropriate for non-RCRA wastes.
Determination of cleanup standards	SARA: Section 121(d)(2)(ii); SDWA: 40 CFR Part 141	Standards that apply to surface & groundwater sources that may be used as drinking water.	Applicable and appropriate for the EcoMat BDN Process used in projects treating groundwater for use as drinking water.	Remedial actions of surface and groundwater are required to meet MCLGs or MCLs established under SDWA.
Waste disposal	RCRA: 40 CFR Part 262	Standards that pertain to generators of hazardous waste.	Waste generated by the EcoMat process which may be hazardous is limited to spent carbon, well purge water, spent media or biocarriers, clarification/filtration residual wastes, and decontamination wastes.	Generators must dispose of wastes at facilities that are permitted to handle the waste. Generators must obtain an EPA ID number prior to waste disposal.
	CWA: 40 CFR Parts 403 and/or 122 and 125	Standards for discharge of wastewater to a POTW or to a navigable waterway.	Applicable and appropriate for well purge water and decontamination wastewater generated from process.	Discharge of wastewater to a POTW must meet pre-treatment standards; discharges to a navigable waterway must be permitted under NPDES.

2.8.2 *Resource Conservation and Recovery Act (RCRA)*

RCRA, an amendment to the Solid Waste Disposal Act (SWDA), is the primary federal legislation governing hazardous waste activities. It was passed in 1976 to address the problem of how to safely dispose of the enormous volume of municipal and industrial solid waste generated annually. Subtitle C of RCRA contains requirements for generation, transport, treatment, storage, and disposal of hazardous waste, most of which are also applicable to CERCLA activities. The Hazardous and Solid Waste Amendments (HSWA) of 1984 greatly expanded the scope and requirements of RCRA. RCRA regulations define hazardous wastes and regulate their transport, treatment, storage, and disposal. These regulations are only applicable to the EcoMat Biological Denitrification and Post-Treatment processes if RCRA defined hazardous wastes are present.

Hazardous wastes that may be present include the aqueous waste to be treated, spent media or biocarriers from each of the reactors, and the residual wastes generated from any process included in the post-treatment system, such as clarification and filtration. If wastes are determined to be hazardous according to RCRA (either because of a characteristic or a listing carried by the waste), essentially all RCRA requirements regarding the management and disposal of this hazardous waste will need to be addressed by the remedial managers. Wastes defined as hazardous under RCRA include characteristic and listed wastes.

Criteria for identifying characteristic hazardous wastes are included in 40 CFR Part 261 Subpart C. Listed wastes from specific and nonspecific industrial sources, off-specification products, spill cleanups, and other industrial sources are itemized in 40 CFR Part 261 Subpart D. RCRA regulations do not apply to sites where RCRA-defined wastes are not present.

Unless they are specifically delisted through delisting procedures, hazardous wastes listed in 40 CFR Part 261 Subpart D currently remain listed wastes regardless of the treatment they may undergo and regardless of the final contamination levels in the resulting effluent streams and residues. This implies that even after remediation, treated wastes are still classified as hazardous wastes because the pre-treatment material was a listed waste.

For generation of any hazardous waste, the site responsible party must obtain an EPA identification number. Other applicable RCRA requirements may include a Uniform Hazardous Waste Manifest (if the waste is transported off-site), restrictions on placing the waste in land disposal units, time limits on accumulating waste, and permits for storing the waste.

Requirements for corrective action at RCRA-regulated facilities are provided in 40 CFR Part 264, Subpart F (promulgated) and Subpart S. These subparts also generally apply to remediation at Superfund sites. Subparts F and S include requirements for initiating and conducting RCRA corrective action, remediating groundwater, and ensuring that corrective actions comply with other environmental regulations. Subpart S also details conditions under which particular RCRA requirements may be waived for temporary treatment units operating at corrective action sites and provides information regarding requirements for modifying permits to adequately describe the subject treatment unit.

2.8.3 *Clean Air Act (CAA)*

The CAA establishes national primary and secondary ambient air quality standards for sulfur oxides, particulate matter, carbon monoxide, ozone, nitrogen dioxide, and lead. It also limits the emission of 189 listed hazardous pollutants such as vinyl chloride, arsenic, asbestos and benzene. States are responsible for enforcing the CAA. To assist in this, Air Quality Control Regions (AQCR) were established. Allowable emission limits are determined by the AQCR, or its sub-unit, the Air Quality Management District (AQMD). These emission limits are based on whether or not the region is currently within attainment for National Ambient Air Quality Standards (NAAQS).

The CAA requires that treatment, storage, and disposal facilities comply with primary and secondary ambient air quality standards. Emissions from post-treatment systems associated with EcoMat's Biological BDN may need to meet current air quality standards. For example, the ozonation system may be regulated by state or local agencies. Also, State air quality standards may require additional measures to prevent emissions, including requirements to obtain permits to install and operate processes (e.g., air strippers for control of VOCs).

2.8.4 *Clean Water Act (CWA)*

The objective of the Clean Water Act is to restore and maintain the chemical, physical and biological integrity of the nation's waters by establishing federal, state, and local discharge standards. If treated water is discharged to surface water bodies or Publicly Owned Treatment Works (POTW), CWA regulations will apply. A facility desiring to discharge water to a navigable waterway must apply for a permit under the National Pollutant Discharge Elimination System (NPDES). When a NPDES permit is issued, it includes waste discharge requirements. Discharges to POTWs also must comply with general pretreatment regulations outlined in 40 CFR Part 403, as well as other applicable state and local administrative and substantive requirements.

The demonstration did have a variety of available options for disposal of the water. These options included discharge 1) to a 1000 gallon septic system, 2) to a nearby down gradient drainage network, 3) back down PWS Well #, and 4) into the ground down gradient of PWS Well #1. After careful review, option #1 was selected as the most viable.

Treated effluent from the SITE demonstration was discharged to an on-site 1000 gallon septic system at a rate of approximately 7,200 gallons per day. Permission for septic system installation and discharge to the system was required by Doniphan County, KS. The county required the completion of a Sewage Facility Application/Permit. Approval for discharge to the septic system was granted by the KDHE.

The only listed option that would have been regulated under the CWA and required a NPDES permit would have been discharge to a nearby down gradient drainage network. It should be noted that depending on the levels of contaminants and permit limitations, additional treatment may be required prior to discharge.

2.8.5 *Safe Drinking Water Act (SDWA)*

The SDWA of 1974, as most recently amended by the Safe Drinking Water Amendments of 1986, requires the EPA to establish regulations to protect human health from contaminants in drinking water. The legislation authorized national drinking water standards and a joint federal-state system for ensuring compliance with these standards.

The National Primary Drinking Water Standards (NPDWS) are found in 40 CFR Parts 141 through 149. Parts 144 and 145 discuss requirements associated with the underground injection of contaminated water. If underground injection of wastewater is selected as a disposal means, approval from EPA or the delegated state for constructing and operating a new underground injection well is required.

Since the actual intent of the EcoMat BDN Process is to render the water as drinkable (i.e., reducing nitrate-N and nitrite-N to below their respective MCLs of 10 and 1 mg/l), in most cases treated effluent would be discharged directly into the community water system. For example, the treated effluent could be routed to 1) a water supply tank, 2) to an existing drinking water treatment system, or 3) a distribution system. If the final effluent of the system were to be used for drinking purposes while providing no additional treatment, the quality of the water would need to meet NPDWS.

During the demonstration elevated concentrations of both heterotrophic bacteria and methanol were found in the treated effluent. Heterotrophic bacteria, which are measured to determine how effective treatment is at controlling microorganisms, have no reported health effects. 40 CFR 141.72 of the NPDWS states that in lieu of measuring the residual disinfectant concentration in the distribution system, heterotrophic bacteria, as measured by the heterotrophic plate count, may be performed. If heterotrophic bacteria concentrations are found above 500/100 ml in the distribution system, the minimum residual disinfectant concentration is not in compliance with the NPDWS. There are no standards or health advisories for methanol in the NPDWS. The agency delegated for enforcement of the NPDWS would need to be notified of these elevated concentrations well before supplying this water to customers.

The NPDWS also have turbidity standards which must be met. A standard of 1.0 turbidity unit (NTU), as determined by a monthly average must be met. During the demonstration the calculated averages for three of the four sampling events were above the 1.0 NTU limit.

2.8.6 *Occupational Safety and Health Administration (OSHA) Requirements*

CERCLA remedial actions and RCRA corrective actions must be performed in accordance with the OSHA requirements detailed in 20 CFR Parts 1900 through 1926, especially Part 1910.120, which provides for the health and safety of workers at hazardous waste sites. On-site construction activities at Superfund or RCRA corrective action sites must be performed in accordance with Part 1926 of OSHA, which describes safety and health regulations for construction sites. State OSHA requirements, which may be significantly stricter than federal standards, must also be met.

If working at a hazardous waste site, all personnel involved with the construction and operation of the EcoMat BDN treatment process are required to have completed an OSHA training course and must be familiar with all OSHA requirements relevant to hazardous waste sites. Workers on hazardous waste sites must also be enrolled in a medical monitoring program. The elements of any acceptable program must include: (1) a health history, (2) an initial exam before hazardous waste work starts to establish fitness for duty and as a medical baseline, (3) periodic examinations (usually annual) to determine whether changes due to exposure may have occurred and to ensure continued fitness for the job, (4) appropriate medical examinations after a suspected or known overexposure, and (5) an examination at termination.

For most sites, minimum PPE for workers will include gloves, hard hats, steel-toe boots, and Tyvek® coveralls. Depending on contaminant types and concentrations, additional PPE may be required, including the use of air purifying respirators or supplied air. Noise levels are not expected to be high, except during well installation which will involve the operation of drilling equipment. During these activities, noise levels should be monitored to ensure that workers are not exposed to noise levels above a time-weighted average of 85 decibels over an eight-hour day. If noise levels increase above this limit, then workers will be required to wear hearing protection. The levels of noise anticipated are not expected to adversely affect the community, but this will depend on proximity to the treatment site.

Section 3.0
Economic Analysis

3.1 Introduction

The purpose of this economic analysis is to estimate costs (not including profits) for commercial treatment of groundwater contaminated with elevated levels of nitrate utilizing the EcoMat BDN Process.

The treatment system evaluated at Bendena was operated in an approximate range of 3-8 gpm during the SITE demonstration. This pilot-scale treatment system is considered by EcoMat to have an extremely low capacity for producing drinking water. The full-scale systems that EcoMat plans to design, own and operate for drinking water applications are 10 to 50 times the size of the pilot unit used at Bendena. Therefore, this analysis will present a cost estimate based on a 100 gpm system.

The costs associated with implementing the EcoMat designed and operated process have been broken down into 12 cost categories that reflect typical cleanup activities at Superfund sites. They include:

(1) Site Preparation
(2) Permitting and Regulatory Activities
(3) Capital Equipment
(4) Start-up and Fixed
(5) Labor
(6) Consumables and Supplies
(7) Utilities
(8) Effluent Treatment and Disposal
(9) Residuals Shipping, & Disposal
(10) Analytical Services
(11) Maintenance and Modifications
(12) Demobilization

To reasonably estimate costs for the technology, some basic assumptions have been made regarding the overall size of the reactors, treatment flow rate, level of nitrate contamination, presence of other contaminants (other than nitrate), treatment duration, and the level of post-treatment required to meet standard Safe Drinking Water criteria for general parameters.

The EcoMat BDN Process is ex-situ and is designed to operate on a continual pump and treat mode. Standard sized tanks are used as the reactors and holding tanks. The only specialized mechanical equipment used is the patented mixing apparatus that is fitted into the standard-sized reactor tank. EcoMat prefers to install and own their treatment systems, and then service the systems with local contractors. EcoMat would then bill monthly for the service. However, this cost estimate assumes the site owner will purchase the treatment system and pay for setup, monitoring, and maintenance.

Table 3-1 presents a categorical breakdown of estimated costs for the one year's treatment of groundwater, using a 100 gpm BDN system, at an assumed online factor of 80% (42 million gallons treated annually). **Table 3-2** projects the first year cost estimates to approximate costs for the same 100 gpm capacity and at the same assumed on-line factor of 80% for multi-year treatment (e.g., 5,10, and 15 years). **Figure 3-1** graphically illustrates the percentage of total cost that each of the twelve cost components comprise, for each treatment scenario.

As with all cost estimates, caveats may be applied to specific cost values based on associated factors, issues, and assumptions. The major factors that can affect estimated costs are discussed in subsection 3.3. The issues and assumptions made regarding the specific treatment system used for this economic analysis are incorporated into the cost estimate. They are discussed in subsection 3.4.

The basis for costing each of the individual 12 categories in Table 3.1 is discussed in detail in subsection 3.5. Much of the information presented in this subsection has been derived from observations made and experiences gained from the SITE demonstration that was conducted as four separate sampling events interspersed over an approximate 7½ month period at the location of a former public water supply well in Bendena, Kansas. Other cost information has been acquired through subsequent discussions with EcoMat and by researching current

Table 3-1. Cost Estimates for Initial Year of 100 GPM BDN System, Online 80%.

Cost Category	Quantity	Units	Unit Cost	$ - 1st Yr.	$/Category
1. Site Preparation					**$67,000**
Treatment System Delivery	1	Each	$5,000	$5,000	
Heated Building Enclosure	1	Each	$60,000	$60,000	
Utility Connections	1	Each	$2,000	$2,000	
2. Permitting & Regulatory Activities					**$30,000**
Permits				$10,000	
Studies and Reports				$20,000	
3. Capital Equipment					**$264,000**
Biodenitrification/Post-Treatment Systems	1	Each	$250,000	$250,000	
In-line Nitrate Analyzer (two cells)	1	Each	$8,000	$8,000	
In-line Dissolved Oxygen Meter	1	Each	$2,000	$2,000	
Portable Water Quality Instrumentation	2	Each	$600	$1,200	
Pressure Washer	1	Each	$2,800	$2,800	
4. Startup & Fixed (10% of Capital Equipment)					**$26,400**
5. Labor					**$69,900**
System Design	100	Hours	$80	$8,000	
Site Setup (EcoMat)	40	Hours	$80	$3,200	
(Contractor)	400	Hours	$50	$20,000	
Startup Testing (EcoMat)	80	Hours	$80	$6,400	
Performance Monitoring/Maintenance					
Remote Monitoring (EcoMat)	210	Hours	$80	$16,800	
On-site Monitoring (Contractor)	310	Hours	$50	$15,500	
6. Consumables and Supplies					**$5,580**
Methanol (99% + grade)	1,200	Gallons	$0.65	$780	
EcoLink Biocarrier	0.2	m^3	$6,000	$1,200	
Hypochlorite solution (for chlorination)	600	Gallons	$6.00	$3,600	
Post-Treatment Media	NA	NA	NA	NA	
7. Utilities	175,000	kW-hr	$0.07	$12,300	**$12,300**
8. Effluent Treatment & Disposal	NA	NA	$0000.00	$0000.00	
9. Residuals Shipping & Disposal	NA	NA	$0000.00	$0000.00	
10. Analytical Services					**$9,940** [2]
Nitrate-N/Nitrite-N in Water	27	Each	$15	$405	
Methanol in Water	27	Each	$100	$2,700	
Fecal Coliform	27	Each	$15	$405	
Trihalomethanes	27	Each	$150	$4,050	
Sample Shipments	54	Each	$30	$1,620	
11. Maintenance & Modifications	1	Year	$2,640	$2,640	**$2,640**
12. Demobilization	NA	NA	NA	NA	_________
			Total Initial Year Cost [1]		**$490,000**

[1] Cost value rounded to two significant digits.
[2] Value increased to account for 10% QA samples.

Table 3-2. Cost Estimates for EcoMat's BDN System for Multi-Year Treatment Scenarios.

Cost Category	Initial Year	5 Years	10 Years	15 Years
1. Site Preparation [2]	**$67,000**	**$67,000**	**$67,000**	**$67,000**
Treatment System Delivery	$5,000	$5,000	$5,000	$5,000
Heated Building Enclosure	$60,000	$60,000	$60,000	$60,000
Utility Connections	$2,000	$2,000	$2,000	$2,000
2. Permitting/Regulatory Activities [2]	**$30,000**	**$30,000**	**$30,000**	**$30,000**
3. Capital Equipment [2]	**$264,000**	**$264,000**	**$264,000**	**$264,000**
4. Startup & Fixed [2]	**$26,400**	**$26,400**	**$26,400**	**$26,400**
5. Labor	**$69,900**	**$225,000**	**$418,200**	**$612,200**
System Design [2]	$8,000	$8,000	$8,000	$8,000
Site Setup [2]	$23,200	$23,200	$23,200	$23,200
Startup Testing [3]	$6,400	$32,000	$64,000	$96,000
Perf. Monitoring/Maintenance	$32,300	$162,000	$323,000	$485,000
6. Consumables & Supplies	**$5,580**	**$27,900**	**$55,800**	**$83,700**
Methanol	$780	$3,900	$7,800	$11,700
Hypochlorite Solution	$3,600	$18,000	$36,000	$54,000
EcoLink Biocarrier	$1,200	$6,000	$12,000	$18,000
Post-Treatment Media	$000.00	$000.00	$000.00	$000.00
7. Utilities (Electricity)	**$12,300**	**$61,500**	**$123,000**	**$184,500**
8. Effluent Treatment & Disposal	**NA**	**NA**	**NA**	**NA**
9. Residuals Shipping & Disposal	**NA**	**NA**	**NA**	**NA**
10. Analytical Services	**$9,940**	**$15,900**	**$23,500**	**$31,100**
Nitrate in water	$405	$645	$945	$1,250
Methanol in water	$2,700	$4,300	$6,300	$8,300
Fecal Coliform	$405	$705	$1,220	$1,670
Trihalomethanes	$4,050	$6,450	$9,450	$12,500
QA samples (10%)	$756	$1,210	$1,790	$2,370
Sample Shipments	$1,620	$2,580	$3,780	$4,980
11. Maintenance & Modifications	**$2,640**	**$13,200**	**$26,400**	**$39,600**
12. Demobilization	**$000,000**	**$000,000**	**$000,000**	**$000,000**
TOTAL COSTS [1]	**$490,000**	**$730,000**	**$1,000,000**	**$1,300,000**

[1] Total costs have been rounded to two significant digits.
[2] Designates a one time cost incurred for all scenarios.
[3] Startup testing is assumed to be repeated once per year.

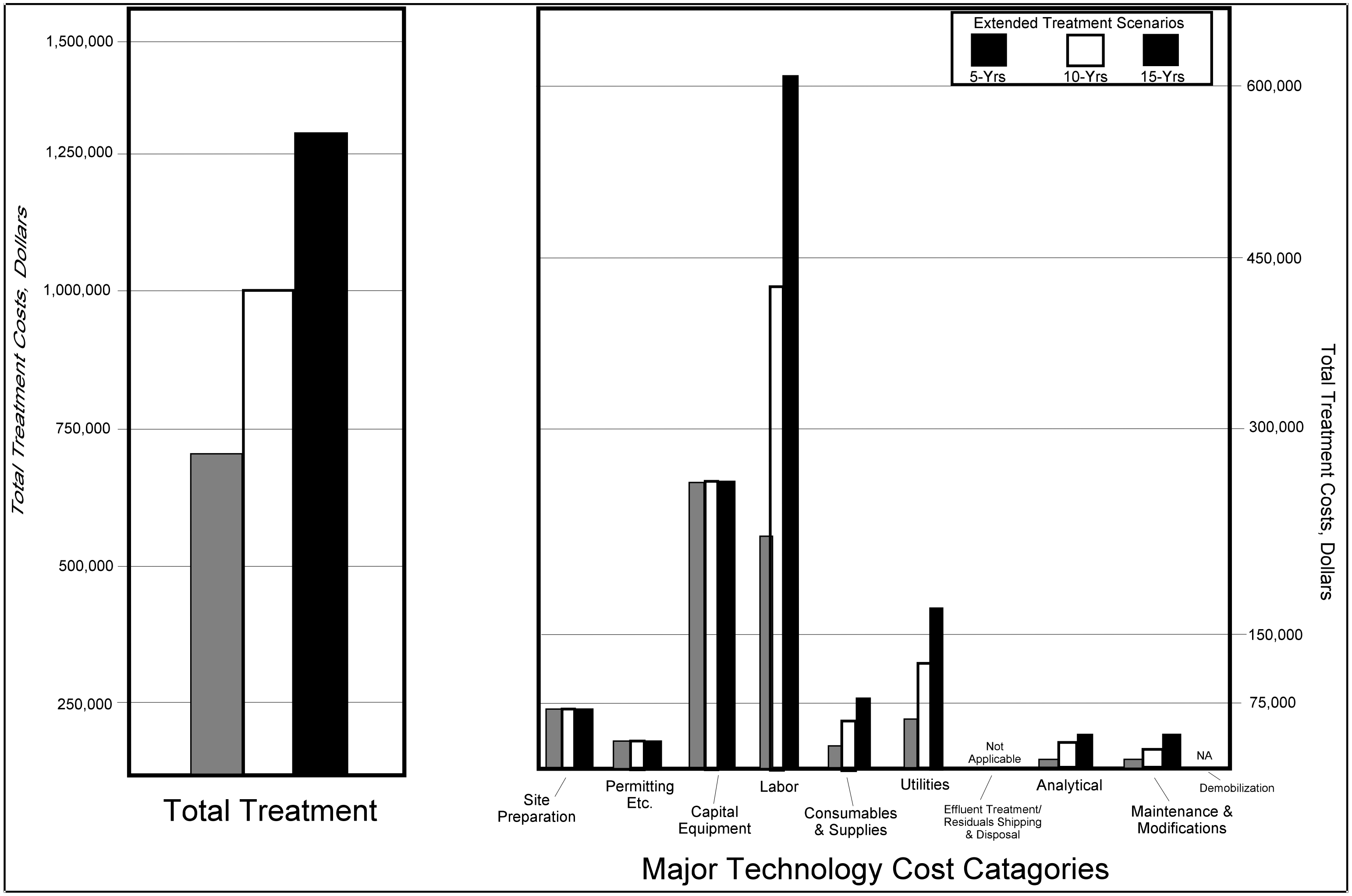


Figure 3-1. Cost Distributions - EcoMat Biodenitrification Multi-Year Treatment Scenarios.

estimates for specific cost items related to the technology. Certain actual or potential costs were omitted because site-specific engineering aspects beyond the scope of this SITE Demonstration project would be required. Certain other functions were assumed to be the obligation of the responsible parties and/or site owners. Although these costs are also not included in the estimate, they are still shown as line items on Tables 3.1 and 3.2 to emphasize that those costs need to be accounted for.

It should be emphasized that the cost figures provided in this section are "order-of-magnitude" estimates, generally + 50% / -30%.

3.2 Conclusions

The majority of the information for the costs (as well as some actual costs) to treat groundwater using the EcoMat BDN System at a flow rate of 100 gpm were provided by EcoMat. These estimates, along with other conclusions of the economic analysis, are presented below:

(1) For a 100 gpm system, the estimated cost to treat nitrate-contaminated groundwater over a one year period is $490,000, or approximately $0.012/gal. The cost over 5, 10,or 15 years is estimated to increase to approximately $730,000 ($0.0034/gal.); $1,000,000 ($0.0024/gal.) and $1,300,000 ($0.002/gal.), respectively.

(2) The largest cost components for the one-year application of a 100 gpm EcoMat BDN system are capital equipment (54%), labor (14%), and site preparation (14%); accounting for over 80% of the total cost. As the treatment duration increases over time, the impact of capital equipment and site preparation diminish considerably. Shortly following five years of treatment, labor becomes the dominant cost component and the impact of consumables and supplies becomes more significant.

(3) The cost of implementing the EcoMat Biodenitrification System may be less or more expensive than the estimate given in this economic analysis depending on several factors. If water recovery wells are not already present at the site, their installation would be a significant added cost to the site owner, especially if the water source is deep (these costs are not directly associated with the EcoMat treatment process and thus have not been included in the estimate). Other factors include, but are not limited to, the nitrate concentration in the water and the presence of other contaminants that would require increased post-treatment or pretreatment.

3.3 Factors Affecting Estimated Cost

There are a number of factors that could affect the cost of treatment of nitrate-contaminated groundwater using an ex situ bioremediation treatment technology. An important factor for initial consideration is the ability to supply contaminated water at an economically viable flow rate (which is dependent on aquifer characteristics). Other important factors include, but are not limited to, the inlet nitrate concentration (as measured as nitrate-N), the presence of other contaminants in the inlet water, and the level of pre-or post-treatment required.

The aquifer yield will affect the size and number of pumping wells required to attain sufficient flow rate to allow treatment to be economically feasible. For aquifers that are capable of yielding high flow rates, the number of wells that are required to be installed and the depth at which they must be screened can significantly impact startup costs, but this would affect any system.

3.4 Issues and Assumptions

This section summarizes the major issues and assumptions used to estimate the cost of implementing the EcoMat BDN Process at full-scale. In general, the assumptions are based on information provided by EcoMat and observations made during the demonstration.

3.4.1 Site Characteristics

The site characteristics used for this economic analysis are considered to be significantly different from those found at the Bendena site. The Bendena demonstration site consisted of a former railroad well constructed in the early 1900's. Pre-demonstration pump testing of this well at just 20 gpm over a 5-day period depleted nearly 30 percent of the well volume. Thus, the aquifer recharge would not be sufficient for adequately supplying a 100 gpm treatment system. Also, nitrate levels in the well water were measured as high as 100 ppm. Such levels of nitrate in a well are uncommon and EcoMat has costed their treatment system to be contingent on an inlet nitrate level of 20 mg/l.

For the purposes of this analysis, there are three major assumptions that have been made regarding site characteristics: 1) the aquifer being treated is capable of supplying groundwater to one or more wells at a rate equal to or greater than 100 gpm for an extended time period; 2) no additional wells are required, and 3) that nitrate-N levels will be consistently above the regulatory limit of 10 mg/l but will not exceed 20 mg/l.

3.4.2 Design and Performance Factors

Design and performance factors would include designing the properly-sized treatment system and process parameters to adequately treat nitrate-contaminated groundwater at a rate of 100 gpm. If need be, a groundwater recovery system may also need to be designed and would include locating and installing groundwater recovery wells and the associated pumps and piping to route the inlet water to the treatment system. For this cost estimate an assumption is made that sufficient groundwater recovery wells and piping are already present at the site.

The developer (EcoMat) designs the properly-sized system anticipated for a particular site. Once designed the system components are manufactured or purchased off-site, usually from one or more vendors. The components are then shipped from the plant(s) to the site location, where EcoMat assembles the system.

With respect to the pilot-scale unit used at Bendena, EcoMat has indicated that a 100 gpm system would be scaled-up in physical size by a factor of between two and three times that of the pilot unit.

3.4.3 Financial Assumptions

All costs are presented in Year 2001 U.S. dollars without accounting for interest rates, inflation, or the time value of money. Insurance and taxes are assumed to be fixed costs lumped into "Startup and Fixed Costs" (see subsection 3.5.4). Any licensing fees passed on by the developer, for using the EcoMat patented mixed reactor and implementing technology-specific functions, would be considered profit. Therefore, those fees are not included in the cost estimate.

3.5 Basis for Economic Analysis

The 12 cost categories reflect typical clean-up activities encountered at Superfund sites. In this section, each of these activities will be defined and discussed. Combined, these 12 cost categories form the basis for the detailed estimated costs presented in Tables 3-1 and 3-2. The labor costs that are continually repeated for each scenario are grouped into two labor categories, one category for developer labor (i.e., EcoMat) and one category for developer contractor labor (see subsection 3.5.5).

3.5.1 Site Preparation

Site preparation for implementing the EcoMat BDN system technology can be subdivided into three distinct phases. These include the initial design of the treatment (system design), shipping and assembly of the designed system (site setup) and conducting initial shakedown/recycle testing. The first two phases are one time occurrences. The shakedown and recycle phase may have to be repeated if the system stops operating for a substantial period of time during the treatment process.

All three of these phases are discussed in the following subsections. However, the majority of the costs associated with site preparation is labor (labor costs are presented in subsection 3.5.5). Therefore, the only costs discussed in this subsection are non-labor costs associated with site setup phase (see 3.5.1.2). The total non-labor cost of site preparation for the beginning operation of the system is estimated to be approximately $67,000, which would be a one time cost.

3.5.1.1 System Design

System design consists of obtaining the anticipated contaminant range from the prospective customer and then selecting the proper sized system components necessary for treating that influent at a specified flow rate. EcoMat does not conduct treatability testing on the water matrix (i.e., influent); however, they do have small reactors that could be used for such a purpose. Generally speaking, the system design does not include the means for pumping the water matrix from its source to the BDN system.

EcoMat has indicated that the design of a 100 gpm system would not radically change from the design of the pilot unit used at Bendena, however the scale-up factor would be between two and three. Therefore the deoxygenating tank (R1) would have an approximate capacity of 2,600 gallons and the EcoMat Reactor (R2) would be on the order of 5 cubic meters (the R2 unit at Bendena was 2 cubic meters). The cost of system design has been estimated by EcoMat to correlate to approximately 100 hours (see subsection 3.5.5 - Labor).

3.5.1.2 Site Setup

The second phase of site preparation is site setup. This phase includes shipping the treatment system components from one or more of EcoMat's suppliers to the site. The costs of shipping will vary depending on location and distance the site is from the supplier(s). EcoMat roughly estimates shipping costs at 2% of the treatment system capital cost. For a 100 gpm treatment unit, this would be approximately $5,000 (see subsection 3.5.3 for capital costs).

Once at the site the entire treatment system is normally housed in a shed or building that provides security and temperature control. Therefore, if an appropriate existing structure does not exist at the site, one has to be assembled or built. EcoMat has estimated that a building twice the size of the Bendena shed would be required to accommodate a 100 gpm system. It is feasible to install a system outside, which may be necessary for even larger systems. In such instances, heat tracing would be installed to provide temperature control where needed.

At the Bendena site, the KDHE provided for the 20 ft. x 15 ft. building and all associated utility hookups at an approximate cost of $40,000 (which included construction labor costs). The cost of a structure about twice that size (i.e., 40 ft. x 30 ft.), not including utility hookups, is estimated at approximately $60,000.

At the Bendena site, electrical hookups, communications, and water supply were also provided by the KDHE and incorporated into the total cost estimate for the shed. Electrical power is required for operating pumps, control panels, etc. for the system; lighting, etc. A water hookup is needed for power washing equipment components (e.g., filters, etc.). For this cost estimate, utility hookups are estimated to be a one time charge of $2,000.

It is assumed that the site used for this cost estimate is secured and cannot be easily vandalized. The treatment system itself would, in most cases, be installed within a secured building, as previously discussed. If security became an issue with a larger outdoor system, then a fence would need to be erected. Assuming no costs for security, the total site setup costs for initiating the activities are estimated to total approximately $67,000. This cost value represents the total non-labor cost estimated for the Site Preparation category.

3.5.1.3 Shakedown and Recycle

Once the full treatment system has been assembled, there is a period of time necessary to acclimate the microbial colony to the biocarrier(s), and the inlet water, make adjustments to methanol feed rates, and check operation of system components. Once this steady-state is reached the system can continually operate effectively as long as there are no significant shutdowns.

The overwhelming majority of the cost associated with the shakedown and recycle process is labor, which is discussed in subsection 3.5.5. The cost of consumables specifically associated with conducting shakedown and recycle activities are negligible with respect to total annual consumables (consumable costs are discussed in subsection 3.5.6).

3.5.2 Permitting and Regulatory Requirements

Several types of permits may be required for implementing a full-scale remediation. The types of permits required will be dependent on the type and concentration of the contamination, the regulations covering the specific location, and the site's proximity to residential neighborhoods.

At the Bendena site, treated water was discharged to a 300 foot long, 1,000 gallon capacity lateral septic system purchased and installed for the demonstration. The KDHE acquired the necessary permits for discharging the treated water to the septic system located in an adjacent field in this manner. Although, ozone treatment and an air stripper were used during portions of the demonstration, a permit was not required.

The non-analytical costs incurred for ultimately receiving approval from the regulatory agency to install the treatment system are included under the Permitting and Regulatory Activities category. These costs would include the preparation of site characterization reports that establish a baseline for the site contamination, the design feasibility study for the pilot system, potential meetings with regulators for discussing comments and supplying other related documentation, and for acquiring approval for installing and implementing the treatment.

Based on past experience, permitting fees for implementing the full-scale treatment system are assumed to be about $10,000. It should be noted that actual permitting fees are usually waived for government-conducted research type projects (e.g., SITE Demonstrations).

Depending upon the classification of the site, certain RCRA requirements may have to be satisfied as well. If the site is an active Superfund site, it is possible that the technology could be implemented under the umbrella of existing permits and plans held by the site owner or other responsible party. Certain regions or states have more rigorous environmental policies that may result in higher costs for permits and verification of treatment performance. Added costs may result from investigating all of the regulations and policies for the location of the site, and for conducting a historical background check for fully understanding the scope of the contamination. From previous experiences, the associated cost with these studies and reports is estimated to be $20,000.

The total cost of all necessary permitting and other regulatory requirements is estimated to be approximately $30,000.

3.5.3 Capital Equipment

Most of the capital equipment cost data directly associated with the BDN and post-treatment system have been supplied by EcoMat. Specific capital equipment associated with their system includes high density polyethylene tanks, high capacity pumps, electronic control systems, a patented mixing apparatus, system piping and valves, rotometers, and various off-the-shelf post-treatment units. Some of the monitoring equipment costs are based on the SITE Program's experience during the demonstration and from other similar products. It is assumed that all equipment parts will be a one time purchase and will have no salvage value at the end of the project.

EcoMat has provided an approximate lump sum cost estimate of $250,000 for a 100 gpm treatment system capable of treating a water matrix having nitrate levels of 20 mg/l. This value does not include the installation of groundwater wells, groundwater pumps, or piping installation required to supply inlet water to the treatment system (at the Bendena site the groundwater supply delivery system consisted of a single submersible pump that supplied the BDN system with groundwater at flow rates varying between 3 and 8 gpm). The $250,000 value also does not include costs for disassembly, shipping and reclaiming system components.

In addition to the main components of the EcoMat BDN and post- treatment systems, in-line monitoring equipment would be an additional capital cost. The most important monitoring instrumentation required for a full-scale system would be an in-line nitrate analyzer equipped with two cells; one for monitoring inlet water nitrate levels and one for monitoring either post BDN or final effluent nitrate levels. The estimated cost for a direct read nitrate analyzer is $8,000.

Dissolved oxygen is another important parameter that requires close monitoring, as evidenced during the demonstration. Since the time of the demonstration, EcoMat has incorporated a dissolved oxygen monitoring unit into their system to immediately identify irregularities in DO. A microprocessor-based DO meter installed within the BDN system is estimated to cost $2,000. Other portable instrumentation required for monitoring parameters such as pH, temperature, and turbidity are estimated to collectively cost about $1,200.

Although an industrial pressure washer could be rented on an as-need-basis, it will be assumed that a dedicated pressure washer would be purchased for EcoMat's full-scale unit. This would allow for quicker response to any periodic clogging of filters and reactor screens (which occurred during the demonstration) and the cost would be relatively minor with respect to the cost of the treatment system itself or renting the equipment over several years. A combination steam cleaner/pressure washer is estimated to cost roughly $2,800.

The total cost of all of the necessary capital equipment for a full-scale 100 gpm system is estimated to be approximately $264,000.

3.5.4 Startup and Fixed Costs

From past experience, the fixed costs for this economic analysis are assumed to include only insurance and taxes. They are estimated as 10 percent of the total capital equipment, or $26,400.

3.5.5 Labor

Included in this subsection are the core labor costs that are directly associated with the EcoMat BDN System. These costs comprise the bulk of the labor required for the full implementation of the technology. It is assumed for this cost analysis that the treatment system will be fully automated and will operate continuously without major interruption at the designed flow rate. Non-core labor costs, associated with periodic system adjustments (i.e., chemical adjustments), regulatory sampling requirements, maintenance activities, and site restoration, are discussed in subsections 3.5.10, 3.5.11 and 3.5.12, respectively.

For the purchased EcoMat treatment system, assembly is a labor intensive operation consisting of unloading equipment from trucks and trailers, as well as actual assembly. EcoMat will have significant hands-on involvement during the site setup phase of the project and early stages of a field project to ensure proper assembly and startup of their technology. EcoMat's labor hours, as specified in Tables 3-1 and 3-2, would include overseeing and training local contractors on the operation of the system and making the proper adjustments to the system during the shakedown and recycle operation. Once the system is acclimated and operating at a steady state, labor should become minimal.

The hourly labor rates presented in this subsection are loaded, which means they include base salary, benefits, overhead, and general and administrative (G&A) expenses. Travel, per diem, and standard vehicle rental have not been included in these figures. The labor tasks have been broken down into four subcategories, each representing distinct phases of technology implementation. They include 1) System Design 2) Site Setup; 3) Startup Testing; and 3) Performance Monitoring & Maintenance.

3.5.5.1 System Design

System design consists of obtaining the anticipated contaminant range from the prospective customer and then selecting the properly-sized system components necessary for treating that influent at a specified flow rate. Specific tasks may include preparation of design parameters and detailed process flow schematics (including piping designs), logistics for procuring the specific system components, and calculating feed rates for methanol solution and other additives. EcoMat has estimated system design labor at 100 hours. Assuming a loaded rate of $80/hr for an EcoMat process design engineer (or comparable professional) to conduct this task, labor for system design is estimated at $8,000.

3.5.5.2 Site Setup

Site setup includes labor costs that are not already included in the system design. These costs would therefore include the labor to assemble the system components and associated monitoring equipment once at the site; organization and storage of the initial year's supplies (e.g., methanol, filter cartridges, etc.); and arranging for and overseeing the utility hookups. Due to the importance of these initial activities, it is assumed that the developer will be on-site to direct and assist subcontracted personnel.

It is assumed that the developer will supply one senior level process engineer, billing out at an estimated $80/hour, to perform oversight duties. It is also assumed that the developer will contract out for supplying a local field team consisting of two technical staff personnel. The average hourly loaded rate for these two individuals is estimated to be $50/hour. To complete the aforementioned tasks for a 100 gpm system, EcoMat has estimated 40 hours of their time ($3,200) and 400 contractor hours ($20,000). Therefore, total labor for the site setup phase has been estimated at approximately $23,200.

3.5.5.3 Startup Testing

The EcoMat process requires a period of time for developing the necessary biological growth on the biocarrier in the EcoMat Reactor under a full recycle mode. EcoMat refers to this startup testing phase as the "Shakedown and Recycle Operation." The shakedown and recycle operation for the SITE demonstration took approximately eight weeks. EcoMat has indicated that this process can be completed in about half of that time under closer control and that the time period does not vary significantly with the size of the project. They have estimated 80 hours of labor for completing this task, which at an $80/hr rate would total $6,400. The shakedown and recycle mode must be repeated if the system goes down for an extended period to re-acclimate the microorganisms (this was necessary during the demonstration). For this cost it will be assumed that system startup will have to be repeated at least once annually. Thus the $6,400 labor cost will be incurred each and every year of operation.

3.5.5.4 Performance Monitoring & Maintenance

Although the full-scale system is assumed to be fitted with an on-line nitrate/nitrite analyzer and other automated systems (i.e., for metering the proper amount of methanol solution, chlorination, etc.), the full-scale system would still require both remote (off-site) and on-site monitoring to ensure reliable and consistent system performance.

Off-site monitoring of the full-scale treatment system would at minimum be capable of continuously tracking inlet and effluent nitrate and nitrite levels, dissolved oxygen levels, and system disruptions as indicated by the control panel alarms (i.e., high tank level alarms, pump malfunctions, high dissolved oxygen levels, etc.).

Actual on-site observation would also be necessary, as would routine maintenance site visits. Observing the system is required to visualize biocarrier suspension in the EcoMat reactor. Periodic maintenance of the system is required for filter backflushing, adjusting methanol solution feed rate, washing the bioballs in the deoxygenating reactor, replenishing hypochlorite solution supply, etc.

With respect to a 100 gpm system, EcoMat has estimated their off-site monitoring labor at four hours per week and contracted on-site labor at six hours per week. Assuming the same labor rates of $80/hr and $50/hr for EcoMat and contractor labor, respectively, the weekly labor cost for performance monitoring is estimated at $620/week. This weekly cost would equate to $32,300 annually.

Total labor costs for the first year of treatment operation would total approximately $69,900. Although labor comprises only about 14% of the total first year treatment costs, labor is projected to become the highest annual cost category over time. Labor costs at five, ten and 15-years of operation are estimated to comprise roughly 30%, 42%, and 47% of the total annual costs, respectively.

3.5.6 Consumables & Supplies

Due to the higher initial capital costs, consumables and supplies comprise a relatively small initial year cost component (i.e., slightly more than 1% of the first year total cost) for the EcoMat system. As the capital cost impact diminishes over time, the consumables and supplies costs gradually increase in significance. Potential consumables and supplies costs for the EcoMat Biodenitrification process can be associated with four subcategories: 1) Nutrients and growth substrate; 2) Biocarrier media; 3) Post-treatment consumables; and 4) Equipment rentals.

3.5.6.1 Nutrients and Growth Substrate

Growth substrate includes any consumable supply that is added to the BDN system to specifically sustain or enhance the viability of microbes used to degrade nitrate and nitrite. The primary substrate is a 50% aqueous methanol solution that is added to both the de-oxygenating reactor tank and the EcoMat reactor.

During the demonstration, the methanol solution feed rate roughly ranged from 7-10 liters per day. EcoMat has indicated that three times that feed rate would be required for a 100 gpm system. Therefore, a high range of 30 liters/day of "solution" would provide a conservative estimate. That daily feed rate would total approximately 8,800 liters of "solution" consumed per year for a system on-line 80%. Thus, approximately 4,400 liters (about 1,200 gallons) of methanol would be consumed annually.

EcoMat has indicated that they have a supplier that provides bulk purchases of methanol at a cost of $0.65 per gallon. Using that value, the annual cost of the methanol would be $780. The remainder of the methanol "solution" consists mostly of water.

Nutrient supplements are also sometimes used. For the demonstration, a small amount of food grade phosphoric acid was added to the methanol solution to achieve a phosphorus concentration of about 0.75 ppm. The cost of the non-methanol portion of the solution is considered negligible and therefore is not included.

In some cases, additional substrates may be utilized. For example, during the demonstration, molasses was added to "kick start" the system. However, supplements such as molasses are not always needed and its cost is considered negligible and is not included here.

3.5.6.2 Biocarrier Media

The "EcoLink" biocarrier material is not replaced as long as it remains in suspension. Overloading does occur, therefore, after a significant period of time the EcoLink must be replaced before they sink and clog screens. EcoMat has indicated that a 100 gpm system requires about two m^3 of EcoLink, which presently costs $6,000 per cubic meter. The developer has also estimated that approximately ten percent of the volume of EcoLink used in any sized system needs "refreshing" on an annual basis. Therefore, an annual cost of $1,200 for EcoLink biocarrier is assumed for this cost estimate.

The bioballs used in the deoxygenating reactor tank are also a type of biocarrier. However, they can last indefinitely if periodically washed. For this reason, they are not considered as consumable. The labor cost of maintaining the bioballs is included in subsection 3.5.5.4

3.5.6.3 Post-Treatment Consumables

Post-treatment consumables would potentially include any chemical treatment added to the post-BDN effluent. Also included would be absorption and filtration media that would be spent over an indefinite time period and need replacement. Examples of such post-treatment media would be sand (used in sand filtration), spent activated carbon, spent filter cartridges, etc.

It is assumed for this cost estimate that chlorination would likely be required when implementing the EcoMat treatment system for drinking water applications. EcoMat has indicated that they would use a 25% solution of liquid hypochlorite for full-scale chlorination post-treatment. For a 100 gpm system, they have estimated hypochlorite consumption at 2 gallons per day at a cost of approximately $6 per gallon. This daily rate would correlate to approximately 600 gallons of hypochlorite consumed annually at an estimated cost of $3,600.

During the demonstration, EcoMat replaced the paper filter cartridges being used with cleanable metal cartridges. Activated carbon was used for one event only, and the sand filter was periodically flushed. For this cost estimate, it will be assumed the cleanable metal filter cartridges would also be used for a larger 100 gpm system. It will also be assumed that activated carbon will not be required and that the cost of replacing sand filtration media would be negligible. Thus the cost of post-treatment consumables would consist solely of the hypochlorite cost, about $3,600 annually.

3.5.6.4 Equipment Rentals

Equipment rentals would be an alternative to purchasing dedicated equipment for the full-scale treatment system. For example, a pressure washer could be rented for flushing out metal cartridge filters and reactor screens during periodic maintenance. A conservative cost estimate for renting a heavy duty pressure washer is $300/week. Assuming that pressure washing would be required quarterly, the annual rental charge would be approximately $1,200 per year. Since this annual cost exceeds 40% of the estimated purchase price, purchase of a pressure washer is the more economical choice.

It should be noted that other equipment listed in the cost estimate as a capital expense may also be rented. During the demonstration, the SITE Program rented a colorimeter, pH/conductivity meter, a temperature/DO meter, a turbidity meter, and water level meter. However, as is the case with the pressure washer, the rental costs of these items for indefinite periods is not cost effective, especially when the periodic shipping charges are included.

Since equipment that could be rented have been included as capital cost items, no rental costs are included in the cost estimates on Tables 3-1 and 3-2.

The total estimated cost of consumables and supplies for the initial year of treatment is $5,580. The cost is estimated to increase proportionately with treatment duration.

3.5.7 Utilities

The main utility required for the EcoMat treatment system is electricity. At the Bendena site the electrical hookup and service were provided by the State of Kansas. The electricity provided the power needed to operate the system pumps and control panels, the submersible pump in the well, and outlets used for the building heater and the telephone/facsimile machine. The SITE Program recorded electric meter readings before, during, and at the conclusion of the demonstration. During the approximate 7½ month period of time encompassed by the four sampling events, a total of approximately 26,400 kW-hr was used. Power usage rates varied in a range of 5.0-10.4 kW. EcoMat has projected a 100 gpm system to utilize approximately 2.5 times the power of the pilot-scale system; which would correlate to a range of 12.5 - 26 kW of power. Conservatively using 20 kW as the power usage for a 100 gpm system, the number of kW-hrs used annually would be approximately 20 kW x 24 hr/day x 7 days/wk. x 52 wk./yr or approximately 175,000 kW-hrs. Assuming a utility charge of $0.07/kWh, the cost of operation of the 100 gpm treatment system for a year would thus be about $12,300. (Note: It is assumed that electric usage will continue when the system is off-line for testing and other maintenance activities.) It should be noted that electricity cost can vary greatly depending on geographical location.

There is also a need for a water line to operate a pressure washer for maintenance activities. However, the water usage is sporadic and is not expected to be substantial. Therefore, water usage is considered negligible for estimating utility costs.

3.5.8 Effluent Treatment and Disposal

For this technology successful treatment will mean that the effluent will become drinking water. Therefore, it is assumed that there will be no effluent treatment and disposal expense. It is assumed that the minimal amount of wastewater generated from periodic power washing of metal filter cartridges and reactor filter screens can be discharged either to a land septic system (as was the case at Bendena), or to a local POTW.

3.5.9 Residuals Shipping and Disposal

The only residuals generated during the demonstration were spent filter media (cartridges and carbon) and spent biocarrier media. Since levels of residual methanol are low in these wastes, most if not all of this material would be classified as non-hazardous and can be disposed of as such.

It should be noted that if carbon is used to treat hazardous organic contaminants, any spent carbon could be classified as a hazardous waste, and thus require disposal as hazardous waste.

For this cost estimate, it is assumed that no hazardous waste will be generated during treatment. Residuals would be discarded as non-hazardous solid waste. Disposal costs are, therefore, considered negligible for this cost estimate.

3.5.10 Analytical Services

Although nitrate and nitrite levels would be monitored continuously by an on-line nitrate analyzer, the state or local regulatory agency would still require independent analysis of effluent samples at some specified frequency. Based on discussions with the Public Works Supply Section of the KDHE, the required monitoring for a water treatment system such as EcoMat's would include four specific drinking water criteria. These four criteria would include nitrate-N/nitrite-N (which is conducted as a single analysis), methanol, Fecal Coliform, and trihalomethanes (THMs). A likely monitoring schedule for a nitrate treatment system producing drinking water would include the following final effluent analyses at the indicated frequency:

(1) Nitrate and nitrite quarterly;
(2) Methanol quarterly;
(3) Trihalomethanes (THM) quarterly; and
(4) Fecal Coliform twice a month.

The required monitoring would be conducted quarterly for the duration of the life of the treatment system, but would be at an increased level for the first 8 weeks of operation. For estimating the cost of the analytical services category, it is assumed that the treatment system effluent will be sampled three times a week for the first 8 weeks of operation (for a total of 24 samples) and then a total of three times for the remainder of the first year of operation in accordance with a quarterly sampling schedule. Therefore, a total of 27 effluent samples will be collected during the initial year of system operation and four effluent samples will be collected for each successive year.

The resulting first year total of 27 water samples, analyzed for nitrate-N/nitrite-N at an estimated cost of $15 per sample, methanol at an estimated cost of $100 per sample, Fecal Coliform at an estimated $15 per sample, and THMs at an estimated $150 per sample would total to approximately $7,560. Assuming an increase of sample cost of 10 percent to cover QA samples, the total cost for the first year samples is estimated at $8,320. The total cost for each subsequent year of quarterly monitoring would be around $1,120. Again, assuming a 10 percent increase in costs to cover QA samples, the total cost for each subsequent year is estimated at about $1,230.

It is anticipated that the VOC (methanol) and biological analyses would be conducted at separate off-site laboratories. The holding time requirements for nitrate-N/nitrite-N analyses and Fecal Coliform would necessitate near immediate shipments to those off-site laboratories, allowing for no holdovers. Therefore, separate shipments would be required for each. As a result there would be 54 overnight shipments to the offsite laboratories during the first year of operation and eight shipments for each successive year. At an estimated $30/shipment for these small sample sets, the total cost of sample shipping services is estimated to be about $1,600 the first year and $240 each successive year.

It should be noted that the stringency and frequency of monitoring required may have a significant impact on this cost category.

3.5.11 Maintenance and Modifications

Once the treatment system is in full operation (following the shakedown and recycling phase) monitoring and periodic maintenance are necessary to maintain the required level of the treatment.

For this cost estimate it will be assumed that most of the system operation will be monitored remotely from off-site.

Based on the observations made during the SITE demonstration, the mostly likely maintenance problems would involve system disruptions due to clogged filters or screens. The cost associated with these problems is mostly labor and did not involve the purchase of replacement parts during the demonstration (see subsection 3.5.5.4). It is assumed that system components having high replacement costs (such as pumps) will operate for the full duration of treatment if maintained properly. Components that were replaced during the demonstration included those having a relatively low cost (such as malfunctioning switches and level sensors).

EcoMat has estimated non-labor cost of maintenance to be approximately 1 percent of the treatment system capital cost annually, which is roughly $2,600.

3.5.12 Demobilization

In general, EcoMat believes that much of the equipment comprising the biodenitrification treatment system (if not all) will be reusable. The end use of the equipment would be determined on a case-by-case basis. Demobilization would be performed at the conclusion of the entire project, which is dependent on the total treatment time. It is possible that treatment would be indefinite or would be of long enough duration that the equipment components would be fully depreciated, thus essentially making the cost of disassembly and shipment to a second location prohibitive. In either case, this cost estimate assumes that the responsible party owns the system through their capital cost investment. Therefore, demobilization is not an issue, and all equipment has zero salvage value.

Section 4.0
Demonstration Results

4.1 Introduction

4.1.1 Project Background

EcoMat's BDN Process was evaluated under the SITE Program at the former PWS Well #1 in Bendena, Kansas. The primary contaminant in the well water is nitrate-N, which historically has been measured at concentrations ranging from approximately 20 to 130 ppm, well above the regulatory limit of 10 mg/l. VOCs, notably CCl_4, have been a secondary problem. The overall goal of EcoMat was to demonstrate the ability of their process to reduce the levels of nitrate-N in the groundwater and restore the public water supply well as a drinking water source.

The SITE demonstration occurred between May and December of 1999 and was conducted in cooperation with the KDHE. The study consisted of four separate sampling events interspersed over a 7½ month time period. During these four events EcoMat operated its system at flows between three and eight gpm. During this same time period well water nitrate-N levels varied from greater than 70 mg/l to approximately 30 mg/l.

During the four sampling events, the SITE Program collected water from four specific sample taps located along EcoMat's process. Sampling rounds were scheduled at pre-specified intervals, and consisted of collecting the water samples from the four sample locations at the approximate same time. By following this procedure the data collected simultaneously from the four sample locations could be compared to one another. A total of 119 samples from each of the four sampling locations were collected for the four field events (28 for Event 1; 31 for Event 2; and 30 each for Events 3 and 4).

The four sample points, as shown on **Figure 4-1**, are:

1. An untreated (**"Inlet Water"**) sample point located between PWS Well # 1 and the Deoxygenating Tank (S1);
2. A **"Partial BDN Treatment"** sample point located between the Deoxygenating Tank and EcoMat Reactor (S2);
3. A **"Post BDN"** sample point located between the EcoMat Reactor and post-treatment system (S3);
4. A **"Final Effluent"** sample point located downstream of the post-treatment system (S4).

4.1.2 Project Objectives

Specific objectives for this SITE demonstration were developed and defined prior to the initiation of field work. These objectives were subdivided into two categories; primary and secondary. Primary objectives are those goals of the project that need to be achieved to adequately compare demonstration results to the claims made by the developer. The field measurements required for achieving primary objectives are referred to as critical measurements. Critical measurements were formally evaluated against regulatory limits using statistical hypothesis tests (which are detailed in the TER).

Secondary objectives are other goals of the project developed for acquiring additional information of interest about the technology, but are not directly related to validating developer claims. The field and laboratory measurements required for achieving secondary objectives are considered to be noncritical. Therefore, the analysis of secondary objectives was more qualitative in nature and involved observations made by summarizing data in tables and graphs.

Table 4-1 presents the one primary and seven secondary objectives of the demonstration, and summarizes the method(s) by which each was evaluated. Except for the cost estimate (*Objective 8*), which is discussed in Section 3, each of these objectives is addressed in this section.

4.2 Detailed Process Description

A process flow diagram of the EcoMat treatment systems used for the demonstration is presented in Figure 4-1. As illustrated, there are two major components comprising the

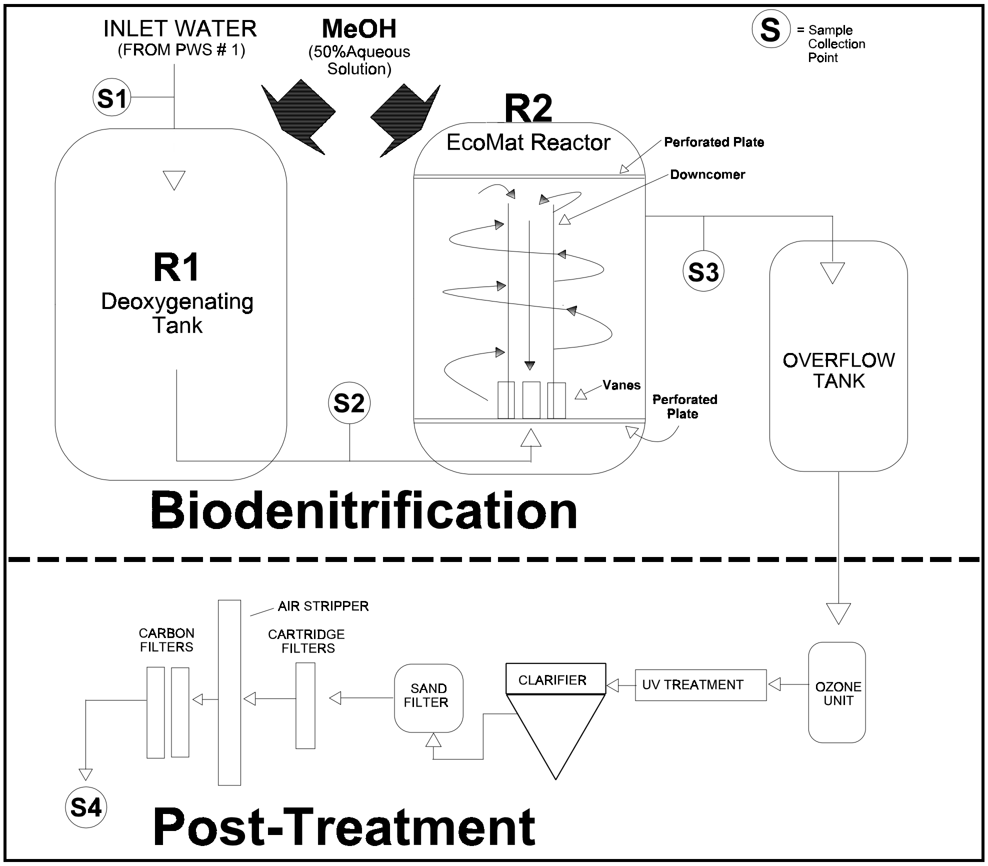


Figure 4-1. Flow Diagram Showing EcoMat's Treatment System and Sample Collection Points

process: a BDN system and a post-treatment system. The BDN system is a type of fixed film bioremediation in which specific biocarriers and bacteria are used to convert nitrates in the groundwater to nitrogen, thus reducing nitrate-N concentrations to acceptable levels. The post-treatment system is designed to either destroy or remove any intermediate compounds potentially generated during the biological breakdown of nitrate, and to remove small amounts of bacteria and suspended solids that are not attached to the biocarrier. The post-treatment system shown in Figure 4-1 is a compilation of the different combinations that were used during the demonstration. As illustrated, the post-treatment system can incorporate traditional methods for treating other contaminants (e.g., VOCs) that may be present in the influent. Both the BDN and post-treatment systems are discussed in greater detail in the following subsections.

4.2.1 BDN System

EcoMat's BDN system is designed to allow for rapid and compact treatment of nitrate with minimal byproducts. Unique to EcoMat's process is a patented mixed reactor that is designed to retain the biocarrier within the system, thus minimizing solids carryover. A detailed schematic of the EcoMat denitrification reactor flow pattern is shown in **Figure 4-2**.

A 50 percent aqueous methanol (MeOH) solution is added to the system to provide an oxygen scavenger for BDN and a source of carbon for cell growth. The resulting oxygen-deficient environment encourages the bacteria to consume nitrate. Methanol is also important to assure that conversion of nitrate proceeds to the production of nitrogen gas rather than to the intermediate nitrite, which is considered to be more toxic.

The mechanism for anoxic biodegradation of nitrate consists of an initial reaction for removal of excess oxygen followed by two sequential denitrification reactions. This mechanism can be expressed as three separate equations as follows:

Oxygen Removal

$$CH_3OH + 1.5O_2 \text{ -------> } CO_2 + 2H_2O \quad (1)$$

Denitrification Step 1:

$$CH_3OH + 3NO_3^- \text{ -------> } 3NO_2^- + CO_2 + 2H_2O \quad (2)$$

Denitrification Step 2:

$$CH_3OH + 2NO_2^- \text{ -------> } N_2 + CO_2 + 2OH^- + H_2O \quad (3)$$

Table 4-1. Demonstration Objectives.

Objective	Description	Method of Evaluation
Primary Objective		
Objective 1	Evaluate the performance of the EcoMat BDN and post-treatment process components, separately; with respect to the following performance estimates: I. With incoming groundwater having nitrate-N concentrations of 20 mg/l or greater, and operating at a flow through rate of 3-15 gpm, the BDN unit would reduce the combined nitrate-N and nitrite-N (total-N) concentration from PWS Well #1 groundwater to at or below a total-N concentration of 10 mg/l. II. The post treatment unit(s) will produce treated groundwater that will meet applicable drinking water standards with respect to nitrate-N, nitrite-N, and the combined nitrate-N plus nitrite-N. III. Coupled with planned or alternative post-treatment, the product water will consistently meet drinking water requirements, except for residual chlorine. Specifically it will not contain turbidity of greater than 1 NTU, detectable levels of methanol (1 mg/l), or increased levels of biological material or suspended solids, and will have a pH in the acceptable 6.5-8.5 range.	Collect post BDN effluent and final effluent samples from two critical outfalls, interspersed over a period of four events. Determine nitrate-N and nitrite-N concentrations in those effluent samples via EPA Standard Method 300.0. Note: For the purpose of performance evaluation, effluent nitrate-N (and similarly the total-N) concentrations of 10.49 mg/l were to be rounded down to 10 mg/l and therefore considered as meeting the MCL and 10.50 mg/l were to be rounded up to 11 and therefore considered as failing the MCL. Similarly, nitrate-N concentrations of 1.49 mg/l were to be rounded down to 1 mg/l and therefore considered as meeting the MCL and 1.50 mg/l were to be rounded up to 2 mg/l and therefore considered as failing the MCL. These decisions were based on discussions with the KDHE and reflect its current practices.<10.5 mg/l when rounded to three significant digits). The detailed statistical equations and data analysis procedures used for evaluating the demonstration data are included in the TER.
Secondary Objectives		
Objective 2	Evaluate the performance of EcoMat's combined BDN and post-treatment system components with respect to influent nitrate-N concentration and with respect to time and/or water flow.	Plot the Objective 1 data versus 1) the influent concentration from PWS Well # 1 and 2) the average flow rate for each event.
Objective 3	Demonstrate that at least 90% of the final effluent samples (downstream of post-treatment) analyzed during the demonstration period for methanol, turbidity, and biological materials meet drinking water requirements or at least do not provide cause for concern where numerical values cannot be used for guidance.	Collect samples for methanol, total heterotrophs, fecal coliform, and facultative anaerobes analyses at a frequency of one per day from all four outfalls and conduct daily turbidity measurements collected at inlet water, post BDN, and final effluent sample streams.
Objective 4	Evaluate the percent mass removal of nitrate-N during each sampling period over the course of the demonstration.	Calculate the total inlet and final effluent nitrate-N masses in grams; determine mass removed as a total and percentage.
Objective 5	Evaluate the effectiveness of the post-treatment system in removing suspended solids, biologically active materials, methanol, and VOCs of interest (e.g., carbon tetrachloride, benzene and tetrachloroethylene).	Collect daily samples at all four outfalls for TSS analysis. Collect inlet water, post-BDN, and final effluent samples for VOC analysis at a frequency of three per event, and conduct PLFA analysis at least once at all four outfalls.
Objective 6	Evaluate the necessity of the post-treatment system for contributing to nitrate and nitrite mass removal.	Compare nitrate-N and nitrite-N mass results before and after post-treatment.
Objective 7	Evaluate the effectiveness of each post-treatment system used during the demonstration for removing suspended solids, bacterial material, methanol and other VOCs.	Compare the data acquired for Objective 3 on an inter-event basis.
Objective 8	Collect and compile information and data pertaining to the cost of implementing the EcoMat BDN Process and necessary post-treatment for the removal of excessive levels of nitrate in drinking water supplies.	Acquire cost estimates from past SITE experience and from developer. Cost treatment for a full-scale system similar in design to the pilot unit used at Bendena. Break down estimates into 12 cost categories that reflect typical cleanup activities at Superfund sites. (See Section 3)

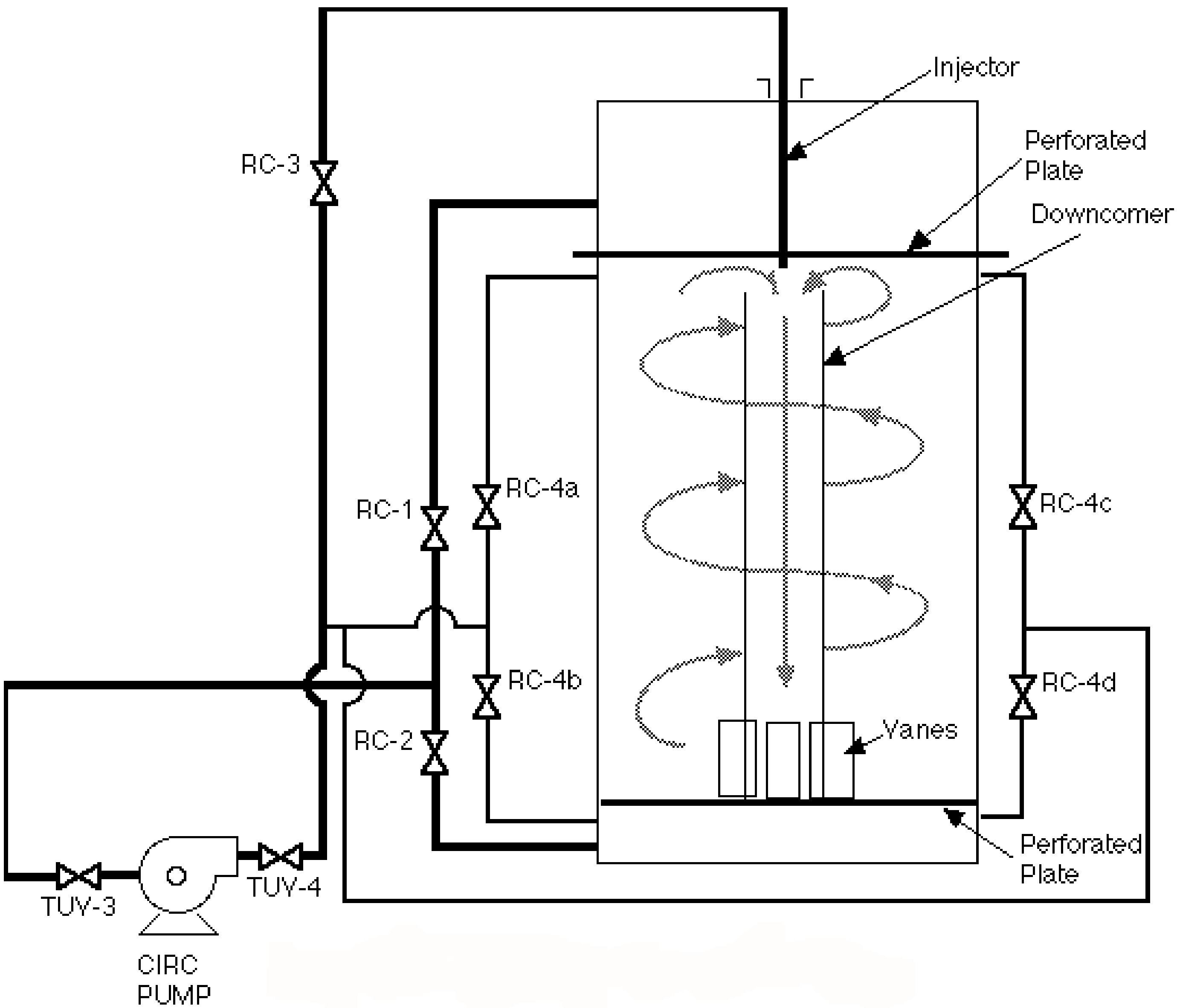


Figure 4-2. Detailed Schematic of the EcoMat Denitrification Reactor.

Overall Denitrification Reaction:

$$5CH_3OH + 6NO_3^- > 3N_2 + 5CO_2 + 6OH^- + 7H_2O \quad (4)$$

Note: The subsequent discussion refers to nitrate-N and nitrite-N values, in which each mg/l of nitrate-N is equivalent to 4.4 mg/l of nitrate and each mg/l of nitrite-N is equivalent to 3.2 mg/l of nitrite.

In the first step, aerobic/facultative bacteria consume oxygen in the process of metabolizing methanol for energy and biomass production. For the first denitrification step (Equation 2) to occur, it is essential that the dissolved oxygen (DO) concentration be less than 1 mg/l. Under these anoxic conditions, the bacteria are forced to substitute the nitrate as the electron acceptor and the nitrate is reduced to nitrite. In the third equation, the nitrite is further reduced to nitrogen gas. Nitrite production is an intermediate step and there is no *a priori* reason to assume that the second reaction (Equation 3) is at least as fast as and/or favored over the first reaction (Equation 2) in the presence of a specific bacterial population. Consequently, any evaluation scheme must establish that there is no buildup of nitrite, particularly since the nitrite-N maximum contaminant level (MCL) is only 1 mg/l, one tenth that of nitrate-N. High concentrations of nitrate and high nitrate/methanol ratios tend to increase the concentration of residual nitrite-N.

BDN is conducted in two reactors, identified as R1 and R2 on Figure 4-1. The majority of the oxygen removal step (Equation 1) is conducted within R1, which EcoMat refers to as the "Deoxygenating Tank". Inside this tank are bioballs (a standard type of biocarrier) which have been loaded with de-nitrifying bacteria purchased from a commercial vendor. These aerobic bacteria initially reduce DO levels of the contaminated influent. A 50 percent aqueous MeOH solution is metered to the tank to encourage the bacteria to begin consuming nitrate in the resulting oxygen deficient water.

The deoxygenated water is pumped from the bottom of R1 to the bottom of R2, which is referred to by the developer as the "EcoMat Reactor". R2 is packed with a synthetic polyurethane biocarrier called "EcoLink", which serves as the biocarrier for a colony of additional bacteria that are also cultured for degrading nitrate. The EcoLink media are 1-cm^3 cubes of sponge-like material that provide a large surface area for growing and sustaining an active bacteria colony. The cubes have contiguous holes so that bacteria can populate them and nitrogen gas can exit. A special additive to the polyurethane makes the surface more hospitable to the bacteria.

Specially designed mixing apparatus within R2 directs the inflowing water into a circular motion, which keeps the suspended media circulating and enables the contaminated water to have intimate contact with the bacteria. Perforated plates at the bottom and top of R2 retain the EcoLink biocarrier within the reactor, while permitting passage of the water. Before the production of nitrogen gas starts the specific gravity of EcoLink is slightly greater than that of water. Within R2, the majority of denitrification (Equations 2 and 3) is conducted by the established anaerobic bacteria colonies that are continually fed methanol as a carbon source. After a sufficient retention time the denitrified water drains by gravity to an overflow tank, which allows for a continuous and smooth transfer to the post-treatment system.

4.2.2 Post-Treatment System

The post-treatment system can be comprised of two primary treatment components; an oxidation component and a filtration component. The oxidation component is intended to oxidize residual nitrite back to nitrate, oxidize any residual methanol, and destroy bacterial matter exiting the EcoMat Reactor (R2). The oxidation component may consist of chlorination, ozonation, or UV treatment; or a combination of the three. During the demonstration, chlorination was used for two events, UV was used for one event, and an ozone/UV combination was used for one event.

The filtration component usually consists of a clarifying tank and one or more filters designed to remove suspended solids generated from the BDN process. During the demonstration, a variety of filter combinations were used, including a sand filter, and a series of variable-sized cartridge filters. The cartridge filters that were used included "rough filters" (20µm), "high efficiency filters" (5µm), and "polishing filters" (1µm). Carbon cartridge filters and an air stripper were used during Events 3 and 4, respectively, to remove small amounts of CCl_4.

4.3 Field Activities

4.3.1 Pre-Demonstration Activities

To confirm contaminant concentrations for the demonstration and assist in sizing the system, pre-demonstration samples were taken from PWS Well # 1 over a nine-day period (September 22-30,1998). Since the pilot-scale system was expected to be operated within the 3-15 gpm range, it was decided to pump groundwater from the well at 10 gpm during the nine-day period. To provide an indication of the variation in nitrate-N concentrations, one sample was collected every two hours over a four-hour period, at the same times each day. It was also realized during the pre-demonstration activities that pumping at a rate of 20 gpm over a five-day period lowered the water level in the well by about 10 feet, over 20 percent of the water column. When the pumping rate was reduced to about 10 gpm, there was little drawdown in the well.

4.3.2 Sample Collection and Analysis

The sampling strategy for evaluating the effectiveness of EcoMat's BDN Process was developed around comparing the post BDN and final effluent (after post-treatment) data to applicable regulatory limits. This comparison addresses the project Primary Objective as presented in Table 4-1.

As was explained previously, there were four separate treatment events during the demonstration. These events were partially determined based on anticipated changes to the post-treatment system. The events were spread out over several months to allow for evaluating the EcoMat technology over a longer time duration.

The goal of the sampling strategy was to collect sufficient samples at each critical outfall during each event so that statistical hypothesis tests could be conducted with an α error rate = 0.10 and a β error rate = 0.10. (The method for calculating the number of samples is presented in more detail in the TER). Using 5.5 mg/l as an estimate of the population variance in the final effluent nitrate-N + nitrite-N (total-N) measures, the number of sampling rounds required per event was found to be 29.

The SITE Program conducted on average ~ 30 sample sampling rounds for each event. Since the samples were collected at each of the four locations at the same time, the resulting sample sets were comparable for evaluating the EcoMat process at different points of the process; either on a "per sample round" or "per event" basis. In order to achieve some level of "flushing" between sampling rounds, the daily sampling frequency during each event was dependent on the water flow rate through the system. Because the flow rate was varied for each event, the number of daily sampling rounds for collecting sample sets varied from 3 to 5 per day.

The effectiveness of the post-treatment systems for all events was evaluated by collecting samples immediately downstream of the BDN system ("post BDN"), and immediately downstream of the developer-selected post-treatment components ("final effluent"); then comparing the sample results from the two outfalls with respect to a variety of microbial and water quality parameters. These parameters included, but were not limited to, residual methanol, total suspended solids (TSS), turbidity, total culturable heterotrophs (TCH), Fecal Coliform (FC), and facultative anaerobes (FA). Phospholipid fatty acids (PLFA) were analyzed for on a very limited basis. Since these limited PLFA results do not impact any developer claims, those results are presented in the TER only.

Table 4-2 presents a summary of the laboratory analyses conducted on samples collected from each of the four sampling points monitoring the EcoMat treatment process, and for the methanol feed (the main additive for the process). All samples collected were grab samples.

4.3.3 Process Monitoring

Process monitoring was conducted on a routine daily basis during all four sampling events. **Table 4-3** presents the type of process monitoring conducted during the demonstration, the frequency and location of that monitoring, and the instrumentation used. Details are provided in the following subsections.

4.3.3.1 Nitrate-N and Nitrite-N Colorimeter Testing

Although daily samples were being collected during each event for laboratory nitrate-N and nitrite-N analyses, colorimeter testing was also conducted daily to approximate real time values for those critical parameters. These measurements aided the developer in making adjustments to its system and aided the analytical laboratory in determining calibration ranges. An on-line nitrate monitor was also installed to provide a continuous record of nitrate entering and leaving the treatment system, but the unit could not be operated routinely and no useful records were obtained.

4.3.3.2 Process Flow Rate

Flow measurements were taken from a totalizer meter to ensure that sampling rounds were being conducted at the properly-spaced time intervals (i.e., the treated water correlated to the previous sampling round had exited the entire treatment system).The flow measurements were also used for later calculation of flow rates that could be correlated to analytical results for each sampling round conducted. A calibration check of the Neptune totalizer gauge was conducted for each event to assure accuracy of the meter.

4.3.3.3 General Water Quality Parameters

Daily measurements of general water quality parameters were taken at all four outfalls to monitor parameters that either could directly affect biological activity (e.g., temperature and DO) or were to be used to evaluate system performance with respect to secondary objectives (e.g., pH and turbidity). All water quality parameters were measured with field instrumentation that was calibrated per manufacturer instructions prior to taking the measurements.

4.3.4 Process Residuals

During the demonstration the developer was responsible for disposing of process residuals. These mostly included spent cartridge filters, spent biocarrier, and spent carbon.

Due to the fact that nitrate and nitrite are non-hazardous with respect to RCRA regulations, and that VOC concentrations were negligible, all residuals from the process were considered non-hazardous. Thus the spent

Table 4-2. Summary of Laboratory Analyses Conducted for the Demonstration.

PARAMETER	Test Method	SAMPLE LOCATION POINTS				METHANOL FEED
		INLET WATER	PARTIAL BDN	POST BDN	FINAL EFFLUENT	
Chemical Analyses						
Nitrate-N	EPA 300.0	Each Round [1]	Each Round [1]	Each Round [1]	Each Round [1]	---
Nitrite-N	EPA 300.0	Each Round [1]	Each Round [1]	Each Round [1]	Each Round [1]	---
TSS	EPA 160.2	1 per day	1 per day	1 per day	1 per day	---
Methanol	SW 8015	1 per day	1 per day	1 per day	1 per day	---
VOCs	SW 8260	3 per Event	---	3 per Event	3 per Event	2 per Demo.
Total Metals	SW 3010/6020	3 per Event	---	3 per Event	3 per Event	---
Sulfate	EPA 300.0	3 per Event	---	3 per Event	3 per Event	---
Alkalinity	EPA 310.1	3 per Event	---	3 per Event	3 per Event	---
Total Solids	EPA 160.3	3 per Event	---	3 per Event	3 per Event	---
Phosphate	EPA 300.0	3 per Event	---	3 per Event	3 per Event	---
Ammonia	EPA 350.2	3 per Event	---	3 per Event	3 per Event	---
Total Organic Carbon	SW 9060	3 per Event	---	3 per Event	3 per Event	---
Microbial Analyses						
Total Heterotrophs	SOP	1 per day	1 per day	1 per day	1 per day	---
Fecal Coliform	SOP	1 per day	1 per day	1 per day	1 per day	---
Facultative Anaerobes	SM 9215 M	1 per day	1 per day	1 per day	1 per day	---
PLFA	SOP GCLIP	1 for Event 1	1 for Event 1; 1 for Event 4	1 for Event 1; 1 for Event 4	1 for Event 1	---

[1] Refers to a round of samples collected from the process sample location points (Figure 4-1) at approximately the same time.
Dashed line indicates that samples collected at that location were not analyzed for that parameter.

Table 4-3. Summary of Field Measurements Conducted for the Demonstration.[1]

PARAMETER	INSTRUMENTATION	SAMPLE LOCATION POINTS			
		INLET WATER	PARTIAL BDN	POST BDN	FINAL EFFLUENT
Nitrate-N	Hach DR-890 Colorimeter	1 per day	---	1 per day	---
Nitrite-N	Hach DR-890 Colorimeter	---	---	1 per day	---
Flow Rate	Neptune Totalizer	Each Round	Each Round	Each Round	Each Round
pH	YSI Mod. 63 pH/Cond. meter	1 per day	1 per day	1 per day	1 per day
Conductivity	YSI Mod. 63 pH/Cond. meter	1 per day	1 per day	1 per day	1 per day
Dissolved Oxygen	YSI M95 DO meter	1 per day	1 per day	1 per day	1 per day
Temperature	YSI M95 DO meter	1 per day	1 per day	1 per day	1 per day
Turbidity	LaMotte 2020 Turbidmeter	1 per day	1 per day	1 per day	1 per day

[1] In addition, daily water levels of PWS Well #1 were recorded and electric usage was periodically recorded during each Event.
Dashed line indicates that samples collected at that location were not analyzed for that parameter.

filter cartridges, carbon, biocarrier, etc. were simply collected in a trash container and disposed of in a solid waste dumpster.

The final effluent was deemed non-hazardous by the KDHE, who arranged for a permit to discharge the treated water to a septic system installed in an agricultural field downgradient of the EcoMat treatment shed and PWS Well #1.

4.4 Performance and Data Evaluation

This subsection presents in summary form the performance data obtained during the EcoMat SITE Demonstration conducted from May to December, 1999. The data are presented in two ways. Subsections 4.4.1 through 4.4.4 evaluates each sampling event (i.e., Events 1 through 4, respectively), independently, with respect to the objectives listed in Table 4-1. Subsection 4.4.5, on the other hand, compares all four events. The latter inter-event comparison may provide the reader with a better understanding of the overall demonstration. Subsection 4.4.6 summarizes data quality assurance aspects of the demonstration.

Since the post-treatment system was varied for each event, the data from the four events were initially analyzed separately. Then a comparison between events was performed. The level of significance (LOS) or α error rate was set to 0.10 for the various statistical tests performed. These tests included the Shapiro-Wilk tests of Normality followed by either the Wilcoxon Signed Rank test or the Student's t-test. The Wilcoxon Signed Rank (WSR) test is a non-parametric, one-sample test, used to test the median against a fixed threshold such as a regulatory limit. The one-sample Student's t-test is a parametric test which tests the mean against a fixed threshold.

Within each of these subsections, the following discussions are presented in sequence:

- a summary of the effectiveness of the EcoMat BDN and post-treatment systems at the various sampling points.
- results of the statistical analysis that were conducted to compare post BDN and final effluent data to the appropriate regulatory limits.
- an evaluation of the BDN system.
- post-treatment system performance.
- a summary on the mass removal of nitrate.
- a discussion of the possible relationship between system performance and flow rate.

To evaluate the post BDN and final effluent data against regulatory limits, the following analytical strategy was used. For each separate event, an Exploratory Data Analysis (EDA) was conducted for the post BDN combined nitrate-N/nitrite-N (total-N), the final effluent nitrate-N, the final effluent nitrite-N, and the final effluent total-N. The EDA consisted of graphing the data in several formats and calculating summary statistics (i.e., mean, median, and standard deviation). These graphs and summary statistics were used to make preliminary assumptions about the shape of the distributions of the variables. This information was needed in order to identify the appropriate statistical hypothesis tests for the data.

After reviewing the graphs and summary statistics, Shapiro-Wilk tests of Normality were performed. Based on the results of these tests, either the WSR test or the Student's t-test was chosen as the appropriate hypothesis test (i.e., the non-parametric WSR test was chosen when the data did not fit either a normal or log-normal distribution and the Student's t-test was chosen when the data resembled a normal distribution). When the WSR test was used the mean of the variable was evaluated against the appropriate demonstration criterion. When the Student's t-test was used the median of the variable was evaluated against the appropriate demonstration criterion.

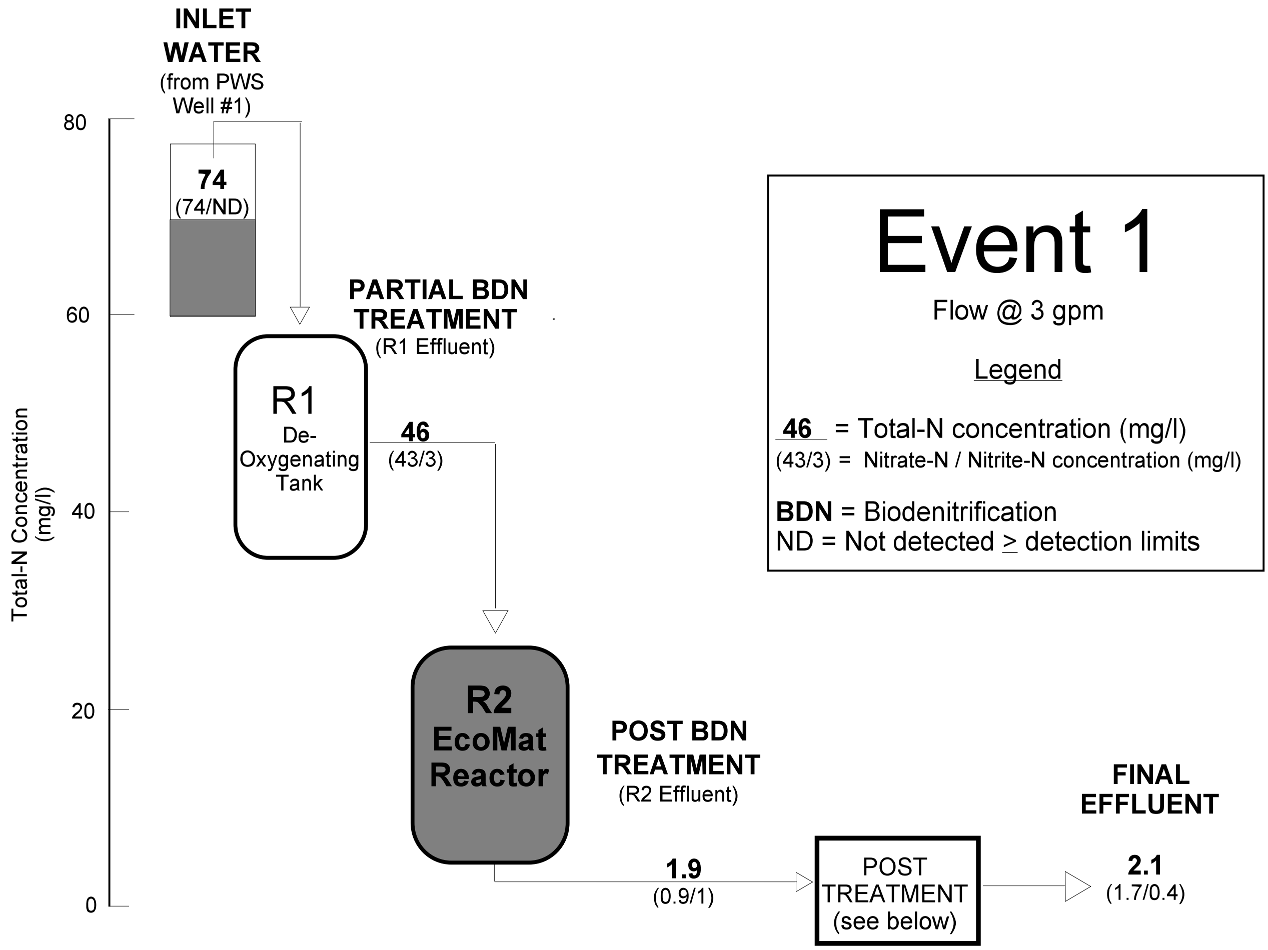
The demonstration criterion was the regulatory limit when rounded to a whole number. The post BDN total-N was tested against the demonstration criterion of < 10.5 mg/l (i.e., regulatory limit = 10 mg/l), using an α error rate of 0.10. The final effluent had to meet a combined criteria where the mean or median nitrate-N was < 10.5 mg/l (i.e., regulatory limit = 10 mg/l), the mean or median nitrite-N was < 1.5 mg/l (i.e., regulatory limit = 1 mg/l), *and* the mean or median total-N was below 10.5 mg/l (i.e., regulatory limit = 10 mg/l). All three of these criteria had to be met in order for the technology to be considered successful. Therefore, a family-wise α error rate was set at 0.10 for these three tests.

4.4.1 Event 1

4.4.1.1 Summary

Event 1 was an 11-day sampling episode conducted May 5-15, 1999. During Event 1 a total of 28 sampling rounds were conducted and ~42,000 gallons of nitrate-contaminated well water passed through EcoMat's treatment system at an average flow rate of 3 gpm. Based on average flow rate and an estimated retention capacity of 1,300 gallons for the reactor tanks, the sample rounds were conducted three times per day and approximately seven hours apart.

Figure 4-3 separately illustrates the effectiveness of the EcoMat BDN and post-treatment systems evaluated during Event 1, on an averaged basis (Note: the term average is also referred to as the mean in subsequent discussions). The top illustration shows BDN effectiveness for reducing nitrate in the well water as a step-by-step process. As



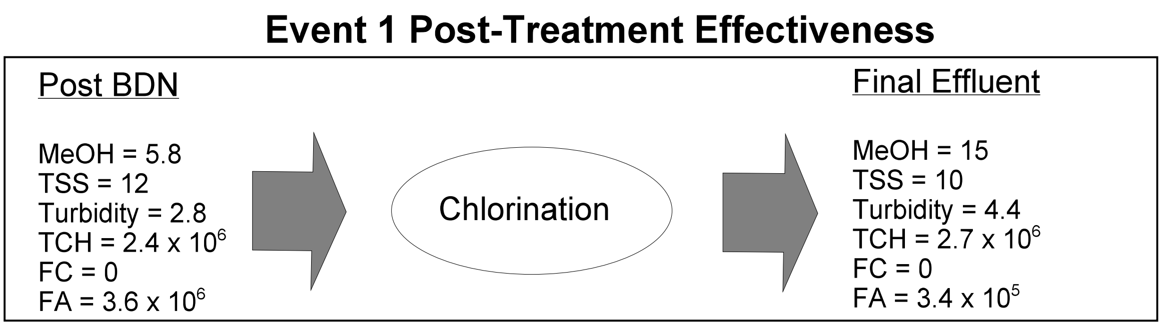


Figure 4-3. Event 1 - Treatment Effectiveness for Averaged Test Results.

illustrated, the nitrate-N concentration in PWS Well #1was in excess of 70 mg/l during the first event in May of 1999. This high level of nitrate-N was reduced by about 38% during the partial BDN treatment process that occurred in the first reactor (R1). A small amount of nitrite, 3 mg/l, remained from the nitrate-nitrite conversion. Subsequent treatment in the EcoMat Reactor (R2) further reduced the mean nitrate-N concentration from 43 mg/l to 0.9 mg/l and reduced the mean nitrite-N level from 3 mg/l to 1 mg/l. Thus, a mean total-N concentration of 1.9 mg/l was attained by BDN treatment for Event 1 effluent samples.

Post-BDN and final effluent samples had essentially the same total-N concentration. Mean total-N concentrations for post-BDN and final effluent samples were 1.9 mg/l and 2.1 mg/l, respectively. However, the mean nitrate-N concentration increased approximately twofold and the mean nitrite-N concentration decreased by more than half.

At these low levels, variability in laboratory analyses may be an explanation, although continued biological activity between the BDN and post-treatment processes may also be a contributing factor. Alternatively, the post-treatment chlorination may simply be re-oxidizing nitrite back to nitrate.

As shown in the bottom illustration of Figure 4-3, the only post-treatment conducted during Event 1 was chlorination. The addition of chlorine had little effect on mean concentrations of methanol. The mean methanol and turbidity levels actually increased following post-treatment, while mean TSS concentrations remained essentially the same. As a disinfecting agent, the chlorination may have had a modest impact on residual biological material. Although TCH remained essentially the same, FA counts were measured on average to decrease by one order of magnitude. There was no growth for FC, thus there was no measured post-treatment effect for that parameter.

4.4.1.2 Event 1 Statistical Analysis

The summary statistics for the critical measurements are presented in **Table 4-4**. The nitrate-N, the nitrite-N, and the total-N results for the four sampling locations, for all 28 tests comprising Event 1 are shown in **Table 4-5**. The average (i.e., mean) values from these data were used in generating Figure 4-3. These data were also used to evaluate the Primary Objective (*Objective 1*).

Table 4-4. Event 1 - Summary Statistics.

Critical Measurement	Mean (mg/l)	Median (mg/l)	Standard Deviation (mg/l)
Post BDN Total-N	1.917	1.270	1.474
Final Effluent Nitrate-N	1.654	1.600	1.509
Final Effluent Nitrite-N	0.410	0.113	0.424
Final Effluent Total-N	2.064	1.676	1.445

The EDA showed that the data for all four measurements from Event 1 more closely resembled a lognormal than a normal distribution. However, normality and lognormality were rejected for all measurements, using an α error rate of 0.10. (In other words, at the selected or error rate of 0.10, these data did not fit either a normal or a lognormal distribution). Therefore, the non-parametric WSR was chosen for analyzing the data and the median was used as the appropriate measure of central tendency.

Statistical hypothesis tests that were conducted yielded the following results:

- Part I: Post BDN median total-N of 1.27 mg/l was significantly below the criterion of 10.5 mg/l.
- Part II: Final Effluent met the combined criterion. The median total-N of 1.68 mg/l was significantly below the criterion of 10.5 mg/l.

Based on the results of these 2 hypothesis tests, Event 1 was shown to be successful in reducing levels of nitrite-N and nitrate-N to below regulatory limits, with a LOS of 0.10. A more detailed explanation of these results is presented in the TER.

4.4.1.3 General Evaluation of BDN System

Table 4-6 presents a summary of all performance criteria results for Event 1. This includes the post-BDN and final effluent nitrate-N, nitrite-N, and total-N data for each of the 28 Event 1 tests. Also included are the additional analytical and field measurement data for specific outfalls that were used for evaluating other performance criteria. As shown, the objectives regarding reductions in nitrate-N, nitrite-N, and total-N in final effluent were attained for all 28 sample sets. However, other performance criteria results indicated the need for more substantial post-treatment, especially for treating residual methanol and removing microbial matter.

The daily DO measurements in **Table 4-7** are key indicators for evaluating the effectiveness of the deoxygenating step required for triggering the anaerobic BDN process. The data show that the deoxygenating process was effective in reducing an average inlet water DO of 10 mg/l to approximately 1 mg/l in partially treated water exiting the Deoxygenating Tank.

4.4.1.4 General Evaluation of Post-Treatment System

Presented in this subsection are the field and laboratory measurement data that were used primarily for evaluating the post-treatment component of EcoMat's process during Event 1 (*Objective 5*). Parameters included pH, turbidity, TSS, microbial analyses, methanol, and "supplemental analyses" which included a variety of parameters sampled and analyzed on a limited basis.

The daily pH measurements in **Table 4-8** show a slight increase in pH to occur following BDN treatment. The post-treatment chlorination that followed BDN may have caused a very slight upward shift in the pH range. This negligible effect was expected since chlorination is not a pH-altering post-treatment (i.e., as opposed to ozone).

The daily turbidity measurements in **Table 4-9** are considered a gross indicator measurement for evaluating the production of solids in the BDN system and a measure of the effectiveness of the post-treatment system in removing solids carryover. Since there is a secondary criteria drinking water standard associated with turbidity, each day of sampling was evaluated independently to

Table 4-5. Event 1 - Nitrate-N and Nitrite-N Results (mg/l).

Sample Round [1]	Inlet Water			Partial BDN			Post BDN			Final Effluent		
	Nitrate-N	Nitrite-N	Total-N [2]	Nitrate-N	Nitrite-N	Total-N [2]	Nitrate-N	Nitrite-N	Total-N [2]	Nitrate-N	Nitrite-N	Total-N [2]
1	77.9	<0.076	77.9	34.9	4.8	39.7	1.2	1.3	2.5	2.5	< 0.15	2.65
2	77.7	<0.076	77.7	47.9	2.9	50.8	1.2	0.67	1.87	2.2	< 0.15	2.35
3	79.2	<0.076	79.2	50.0	2.6	52.6	4.7	1.1	5.8	5.3	0.26	5.56
4	79.3	<0.076	79.3	47.7	3.3	51.0	3.7	1.4	5.1	3.8	1.3	5.10
5	79.5	<0.076	79.5	50.5	2.9	53.4	0.63	0.64	1.27	2.1	< 0.076	2.18
6	79.2	<0.076	79.2	49.7	3.6	53.3	2.4	1.4	3.8	2.9	1.0	3.90
7	79.7	<0.076	79.7	43.3 J	3.8	47.1 J	0.76	0.74	1.5	1.2	0.51	1.71
8	78.6	<0.076	78.6	49.1	3.3	52.4	1.3	0.82	2.12	0.087	< 0.076	0.16
9	74.3 J	<0.076	74.3 J	38.7 J	4.6 J	43.3 J	0.65 J	0.42 J	1.07 J	1.7 J	< 0.076	1.78
10	73.7 J	<0.076	73.7 J	46.1 J	2.9 J	49.0 J	0.72 J	R	NC	1.6 J	< 0.076	1.68
11	73.7	<0.076	73.7	48.5	2.9	51.4	3.7	2.3	6.0	6.2	< 0.076	6.28
12	72.4	<0.076	72.4	42.0	3.7	45.7	0.77	0.92	1.69	2.2	< 0.076	2.28
13	73.4	<0.076	73.4	42.2	2.9	45.1	0.47	0.87	1.34	1.6	< 0.076	1.68
14	71.4	<0.076	71.4	43.0	2.5	45.5	0.92	0.86	1.78	1.7	< 0.076	1.78
15	72.2	<0.076	72.2	39.9	2.8	42.7	0.22	0.77	0.99	1.5	< 0.076	1.58
16	73.6	<0.076	73.6	45.2	2.5	47.7	0.14	1.0	1.14	0.57	0.83	1.40
17	72.4	<0.076	72.4	41.6	2.9	44.5	0.21	0.79	1.0	0.097	0.78	0.88
18	69.8	<0.076	69.8	41.3	2.8	44.1	0.27	0.91	1.18	0.14	0.83	0.97
19	71.0	<0.076	71.0	43.8	2.4	46.2	0.084	0.97	1.05	< 0.056	0.86	0.92
20	72.2	<0.076	72.2	43.3	2.5	45.8	0.068	0.69	0.76	< 0.056	0.67	0.73
21	71.0	<0.076	71.0	41.1	2.6	43.7	0.14	0.93	1.07	1.4	< 0.076	1.48
22	71.5	<0.076	71.5	42.8	2.6	45.4	0.07	1.1	1.17	1.8	< 0.076	1.88
23	69.7	<0.076	69.7	43.0	2.5	45.5	0.22	1.3	1.52	1.8	< 0.076	1.88
24	69.6	<0.076	69.6	39.8	3.6	43.4	0.23	1.0	1.23	1.6	< 0.076	1.68
25	68.9	<0.076	68.9	39.1	2.7	41.8	0.085	1.1	1.19	0.13	1.1	1.23
26	69.1	<0.076	69.1	40.9	2.7	43.6	0.057	1.2	1.26	< 0.056	1.1	1.16
27	69.2	<0.076	69.2	19.3	1.4	20.7	< 0.056	0.88	0.88	1.46	< 0.076	1.54
28	67.9	<0.076	67.9	42.4	2.5	44.9	0.14	1.3	1.44	0.57	0.88	1.45
Mean [3]	**74 J**	**ND**	**74 J**	**43 J**	**3.0 J**	**46 J**	**0.9 J**	**1.0 J**	**1.9 J**	**1.7 J**	**0.4**	**2.1**

[1] Represents a sample set in which samples from all four locations were collected at the approximate same time.
[2] Represents combined Nitrate-N and Nitrite-N in which values < the detection limit were considered zero for summing totals.
[3] Means are rounded to two significant digits. Values < detection limit considered zero for calculating means.
J = Estimated value. R = Value rejected by QC. NC = Not calculated. ND = Not detected at or above MDL.

Table 4-6. Event 1 - Summary of Treatment Effectiveness.

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	Nitrate-N/Nitrite-N Results (mg/l)				Final Effluent - Other Performance Criteria					
	Post BDN	Final Effluent								
Sample Round[1]	Total-N [2]	Nitrate-N	Nitrite-N	Total-N [2]	Flow (gpm)	MeOH (mg/l)	TSS (mg/l)	Turbidity (NTU)	pH [3] (SU)	Total Heterotrophs (CFU/ml)[3]
1	2.5	2.5	< 0.15	2.65	---	91	9	8.6	7.7 / 8.6	1,300 / NG
2	1.87	2.2	< 0.15	2.35	3.2	---	---	---	---	---
3	5.8	5.3	0.26	5.56	3.1	---	---	---	---	---
4	5.1	3.8	1.3	5.10	3.1	< 0.23	9	3.1	7.7 / 8.2	2,300 / 2,000,000
5	1.27	2.1	< 0.076	2.18	3.1	---	---	---	---	---
6	3.8	2.9	1.0	3.90	0.02 [4]	---	—	—	—	—
7	1.5	1.2	0.51	1.71	5.3	< 0.23	6	3.1	7.5 / 7.5	NG / 4,500,000
8	2.12	0.087	< 0.076	0.16	---	---	---	---	---	---
9	1.07 J	1.7 J	< 0.076	1.78	---	---	---	---	---	---
10	R	1.6 J	< 0.076	1.68	2.6	5	10.5	5.2	8.1 / 8.2	---
11	6.0	6.2	< 0.076	6.28	2.8	---	---	---	---	---
12	1.69	2.2	< 0.076	2.28	3.1	3.4	10	4.8	8.1 / 7.7	---
13	1.34	1.6	< 0.076	1.68	2.9	---	---	---	---	---
14	1.78	1.7	< 0.076	1.78	3.5	7.8	11.5	5.0	7.7 / 8.2	NG / 670
15	0.99	1.5	< 0.076	1.58	3	---	---	---	---	---
16	1.14	0.57	0.83	1.40	3	---	---	---	---	---
17	1.0	0.097	0.78	0.88	3.1	< 0.23	10	2.0	7.8 / 8.1	3,200 / 3,200,000
18	1.18	0.14	0.83	0.97	2.8	---	---	---	---	---
19	1.05	< 0.056	0.86	0.92	2.8	---	---	---	---	---
20	0.76	< 0.056	0.67	0.73	2.9	< 0.23	11.3	2.8	7.8 / 8.3	1,000 / 7,200,000
21	1.07	1.4	< 0.076	1.48	3	---	---	---	---	---
22	1.17	1.8	< 0.076	1.88	3	---	---	---	--	---
23	1.52	1.8	< 0.076	1.88	3.2	27	10.5	6.2	7.7 / 8.2	1,800 / 1,300
24	1.23	1.6	< 0.076	1.68	2.9	---	---	---	---	---
25	1.19	0.13	1.1	1.23	3	---	---	---	---	---
26	1.26	< 0.056	1.1	1.16	2.9	< 0.23	14.2	2.8	---	---
27	0.88	1.46	< 0.076	1.54	2.9	---	---	---	---	---
28	1.44	0.57	0.88	1.45	3	26	11	4.8	---	---
Mean [5]	**1.9** J	**1.7** J	**0.4**	**2.1**	**3**	**14.6**	**10.3**	**4.4**	**7.5-8.6**	**1,400 / 2,700,000**

[1] Represents a sample set in which samples from all four locations were collected at the approximate same time.
[2] Total-N is equal to the combined Nitrate-N + Nitrite-N concentration.
[3] The first value represent the inlet water and the second value represents the final effluent.
[4] Flow rate value represents a likely interruption in the system followed by increased flow to compensate.
[5] All values, except for pH, are means, rounded to two significant digits. Values < detection limit considered zero when calculating means.
R = Value rejected by QC. J = Estimated value. Dashed line indicates that samples collected at that location were not analyzed for that parameter.

Table 4-7. Event 1 - Dissolved Oxygen Measurements (mg/l).

DATE	TIME INTERVAL	Associated Round No(s.)[1]	SAMPLE POINT			
			Inlet Water	**Partial BDN**	**Post BDN**	**Final Effluent**
5-5-99	1000-1100	1	9.76	2.34	6.17	7.00
5-5-99	1600-1625	**2**-3	9.78	1.10	4.65	6.78
5-6-99	0930	**4**-6	10.68	1.10	5.70	6.35
5-7-99	1130	7,**8**,9	8.91	1.02	5.30	6.90
5-8-99	1000	**10**-11	11.40	0.92	5.80	5.90
5-9-99	1630	**12**-13	10.98	0.95	6.35	7.95
5-10-99	0930	**14**,15,16	12.04	1.05	5.65	7.15
5-11-99	2030	**17**,18,19	9.66	0.65	4.50	4.52
5-12-99	0945	**20**,21,22	9.52	1.28	4.50	4.20
5-13-99	0900	**23**,24,25	9.48	1.00	4.90	5.35
5-14-99	0945	26-27	9.67	0.91	4.85	5.02
5-15-99	~ 0730	28	9.61	0.72	4.92	5.90
		Mean [2]	**10**	**1.1**	**5.3**	**6.1**

[1] Sample rounds conducted closest in time to the measurement are bolded. [2] Mean values are rounded to two significant digits.

Table 4-8. Event 1 - pH Measurements.

DATE	TIME INTERVAL	Associated Round No(s.)[1]	SAMPLE POINT			
			Inlet Water	**Partial BDN**	**Post BDN**	**Final Effluent**
5-5-99	1000-1100	1	7.74	7.81	8.43	8.61
5-5-99	1445-1500	**2**-3	7.67	7.73	8.24	8.45
5-6-99	0727-1100	**4**-6	7.66	7.66	8.21	8.21
5-7-99	1315-1330	7,**8**,9	7.50	7.5	7.2	7.5
5-8-99	0758-0810	**10**-11	8.10	7.58	8.20	8.23
5-9-99	1455-1510	**12**-13	8.07	7.5	7.5	7.7
5-10-99	0837-0850	**14**,15,16	7.70	7.79	8.0	8.20
5-11-99	0805-0825	**17**,18,19	7.79	7.75	8.05	8.12
5-12-99	0832-0859	**20**,21,22	7.79	7.78	8.15	8.25
5-13-99	0942-0955	**23**,24,25	7.65	7.74	8.12	8.21
5-14-99	---	26-27	---	---	---	---
5-15-99	---	28	---	---	---	---
		Range [2]	**7.5 - 8.1**	**7.5 - 7.8**	**7.2 - 8.4**	**7.5 - 8.6**

[1] Sample rounds conducted closest in time to the measurement are bolded. [2] Range values are rounded to two significant digits.
Dashed line indicates that samples collected at the locations were not analyzed for that parameter.

Table 4-9. Event 1- Turbidity Measurements (NTU).

DATE	TIME INTERVAL	Associated Round No(s.)[1]	SAMPLE POINT				Pass/ Fail [2]
			Inlet Water	**Partial BDN**	**Post BDN**	**Final Effluent**	
5-5-99	1000-1100	1	0.00	---	4.4	8.6	F
5-6-99	0727-1100	**4**-6	0.00	0.00	3.4	3.10	F
5-7-99	0941-0950	7,**8**,9	0.00	0.00	2.95	3.13	F
5-8-99	0835-0844	**10**-11	0.00	0.00	1.69	5.15	F
5-9-99	1555-1610	**12**-13	0.00	0.00	2.14	4.81	F
5-10-99	0752-0800	**14**,15,16	0.00	0.00	2.68	5.03	F
5-11-99	0758-0820	**17**,18,19	0.00	0.00	2.31	2.00	F
5-12-99	0847-0855	**20**,21,22	0.00	0.00	2.85	2.82	F
5-13-99	0847-0855	**23**,24,25	0.00	0.00	2.62	6.18	F
5-14-99	1005-1010	26-27	0.00	0.00	2.61	2.75	F
5-15-99	0715	28	0.00	0.00	3.63	4.82	F
		Mean [3]	**0.00**	**0.00**	**2.8**	**4.4**	**0/11**

[1] Sample rounds conducted closest in time to the measurement are bolded.
[2] A sample round is considered passing if the final effluent value is ≤ 1 NTU. In the last row, the number of passing values is shown in the numerator; the total number of values (pass + fail, minus any blank values) is shown in the denominator.
[3] Mean values are rounded to two significant digits.
Dashed line indicates that samples collected at that location were not analyzed for that parameter.

determine if final effluent met the goal of ≤ 1 normal turbidity units (NTU) (*Objective 3*). The readings indicate turbidity to be measured consistently above that goal each day of sampling and to average 4.4 NTU.

The TSS data in **Table 4-10** provide information on the amount of solids added to the inlet water by the BDN process during Event 1. More importantly, the laboratory-derived TSS data can be used in conjunction with the field turbidity measurements to assess the effectiveness of the post-treatment system for removing those solids. The data show the inlet water to be essentially free of TSS (i.e., only one value was above the MDL). As would be expected, the post-treatment chlorination used during Event 1 had no effect on the increased TSS levels produced during BDN. The average post BDN and final effluent values were essentially the same (12 mg/l and 10 mg/l, respectively). On a per round basis, all final effluent values were greater than their paired inlet water values.

The Event 1 microbial results presented in **Table 4-11** include data for the three separate types of microbial analyses conducted: TCH, FA, and FC. Inlet water, post BDN, and final effluent outfalls were sampled for these parameters.

The results of the TCH analyses can be used to measure the additional bacteria produced by EcoMat's BDN process (relative to inlet water) and to determine how effective the post-treatment system was for removing the increased level of bacteria. The data indicated that the TCH population associated with the BDN process effluent was, on average, three orders of magnitude higher than TCH levels in the well water. The carryover of this bacteria from the BDN process to the final effluent was measured, on average, to exceed 100 percent. Final effluent TCH values were measured to be less than corresponding inlet water TCH values in only two of the seven sampling rounds.

The FA analyses provide a useful measure of the production of active biodenitrifying bacteria during the BDN process. The concentration of these bacteria in inlet water gives some indication of the character and quality of the well water. Their numbers would be expected to greatly increase in the post-BDN effluent and then greatly decrease in final effluent due to post-treatment.

The FA data followed the expected pattern only to a certain degree. The average of the FA plate count mean in inlet water was increased by three orders of magnitude in post BDN effluent. However, the post-treatment effectiveness for reducing FA in final effluent was inconsistent. Final effluent plate count means for individual samples ranged from < 1000 cfu/ml to > 800,000 cfu/ml. The final effluent

Table 4-10. Event 1- TSS Results (mg/l).

Sample Round No.	SAMPLE POINT				Pass/ Fail [1]
	Inlet Water	**Partial BDN**	**Post BDN**	**Final Effluent**	
1	< 5	---	15.2	9	F
4	< 5	---	7.5	9	F
7	< 5	---	8	6	F
10	5.5	---	14.7	10.5	F
12	< 5	---	9.5	10	F
14	< 5	---	12.7	11.5	F
17	< 5	---	12	10	F
20	< 5	---	13.3	11.3	F
23	< 5	---	14	10.5	F
26	< 5	---	12.7	14.2	F
28	< 5	---	14	11	F
Mean [2]	**< 5**	**---**	**12**	**10**	**0/11**

[1] A sample round is considered passing if the final effluent value is ≤ the inlet water value. In the last row, the number of passing values is shown in the numerator; the total number of values (pass + fail, minus any blank values) is shown in the denominator.
[2] Mean values are rounded to two significant digits. Values < detection limit are considered zero when calculating means.

mean value was less than the inlet water mean value for only one sample round.

A possible contributing factor to the high variability of post-treatment performance on FA could have been the lack of controlled chlorination. At least on one occasion during Event 1, the chlorine tablets being used were completely depleted without being replenished for an indefinite time period. This lapse was recorded to occur a couple of hours after round #20 samples were collected and almost a day before round #23 samples were collected. Round #20 and the preceding round #17 had the two poorest results with respect to large percentage increases in FA as measured from post-BDN to final effluent (i.e., > 100 % carryover from BDN); whereas for round #23 the final effluent was measured to have had less than 6% of the post-BDN plate count mean.

The FC analyses can be used to compare the quality of the inlet water with final effluent. Ideally, there should be no increase. Since fecal coliform are aerobic, they could become dormant during the BDN process and difficult to measure among the other bacteria. For Event 1, there was no growth of FC measured in inlet water, nor was there any growth for the post-BDN and final effluent streams.

Table 4-12 presents the Event 1 laboratory results for methanol analyses conducted on inlet water, post-BDN effluent, and final effluent. There were small detectable concentrations of methanol in three of the eleven inlet water samples. Round #1 results indicate that initially there may have been a larger than expected imbalance in the methanol-nitrate ratio, causing excess methanol in the post-BDN effluent to carry over to the final effluent. For all subsequent test samples, methanol was not detectable in the post-BDN effluent, indicating that most of the carbon source had been used up in the BDN process. There is no explanation why detectable concentrations of methanol were measured in five of the final effluent samples corresponding to the post-BDN samples showing no detectable concentrations of methanol. The post-treatment chlorination was primarily used as a disinfectant and should not have impacted methanol concentrations.

Table 4-13 presents the results of supplemental analyses that were carried out on a limited number of samples to obtain general background information on the technology. These analyses included VOCs, total metals, sulfate, alkalinity, total solids, phosphate, ammonia, and total organic carbon (TOC).

CCl_4, which had been historically detected in PWS Well #1 water, was not detected in the inlet water sample nor in effluent samples. A small concentration of the VOC chloroform, which is a also a trihalomethane (THM), was detected in the final effluent. It is possible that chloroform is a reaction by-product of CCl_4 and chlorine in the presence of organic matter.

The majority of the supplemental analyses results indicates the BDN and post-treatment systems to have little to no effect on the measured parameters. The increase in TOC

Table 4-11. Event 1 - Microbial Results.[1]

Sample Round No.	Inlet Water [2]	Post BDN [2]	Final Effluent [2]	% Carryover from BDN	% Change from Inlet Water	Pass/ Fail [3]
	TOTAL CULTURABLE HETEROTROPHS - Plate Count Mean (cfu/ml)[2]					
1	1,300	90,000	NG	0 %	- 100 %	P
4	2,300	29,800	2,000,000	6,700 %	+ 870 %	F
7	NG	28,000	4,500,000	16,000 %	NC	F
14	NG	15,000	670	4.5 %	NC	F
17	3,200	4,500,000	3,200,000	71 %	+ 1,000 %	F
20	1,000	11,300,000	7,200,000	64 %	+ 7,200 %	F
23	1,800	680,000	1,300	0.2 %	- 28 %	P
Avg.	**1,400**	**2,400,000**	**2,700,000**	**113 %**	**+ 19,000 %**	**2/7**
	FACULTATIVE ANAEROBES - Plate Count Mean (cfu/ml)[2]					
1	23,000	150,000	6,600	4.4 %	- 71 %	P
4	4,600	17,000,000	620,000	3.6 %	+ 13,000 %	F
7	3,500	5,300,000	350,000	6.6 %	+ 9,900 %	F
14	250	810,000	---	---	---	---
16	---	---	330	NC	NC	---
17	280	380,000	810,000	213 %	+ 290,000 %	F
20	260	360,000	480,000	133 %	+ 190,000 %	F
23	440	1,300,000	76,000	5.8 %	+ 17,000 %	F
Avg.	**4,600**	**3,600,000**	**335,000**	**9.3 %**	**+ 7,300 %**	**1/6**
	FECAL COLIFORM (Fecal coliforms/100ml)					
1	NG	NG	NG	NC	NC	---
4	NG	NG	NG	NC	NC	---
7	NG	NG	NG	NC	NC	---
14	NG	NG	NG	NC	NC	---
17	NG	NG	NG	NC	NC	---
20	NG	NG	NG	NC	NC	---
23	NG	NG	NG	NC	NC	---
Avg.	**NG**	**NG**	**NG**	**NC**	**NC**	**---**

[1] Post-treatment for Event 1 consisted solely of chlorination.
[2] Plate count mean = average of three separate analyses, reported in colony forming units per milliliter.
[3] A sample round is considered passing if the final effluent value is ≤ the inlet water value. In the last row for each parameter, the number of passing values is shown in the numerator; the total number of values (pass + fail, minus any blank values) is shown in the denominator.
NG = No growth; for purposes of percent change calculations, it is assumed that this value is zero.
NC = Not calculated; when the initial reading to be used in a calculation indicated no growth, no calculation was performed.
Dashed line indicates that samples collected at that location were not analyzed for that parameter.

Table 4-12. Event 1- Methanol Results (mg/l).

Sample Round No.	SAMPLE POINT				Pass/ Fail [1]
	Inlet Water	Partial BDN	Post BDN	Final Effluent	
1	1	---	64	91	F
4	< 0.23	---	< 0.23	< 0.23	P
7	---	---	< 0.23	< 0.23	P
10	2.5	---	< 0.23	5	F
12	< 0.23	---	< 0.23	3.4	F
14	< 0.23	---	< 0.23	7.8	F
17	< 0.23	---	< 0.23	< 0.23	P
20	3.9	---	< 0.23	< 0.23	P
23	< 0.23	---	< 0.23	27	F
26	< 0.23	---	< 0.23	< 0.23	P
28	< 0.23	---	< 0.23	26	F
Mean [2]	**0.7**	**---**	**5.8**	**15**	**5/11**

[1] A sample round is considered passing if the final effluent value is < 1 mg/l. In the last row, the number of passing values is shown in the numerator; the total number of values (pass + fail, minus any blank values) is shown in the denominator.
[2] Mean values are rounded to two significant digits. Values < detection limit are considered zero when calculating means.
Dashed line indicates that samples collected at that location were not analyzed for that parameter.

Table 4-13. Event 1 - Supplemental Analyses Results (mg/l).[1]

Sample Round Nos.	Analyte [2]	SAMPLE POINT			
		Inlet Water	Partial BDN	Post BDN	Final Effluent
7,14, 20	CCl_4	< 0.001	---	< 0.001	< 0.001
7,14,20	Chloroform	< 0.001	---	< 0.001	0.006
7,14, 20	Total Solids	855	---	602	635
7,14, 20	Ammonia	< 0.8	---	< 0.8	< 0.8
7,14, 20	Total Organic Carbon	1.2	---	6.47	6.07
7,14, 20	Sulfate	106*	---	102	104
7,14, 20	Phosphate	< 0.082*	---	1.21	---
7,14, 20	Alkalinity	166	---	373	367
	Metals				
7,14, 20	Barium	0.08	---	0.074	0.073
7,14, 20	Calcium	150	---	130	130
7,14,20	Potassium	1.8	---	1.8	1.8
7,14, 20	Magnesium	42	---	42	42
7,14, 20	Sodium	12	---	13	14
7,14,20	Phosphorus	< 0.37	---	0.61	0.65

[1] Values are the mean of the three test results (except where indicated) and are rounded to a maximum three significant digits.
[2] Except for CCl_4 only The SW-846 Method 8260 contaminants with mean values above detection limits are reported.
Metals analyzed for included Ag, Al, Ba, Be, Ca, Cd, Co, Cr, Cu, Fe, K, Mg, Mn, Mo, Na, Ni, P, Sb, and Zn.
Dashed line indicates that samples collected at that location were not analyzed for that parameter; and no pass/fail determination was made.
* Two samples collected only.

following BDN is likely attributable to the carryover of biological material and methanol. The increased alkalinity following BDN is consistent with the slight increase in pH (refer to Table 4-8). The small amount of phosphate and phosphorus measured in the effluent samples is residuum from the 50% methanol solution, which contains food grade phosphoric acid.

4.4.1.5 Mass Removal of Nitrate

The percent mass removal of nitrate, as measured as Nitrate-N, was estimated for Event 1 (*Objective 4*). A total of approximately 42,000 gallons, or about 160,000 liters of well water was treated during Event 1. Each mg/l of nitrate-N is equivalent to 4.4 mg/l of nitrate. Since the mean nitrate-N concentration for Event 1 inlet water was 74 mg/l, the total mass of nitrate treated during Event 1 would be (74 x 4.4) mg/l x 160,000 liters = 52,000,000 mg. The mean nitrate-N concentration for Event 1 final effluent was 1.7 mg/l. The total mass of nitrate in the final effluent = (1.7 x 4.4) mg/l x 160,000 liters = 1,200,000 mg. Therefore, the mass removal of nitrate during Event 1 would be approximately 52,000,000 mg - 1,200,000 mg = 51,000,000 mg (a 98% reduction in nitrate). This would correlate to 51,000 grams or 112 pounds. However, the contribution of nitrite should not be discounted since it can be re-converted to nitrate. Including the nitrite that remains in the final effluent, the mass removal would be 111 pounds.

4.4.1.6 System Performance Vs. Flow Rate

The performance of EcoMat's combined BDN and post-treatment system components were evaluated with respect to water flow through the system (*Objective 2*). The variation in inlet water flow rate during Event 1 was compared with the total-N concentrations in the final effluent. **Figure 4-4** directly compares the Event 1 fluctuation for inlet water flow rate to the Event 1 fluctuation in total-N final effluent concentrations for the same sample rounds. There is a similar pattern to both of the plots that suggests a relationship between flow rate and BDN effectiveness (i.e., lower flow rates corresponding to more effective BDN). This is evident where the somewhat sharp decrease in flow rate occurred about one quarter the way

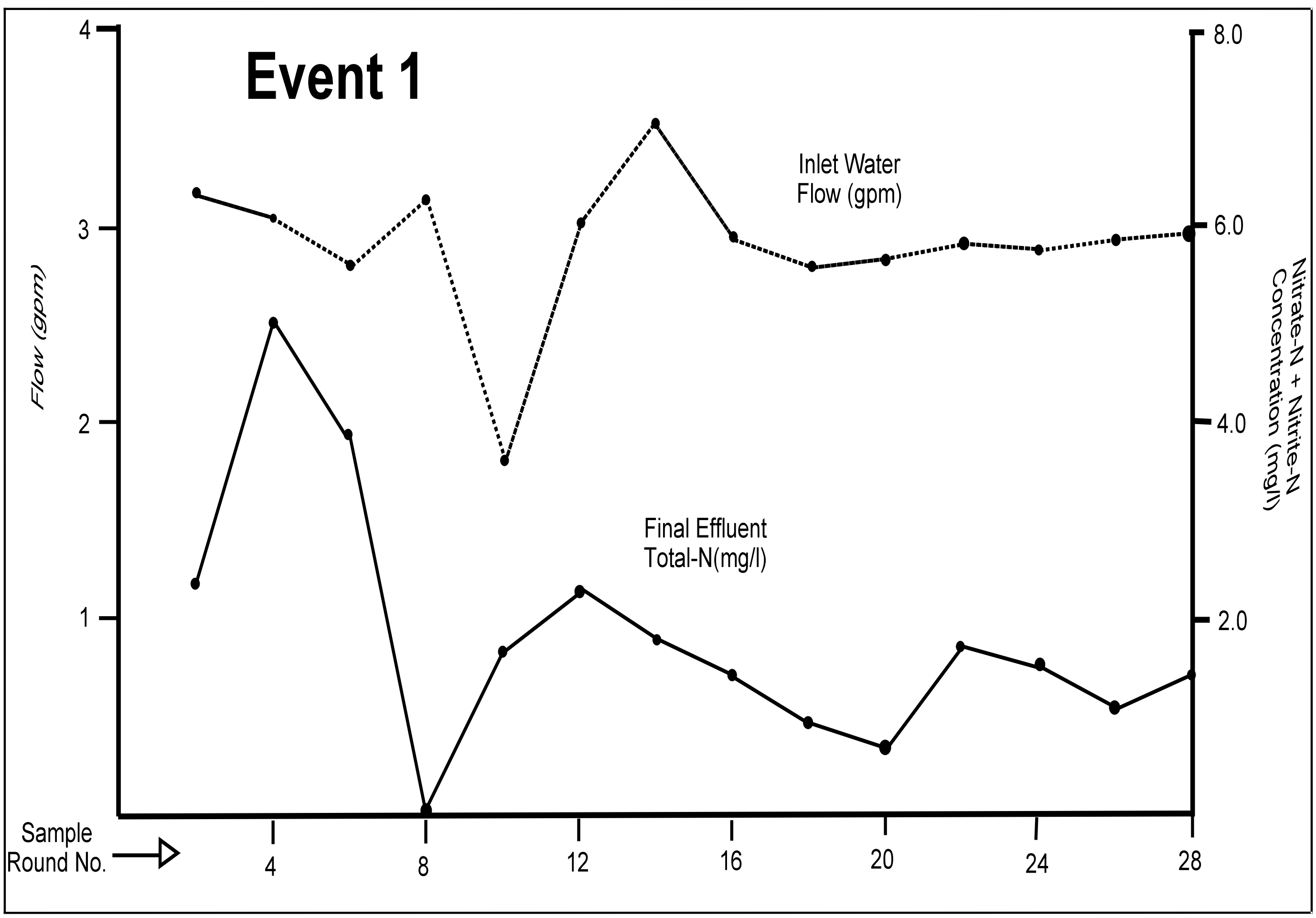

Figure 4-4. Event 1 - Comparison of Flow Rate Fluctuations and Final Effluent Total-N Concentrations.

through the event correlates to a sharp reduction in total-N concentration. However, elsewhere during the event there are variations in the total-N values that cannot be correlated with fluctuations in flow; these may correspond to upsets in the treatment process. The plots in Figure 4-4 also indicate that once the system was kept at a consistent flow rate (i.e., the average event flow rate of 3 gpm), the BDN performance remained stable and quite effective.

4.4.2 Event 2

4.4.2.1 Summary

Event 2 was a 10-day sampling episode conducted August 3-12, 1999. During Event 2, a total of 31 sampling rounds were conducted and ~ 45,000 gallons of nitrate-contaminated well water passed through EcoMat's treatment system at an average flow rate of 3.5 gpm. Based on this average flow rate, and on an estimated retention capacity of 1,300 gallons for the reactor tanks, sampling rounds were normally conducted four times per day at approximately 6½ hour intervals.

Figure 4-5 separately illustrates the effectiveness of the EcoMat BDN and post-treatment systems evaluated during Event 2. The nitrate-N in PWS Well #1 had a mean concentration of 68 mg/l during the second event. This mean inlet water concentration was slightly less than for Event 1 (74 mg/l), possibly due to inflow of clean water into the aquifer as contaminated water was removed. During the partial BDN treatment process that occurred in the first reactor (R1), the nitrate-N levels were reduced by about 40%, with a small amount of nitrite remaining from the nitrate to nitrite conversion. Subsequent treatment in the EcoMat Reactor (R2) further reduced the nitrate-N concentration from a mean of 41 mg/l to a mean of 4.6 mg/l. The mean nitrite-N concentration increased from 1mg/l to 1.5 mg/l between partial BDN and post-BDN samples. A mean total-N concentration of 6.1 mg/l was attained by the BDN treatment for Event 2 samples.

During Event 2 post-treatment consisted of an initial separation of suspended solids in a clarifying tank ("clarification"), followed by sand and cartridge filtration and finally by UV oxidation. The post-treatment had no effect on nitrite-N concentrations and only a minimal effect on nitrate-N concentrations. The mean values for total-N concentrations for post-BDN and final effluent samples were 6.1 mg/l and 5.6 mg/l, respectively.

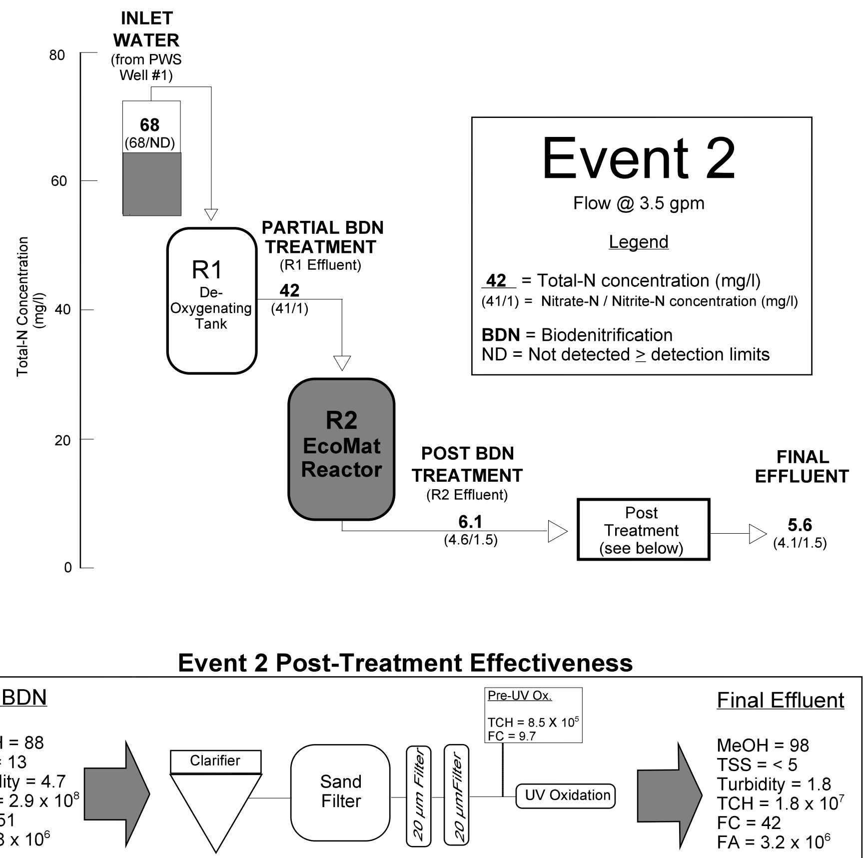

Figure 4-5. Event 2 - Treatment Effectiveness for Averaged Test Results.

4.4.2.2 Event 2 Statistical Analysis

The summary statistics for the critical measurements are presented in **Table 4-14**. Nitrate-N, nitrite-N, and total-N results for the four sampling locations for all 31 sample rounds comprising Event 2 are shown in **Table 4-15**. The mean values from this data were used in generating Figure 4-5. This data was also used to evaluate the Primary Objective (*Objective 1*).

Table 4-14. Event 2 - Summary Statistics.

Critical Measurement	Mean (mg/l)	Median (mg/l)	Standard Deviation (mg/l)
Post BDN Total-N	6.145	4.600	3.781
Final Effluent Nitrate-N	4.132	2.220	4.237
Final Effluent Nitrite-N	1.459	1.200	1.155

The EDA indicated that the data from Event 2 more closely resembled a lognormal than a normal distribution. When Shapiro-Wilk tests were run, both normality and lognormality were rejected for all measurements except the final effluent nitrite-N data, which fit a lognormal distribution. However, the presence of one extreme point may have biased the results. Therefore, the non-parametric WSR was chosen for analyzing all of the data and the median was used as the appropriate measure of central tendency.

Statistical hypothesis tests that were conducted yielded the following results:

- Part I: Post BDN median total-N of 4.60 mg/l was significantly below the criterion of 10.5 mg/l.
- Part II: Final Effluent met all criteria. The median nitrate-N, nitrite-N, and total-N concentrations were 2.22, 1.20, and 3.61 mg/l, respectively. These values were below their respective criterion of 10.5, 1.5, and 10.5 mg/l.

Based on the results of these 2 hypothesis tests, Event 2 was shown to be successful in reducing levels of nitrite-N and nitrate-N to below regulatory limits.

4.4.2.3 General Evaluation of BDN System

Table 4-16 presents a summary of all performance criteria results for Event 2. This includes the post-BDN and final effluent nitrate-N, nitrite-N, and total-N data for each of the 31 Event 2 tests. Also included are the additional analytical data and field measurement results that were used for evaluating other performance criteria. On a per round basis, the objectives regarding reductions in nitrate-N, nitrite-N, and total-N in the final effluent were attained for 17 of the 31 sample rounds. Other performance criteria results shown in Table 4-16 indicate the need for more substantial post-treatment, especially for treating residual methanol and removing microbial matter.

The daily DO measurements in **Table 4-17** show that for approximately the first half of the event (i.e., rounds 1-14) the daily measured DO in the partially treated BDN effluent was consistently above 1 mg/l. Then, for the remainder of the event, DO was consistently below 1 mg/l. The deoxygenating process was effective in reducing the mean inlet water DO of approximately 9 mg/l down to approximately 1 mg/l in partially treated water exiting the Deoxygenating Tank.

4.4.2.4 General Evaluation of Post-Treatment System

The field and laboratory measurements used primarily for evaluating the post-treatment component of EcoMat's Process during Event 2 (*Objective 5*) included pH; turbidity; TSS; microbial analyses; methanol; and "supplemental analyses".

The daily pH measurements in **Table 4-18** indicate a very slight increase in alkalinity from inlet water to post BDN effluent. However, there was essentially no change in pH range in the final effluent following post-treatment.

The daily turbidity measurements in **Table 4-19** indicate turbidity to be consistently above the secondary drinking water criterion of 1 NTU. However, the mean NTU of 1.8 was much improved over the Event 1 turbidity results.

The TSS data in **Table 4-20** show that the inlet water contain no detectable levels of TSS and post BDN effluent to contains, on average, 13 mg/l of TSS. The final effluent data indicated the post-treatment system had a positive effect on reducing TSS levels, on average to less than 5 mg/l, most likely due to filtration. Six of nine final effluent values were less than their paired inlet water values.

Table 4-21 presents the laboratory results for Total TCH, FC, and FA at each of the four outfalls. An additional sample was collected immediately upstream of the UV oxidation unit and analyzed for TCH and FC to evaluate that unit independently of the remainder of the post-treatment system (refer back to Figure 4-5).

The results of the TCH analyses indicated that the TCH population associated with the BDN process was, on average, three orders of magnitude higher than TCH levels in the well water. On average, approximately 6 percent of this bacteria carried over from the BDN process to the final effluent. This marked a substantial improvement from the first Event when no filtration was used. However, all seven final effluent TCH values were measured to be above the

Table 4-15. Event 2 - Nitrate-N and Nitrite-N Results (mg/l).

Sample Round[1]	Inlet Water			Partial BDN			Post BDN			Final Effluent		
	Nitrate-N	Nitrite-N	Total-N[2]	Nitrate-N	Nitrite-N	Total-N[2]	Nitrate-N	Nitrite-N	Total-N[2]	Nitrate-N	Nitrite-N	Total-N[2]
1	71.5	< 0.076	71.5	54.1	0.29	54.4	6.6	0.34	6.9	5.2	0.37	5.6
2	71.3	< 0.076	71.3	58.7	0.17	58.9	14.4	0.52	14.9	13.2	0.48	13.7
3	71.4	< 0.076	71.4	32.4	0.73	33.1	6.8	0.72	7.5	10.8	0.94	11.7
4	72.0	< 0.076	72.0	42.6	0.22	42.8	11.9	0.19	12.1	9.6	0.28	9.9
5	71.5	< 0.076	71.5	53.4	0.21	53.6	12.5	0.88	13.4	11.1	0.79	11.9
6	72.9	< 0.076	72.9	27.1	1.7	28.8	12.3	6	18.3	18.6	6.7	25.3
7	73.1	< 0.076	73.1	49.1	0.69	49.8	4.6	1.5	6.1	4.1	1.7	5.8
8	73.1	< 0.076	73.1	45.4	0.74	46.1	4	0.94	4.9	2.8	0.81	3.6
9	67.0	< 0.076	67.0	41.2	0.85	42.1	2.7	0.82	3.5	1.2	0.74	1.9
10	65.6	< 0.076	65.6	42.8	0.99	43.8	1.8	0.77	2.6	1.5	0.76	2.3
11	66.5	< 1.9	66.5	36	< 1.9	36	3	1.6	4.6	2.2	1.6	3.8
12	69.3	< 0.076	69.3	43.3	0.86	44.2	3.34	1.52	4.9	1.7	0.95	2.7
13	68.7	< 0.076	68.7	47.2	1.16	48.4	4.8	2.11	6.9	2.54	1.8	4.3
14	68.5	< 0.076	68.5	38.1	1.37	39.5	2.42	0.813	3.2	1.34	0.73	2.1
15	69.8	< 0.076	69.8	41.4	1.3	42.7	2.9	1.6	4.5	3.5	1.9	5.4
16	69.8	< 0.076	69.8	49.3	0.99	50.3	6.3	2.6	8.9	6.0	2.8	8.8
17	67.5	< 0.076	67.5	47.2	0.99	48.2	5.8	2.9	8.7	6.1	2.9	9.0
18	67.5	< 0.076	67.5	41	1.5	42.5	4	2.1	6.1	3.5	2.1	5.6
19	66.7	< 0.076	66.7	38.3	1.3	39.6	3.1	1.8	4.9	3.1	1.9	5.0
20	64.4	< 0.076	64.4	38.4	1.4	39.8	2.8	1.5	4.3	2.1	1.4	3.5
21	65.2	< 0.076	65.2	37.8	1.5	39.3	2	1.4	3.4	1.1	0.99	2.1
22	63.2	< 0.076	63.2	41.3	1.3	42.6	3.7	1.9	5.6	3.1	1.8	4.9
23	64.0	< 0.076	64.0	37.8	1.3	39.1	2.2	1.2	3.4	1.5	1.0	2.5
24	65.7	< 0.076	65.7	39.1	1.1	40.2	2.7	1.4	4.1	1.7	1.3	3.0
25	66.1	< 0.076	66.1	37.8	1.1	38.9	2.7	1.5	4.2	1.5	1.3	2.8
26	66.2	< 0.076	66.2	35.6	1.4	37.0	2.5	1.6	4.1	2.1	1.5	3.6
27	67.0	< 0.076	67	38.4	1.1	39.5	2.5	1.5	4.0	1.7	1.4	3.1
28	65.7	< 0.076	65.7	36.2	1.2	37.4	2.2	1.3	3.5	1.6	1.1	2.7
29	67.2	< 0.076	67.2	35.7	1.4	37.1	2.4	1.4	3.8	1.5	1.2	2.7
30	67.6	< 0.076	67.6	35.3	1.3	36.6	2.2	1.4	3.6	0.9	1.0	1.9
31	66.4	< 0.076	66.4	34.5	1.4	35.9	2.2	1.3	3.5	1.2	0.98	2.2
Mean[3]	**68**	**ND**	**68**	**41**	**1.0**	**42**	**4.6**	**1.5**	**6.1**	**4.1**	**1.5**	**5.6**

[1] Represents a sample set in which samples from all four locations were collected at the approximate same time.
[2] Represents combined Nitrate-N and Nitrite-N. Values < the detection limit were considered 0.0 when summing totals.
[3] Means are rounded to two significant digits. Values < detection limit are considered zero when calculating means.
ND = Not detected at or above MDL.

Table 4-16. Event 2 - Summary of Treatment Effectiveness.

	Nitrate-N/Nitrite-N Results (mg/l)				Final Effluent - Other Performance Criteria					
	Post	Final Effluent								
Sample Round[1]	Total-N[1]	Nitrate-	Nitrite-N	Total-N[1]	Flow (gpm)	MeOH (mg/l)	TSS (mg/l)	Turbidity (NTU)	pH [2] (SU)	Total Heterotrophs [2] (CFU/ml)
1	6.9	5.2	0.37	5.6	---	---	---	---	---	---
2	14.9	13.2	0.48	13.7	2.9	---	---	---	---	---
3	7.5	10.8	0.94	11.7	2.5	34	5.6	2.7	7.8 / 7.6	5,000 / 380,000
4	12.1	9.6	0.28	9.9	3.1	---	---	---	---	---
5	13.4	11.1	0.79	11.9	3.9	---	---	---	---	---
6	18.3	18.6	6.7	25.3	4.4	---	---	---	---	---
7	6.1	4.1	1.7	5.8	3.4	70	6	2.6	8.2 / 7.9	27,000 / 3,300,000
8	4.9	2.8	0.81	3.6	2.9	---	---	---	---	---
9	3.5	1.2	0.74	1.9	2.7	---	---	---	---	---
10	2.6	1.5	0.76	2.3	2.7	---	---	---	7.4 / 7.8	---
11	4.6	2.2	1.6	3.8	3.2	180	< 5	2.3	---	17,000 / 250,000
12	4.9	1.7	0.95	2.6	3.5	---	---	---	---	---
13	6.9	2.5	1.8	4.4	1.6	110	< 5	2.4	7.5 / 7.8	---
14	3.2	1.3	0.73	2.1	2.6	---	---	---	---	---
15	4.5	3.5	1.9	5.4	3.3	---	---	---	---	---
16	8.9	6.0	2.8	8.8	4.7	39	< 5	1.6	7.5 / 8.2	28,000 / 620,000
17	8.7	6.1	2.9	9.0	4.5	---	---	---	---	---
18	6.1	3.5	2.1	5.6	---	94	< 5	1.2	7.6 / 8.4	33,000 / 130,000
19	4.9	3.1	1.9	5.0	---	---	---	---	---	---
20	4.3	2.1	1.4	3.5	4	---	---	---	---	---
21	3.4	1.1	0.99	2.1	3.7	---	---	---	7.6 / 7.7	---
22	5.6	3.1	1.8	4.9	---	100	< 5	1.1	---	370,000 / 25,000,000
23	3.4	1.5	1.0	2.5	4	---	---	---	---	---
24	4.1	1.7	1.3	3.0	3.9	---	---	---	---	---
25	4.2	1.5	1.3	2.8	4	---	---	---	---	---
26	4.1	2.1	1.5	3.6	3.9	77	9	1.2	7.4 / 8.3	230,000 / 97,000,000
27	4.0	1.7	1.4	3.1	3.9	---	---	---	---	---
28	3.5	1.6	1.1	2.7	3.6	---	---	---	---	---
29	3.8	1.5	1.2	2.7	3.8	---	---	---	---	---
30	3.6	0.9	1.0	1.9	3.8	180	< 5	1.5	7.4 / 8.2	---
31	3.5	1.2	0.98	2.2	3.8	---	---	---	---	---
Mean [2]	**6.1**	**4.1**	**1.5**	**5.6**	**3.5**	**98**	**< 5**	**1.8**	**7.4-8.4**	**100,000 / 18,000,000**

[1] Total-N is equal to the combined Nitrate-N + Nitrite-N concentration.
[2] The first value represent the inlet water and the second value represents the final effluent.
[3] All values, except for the pH range, are means rounded to two significant digits. Values < detection limit are considered zero when calculating means.
Dashed line indicates that samples collected at that location were not analyzed for that parameter.

Table 4-17. Event 2 - Dissolved Oxygen Measurements (mg/l).

DATE	TIME INTERVAL	Associated Round No(s.)[1]	SAMPLE POINT			
			Inlet Water	**Partial BDN**	**Post BDN**	**Final Effluent**
8-4-99	0945-1015	**2-3**,4,5	---	1.65	5.88	2.11
8-5-99	1000-1054	**6-7**,8,9	8.70	1.78	5.90	4.55
8-6-99	0900- 1000	**10-11**,12	8.74	1.14	5.89	0.51
8-7-99	0820-0842	**13**,14	9.45	1.45	5.61	1.03
8-8-99	1440-1523	**15**,16	8.85	0.72	6.14	5.9
8-9-99	0830-0955	**17-18**,19,20	9.33	0.61	6.30	4.30
8-10-99	0845-0950	**21-22**,23,24	8.8	0.5	5.90	4.64
8-11-99	0800-0837	**25,**26,27,28	9.09	0.5	6.30	3.55
8-12-99	0830	**29-30**,31	8.81	0.67	5.40	0.5
		Mean [2]	**9.0**	**1.0**	**5.9**	**3.0**

[1] Sample rounds conducted closest in time to the measurement are bolded.
[2] Mean values are rounded to two significant digits.
Dashed line indicates that samples collected at that location were not analyzed for that parameter.

Table 4-18. Event 2 - pH Measurements.

DATE	TIME INTERVAL	Associated Round No(s.)[1]	SAMPLE POINT			
			Inlet Water	**Partial BDN**	**Post BDN**	**Final Effluent**
8-4-99	0920-1016	**2-3**,4,5	7.76	7.5	7.62	7.61
8-5-99	0956-1054	**6-7**,8,9	8.18	7.72	7.72	7.91
8-6-99	0919-1006	**10-11**,12	7.35	7.57	8.01	7.82
8-7-99	0821-0843	**13**,14	7.45	7.25	7.91	7.84
8-8-99	1445-1524	**15**,16	7.48	7.39	8.19	8.19
8-9-99	0855-0956	**17-18**,19,20	7.56	7.75	8.46	8.38
8-10-99	0921-0934	**21-22**,23,24	7.64	7.67	8.39	8.38
8-11-99	0804-0830	**25,**26,27,28	7.44	7.61	8.36	8.32
8-12-99	0915-0925	**29-30**,31	7.39	7.58	8.25	8.2
		Range [2]	**7.4 - 8.2**	**7.4 - 7.8**	**7.6 - 8.5**	**7.6 - 8.4**

[1] Sample rounds conducted closest in time to the measurement are bolded.
[2] Range values are rounded to two significant digits.

Table 4-19. Event 2 -Turbidity Measurements (NTU).

DATE	TIME INTERVAL	Associated Round No(s.)[1]	SAMPLE POINT				Pass/ Fail [2]
			Inlet Water	**Partial BDN**	**Post BDN**	**Final Effluent**	
8-4-99	0931-1018	**2-3**,4,5	0.45	0.95	8.3	2.7	F
8-5-99	1003-1056	**6-7**,8,9	0.30	0.35	4.7	2.6	F
8-6-99	0925-1008	**10-11**,12	0.15	0.85	7.2	2.3	F
8-7-99	0825-0845	**13**,14	0.0	0.9	7.6	2.4	F
8-8-99	1448-1526	**15**,16	0.45	0.25	2.7	1.6	F
8-9-99	0855-0958	**17-18**,19,20	0.0	0.3	5.0	1.2	F
8-10-99	0921-0953	**21-22**,23,24	0.05	0.4	4.5	1.1	F
8-11-99	0804-0843	**25,**26,27,28	0.00	0.25	2.2	1.2	F
8-12-99	0915-0925	**29-30**,31	0.00	0.5	0.5	1.5	F
		Mean[3]	**0.16**	**0.53**	**4.7**	**1.8**	**0/9**

[1] Sample rounds conducted closest in time to the measurement are bolded.
[2] A sample round is considered passing if the final effluent is <u><</u>1 NTU. In the last row, the number of passing values is shown in the numerator; the total number of values (pass + fail, minus any blank values) is shown in the denominator.
[3] Mean values are rounded to two significant digits. Values < detection limit considered zero when calculating means.

Table 4-20. Event 2 - TSS Results (mg/l).

Sample Round No.	SAMPLE POINT				Pass/ Fail [1]
	Inlet Water	**Partial BDN**	**Post BDN**	**Final Effluent**	
3	< 5	---	23	5.6	F
7	< 5	---	17.1	6	F
11	< 5	---	11	< 5	P
13	< 5	---	8	< 5	P
16	< 5	---	10.4	< 5	P
18	< 5	---	12	< 5	P
22	< 5	---	13.3	< 5	P
26	< 5	---	17.8	9	F
30	< 5	---	< 5	< 5	P
Mean [2]	< 5	---	13	< 5	6/9

[1] A sample round is considered passing if the final effluent value is <u><</u> the inlet water value. In the last row, the number of passing values is shown in the numerator; the total number of values (pass + fail, minus any blank values) is shown in the denominator.
[2] Mean values are rounded to two significant digits. Values < detection limit considered zero when calculating means.
Dashed line indicates that samples collected at that location were not analyzed for that parameter.

Table 4-21. Event 2 - Microbial Results.[1]

Sample Round No.	TOTAL CULTURABLE HETEROTROPHS - Plate Count Mean (cfu/ml)[2]					
	Inlet Water [2]	**Post BDN** [2]	**Final Effluent** [2]	**% Carryover from BDN**	**% Change from Inlet Water**	**Pass/ Fail** [3]
3	5,000	7,300,000	380,000	5.2 %	+ 7,600 %	F
7	27,000	117,000,000	3,300,000	2.8 %	+ 12,000 %	F
11	17,000	33,000,000	250,000	0.8 %	+ 1,500 %	F
16	28,000	880,000,000	620,000	0.7 %	+ 2,200 %	F
18	33,000	420,000,000	130,000	0.03 %	+ 390 %	F
22	370,000	470,000,000	25,000,000	5.4 %	+ 6,800 %	F
26	230,000	97,000,000	97,000,000	100 %	+ 42,000 %	F
Avg.	**101,000**	**289,000,000**	**18,100,000**	**6.3 %**	**+ 18,000 %**	**0/7**
	FACULTATIVE ANAEROBES - Plate Count Mean (cfu/ml)[2]					
3	2,900	360,000	85,000	24 %	+2,800 %	F
7	3,100	760,000	70,000	9.2 %	+ 2,200 %	F
11	320	320,000	150,000	53 %	+ 47,000 %	F
16	220	11,000,000	37,000	0.3 %	+ 17,000 %	F
18	520	9,600,000	3,600,000	38 %	+ 690,000 %	F
22	2,400	19,000,000	11,000,000	58 %	+ 460,000 %	F
26	3,400	15,000,000	7,400,000	49 %	+ 220,000 %	F
Avg.	**1,840**	**8,000,000**	**3,190,000**	**40 %**	**+ 170,000 %**	**0/7**
	FECAL COLIFORM (Fecal coliforms/100ml)					
3	232	135	NG	0 %	- 100 %	P
7	190	22	173	790 %	- 9.1 %	P
11	335	2	28	1,400 %	- 92 %	P
16	278	62	88	140 %	- 32 %	P
18	27	2	NG	0 %	- 100 %	P
22	73	28	3	11 %	- 96 %	P
26	62	105	3	2.9 %	- 95 %	P
Avg.	**170**	**51**	**42**	**82 %**	**- 75 %**	**7/7**

[1] Post-treatment for Event 2 consisted of clarification, followed by sand filtration, cartridge filtration, and UV oxidation.
[2] Plate count mean = average of three separate analyses, reported in colony forming units per milliliter.
[3] A sample round is considered passing if the final effluent value is $\leq$ the inlet water value. In the last row, the number of passing values is shown in the numerator; the total number of values (pass + fail, minus any blank values) is shown in the denominator.
NG = No growth.
NC = Not calculated.

corresponding inlet water values. Thus, the secondary criterion was not met for TCH. The pre-UV oxidation mean value for TCH was two orders of magnitude lower than the final effluent plate count mean average, indicating that the clarification and filtration preceding UV oxidation may have been the only effective post-treatment. Based on the limited results, UV was, at best, non-effective and, at worst, detrimental with respect to TCH treatment. It is not clear whether the UV oxidation system was correctly sized for the role or whether other factors adversely affected its utility.

As was the case with Event 1, the FA data followed the expected pattern to a certain degree. The average of the FA plate count means for inlet water increased by three orders of magnitude in post BDN effluent. The post-treatment effectiveness was improved over Event 1, but was inconsistent. Final effluent plate count means for individual sample rounds ranged from 37,000 cfu/ml to 11,000,000 cfu/ml. None of the final effluent mean values was less than the inlet water mean value. Thus, the secondary criterion was not met for FA. The sharp increase (i.e., two orders of magnitude) for final effluent FA values, starting midway through Event 2, could have been the result of filter breakthrough.

For Event 2, the FC values in final effluent were below inlet water values, both on a per round and total average basis. Thus, the secondary criterion was met for FC. The pre-UV oxidation sample indicated UV oxidation to have no positive effect on FC (refer back to Figure 4-5).

The methanol results in **Table 4-22** indicate that methanol was not detected in inlet water samples, but was detected in all post BDN and final effluent samples. The mean methanol concentrations in post BDN and final effluent were 88 and 98 mg/l, respectively. The post BDN and final effluent values were also very similar on a per round basis, indicating that the UV oxidation post-treatment had no effect on reducing residual methanol concentrations. The secondary criterion of < 1 mg/l was, therefore, not met for any of the sample rounds.

Table 4-23 presents results of supplemental analyses for all outfalls sampled. The majority of these results indicate that the BDN and post-treatment systems to had little to no effect on the measured parameters. The mean concentration of CCl_4 detected in the inlet water during Event 2 was small (i.e., 1.4 µg/l). CCl_4 was not detected in effluent samples. This indicates that the compound was either volatilized or biodegraded during the BDN process. The only other VOC detected was chloroform, which was measured at a low concentration in the final effluent.

The somewhat significant increase in TOC following BDN can be attributed to the carryover of biological material and/or methanol. The increased alkalinity following BDN is consistent with the slight increase in pH (refer to Table 4-18). The small amounts of phosphate and phosphorus measured in effluent samples is residuum from the 50%

Table 4-22. Event 2- Methanol Results (mg/l).

Sample Round No.	SAMPLE POINT				Pass/ Fail [1]
	Inlet Water	**Partial BDN**	**Post BDN**	**Final Effluent**	
3	< 0.23	---	46	34	F
7	< 0.23	---	73	70	F
11	< 0.23	---	160	180	F
13	< 0.23	---	90	110	F
16	< 0.23	---	21	39	F
18	< 0.23	---	60	94	F
22	< 0.23	---	100	100	F
26	< 0.23	---	68	77	F
30	< 0.23	---	170	180	F
Mean [2]	**< 0.23**	**---**	**88**	**98**	**0/9**

[1] A result is considered passing if the final effluent value is < 1 mg/l. In the last row, the number of passing values is shown in the numerator; the total number of values is shown in the denominator.
[2] Mean values are rounded to two significant digits. Values < detection limit considered zero for calculating means.
NG = No growth.
Dashed line indicates that samples collected at that location were not analyzed for that parameter.

Table 4-23. Event 2 - Supplemental Analyses Results (mg/l).[1]

SAMPLE ROUND NOs.	Analyte [2]	SAMPLE POINT			
		Inlet Water	**Partial BDN**	**Post BDN**	**Final Effluent**
7, 16, 26	CCl_4	< 0.0014	---	< 0.001	< 0.001
7,16,26	Chloroform	< 0.001	---	< 0.001	0.002
7, 16, 26	Total Solids	877	---	612	600
7, 16, 26	Ammonia	< 0.8	---	< 0.8	< 0.8
7, 16, 26	Total Organic Carbon	1.1	---	47	45
7, 16, 26	Sulfate	80	---	77	76
7, 16, 26	Phosphate	< 0.082	---	1.2	---
7, 16, 26	Alkalinity	162	---	374	370
7, 16, 26	Barium	0.078	---	0.073	0.072
7, 16, 26	Calcium	130	---	123	123
7, 16, 26	Potassium	1.8	---	1.7	1.6
7, 16, 26	Magnesium	37	---	37	38
7, 16, 26	Sodium	12	---	13	13
7, 16, 26	Phosphorus	< 0.35	---	1.3	1.3

[1] Values are the Mean of the three test results and are rounded to a maximum three significant digits.
[2] Except for CCl_4 only SW-846 Method 8260 contaminants with mean values above detection limits are reported.
Metals analyzed for included Ag, Al, Ba, Be, Ca, Cd, Co, Cr, Cu, Fe, K, Mg, Mn, Mo, Na, Ni, P, Sb, and Zn.
Dashed line indicates that samples collected at that location were not analyzed for that parameter.

methanol solution, which contains food grade phosphoric acid.

4.4.2.5 Mass Removal of Nitrate

The percent mass removal of nitrate, measured as Nitrate-N, was estimated for Event 2 (*Objective 4*). A total of approximately 45,000 gallons, or about 170,000 liters of well water was treated during Event 2. Each mg/l of nitrate-N is equivalent to 4.4 mg/l of nitrate. Since the mean nitrate-N concentration for Event 2 inlet water was about 68 mg/l, the total mass of nitrate treated during Event 2 would be (68 x 4.4)mg/l x 170,000 liters = 51,000,000 mg. The mean nitrate-N concentration for Event 2 final effluent was 4.1 mg/l. The total mass of nitrate in the final effluent = (4.1 x 4.4) mg/l x 170,000 liters = 3,000,000 mg. Therefore the mass removal of nitrate during Event 2 would be approximately 52,000,000 mg - 3,000,000 mg = 49,000,000 mg (a 94% reduction in nitrate). This correlates to 49,000 grams or 108 pounds. Adding the nitrite-N in the final effluent would reduce the removal by 2 pounds.

4.4.2.6 System Performance Vs. Flow Rate

The performance of EcoMat's combined BDN and post-treatment system components were evaluated with respect to water flow through the system (*Objective 2*). The variation in inlet water flow rate during Event 2 was compared with the total-N concentrations in the final effluent. **Figure 4-6** directly compares the Event 2 fluctuation for inlet water flow rate to the Event 2 fluctuation in total-N final effluent concentrations throughout the duration of Event 2. As was the case with the first event the flow rate and final effluent total-N concentrations patterns are similar to one another; although there was a lot more variability during the first half of the event testing. Nonetheless, the inverse relationship showing lower flow rates consistent with increased BDN effectiveness is still apparent. Similar to Event 1 a rather sharp decrease in flow rate occurred about one quarter the way through the event and correlated to a sharp reduction in total-N concentration. The plot in figure 4-6 also indicates that the system became stabilized past the halfway point of Event 2. Once again, other operating factors may mask the expected correlation of flow and denitrification.

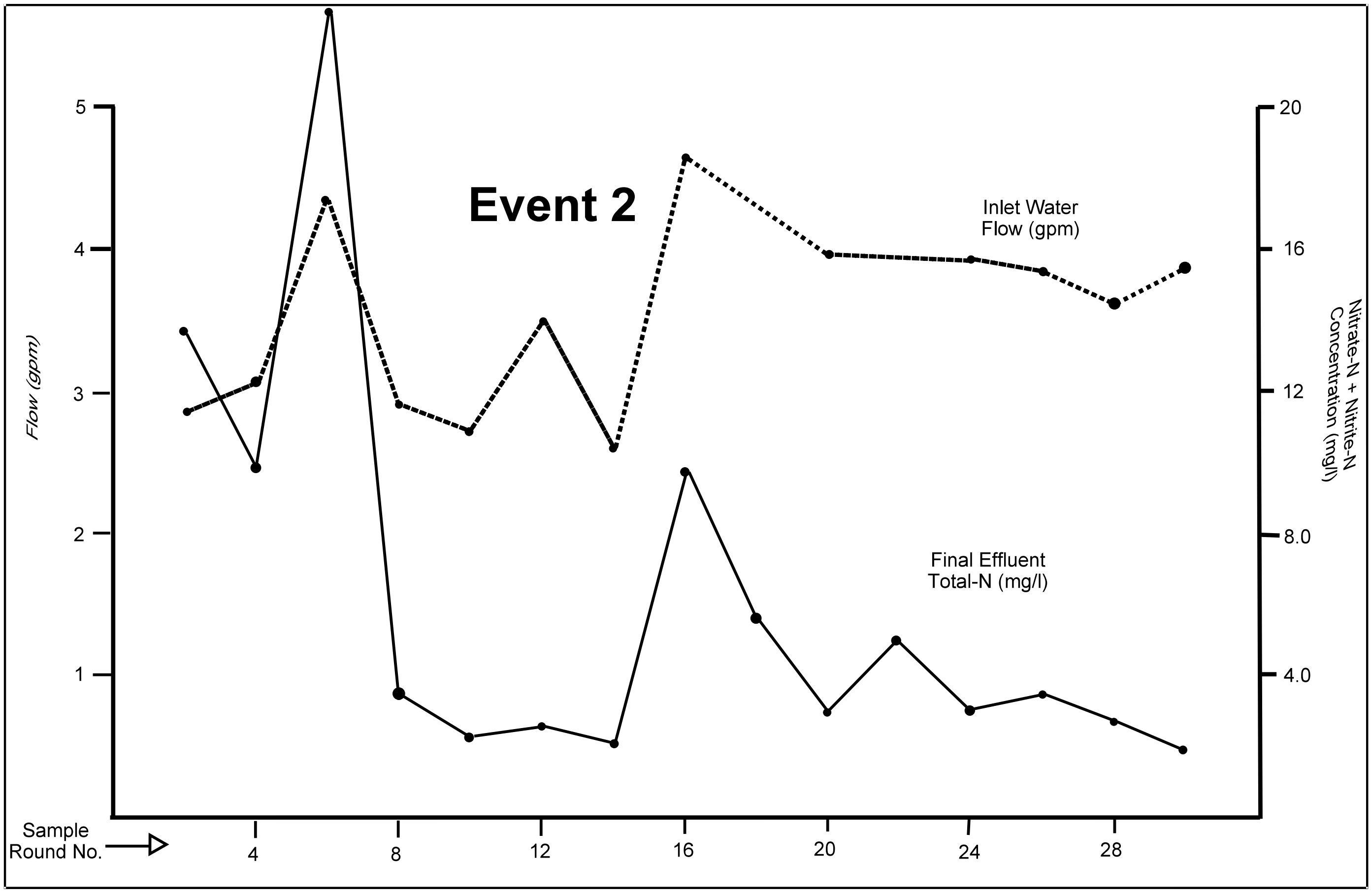

Figure 4-6. Event 2 - Comparison of Flow Rate Fluctuations and Final Effluent Total N-Concentrations.

4.4.3 Event 3

4.4.3.1 Summary

Event 3 was a 9-day sampling episode conducted October 20-28, 1999. During Event 3, a total of 30 sampling rounds were conducted and ~ 49,000 gallons of nitrate-contaminated well water passed through EcoMat's treatment system at an average flow rate of 4 gpm. Flow rates among the individual sampling rounds varied considerably, ranging between ~2 and 7 gpm. Based on the average flow rate, and an estimated retention capacity of 1,300 gallons for the reactor tanks, the sampling rounds were normally conducted three times per day. However, due to the high variability in flow rate, the sample rounds were conducted at intervals anywhere between 3-7 hours apart.

Figure 4-7 illustrates the effectiveness of the EcoMat BDN and post-treatment systems used for Event 3. The mean nitrate-N concentration in PWS Well #1 during Event 3 was 38 mg/l. This concentration was significantly less than that measured for Event 2, which occurred approximately 2½ months earlier. During the partial BDN in the first reactor (R1), the mean nitrate-N levels were reduced by about 47%, with a small amount of nitrite generated by the nitrate to nitrite conversion. Subsequent treatment in the EcoMat reactor (R2) further reduced the mean nitrate-N concentration from of 20 mg/l to 7.7 mg/l. The average nitrite-N concentration increased from 1.3 mg/l to 2.9 mg/l between partial and post-BDN samples. Mean total-N effluent concentration of approximately11mg/l was attained by the BDN treatment for Event 3 samples.

Event 3 post-treatment consisted of ozone followed by UV oxidation followed by clarification. Clarification was followed by "rough" filtration, "high efficiency" filtration, carbon adsorption, and "polishing" filtration. The post-treatment system had no effect on nitrate-N or nitrite-N levels. When rounded to two significant digits, the mean total-N concentrations for post-BDN and final effluent samples were ~ 11 mg/l and 9.9 mg/l, respectively.

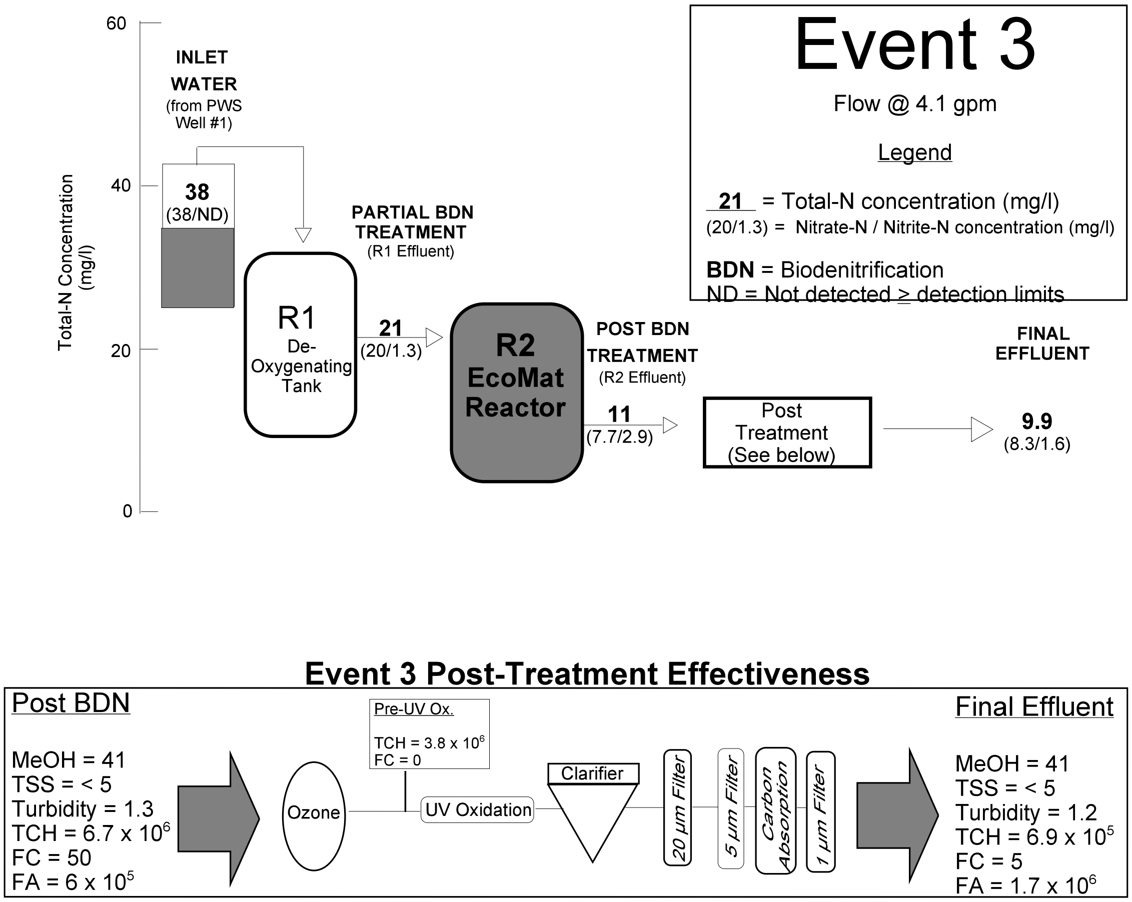

Figure 4-7. Event 3 - Treatment Effectiveness for Averaged Test Results.

4.4.3.2 Event 3 Statistical Analysis

The summary statistics for the critical measurements are presented in **Table 4-24**. Nitrate-N, nitrite-N, and total-N results for the four sampling locations for all 30 Event 3 sample rounds are shown in **Table 4-25**. The mean values from these data were to evaluate the primary objective (*Objective 1*) and for generating Figure 4-7.

Table 4-24. Event 3 - Summary Statistics.

Critical Measurement	Mean (mg/l)	Median (mg/l)	Standard Deviation (mg/l)
Post BDN Total-N	10.613	10.950	3.706
Final Effluent Nitrate-N	8.347	8.350	2.854
Final Effluent Nitrite-N	1.545	1.400	0.851
Final Effluent Total-N	9.897	9.825	2.978

The EDA indicated that the data from Event 3 closely resembled a normal distribution, except for the post BDN data. When Shapiro-Wilk tests were run, normality was accepted for all variables except the post BDN data. For these data neither the normal nor lognormal distribution was shown to fit the data. Therefore, the non-parametric WSR was chosen for analyzing the post BDN data and the median was used as the appropriate measure of central tendency. The Student's t-test was chosen for analyzing the other three measurements (i.e., final effluent nitrate-N, final effluent nitrite-N, and final effluent total-N), thus the mean was used as the appropriate measure of central tendency.

Statistical hypothesis tests that were conducted yielded the following results:

- Part I: For the Post BDN total-N data, both the mean of 10.613 mg/l and the median of 10.950 mg/l were above the criterion of 10.5 mg/l. Thus, no statistical test was needed to determine that the Post BDN data did not meet that criterion.

Table 4-25. Event 3 - Nitrate-N and Nitrite-N Results (mg/l).

Sample Round[1]	Inlet Water			Partial BDN			Post BDN			Final Effluent		
	Nitrate-N	Nitrite-N	Total-N[2]	Nitrate-N	Nitrite-N	Total-N[2]	Nitrate-N	Nitrite-N	Total-N[2]	Nitrate-N	Nitrite-N	Total-N[2]
1	43.9	< 0.076	43.9	10	1.4	11.4	3.9	4.0	7.9	1.7	0.44	2.14
2	41.8	< 0.076	41.8	22.3	1.7	24	6.4	2.6	9.0	5.3	0.85	6.15
3	44.1	< 0.076	44.1	19.9	1.4	21.3	6.4	3.0	9.4	8.9	0.95	9.85
4	45.7	< 0.076	45.7	23.7	1.8	25.5	6.6	2.0	8.6	7.6	<0.076	7.6
5	45.3	< 0.076	45.3	22.4	1.8	24.2	12	3.0	15	13.3	1.1	14.4
6	41.8 J	< 0.076	41.8 J	18.7	1.7	20.4	6.7	3.2	9.9	9.4	1.1	10.5
7	41.1	< 0.076	41.1	21.6	1.5	23.1	10.1	2.8	12.9	9.9	1.1	11
8	41.8	< 0.076	41.8	7.6	1.8	9.4	7.2	3.4	10.6	11	1.4	12.4
9	40.3	< 0.076	40.3	17.3	3.0	20.3	10.5	2.8	13.3	8.2	1.3	9.5
10	40.4	< 0.076	40.4	23.9	0.74	24.6	7.5	2.5	10	7.4	1.1	8.5
11	38.5	< 0.076	38.5	26.9	0.96	27.9	12.5	2.9	15.4	12.2	1.3	13.5
12	40.3	< 0.076	40.3	27.1	1.1	28.2	12.2	3.7	15.9	12.6	2.5	15.1
13	38.9	< 0.076	38.9	26.3	1.1	27.4	12.1	3.7	15.8	12.7	2.4	15.1
14	39.0	< 0.076	39.0	24.6	1.1	25.7	11.4	3.7	15.1	11.8	2.1	13.9
15	38.7	< 0.076	38.7	23.7	0.88	24.6	9.2	1.8	11	9.1	3.5	12.6
16	36.9	< 0.076	36.9	22.3	0.89	23.2	8.8	3.3	12.1	8.6	1.8	10.4
17	36.8	< 0.076	36.8	22.5	0.77	23.3	8.5	3.1	11.6	7.8	2.0	9.8
18	37.3	< 0.076	37.3	14.4	0.76	15.2	<.056	0.19	0.19	5.4	1.5	6.9
19	36.8	< 0.076	36.8	24.1	0.66	24.8	8.7	2.2	10	8.4	0.84	9.24
20	37.1	< 0.076	37.1	25	0.63	25.6	10.1	2.9	13	11.1	1.1	12.2
21	36.6	< 0.076	36.6	23	0.69	23.7	9.6	3.2	12.8	6.6	1.4	8.0
22	35.4	< 0.076	35.4	22.4	0.88	23.3	8.9	3.7	12.6	9.1	1.6	10.7
23	35.5	< 0.076	35.5	21.8	0.78	22.6	8.3	3.4	11.7	8.3	<0.076	8.3
24	35.3	< 0.076	35.3	20	0.91	20.9	7.0	3.2	10.2	9.4	0.38	9.78
25	34.8	< 0.076	34.8	14.1	2.9	17	4.5	2.5	7.0	5.5	3.0	8.5
26	34.7	< 0.076	34.7	10	3.0	13	2.5	2.6	5.1	2.5	2.6	5.1
27	33.7	< 0.076	33.7	13.3	1.9	15.2	8.0	3.0	11	7.8	2.6	10.4
28	33.6	< 0.076	33.6	15.2	1.7	16.9	4.8	3.3	8.1	5.2	2.5	7.7
29	32.7	< 0.076	32.7	7.5	0.99	8.49	0.15	1.2	1.35	5.6	1.9	7.5
30	31.4	< 0.076	31.4	19	0.8	19.8	7.4	3.0	10.4	8.0	2.0	10
Mean[2]	**38 J**	**ND**	**38 J**	**20**	**1.3**	**21**	**7.7**	**2.9**	**11**	**8.4**	**1.5**	**9.9**

[1] Represents a sample set in which samples from all four locations were collected at the approximate same time.
[2] Represents combined Nitrate-N and Nitrite-N. Values below the detection limit were considered 0.0 when summing totals.
[3] Means are rounded to two significant digits. Values < detection limit considered zero when calculating means.
J = Estimated value. ND = Not detected at or above MDL.

- Part II: Final Effluent did not meet its performance estimate since the nitrite-N mean was above the 1.5 mg/l criterion.

Based on the results of these 2 hypothesis tests, Event 3 was not shown to be successful in reducing levels of nitrite-N and nitrate-N to below regulatory limits.

4.4.3.3 General Evaluation of BDN System

Table 4-26 presents the post-BDN and final effluent nitrate-N; the nitrite-N; and total-N results for the four sampling points for each of the 30 Event 3 sampling rounds. Also included in Table 4-26 are additional analytical data and field measurement results that were used for evaluating other performance criteria. A total of 11 of the 30 sample rounds showed reductions in nitrate-N, nitrite-N, and total-N in the final effluent to below the respective regulatory criteria (when the results are rounded to the nearest whole number). Results for other performance criteria indicated a steady improvement in mean turbidity values with substantially less biological carryover than in the first two events. However, those same results indicated that neither the ozone nor the UV oxidation treatment was effective in reducing mean residual methanol concentrations to below 1 mg/l.

The daily DO measurements in **Table 4-27** showed DO in the partially treated BDN effluent to be consistently above 1 mg/l and to average slightly over 2 mg/l for the entire event. Although the deoxygenating process was effective in reducing mean inlet water DO of 9.5 mg/l down to ~ 2 mg/l, the elevated DO values are an indicator that anaerobic processes were not optimized. This was a likely contributing factor to the poorer performance of Event 3 with respect to nitrate-N and nitrite-N reduction. Also, the addition of ozone as a post-treatment step did not significantly increase the DO of the final effluent.

4.4.3.4 General Evaluation of Post-Treatment System

The field and laboratory measurements used primarily for evaluating the post-treatment component of the EcoMat's Process during Event 3 (*Objective 5*) included pH, turbidity, TSS, microbial analyses, residual methanol, and "supplemental analyses".

The daily pH measurements in **Table 4-28** showed little to no change between all four sample points. Potential pH-altering post-treatment units used during Event 3, such as ozone, apparently had no impact on pH.

The daily turbidity measurements in **Table 4-29** indicate that although just two of nine final effluent values were measured below the secondary drinking water criteria of 1 NTU, the 1.2 mean value of NTU in the final effluent showed continued improvement from Events 1 and 2.

The TSS data in **Table 4-30** showed that the inlet water contained no detectable levels of TSS and the post BDN effluent to contain detectable levels of TSS in six of the nine rounds. The final effluent data indicated that the post-treatment system had a positive effect on reducing TSS levels in all but one of those rounds, and that the final effluent mean TSS value was below the detection limit. Two of nine final effluent values were higher than their paired inlet water value. Thus, the secondary criteria was met for seven of nine rounds. Therefore, the combination of filters used for Event 3 was, for the most part, effective.

Table 4-31 presents the laboratory results for Total TCH, FC, and FA at each of the four outfalls. An additional sample was collected immediately upstream of the UV oxidation unit and analyzed for TCH and FC to evaluate that post-treatment system independently of ozone treatment (refer to Figure 4-7).

The results of the TCH analyses indicated the TCH population associated with the BDN process was, on average, two orders of magnitude higher than TCH levels in the well water. On average, approximately 10 percent of this bacteria carried over from the BDN process to the final effluent (similar to that measured for Event 2). And, like Event 2, all seven final effluent TCH values were measured to be above their paired inlet water values. Thus, the secondary criterion was not met for TCH.

The pre-UV oxidation mean value for TCH (obtained from the added sample point upstream of the UV oxidation unit) was the same order of magnitude as the average of the mean inlet water values. Therefore, the ozone treatment may not have had any effect on TCH. The post-treatment train downstream of the ozone unit may have had all of the impact for reducing TCH levels in final effluent.

Like the two previous events, the FA data generally followed the expected pattern of greatly increasing in the post-BDN effluent and then greatly decreasing in final effluent due to post-treatment (the values for round # 23 were an exception). The average of the FA plate count mean values in inlet water was increased by one order of magnitude in post BDN effluent. The post-treatment effectiveness was improved over both previous events, but the results were skewed by the unexplainable final effluent mean value for round # 23. Only one of the final effluent mean values was less than the corresponding inlet water mean value. Thus, the criterion was not met for FA. (It should also be noted that the inlet water in round #19 exhibited an unusually high FA).

For Event 3, a small amount of FC was measured in final effluent of round 1 only. There was no FC measured in the paired inlet water sample for round 1. Conversely, there was FC measured in the last inlet water sample collected (round 30). A similar number of colonies was measured in the corresponding post BDN sample, but no FC was measured in the final effluent. On a per round basis the

Table 4-26. Event 3 - Summary of Treatment Effectiveness.

Sample Round[1]	Nitrate-N/Nitrite-N Results (mg/l) Post BDN Total-N	Final Effluent Nitrate-N	Final Effluent Nitrite-N	Final Effluent Total-N[2]	Final Effluent - Other Performance Criteria Flow (gpm)	MeOH (mg/l)	TSS (mg/l)	Turbidity (NTU)	pH [3] (SU)	Total Heterotrophs [3] (CFU/ml)
1	7.9	1.7	0.44	2.14	---	59	< 5	1.4	8.1 / 7.9	46,000 / 310,000
2	9.0	5.3	0.85	6.15	3.9	---	---	---	---	---
3	9.4	8.9	0.954	9.85	4.4	---	---	---	---	---
4	8.6	7.6	<0.076	7.6	2	32	< 5	1.1	8.1 / 8.2	---
5	15	13.3	1.1	14.4	5	---	---	---	---	42,000 / 360,000
6	9.9	9.4	1.1	10.5	3.6	---	---	---	---	---
7	12.9	9.9	1.1	11	5	---	---	---	---	---
8	10.6	11	1.4	12.4	4.3	---	---	---	---	---
9	13.3	8.2	1.3	9.5	4.9	62	< 5	1.0	8.1 / 8.0	18,000 / 110,000
10	10	7.4	1.1	8.5	3.6	---	---	---	---	---
11	15.4	12.2	1.3	13.5	4.6	---	---	---	---	---
12	15.9	12.6	2.5	15.1	4.9	---	---	---	---	---
13	15.8	12.7	2.4	15.1	4.7	27	< 5	0.64	8.2 / 8.0	---
14	15.1	11.8	2.1	13.9	5.7	---	---	---	---	---
15	11	9.1	3.5	12.6	4.3	---	---	---	---	---
16	12.1	8.6	1.8	10.4	4.7	---	---	---	---	---
17	11.6	7.8	2.0	9.8	4.3	35	5	1.0	8.1 / 8.0	---
18	0.19	5.4	1.5	6.9	2.3	---	---	---	---	---
19	10	8.4	0.84	9.24	4.8	34	7	1.8	8.2 / 8.0	180,000 / 630,000
20	13	11.1	1.1	12.2	5	---	---	---	---	---
21	12.8	6.6	1.4	8	4.6	---	---	---	---	---
22	12.6	9.1	1.6	10.7	4.5	---	---	---	---	---
23	11.7	8.3	<0.076	8.3	4.5	54	< 5	1.1	---	17,000 / 49,000
24	10.2	9.4	0.38	9.78	7.2	---	---	---	---	---
25	7.0	5.5	3.0	8.5	3.3	---	---	---	---	---
26	5.1	2.5	2.6	5.1	4	---	---	---	---	---
27	11	7.8	2.6	10.4	5	30	< 5	1.9	8.1 / 8.1	14,000 / 240,000
28	8.1	5.2	2.5	7.8	5.2	---	---	---	---	---
29	1.35	5.6	1.9	7.5	3.3	---	---	---	---	---
30	10.4	8	2.0	10	4.8	33	< 5	0.84	8.2 / 8.1	120,000 / 3,200,000
Mean[4]	**11**	**8.4**	**1.5**	**9.9**	**4.2**	**41**	**< 5**	**1.2**	**7.9-8.2**	**63,000 / 690,000**

[1] Represents a sample set in which samples from all four locations were collected at the approximate same time.
[2]Total-N is equal to the combined Nitrate-N + Nitrite-N concentration.
[3] The first value represent the inlet water and the second value represents the final effluent.
[4] All values, except for the pH range, are means rounded to two significant digits. Values < detection limit considered zero for calculating means.
Dashed line indicates that samples collected at that location were not analyzed for that parameter.

Table 4-27. Event 3 - Dissolved Oxygen Measurements (mg/l).

DATE	TIME INTERVAL	Associated Round No(s.)[1]	SAMPLE POINT			
			Inlet Water	**Partial BDN**	**Post BDN**	**Final Effluent**
10-20-99	1300	1,**2**,3	9.20	1.90	3.9	4.88
10-21-99	1100	4,**5**,6,7	9.18	1.91	3.24	8.67
10-22-99	0800	**8**,9,10,11	9.18	1.91	0.6*	7.90
10-23-99	0900	**12-13**,14	9.25	2.56	4.1	1.2 [3]
10-24-99	1400	**15**,16,17	10.0	2.59	3.74	0.44
10-25-99	1045	**18-19**,20,21	9.62	2.62	2.10	6.51
10-26-99	1630	**24**,25	---	---	---	---
10-27-99	1130	26,**27**,28,29	9.37	1.66	2.65/0.2*	3.21
10-28-99	0800	30	10.3	1.66	2.22	3.68
		Mean [2]	**9.5**	**2.1**	**3.1/0.4**	**4.6**

[1] Sample Rounds conducted closest in time to the measurement are bolded.
[2] Mean values are rounded to two significant digits.
[3] Average of two readings.
* Measurement taken inside R2 tank due to air bubbles in hose.
Dashed line indicates that samples collected at that location were not analyzed for that parameter.

Table 4-28. Event 3 - pH Measurements.

DATE	TIME INTERVAL	Associated Round No(s.)[1]	SAMPLE POINT			
			Inlet Water	**Partial BDN**	**Post BDN**	**Final Effluent**
10-20-99	1300	1,**2**,3	8.08	8.09	8.15	7.93
10-21-99	1100	4,**5**,6,7	8.05	7.94	8.15	8.17
10-22-99	0800	**8**,9,10,11	8.09	8.03	8.16	8.03
10-23-99	0900	**12-13**,14	8.22	8.12	8.17	8.00
10-24-99	1400	**15**,16,17	8.10	8.06	8.17	7.98
10-25-99	1045	**18-19**,20,21	8.19	8.03	8.15	8.02
10-26-99	1630	**24**,25	---	---	---	---
10-27-99	1130	26,**27**,28,29	8.11	8.14	8.21	8.10
10-28-99	0800	30	8.15	8.06	8.18	8.06
		Range [2]	**8.1 - 8.2**	**7.9 - 8.1**	**8.2 - 8.2**	**7.9 - 8.2**

[1] Sample rounds conducted closest in time to the measurement are bolded.
[2] Range values are rounded to two significant digits.
Dashed line indicates that samples collected at that location were not analyzed for that parameter.

Table 4-29. Event 3 - Turbidity Measurements (NTU).

DATE	TIME INTERVAL	Associated Round(s)[1]	SAMPLE POINT				Pass/ Fail [2]
			Inlet Water	**Partial BDN**	**Post BDN**	**Final Effluent**	
10-20-99	1300	1,**2**,3	---	---	---	1.4	F
10-21-99	1100-1400	4,**5**,6,7	0.13	0.38	1.20	1.07	F
10-22-99	0800-0900	**8**,9,10,11	0.10	0.65	2.14	1.03	F
10-23-99	0900	**12-13**,14	0.32	0.39	0.86	0.64	P
10-24-99	1400	**15**,16,17	0.18	1.38	1.10	1.02	F
10-25-99	1045	**18-19**,20,21	0.65	---	1.51	1.82	F
10-26-99	1630	**24**,25	0.17	1.60	1.09	1.06	F
10-27-99	1130	26,**27**,28,29	0.21	---	1.67	1.86	F
10-28-99	0800	30	0.15	4.25	0.95	0.84	P
		Mean [3]	**0.24**	**1.4**	**1.3**	**1.2**	**2/9**

[1] Sample rounds conducted closest in time to the measurement are bolded.
[2] A round is considered passing if the final effluent is $\leq$ 1 NTU. In the last row, the number of passing values is shown in the numerator; the total number of values (pass + fail, minus any blank values) is shown in the denominator
[3] Mean values are rounded to two significant digits.
Dashed line indicates that samples collected at that location were not analyzed for that parameter.

Table 4-30. Event 3 -TSS Results (mg/l).

Sample Round No.	SAMPLE POINT				Pass/ Fail [1]
	Inlet Water	**Partial BDN**	**Post BDN**	**Final Effluent**	
1	< 5	---	6	< 5	P
4/5	< 5	---	5	< 5	P
9	< 5	---	6	< 5	P
13	< 5	---	< 5	< 5	P
17	< 5	---	< 5	5	F
19	< 5	---	5	7	F
23	< 5	---	5.3	< 5	P
27	< 5	---	8	< 5	P
30	< 5	---	< 5	< 5	P
Mean [2]	**< 5**	**---**	**< 5**	**< 5**	**7/9**

[1] A round is considered passing if the final effluent value is $\leq$ the inlet water value. In the last row, the number of passing values is shown in the numerator; the total number of values (pass + fail, minus any blank values) is shown in the denominator.
[2] Mean values are rounded to two significant digits. Values < detection limit considered zero when calculating means.
Dashed line indicates that samples collected at that location were not analyzed for that parameter.

Table 4-31. Event 3 - Microbial Results.[1]

Sample Round No.	Inlet Water [2]	Post BDN[2]	Final Effluent[2]	% Carryover from BDN	% Change from Inlet Water	Pass/ Fail [3]
	TOTAL CULTURABLE HETEROTROPHS - Plate Count Mean (cfu/ml)[2]					
1	46,300	3,100,000	305,000	9.8 %	+ 660 %	F
5	42,000	7,550,000	362,000	4.8 %	+ 860 %	F
9	17,700	3,370,000	113,000	3.4 %	+ 640 %	F
19	183,000	5,150,000	632,000	12 %	+ 350 %	F
23	17,300	4,230,000	49,000[4]	1.2 %	+ 280 %	F
27	14,200	21,300,000	240,000	1.1 %	+ 1,690 %	F
30	120,000	1,970,000	3,160,000	160 %	+ 2,600 %	F
Avg.	**62,900**	**6,670,000**	**694,000**	**10 %**	**+ 1,100 %**	**0/7**
FACULTATIVE ANAEROBES - Plate Count Mean (cfu/ml)[2]						
1	2,300	240,000	16,000	6.7 %	+ 700 %	F
5	3,300	1,100,000	3,500	0.3 %	+ 6.1 %	F
9	2,000	430,000	7,100	1.7 %	+360 %	F
19	350,000[4]	1,900,000	1,500[4]	0.1 %	- 99 %	P
23	470	190,000	12,000,000[4]	6,300 %	+ 2,500,000 %	F
27	1,000	65,000	2,200	3.4 %	+ 220 %	F
30	2,100	290,000	8,400	2.9 %	+ 400 %	F
Avg.	**51,600**	**602,000**	**1,720,000**	**+ 290 %**	**+ 3,300 %**	**1/7**
FECAL COLIFORM (Fecal coliforms/100ml)						
1	NG	NG	33	NC	NC	F
5	NG	NG	NG	NC	NC	---
9	NG	NG	NG	NC	NC	---
19	NG	NG	NG	NC	NC	---
23	NG	NG	NG	NC	NC	---
27	NG	NG	NG	NC	NC	---
30	378	348	NG	0 %	- 100 %	P
Avg.	**54**	**50**	**5**	**10 %**	**- 91 %**	**1/2**

[1] Post-treatment for Event 3 consisted of chlorination, ozonation, UV treatment, a clarifying tank, high efficiency filtration, carbon filtration, and polishing filtration.
[2] Plate count mean = average of three separate analyses, reported in colony forming units per milliliter.
[3] A round is considered passing if the final effluent value is ≤ the inlet water value. In the last row, the number of passing values is shown in the numerator; the total number of values (pass + fail, minus any blank values) is shown in the denominator.
[4] Anomalous results indicate potential problems with sampling or labeling. No corrective action is required. Data are suspect and should be used with extreme caution.
NG = No growth. NC = Not calculated.

criterion for FC was met for one of two rounds for which any FC growth occurred; no growth occurred in the inlet water, post-BDN, or final effluent for the other five tests. No FC was detected in the single analysis of the sample collected between the ozone and UV oxidation treatment units during the 3rd round of Event 3 (refer to Figure 4-7). Thus, no evaluation of UV oxidation effectiveness can be made with respect to FC based on these limited data.

The laboratory results in **Table 4-32** indicate that methanol was not detected in inlet water samples, but was detected in all post BDN and final effluent samples. The mean concentration of methanol in post BDN and final effluent were both 41 mg/l. The post BDN and final effluent values were very similar on a per round basis, indicating that the combined ozone and UV oxidation post-treatment had no effect on reducing residual methanol concentrations. Thus, the secondary criterion of achieving a final effluent with < 1 mg/l methanol was not met.

Table 4-33 presents the results of supplemental analyses for all outfalls sampled. The majority of the supplemental analyses results indicates the BDN and post-treatment systems to have little to no effect on the measured parameters. As was the case with the previous event, a small average concentration of CCl_4 (i.e., 19 µg/l) was detected in the inlet water during Event 3. Based on a post BDN mean value of 10 µg/l and a final effluent estimated mean value of 1µg/l for CCl_4, the post-treatment system (likely the UV oxidation) may have contributed to the reduction of that VOC contaminant.

The increase in TOC following BDN can be attributed to the carryover of biological material and/or methanol. The increased alkalinity following BDN is consistent with the slight increase in pH (refer to Table 4-28). The small amounts of phosphate and phosphorus measured in the effluent samples is residuum from the 50% methanol solution, which contains food grade phosphoric acid.

4.4.3.5 Mass Removal of Nitrate

The percent mass removal of nitrate, measured as Nitrate-N, was estimated for Event 3 (*Objective 4*). A total of approximately 49,000 gallons, or about 185,000 liters of well water was treated during Event 3. Each mg/l of nitrate-N is equivalent to 4.4 mg/l of nitrate. Since the mean nitrate-N concentration for Event 3 inlet water was 38 mg/l, the total mass of nitrate treated during Event 3 final effluent was (38 x 4.4) mg/l x 185,000 liters = 31,000,000 mg. The mean nitrate-N concentration for Event 3 final effluent was 8.3 mg/l. The total mass of nitrate in the final effluent = (8.3 x 4.4) mg/l x 185,000 liters = 6,800,000 mg. Therefore the mass removal of nitrate during Event 3 would be approximately 31,000,000 mg - 6,800,000 mg = 24,000,000 mg (a 77% reduction in nitrate). This correlates to 24,000 grams or 53 pounds. Considering the residual nitrite-N in the final effluent, the nitrate-N reduction would decrease to 51 pounds.

Table 4-32. Event 3 - Methanol Results (mg/l).

Sample Round No.	SAMPLE POINT				Pass/ Fail [1]
	Inlet Water	**Partial BDN**	**Post BDN**	**Final Effluent**	
1	< 0.23	---	83	59	F
4/5	< 0.23	---	33	32	F
9	< 0.23	---	34	62	F
13	< 0.23	---	38	27	F
17	< 0.23	---	42	35	F
19	< 0.23	---	31	34	F
23	< 0.23	---	49	54	F
27	< 0.23	---	35	30	F
30	< 0.23	---	26	33	F
Mean [2]	**< 0.23**	**---**	**41**	**41**	**0/9**

[1] A round is considered passing if the final effluent value is < 1 mg/l. In the last row, the number of passing values is shown in the numerator; the total number of values (pass + fail, minus any blank values) is shown in the denominator.
[2] Mean values are rounded to two significant digits. Values < detection limit considered zero when calculating means.
Dashed line indicates that samples collected at that location were not analyzed for that parameter.

Table 4-33. Event 3 - Supplemental Analyses Results (mg/l).[1]

Sample Round No.	Analyte [2]	SAMPLE POINT			
		Inlet Water	**Partial BDN**	**Post BDN**	**Final Effluent**
4/5,17,27	CCl_4	0.019	---	0.01	0.001J
4/5,17,27	Total Solids	582	---	459	467
4/5,17,27	Ammonia	< 0.8	---	< 0.8	< 0.8
4/5,17,27	Total Organic	1.1	---	24	21
4/5,17,27	Sulfate	59	---	55	56
4/5,17,27	Phosphate	< 0.082	---	1.4	1.4
4/5,17,27	Alkalinity	157	---	252	250
	Metals				
4/5,17,27	Barium	0.069	---	0.068	0.067
4/5,17,27	Calcium	103	---	103	102
4/5,17,27	Potassium	1.4	---	1.2	1.2
4/5,17,27	Magnesium	28	---	29	30
4/5,17,27	Sodium	13	---	15	16
4/5,17,27	Phosphorus	< 0.37	---	1.6	1.6

[1] Values are the mean of the three test results and are rounded to a maximum three significant digits.
[2] Except for CCl_4 only SW-846 8260 contaminants with mean values above detection limits are reported.
Metals analyzed for included Ag, Al, Ba, Be, Ca, Cd, Co, Cr, Cu, Fe, K, Mg, Mn, Mo, Na, Ni, P, Sb, and Zn.
J = Estimated average value. Dashed line indicates that samples collected at that location were not analyzed for that parameter.

4.4.3.6 System Performance Vs. Flow Rate

The performance of EcoMat's combined BDN and post-treatment system components were evaluated with respect to water flow through the system (*Objective 2*). The variation in inlet water flow rate during Event 3 was compared with the total-N concentrations in the final effluent. **Figure 4-8** directly compares the Event 3 fluctuation for inlet water flow rate to the Event 3 fluctuation in total-N final effluent concentrations on a per round basis. The patterns for both plots reflect the high variability in flow rate for Event 3, but still do suggest an inverse correlation with system performance. Again, a relationship between lower flow rate and increased BDN effectiveness is evident where the somewhat sharp decrease in flow rate occurred about one quarter the way through the event, which correlates with a reduction in total-N concentration. The plots in Figure 4-8 also indicate that the system was never really stabilized which in large part was due to system perturbations that disrupted Event 3.

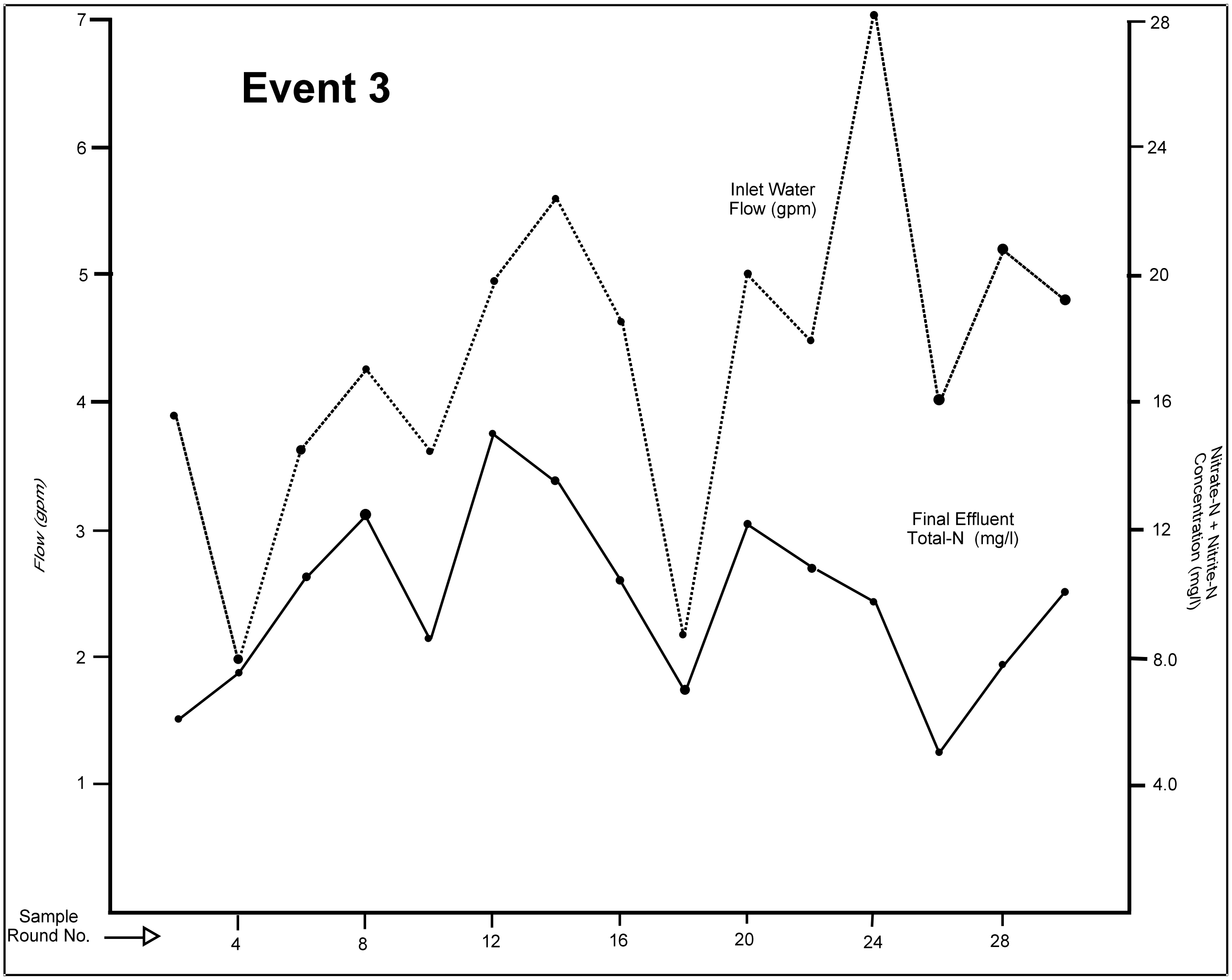

Figure 4-8. Event 3 - Comparison of Flow Rate Fluctuation and Final Effluent Total-N Concentration.

4.4.4 Event 4

4.4.4.1 Summary

Event 4 was an 8-day sampling episode conducted December 7-14, 1999. During Event 4 a total of 30 sampling rounds were conducted and - 61,000 gallons of nitrate-contaminated well water passed through EcoMat's treatment system at an average flow rate of 6 gpm. The flow rate among the 30 sampling rounds ranged between 4.7and 8.3 gpm. Based on an estimated retention capacity of 1,300 gallons for the reactor tanks, the sampling rounds were conducted - 2 to 3½ hours apart and from three to five times per day.

Figure 4-9 illustrates the effectiveness of the EcoMat BDN and post-treatment systems evaluated during Event 4. The mean nitrate-N concentration in PWS Well #1 had continued to drop in the six-week period since the Event 3 testing in October. The mean concentration of nitrate-N in the well water during the fourth event was 34 mg/l. During the partial BDN in the first reactor (R1), the mean nitrate-N levels were reduced by about 44% to 19 mg/l, with a small amount of nitrite left over from the nitrate to nitrite conversion. Subsequent treatment in the EcoMat reactor (R2) further reduced the mean nitrate-N concentration from 19 mg/l to 8 mg/l. The mean nitrite-N concentration increased from 1.3 mg/l to 3.2 mg/l between partial BDN and post-BDN samples. A mean total-N concentration of approximately 11 mg/l was attained by the BDN treatment for Event 4 samples.

Event 4 post-treatment consisted of chlorination followed by clarification, "high efficiency" filtration, air stripping, and "polishing" filtration. The post-treatment system had no effect on nitrite-N levels; mean nitrate-N concentrations were reduced from 3.2 to 0.81 mg/l. The mean total-N concentrations for post-BDN and final effluent samples were 11.2 mg/l and 11.9 mg/l, respectively.

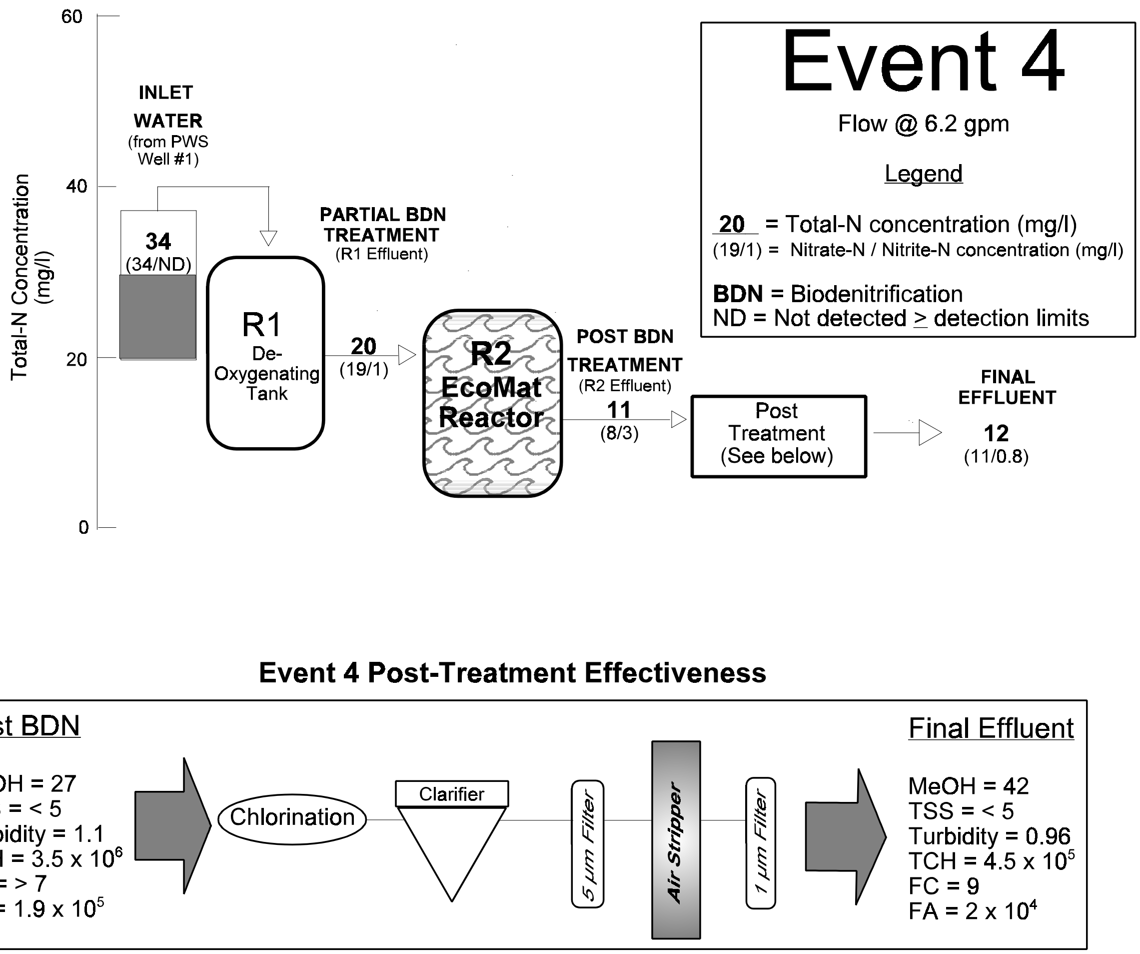

Figure 4-9. Event 4 - Treatment Effectiveness for Averaged Test Results.

4.4.4.2 Event 4 Statistical Analysis

The summary statistics for the critical measurements are presented in **Table 4-34**. Nitrate-N, nitrite-N, and total-N results for the four sampling locations for all 30 tests comprising Event 4 are shown in **Table 4-35**. The mean values from these data were used in generating Figure 4-9.

Table 4-34. Event 4 - Summary Statistics.

Critical Measurement	Mean (mg/l)	Median (mg/l)	Standard Deviation (mg/l)
Post BDN Total-N	11.197	10.550	5.079
Final Effluent Nitrate-N	10.63	11.750	5.023
Final Effluent Nitrite-N	0.870	0.076	1.523
Final Effluent Total-N	11.993	12.076	5.324

These data were also used to evaluate the Primary Objective (*Objective 1*).

The EDA showed that the data from Event 4 closely resembled a normal distribution, except for the final effluent nitrite-N data which had a large percentage of non-detects. When Shapiro-Wilk tests were run, normality was accepted for all measurements except the final effluent nitrite-N data. For these data neither the normal nor lognormal distribution was shown to fit. Therefore, the non-parametric WSR was chosen for analyzing the final effluent nitrite-N data, but the Student's t-test was chosen for analyzing the post BDN total-N, final effluent nitrate-N, and final effluent total-N.

Statistical hypothesis tests that were conducted yielded the following results:

- Part I: For the Post BDN total-N data, both the mean and median were above 10.5 mg/l, so no statistical test was needed to determine that the Post BDN data did not meet the regulatory limit.
- Part II: Final Effluent did not meet its performance estimate criteria since both the nitrate-N mean and median concentrations were > 10.5 mg/l.

Based on the results of these 2 hypothesis tests, Event 4 was not shown to be successful in reducing levels of nitrite-N and nitrate-N to below regulatory limits.

4.4.4.3 General Evaluation of BDN System

Table 4-36 presents the post-BDN and final effluent nitrate-N; nitrite-N and total-N results for the four sampling points for each of the 30 Event 4 sampling rounds. Also included in Table 4-36 are additional analytical data and field measurement data that were used for evaluating other performance criteria. A total of 11 of the 30 sample rounds showed reductions in nitrate-N, nitrite-N, and total-N in the final effluent to below the respective regulatory criteria (when rounding results to the nearest whole number). Other performance results indicated that, on average, the Event 4 filtration achieved the best removal of biological carryover among all four events, although the levels were still well above inlet water levels. The secondary criteria results also indicated that the air stripping treatment was not effective in reducing residual methanol levels to near the desired level of 1 mg/l.

The daily DO measurements in **Table 4-37** show that DO in the partial BDN effluent was consistently above 1 mg/l, averaged close to 3 mg/l, and was highly variable over the entire event. System disruptions, including unexplainable shut-offs of the methanol feed pump, contributed to the erratic DO levels. Elevated DO values are an indicator that anaerobic processes were not optimized and likely contributed to the poor performance of Event 4 with respect to nitrate-N and nitrite-N removal.

4.4.4.4 General Evaluation of Post-Treatment System

The field and laboratory measurements that were used primarily for evaluating the post-treatment component of EcoMat's process during Event 4 (*Objective* 5) included pH, turbidity, TSS, microbial analyses, methanol, and "supplemental analyses".

The daily pH measurements in **Table 4-38** indicated a continued increase for the inlet water from PWS Well # 1, as compared to previous events. However, the pH range appears to decrease following BDN treatment.

Although two final effluent pH values were slightly outside of the acceptable drinking water standard range of 6.5 - 8.5, the pH values for final effluent were improved over inlet water values.

The final effluent turbidity measurements in **Table 4-39** were consistently the lowest of all four events, indicating improved post-treatment effectiveness with respect to turbidity. Five of seven final effluent measurements, and the mean of the seven measurements, were below the criterion of 1 NTU.

Table 4-40 presents the Event 4 laboratory results for TSS. As was the case for Event 3, the data show that the inlet water and post BDN effluent contain detectable levels of TSS in just two of the eight samples. The final effluent data indicated that the post-treatment system had a positive effect on reducing TSS levels in both of those sample rounds, and that the final effluent mean TSS value was below the detection limit. One of eight final effluent values was higher than the paired inlet water value. Thus, the

Table 4-35. Event 4 - Nitrate-N and Nitrite-N Results (mg/l).

Sample Round[1]	Inlet Water			Partial BDN			Post BDN			Final Effluent		
	Nitrate-N	Nitrite-N	Total-N[2]	Nitrate-N	Nitrite-N	Total-N[2]	Nitrate-N	Nitrite-N	Total-N[2]	Nitrate-N	Nitrite-N	Total-N[2]
1	34.8	< 0.076	34.8	25.4	0.68	26.1	13.9	4	17.9	14.6	3.8	18.4
2	35	< 0.076	35	27	0.43	27.4	15.5	3.7	19.2	15.8	3.7	19.5
3	35	< 0.076	35	26.8	0.39	27.2	13	4.4	17.4	19.4	<0.076	19.4
4	34.8	< 0.076	34.8	25.6	0.48	26.1	12.1	4.2	16.3	16.8	<0.076	16.8
5	34.6	< 0.076	34.6	27.4	0.48	27.9	14.8	3.9	18.7	18.9	<0.076	18.9
6	35.3	< 0.076	35.3	26.6	0.5	27.1	14	3.9	17.9	18.6	<0.076	18.6
7	35.3	< 0.076	35.3	18.3	1.4	19.7	7	4	11	15.3	<0.076	15.3
8	33.9	< 0.076	33.9	19.8	1	20.8	9.1	3.1	12.2	12	<0.076	12
9	34.5	< 0.076	34.5	19.1	0.92	20.0	8.4	3.3	11.7	12.8	<0.076	12.8
10	34	< 0.076	34	21.1	1.1	22.2	9.1	3.5	12.6	13.8	<0.076	13.8
11	33.5	< 0.076	33.5	17.1	1.5	18.6	4.5	2.9	7.4	8.8	<0.076	8.8
12	33.5	< 0.076	33.5	20.3	0.65	21	5.6	3.5	9.1	10.6	<0.076	10.6
13	33.6	< 0.076	33.6	20.7	1.5	22.2	8	3.4	11.4	12	<0.076	12
14	33.6	< 0.076	33.6	20.6	1.6	22.2	8.3	3.8	12.1	12.1	0.73	12.8
15	33.2	< 0.076	33.2	21.3	1.4	22.7	14.1	2.7	16.8	17	<0.076	17
16	34	< 0.076	34	13.5	2.4	15.9	3	2.5	5.5	5.0	<0.076	5.0
17	33.9	< 0.076	33.9	15.3	2.5	17.8	5.8	3.1	8.9	7.6	<0.076	7.6
18	33.8	< 0.076	33.8	22.3	1.3	23.6	7	3.1	10.1	9.0	<0.076	9.0
19	33	< 0.076	33	10.8	<0.076	10.8	2.5	2.4	4.9	5.1	<0.076	5.1
20	33.9	< 0.076	33.9	17.8	1.8	19.6	5.7	2.6	8.3	9.3	<0.076	9.3
21	33.1	< 0.076	33.1	29.2	0.1	29.3	6.4	2.2	8.6	12.5	<0.076	12.5
22	33	< 0.076	33	32.4	<0.076	32.4	16.5	4.4	20.9	16.6	4.5	21.1
23	33.3	< 0.076	33.3	15	<0.076	15	9.4	4.4	13.8	11.5	4.6	16.1
24	33	< 0.076	33	15.4	<0.076	15.4	5	3.3	8.3	4.9	3.6	8.5
25	32.8	< 0.076	32.8	9.4	<0.076	9.4	2.3	3.4	4.7	2.3	2.4	4.7
26	33.2	< 0.076	33.2	14.5	<0.076	14.5	5.8	3	8.8	7.2	1.1	8.3
27	33.3	< 0.076	33.3	13.4	2.3	15.7	5.5	3.3	8.8	9.0	<0.076	9.0
28	32.8	< 0.076	32.8	14	2.3	16.3	4.4	3	7.4	7.6	<0.076	7.6
29	33.6	< 0.076	33.6	7.9	1.4	9.3	1.4	1.4	2.8	3.3	<0.076	3.3
30	33.6	< 0.076	33.6	7.9	1.2	9.1	1.3	1.1	2.4	2.5	<0.076	2.5
Mean[3]	**34**	**< 0.076**	**34**	**19**	**0.98**	**20**	**8.0**	**3.2**	**11**	**11**	**0.81**	**12**

[1] Represents a sample set in which samples from all four locations were collected at the approximate same time.
[2] Represents combined Nitrate-N and Nitrite-N. Values below the detection limit were considered 0.0 when summing totals.
[3] Means are rounded to two significant digits. Values < detection limit considered zero when calculating means.

Table 4-36. Event 4 - Summary of Treatment Effectiveness.

Sample Round No.	Nitrate-N/Nitrite-N Results (mg/l) Post BDN Total-N[1]	Final Effluent Nitrate-N	Final Effluent Nitrite-N	Final Effluent Total-N[1]	Final Effluent - Other Performance Criteria Flow (gpm)	MeOH (mg/l)	TSS (mg/l)	Turbidity (NTU)	pH [2] (SU)	Total Heterotrophs [2] (CFU/ml)
1	17.9	14.6	3.8	18.4	---	---	---	---	---	---
2	19.2	15.8	3.7	19.5	7.9	< 0.23	< 5	0.85	9.0 / 6.8	22,000 / 1,400,000
3	17.4	19.4	<0.076	19.4	7.9	---	---	---	---	---
4	16.3	16.8	<0.076	16.8	6.7	---	---	---	---	---
5	18.7	18.9	<0.076	18.9	7.7	---	---	---	---	---
6	17.9	18.6	<0.076	18.6	7.7	33	< 5	1.3	9.0 / 8.4	---
7	11	15.3	<0.076	15.3	7.5	---	---	---	---	---
8	12.2	12	<0.076	12	7.1	---	---	---	---	34,000 / 8,300
9	11.7	12.8	<0.076	12.8	7.9	---	---	---	---	---
10	12.6	13.8	<0.076	13.8	8.3	---	---	---	---	---
11	7.4	8.8	<0.076	8.8	5.9	---	---	---	---	---
12	9.1	10.6	<0.076	10.6	5.5	43	6	1.7	8.7 / 8.9	600,000 / 2,000
13	11.4	12	<0.076	12	7.7	---	---	---	---	---
14	12.1	12.1	0.73	12.8	7.4	---	---	---	---	---
15	16.8	17	<0.076	17	8	---	---	---	---	---
16	5.5	5	<0.076	5.0	5	---	---	---	---	---
17	8.9	7.6	<0.076	7.6	6.2	38	< 5	0.95	9.2 / 8.2	9,800 / 1,200,000
18	10.1	9	<0.076	9.0	5.5	---	---	---	---	---
19	4.9	5.1	<0.076	5.1	5.2	---	---	---	---	---
20	8.3	9.3	<0.076	9.3	6.8	20	< 5	0.77	9.1 / 8.1	---
21	8.6	12.5	<0.076	12.5	6	---	---	---	---	---
22	20.9	16.6	4.5	21.1	5.3	---	---	---	---	---
23	13.8	11.5	4.6	16.1	6	29	< 5	0.77	9.1 / 8.3	5,200 / 1,300,000
24	8.3	4.9	3.6	8.5	5.9	---	---	---	---	---
25	4.7	2.3	2.4	4.7	5.4	---	---	---	---	---
26	8.8	7.2	1.1	8.3	6.7	43	< 5	0.40	8.3 / 8.6	480,000
27	8.8	9	<0.076	9.0	6.1	---	---	---	---	---
28	7.4	7.6	<0.076	7.6	6.2	---	---	---	---	---
29	2.8	3.3	<0.076	3.3	4.7	---	---	---	---	---
30	2.4	2.5	<0.076	2.5	4.7	91	< 5	---	9.0 / 8.2	5,200 / NG
Mean [3]	**11**	**11**	**0.81**	**12**	**6.2**	**37**	**< 5**	**0.96**	**6.8-9.1**	**97,000 / 450,000**

[1] Total-N is equal to the combined Nitrate-N + Nitrite-N concentration.
[2] The first value represents the inlet water and the second value represents the final effluent.
[3] All values, except for the pH range, are means rounded to two significant digits. Values < detection limit considered zero when calculating means. Dashed line indicates that samples collected at that location were not analyzed for that parameter.

Table 4-37. Event 4 - Dissolved Oxygen Measurements (mg/l).

DATE	TIME INTERVAL	Associated Round No(s.)	SAMPLE POINT			
			Inlet Water	**Partial BDN**	**Post BDN**	**Final Effluent**
12-7-99	Not Available	1-5	9.55	5.65*	---	9.55
12-8-99	1200	6-10	9.55	3.70	4.89	9.60
12-9-99	0915	11-15	9.51	1.50	---	9.75
12-10-99	Not Available	16-18	9.66	1.87	3.88	9.55
12-11-99	Not Available	19-21	10.32	2.10	3.65	9.58
12-12-99	Not Available	22-24	9.56	4.56**	---	9.61
12-13-99	Not Available	25-29	9.70	1.34	---	9.60
12-14-99	Not Available	30	10.1	1.28	---	9.56
		Mean[1]	**9.7**	**2.8**	**4.1**	**9.6**

[1] Mean values are rounded to two significant digits.
* Discovered methanol feed pump off. Turned on 1 hour later.
** Discovered methanol feed pump off. Turned on 2 hours later.
Dashed line indicates that samples collected at that location were not analyzed for that parameter.

Table 4-38. Event 4 - pH Measurements

DATE	TIME INTERVAL	Associated Round No(s.)	SAMPLE POINT			
			Inlet Water	**Partial BDN**	**Post BDN**	**Final Effluent**
12-7-99	Not Available	1-5	9.04	7.48	---	6.79
12-8-99	Not Available	6-10	9.04	8.59	8.25	8.37
12-9-99	Not Available	11-15	8.65	8.47	8.40	8.93
12-10-99	Not Available	16-18	9.20	8.19	8.13	8.15
12-11-99	Not Available	19-21	9.10	8.32	8.33	8.10
12-12-99	Not Available	22-24	9.05	8.38	8.45	8.27
12-13-99	Not Available	25-29	8.31	8.10	8.88	8.63
12-14-99	Not Available	30	9.04	7.96	8.30	8.17
		Range[1]	**8.3 - 9.2**	**7.5 - 8.6**	**8.1 - 8.9**	**6.8 - 8.9**

[1] Range values are rounded to two significant digits.
Dashed line indicates that samples collected at that location were not analyzed for that parameter.

Table 4-39. Event 4 - Turbidity Measurements (NTU).

DATE	TIME INTERVAL	Associated Round No(s.)	SAMPLE POINT				Pass/ Fail [1]
			Inlet Water	**Partial BDN**	**Post BDN**	**Final Effluent**	
12-7-99	1330	1-5	0.05	---	---	0.85	P
12-8-99	1000-1500	6-10	0.00	---	2.3/1.3	1.3	F
12-9-99	0815	11-15	0.00	---	2.2/1.7	1.7	F
12-10-99	0830	16-18	0.03	---	1.9/1.0	0.95	P
12-11-99	0715-1110	19-21	0.00	---	0.9/1.0	0.77	P
12-12-99	1445	22-24	0.05	---	0.9/0.75	0.77	P
12-13-99	0705	25-29	0.00	---	1.3/0.9	0.40	P
12-14-99	0830	30	0.05	---	---	---	---
		Mean [2]	**0.02**	**---**	**1.6/1.1**	**0.96**	**5/7**

[1] A round is considered passing if the final effluent is ≤ 1 NTU. In the last row, the number of passing values is shown in the numerator; the total number of values (pass + fail, minus any blank values) is shown in the denominator.
[2] Mean values are rounded to two significant digits.
Dashed line indicates that samples collected at that location were not analyzed for that parameter.

Table 4-40. Event 4 -TSS Results (mg/l).

Sample Round No.	SAMPLE POINT				Pass/ Fail [1]
	Inlet Water	**Partial BDN**	**Post BDN**	**Final Effluent**	
2	< 5	---	< 5	< 5	P
6	< 5	---	< 5	< 5	P
12	< 5	---	12	6	F
17	< 5	---	< 5	< 5	P
20	< 5	---	< 5	< 5	P
23	< 5	---	6	< 5	P
26	< 5	---	< 5	< 5	P
30	< 5	---	< 5	< 5	P
Mean [2]	**< 5**	**---**	**< 5**	**< 5**	**7/8**

[1] A round is considered passing if the final effluent value is ≤ the inlet water value. In the last row, the number of passing values is shown in the numerator; the total number of values (pass + fail, minus any blank values) is shown in the denominator.
[2] Mean values are rounded to two significant digits. Values < detection limit considered zero when calculating means.
Dashed line indicates that samples collected at that location were not analyzed for that parameter.

secondary drinking water criterion was met for seven of eight rounds, which indicated that the filter combination used for Event 4 was, for the most part, effective.

Table 4-41 presents the laboratory results for TCH, FA, and FC, at each of the four outfalls. The data indicated the TCH population associated with the BDN process was, on average, two orders of magnitude higher than TCH levels in the well water. On average, approximately 13 percent of this bacteria carried over from the BDN process to the final effluent. This carryover was similar to that measured for Events 2 and 3, which also had filtration incorporated into the post-treatment system. However, unlike the previous two events, four of the seven final effluent TCH values were measured to be below the corresponding inlet water values on a per-round basis. Thus, the secondary criteria for TCH was met for those tests, but not on an overall average basis.

Like the previous three events, the FA data for Event 4 followed the expected pattern of greatly increasing in the post-BDN effluent and then greatly decreasing in the final effluent. The average of the FA plate count mean in the inlet water was increased by three orders of magnitude in post BDN effluent. The post-treatment was effective in reducing the average mean post BDN effluent by one order of magnitude. The average mean carryover for the seven tests measured was 11 percent and four of the seven final effluent mean values were less than the inlet water mean value. Thus, the secondary criterion for FA was met for those sample rounds, but not met on an overall average basis.

For Event 4, FC was detected in six of the seven inlet water samples collected. Of these six samples FC carried over to final effluent in only the first sample (although the FC in this sample was measured at a concentration above that of the inlet water). The secondary criterion for FC was met for five of six sample rounds. Comparable to Event 3, results showed that on average, the majority of FC was removed during Event 4 post-treatment.

Table 4-42 presents the Event 4 laboratory results for methanol analyses conducted on inlet water, post-BDN effluent, and final effluent. Methanol was detected in two of eight inlet water samples at low (estimated) concentrations. Methanol was also detected in all post BDN and final effluent samples (many concentrations were estimated values). The mean methanol concentrations in post BDN and final effluent were 27 and 42 mg/l, respectively. With the exception of sample rounds 12 and 17, the post BDN and final effluent values were similar on a per round basis. This indicates that the air stripping post-treatment did not have a measured effect on reducing residual methanol concentrations, except possibly for round 2, where an estimated 1mg/l of methanol in post BDN effluent was not detected in the paired final effluent sample. Thus, the secondary criteria of achieving a final effluent with < 1 mg/l methanol was not met as a mean, nor for 7 of the 8 sampling rounds.

Table 4-43 presents the results of supplemental analyses for all outfalls sampled. Most of the results of these supplemental analyses indicate that the BDN and post-treatment systems had little to no effect on the measured parameters. The only VOC detected in the inlet water was a small amount of CCl_4. Since CCl_4 was not detected in either the post BDN or final effluents, it is likely that the 0.007 mg/l of that compound was volatilized or degraded during the BDN process.

The increase in TOC following BDN can be attributed to carryover of biological material and/or methanol. The subsequent drop in TOC in final effluent may be an indication of a positive post-treatment impact (e.g., filtration). The increased alkalinity following BDN, unlike the other three events, does not correlate with the slight decrease in pH measurements recorded for the final effluent (refer to Table 4-38). The small amounts of phosphate and phosphorus measured in the effluent samples is residuum from the 50% methanol solution, which contains food grade phosphoric acid.

4.4.4.5 Mass Removal of Nitrate

The percent mass removal of nitrate, measured as Nitrate-N, was estimated for Event 4 (*Objective 4*). A total of ~ 61,000 gallons (~230,000 liters) of well water was treated during Event 4. Each mg/l of nitrate-N is equivalent to 4.4 mg/l of nitrate. Since the mean nitrate-N concentration for Event 4 inlet water was about 34 mg/l, the total mass of nitrate treated during Event 4 was (34 x 4.4) mg/l x 230,000 liters = 34,000,000 mg. The mean nitrate-N concentration for Event 4 final effluent was 11.4 mg/l. The total mass of nitrate in the Event 4 final effluent = (11 x 4.4) mg/l x 230,000 liters = 11,000,000 mg. Therefore, the mass removal of nitrate would be about 34,000,000 mg - 11,000,000 mg = 23,000,000 mg (a 68% reduction in nitrate). This correlates to 23,000 grams or 51 pounds.

4.4.4.6 System Performance Vs. Flow Rate

The performance of EcoMat's combined BDN and post-treatment system components were evaluated with respect to water flow through the system (*Objective 2*). The variation in inlet water flow rate during Event 4 was compared with the total-N concentrations in the final effluent. **Figure 4-10** directly compares the Event 4 fluctuation for inlet water flow rate to the Event 4 fluctuation in total-N final effluent concentrations on a per round basis. As was the case with third event, Event 4 was typified by rather high variability in flow rate and system performance. The pattern for both of the plots reflects a very close relationship between flow rate and system performance. There is also an obvious trend of steady flow rate reduction coupled with a steady BDN improvement from start to

Table 4-41. Event 4 - Microbial Results.[1]

Sample Round No.	Inlet Water [2]	Post BDN [2]	Final Effluent [2]	% Carryover from BDN	% Change from Inlet Water	Pass/ Fail [3]
	TOTAL CULTURABLE HETEROTROPHS - Plate Count Mean (cfu/ml)[2]					
2	21,500	7,500,000	1,370,000	18 %	+ 6,400 %	F
8	33,500	5,800,000	8,300	0.14 %	- 75 %	P
12	600,000	3,800,000	2,000	0.05 %	- > 99 %	P
17	9,800	1,950,000	670	0.03 %	- 93 %	P
23	5,200	1,970,000	1,300,000	66 %	+ 25,000 %	F
26	4,000	1,800,000	480,000	27 %	+ 12,000 %	F
30	5,200	1,700,000	0	0 %	- 100 %	P
Avg.	**97,000**	**3,500,000**	**450,000**	**13 %**	**+ 460 %**	**4/7**
FACULTATIVE ANAEROBES - Plate Count Mean (cfu/ml)[2]						
2	180	88,000	9,200	10 %	+ 5,100 %	F
8	190	90,000	58	0.06 %	- 70 %	P
12	260	440,000	28	0.01 %	- 89 %	P
17	180	130,000	6	0.01 %	- 97 %	P
23	1,200	380,000	130,000	34 %	+ 11,000 %	F
26	440	120,000	440	0.4 %	0.0 %	P
30	340	80,000	2,400	3 %	+ 700 %	F
Avg.	**400**	**190,000**	**20,300**	**11 %**	**+ 5,100 %**	**4/7**
FECAL COLIFORM (Fecal coliforms/100ml)						
2	40	48	62	130 %	1.6	F
8	94	TNC	NG	0 %	- 100 %	P
12	158	NG	NG	0 %	- 100 %	P
17	210	NG	NG	0 %	- 100 %	P
23	38	NG	NG	0 %	- 100 %	P
26	55	NG	NG	0 %	- 100 %	P
30	NG	NG	NG	NC	NC	---
Avg.	**85**	**> 7**	**9**	**NC**	**- 89 %**	**5/6**

[1] Post-treatment for Event 4 consisted of chlorination, clarification, high efficiency filtration, air stripping, and polishing filtration.
[2] Plate count mean = average of three separate analyses, reported in colony forming units per milliliter.
[3] A result is considered passing if the final effluent value is ≤ the inlet water value.
NG = No growth. NC = Not calculated. TNC = Too Numerous to Count.

Table 4-42. Event 4 - Methanol Results (mg/l).

Sample Round No.	SAMPLE POINT				Pass/ Fail [1]
	Inlet Water	**Partial BDN**	**Post BDN**	**Final Effluent**	
2	2.8 J_1	---	1 J	< 0.23	P
6	< 0.23	---	14	33	F
12	< 0.23	---	4.1 J_1	43 J_2	F
17	< 0.23	---	5.1 J_2	38	F
20	< 0.23	---	37 J_2	55 J_2	F
23	< 0.23	---	32 J_2	29 J_2	F
26	< 0.23	---	43 J_2	43	F
30	0.3 J_1	---	79 J_2	91	F
Mean [2]	**0.4 J**	**---**	**27**	**42**	**1/8**

[1] A round is considered passing if the final effluent value is < 1 mg/l. In the last row, the number of passing values is shown in the numerator; the total number of values (pass + fail, minus any blank values) is shown in the denominator.
[2] Mean values are rounded to two significant digits. Values < detection limit considered zero when calculating means.
J_1 These values should be considered estimates due to the uncertainty in the low end of the curve.
J_2 These values should be considered estimates due to the possibility of peak interferences from a second peak.
Dashed line indicates that samples collected at that location were not analyzed for that parameter.

Table 4-43. Event 4 - Supplemental Analyses Results (mg/l).[1]

Sample Round Nos.	Analyte [2]	SAMPLE POINT			
		Inlet Water	**Partial BDN**	**Post BDN**	**Final Effluent**
6, 17, 27	CCl_4	0.007	---	< 0.005	< 0.003
6, 17, 27	Total Solids	365	---	437	495
6, 17, 27	Ammonia	< 0.8	---	< 0.8	< 0.8
6, 17, 27	Total Organic Carbon	< 1	---	49.8	16.2
6, 17, 27	Sulfate	54.8	---	54.8	54.7
6, 17, 27	Phosphate	< 0.082	---	1.4	0.84*
6, 17, 27	Alkalinity	147	---	225	229
	Metals				
6, 17, 27	Barium	0.061	**---**	0.055	0.052
6, 17, 27	Calcium	82	**---**	91	87
6, 17, 27		Potassium	1.1	**---**	1.21.1
6, 17, 27	Magnesium	23	**---**	25	25
6, 17, 27	Sodium	13	**---**	15	33
6, 17, 27	Phosphorus	< 0.37	**---**	1.5	1.5

[1] Values are the mean of the three test results and are rounded to a maximum three significant digits.
[2] Except for CCl_4 only SW-846 Method contaminants with mean values above detection limits are reported. Metals analyzed for included Ag, Al, Ba, Be, Ca, Cd, Co, Cr, Cu, Fe, K, Mg, Mn, Mo, Na, Ni, P, Sb, and Zn.

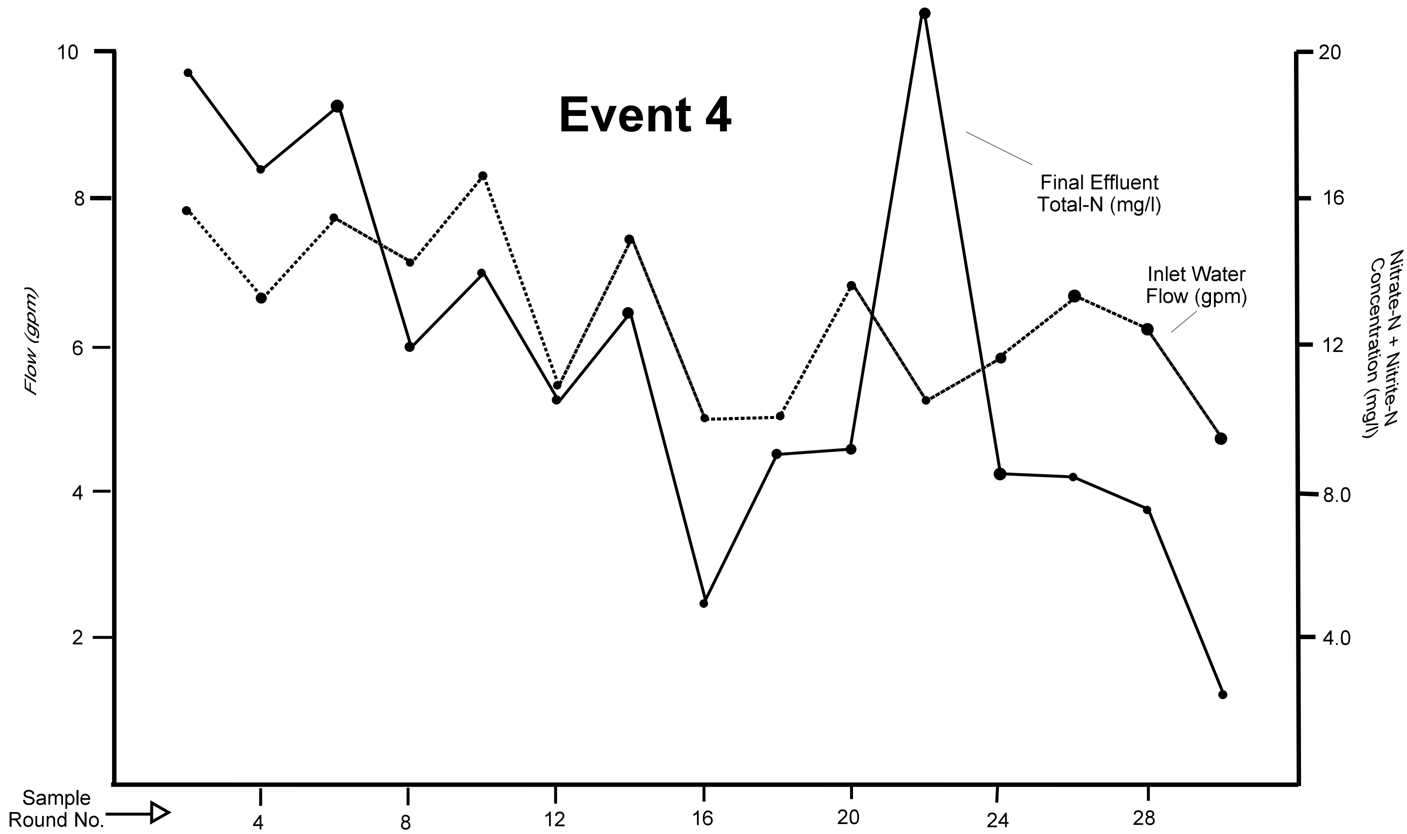

Figure 4-10. Event 4 - Comparison of Flow Rate Fluctuation and Final Effluent Total-N Concentration

finish. The only exception to this pattern is an abrupt sharp increase in the total-N levels about 3/4 of the way through the event. This anomalous peak is believed to be the result of an inadvertent shut off of the methanol feed pump that disrupted the treatment system.

4.4.5 Inter-Event Comparison

This section evaluates the overall demonstration performance of the EcoMat BDN treatment system with respect to nitrate-N, nitrite-N, total-N and several key field and analytical parameters. Direct comparisons are made among the four events in order to investigate possible reasons for variable performance.

4.4.5.1 BDN Performance

Figure 4-11 shows the mean total-N concentrations for each individual event plotted against one another. The mean nitrate-N and nitrite-N concentrations for all tests conducted during a particular event are presented as data pairs in boxes. Several observations can be made from this figure. First, for all four events, the concentration of nitrate-N in the untreated inlet water from PWS Well # 1 was well in excess of both the 10 mg/l MCL and the 20 mg/l threshold set for the demonstration. The inlet water nitrate-N concentrations were considerably higher for Events 1 and 2, as compared to Events 3 and 4. Based on daily water level measurements taken during all four events, there was a significant water level drop of approximately 14 feet in PWS Well # 1 between Events 2 and 3. Thus, there may have been a corresponding drop in the amount of nitrate being flushed into the well during the dryer months preceding Events 3 and 4.

Figure 4-11 also illustrates that, during the initial stages of BDN, the nitrate-N concentrations were reduced by similar percentages for all four events (i.e., 52-60%), while at the same time small amounts of nitrite-N were being generated from the reduction of nitrate. Following BDN, the mean nitrate-N concentrations were further reduced to below 10 mg/l, and mean nitrite-N concentrations increased for three of the four events. Following post-treatment the mean nitrite-N concentrations were reduced for all events, except for Event 2, where the mean nitrite-N level remained essentially the same. As expected, there was no appreciable difference in the mean final effluent nitrate-N concentration, following post-treatment.

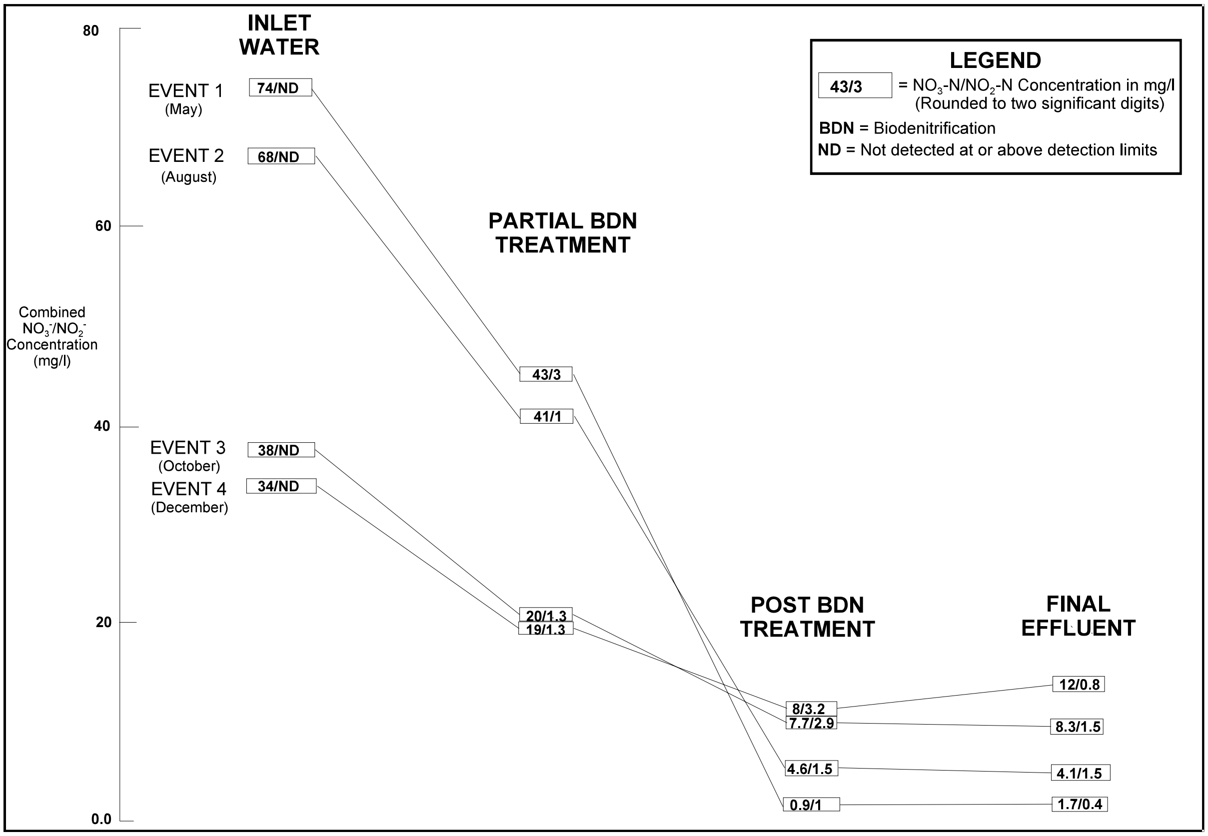

Figure 4-11. Inter-Event Comparison - Treatment Effectiveness for Nitrate-N/Nitrite-N

4.4.5.2 Final Effluent Water Quality

Table 4-44 summarizes relevant criteria-oriented final effluent data collected during the demonstration as averages for all four events. Except for the relevant process parameters, all values represent final effluent means. The mean DO levels for water exiting the deoxygenating tank have been included due to the importance of that field measurement in determining proper anoxic conditions. In general terms, the final effluent mean nitrate-N concentrations increased when the DO was not maintained near the desired 1 mg/l level.

The increased post-treatment following the first event had less impact than anticipated (e.g., neither the carbon filtration employed during Event 3 nor the air stripping employed during Event 4 appears to have had a significant impact on methanol levels in the final effluent). Although TSS and turbidity improved to or near acceptable concentrations when filtration was employed, carryover of biological material from the EcoMat reactor to the final effluent remained considerable.

None of the oxidation post-treatments (chlorination, UV oxidation, or ozone) appeared to have any beneficial effects on residual bacterial matter, methanol destruction, or re-oxidation of nitrite to nitrate. It is not known whether this was due to inappropriate sizing, variability in feed rate or other, unknown factors. There also was some question whether ongoing biodegradation was occurring in some sample containers between collection and analysis. This could have taken place in BDN samples, resulting in lower methanol results before post-treatment, but would have been inhibited in oxidized samples. The overall EcoMat process appears to have little impact on pH.

Table 4-44. Inter-Event Comparison of Demonstration Criteria for Final Effluent.[1]

Parameter	Criterion	SAMPLING EVENT			
		Event 1 (May 6-15)	**Event 2** (August 3-12)	**Event 3** (October 20-28)	**Event 4** (December 7-14)
Process Parameters					
Flow (gpm)	3-15	3.0	3.5	4.2	6.2
Total Gallons Treated	---	42,000	45,000	49,000	61,000
DO in Partial BDN Effluent (mg/l)	---	1.1	1.0	2.1	2.8
Biodenitrification Parameters					
Nitrate-N (mg/l)	≤ 10		**4.1**	**8.3**	11
Nitrite-N (mg/l)	≤ 1		1.5	1.5	**0.8**
Total-N (mg/l) [2]	≤ 10		**5.6**	**9.9**	12
Post-Treatment Parameters					
Post-Treatment System	---	‣ Chlorination	‣ Clarification ‣ Sand Filtration ‣ Rough Filtration ‣ UV Oxidation	‣ Ozone ‣ UV Oxidation ‣Clarification ‣ Rough Filtration ‣ High Eff. Filtration ‣ Carbon Filtration ‣ Polishing Filtration	‣ Chlorination ‣ Clarification ‣ High Eff. Filtration ‣ Air Stripping ‣ Polishing Filtration
Residual Methanol (mg/l)	≤ 1 mg/l	15	98	41	37
Turbidity (NTU)	≤ 1 NTU	4.4	1.8	1.2	**0.96**
Total Suspended Solids [3]	≤ inlet water	<5 / 10	**<5 / < 5**	**<5 / < 5**	**< 5 / <5**
pH Range (min-max)	6.5 - 8.5	7.5 - 8.6	**7.6 - 8.4**	**7.9 - 8.2**	6.8 - 8.9
Total Heterotrophs (% change)	≤ inlet water	+ 19,000	+ 18,000	+ 1,100	+ 460
Fac. Anaerobes (% change)	≤ inlet water	+ 7,300	+ 170,000	+ 3,300	+ 5,100
Fecal Coliform (% change)	≤ inlet water	NC	**- 75**	**- 91**	**- 89**

[1] Values are means that have been rounded to a maximum two significant digits. Bolded values meet criteria; shaded boxes denote best result of the four events.
[2] Total-N is equal to the combined Nitrate-N + Nitrite-N.

4.4.6 Data Quality Assurance

This section of the ITER contains a review of the critical sample data and associated QC analyses that were performed to determine whether the data collected were of adequate quality to provide proper evaluation of the project's technical objectives. A more detailed summary and discussion of quality assurance/quality control information regarding the EcoMat SITE demonstration is included in the TER. The results of the critical measurements designed to assess the data quality objectives are summarized in the following subsections.

4.4.6.1 Accuracy

Accuracy objectives for nitrate-N and nitrite-N were assessed by the evaluation of 46 spiked duplicates analyzed in the same manner as the samples. Recovery values for the critical compounds were well within project objectives, with two exceptions. Two of the samples contained sufficient chemical (intentionally introduced into the EcoMat treatment stream for this same purpose) to convert the nitrite spike added to nitrate. The chemicals added, or treatments, were done to convert the nitrite to nitrate and assist in meeting the 1 ppm concentration limit for nitrite. The following adjustments were done:

Event 1- Chlorination-calcium hypochlorite-
pool filter chlorine tablets
Event 2 - UV oxidation
Event 3 - Ozone and UV oxidation
Event 4 - Chlorine liquid

Oxidation of the nitrite to nitrate likely continued after sample collection. This oxidation reaction is part of the treatment process. Any residual nitrite in the samples would be considered more hazardous in terms of health effects and therefore the oxidation reaction which is considered beneficial, would convert residual nitrite to nitrate, with total nitrate levels still expected to be below 10 ppm. Chemicals added in the final stage of treatment were specifically designed for this purpose. This explains poor recoveries of some of the matrix spikes for nitrite. Therefore, this is not believed to be an analytical problem.

It is likely that residual chemicals (e.g., chlorine and ozone) continued to react with samples after spike addition and prior to analysis. Low recoveries for matrix spikes in these samples should therefore be treated as a “matrix problem” due to a continued oxidation reaction. LCS results are therefore considered as the “analytical indicator” showing reasonable recovery of nitrite for these particular sample batches. The preceding text explains the rationale for addition of oxidizing agents.

The two spike recovery values (one from each of the chemically treated Events 1 and 4) are not included in the statistical evaluation of the spikes; therefore, a total of 44 of the 46 matrix spike/matrix spike duplicate (MS/MSD) sample sets are used in the statistical evaluation. Recovery for nitrate-N averaged 95.4% and for nitrite-N the average recovery was 95.8% (**Tables 4-45 and 4-46**).

4.4.6.2 Precision

Precision was assessed through the analysis of 44 duplicate spikes. Again, 46 MS/MSD were performed by the laboratory; however, due to the conversion of nitrite to nitrate by the sample only 44 are statistically evaluated. Data quality objectives for precision, established as relative percent difference (RPD) values less than 15%, were met with one exception. Nitrate-as-nitrogen RPDs averaged 2.7% and nitrite-as-nitrogen RPD values averaged 2.1% (**Tables 4-47 and 4-48**).

4.4.6.3 Detection Limits

Detection limits were established so as to be sufficiently below the concentration of interest (established by regulatory limits) for nitrite and nitrate. Nitrite had a detection limit of 0.076 mg/l with a concentration of interest (decision point) of 1 mg/l. Nitrate had a detection limit of 0.056 mg/l with a concentration of interest (decision point) of 10 mg/l. The concentration of interest for methanol was established by the project since there is no regulatory level for methanol in drinking water. The methanol concentration of interest was established as 1.0 mg/l with a detection limit of 0.23 mg/l.

4.4.6.4 Comparability

Comparability was achieved through the use of QAPP approved EPA protocols and verified by the validation of analytical data, which indicated that QAPP and method-specified criteria were met.

4.4.6.5 Completeness

Sufficient samples were collected to satisfy statistical completeness requirements. A minimum of 28 sample sets were collected for each event for evaluating nitrate and nitrite treatment effectiveness.

4.4.6.6 Representativeness

Representativeness refers to the degree with which a sample exhibits average properties of the waste stream at the particular time being evaluated. This is assessed in part by the analysis of field duplicates, which also provide insight into the homogeneity, or heterogeneity, of the matrix. Field duplicate samples have, inherent in the result, combined field and analytical variability. For this project, the primary sample and duplicate sample were collected immediately after each other. These indicated reasonable agreement in results, with RPD values for field duplicates from all four events generally less than 25%. The average RPD for nitrate was 10.9% and for nitrite 4.3% (**Tables 4-49 and 4-50**).

Table 4-45. Nitrate Matrix Spike Percent Recovery Summary.

Event	Recovery Range	Number of Duplicate Pairs	Percent Recovery Average
Event 1 (May 99)	87.8% to 103.1%	n=14	95.3%
Event 2 (August 99)	86.9% to 105.4%	n=10	93.7%
Event 3 (November 99)	86.8% to 107.6%	n=12	96.8%
Event 4 (December 99)	89.4% to 108.1%	n=8	95.7%
Overall Demonstration	86.8% to 107.6%	n=44	95.4%

Table 4-46. Nitrite Matrix Spike Percent Recovery Summary.

Event	Recovery Range	Number of Duplicate Pairs	Percent Recovery Average
Event 1 (May 99)	83.1% to 104.8%	n=14	90.8%
Event 2 (August 99)	92.0% to 103.4%	n=10	96.5%
Event 3 (November 99)	91.6% to 107.1%	n=12	99.0%
Event 4 (December 99)	95.6% to 107.8%	n=8	98.7%
Overall Demonstration	83.1% to 107.8%	n=44	95.8%

Table 4-47. Nitrate MS/MSD Relative Percent Difference Summary.

Event	MS/MSD RPD Range	Number of Duplicate Pairs	Average MS/MSD RPD
Event 1 (May 99)	0.0% to 9.7%	n=14	2.6%
Event 2 (August 99)	1.4% to 4.9%	n=10	2.9%
Event 3 (November 99)	0.0% to 24.2%	n=12	3.6%
Event 4 (December 99)	0.2% to 3.8%	n=8	1.5%
Overall Demonstration	0.0% to 24.2%	n=44	2.7%

Table 4-48. Nitrite MS/MSD Relative Percent Difference Summary.

Event	MS/MSD RPD Range	Number of Duplicate Pairs	Average MS/MSD RPD
Event 1 (May 99)	0.4% to 7.1%	n=14	2.1%
Event 2 (August 99)	0.3% to 5.9%	n=10	1.4%
Event 3 (November 99)	0.0% to 6.5%	n=12	2.1%
Event 4 (December 99)	0.0% to 8.3%	n=8	3.1%
Overall Demonstration	0.0% to 8.3%	n=44	2.1%

Table 4-49. Nitrate Field Duplicate Summary.

Event	RPD Range	Number of Field Duplicates	Average RPD
Event 1 (May 99)	0.0% to 108%	n=7	31.9%
Event 2 (August 99)	0.0% to 4.7%	n=6	0.8%
Event 3 (November 99)	0.0% to 3.2%	n=5	1.5%
Event 4 (December 99)	0.0% to 23.9%	n=7	5.4%
Overall Demonstration	0.0% to 108%	n=25	10.9%

Table 4-50. Nitrite Field Duplicate Summary.

Event	RPD Range	Number of Field Duplicates	Average RPD
Event 1 (May 99)	3.4% to 16.0%	n=7	7.7%
Event 2 (August 99)	0.0% to 3.5%	n=5	1.0%
Event 3 (November 99)	0.0% to 5.8%	n=4	3.5%
Event 4 (December 99)	0.0% to 5.9%	n=4	3.4%
Overall Demonstration	0.0% to 16.0%	n=20	4.3%

Section 5.0
Other Technology Requirements

5.1 Environmental Regulation Requirements

State and local regulatory agencies may require permits prior to implementing a BDN technology. Most federal permits will be issued by the authorized state agency. An air permit issued by the state Air Quality Control Region may be required if an air stripper is utilized as part of the post-treatment system (i.e., if the air emissions are of toxic concern or anticipated to be in excess of regulatory criteria). Wastewater discharge permits may be required if any such wastewater were to be discharged to a POTW. If remediation is conducted at a Superfund site, federal agencies, primarily the U.S. EPA, will provide regulatory oversight. If off-site disposal of contaminated waste is required, the waste must be taken to the disposal facility by a licensed transporter. Section 2 of this report discusses the environmental regulations that may apply to the EcoMat Inc. BDN treatment process.

5.2 Personnel Issues

The number of personnel required to operate the EcoMat Biodenitrification technology should be small and is not critically dependent on the size of the treatment system. Large systems may, however, require extensive site preparation and assembly operations that may require several individuals (inclusive of contractors), especially if there are constraints on time. For smaller treatment systems, requiring minimal site preparation, as few as one person may be needed to assemble and conduct the initial startup testing of the system.

During the demonstration EcoMat, in most instances, had one company employee at the pilot unit. They also had one local person to periodically monitor the system and collect samples in their absence. Estimated labor requirements for a full-scale 100 gpm system are discussed in detail in Section 3 of this report.

During the demonstration sampling events, two SITE team members were required to conduct field measurements and to collect and prepare samples. Personnel present during sample collection activities at a hazardous waste site must have current OSHA health and safety certification. Although the BDN technology targets nitrate and other inorganic contaminants, gas detection tubes should be used to monitor the air in the vicinity of the treatment system to monitor for sulfide, chlorine, ozone, and other potential gases. Respiratory protective equipment may be needed in rare instances, but are not anticipated.

At sites with greater complexity and risk, the personnel protective equipment (PPE) for workers will include steel-toed shoes or boots, safety glasses, hard hats, and chemical resistant gloves. Depending on contaminant types, additional PPE (such as respirators) may be required. Noise levels would usually not be a concern. However, loud pumps for larger systems could create appreciable noise. Thus, noise levels should be monitored to ensure that workers are not exposed to noise levels above the time weighted average of 85 decibels over an 8-hour day. If this level is exceeded and cannot be reduced, workers would be required to wear hearing protection.

5.3 Community Acceptance

Potential hazards to a surrounding community may include exposure to air emissions of VOCs, if those contaminants are also present in the water stream (along with the nitrates). Ozone and chlorine emissions are also possible if such post-treatment is incorporated.

Overall, there are few environmental disturbances associated with the BDN processes. No appreciable noise is anticipated beyond that generated by the short term use of power washing equipment (used during general maintenance), or by excessively loud pumps. Since most units are contained in a secured building, disturbances from the system are kept within the building confines.

Section 6.0
Technology Status

6.1 Previous Experience

The pilot-scale treatment system that was set up at the Bendena, Kansas site was EcoMat's first application of their BDN technology for treatment of contaminated groundwater. Prior to this project, EcoMat has applied their technology to the commercial aquarium industry where health of the fish is a prime economic concern. EcoMat is presently the only company to provide the denitrification technology for the aquarium industry. EcoMat's systems are applied at the following aquariums.

- The John G. Shedd Aquarium (Chicago)
- The Albuquerque Biological Park Aquarium
- Biodome de Montreal
- New Jersey State Aquarium
- Sea World of Florida
- Large Aquarium System
- Colorado's Ocean Journey (Denver)

Based on their experience gained during the SITE Demonstration in Bendena, EcoMat has improved dissolved oxygen monitoring by inserting a dissolved oxygen meter into their system.

Currently, EcoMat has installed a small reactor to remove perchlorate from a Department of Defense facility in Southern California (see Appendix A). To treat perchlorate, the process operates on the same principle as for nitrate treatment. In the absence of both dissolved oxygen and nitrate, the bacteria take oxygen from perchlorate and yield a simple chloride ion.

In-house research is being conducted for the nitrification of ammonia. EcoMat has slightly modified their pilot-scale reactor to permit the addition of large amounts of air into the reactor. The bacteria used for nitrification are very different from denitrification bacteria, in that they are highly sensitive to a number of parameters. EcoMat uses an on-line fermentation process to continually produce them.

6.2 Ability to Scale Up

EcoMat has sold systems treating less than one gpm to aquariums and has supplied reactors as large as three cubic meters. They currently have a single reactor design that would treat influent at a flow rate of 200 gpm. EcoMat has also indicated that there is no upper limit to capacity to their technology. For very large systems multiple reactors would be used.

Section 7.0
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Appendix A

Developer Claims and Discussion

Note: Information contained in this appendix was provided by EcoMat, Inc. and has not been independently verified by the U.S. EPA SITE Program

A.1 Case Study - Perchlorate Remediation at a DOD Facility

The site is a Department of Defense facility located in Southern California. Under the Installation Restoration Program (IRP), Earth Tech, Inc. has a contract to provide environmental services, including evaluating the perchlorate levels in shallow groundwater under the facility. The test water that they pump from this activity is temporarily stored in Baker tanks on the site. The major contaminant in this water is perchlorate, at concentrations varying from 300 ppb to 1000 ppb. Beginning in October 1999 Earth Tech evaluated EcoMat's ability to remediate perchlorate and in December 1999 they contracted with EcoMat to provide a small system for removing perchlorate from the test water.

A.1.1 Project Activity

EcoMat designed a system to achieve the removal of perchlorate from the Baker tanks within a period of several months. At the beginning there was not sufficient information to determine the hydraulic residence time for removal of perchlorate down to non-detectable levels, so the system was designed for a residence time of approximately one-half hour with an active volume of 200 liters. Given average tank volumes of 20,000 gallons this would enable complete reduction in a period of seven days after the bacteria are firmly established.

EcoMat had designed and built an identical system and installed it in the John G. Shedd Aquarium in Chicago. The design is described in the following section. It was built on a single skid in our Hayward facility. Denitrification bacteria which had been exposed to perchlorate were placed in the reactors and then the entire skid was loaded onto a panel truck and driven down to Southern California. At the site, it was lifted off the truck and placed in a temporary shelter near the Baker tanks, and started up. Within a few days it was functioning and reducing perchlorate. After the first few days the system's operation was transferred to Earth Tech, with telephone contact and advice from EcoMat.

After several months during which various operating problems were dealt with, the tanks were completely clean of perchlorate, below the detectable concentration. The system was then moved to a similar site on the base, where it remains in operation.

A.1.2 System Design

The system is best described using a flow diagram (see **Figure A-1**). Water is drawn from the Baker tank into the top of the deaeration reactor. This reflects a basic understanding by EcoMat that a two-stage process works best for biological oxygen removal. In the deaeration tank there is a large number of ordinary bio-balls that provide surface for bacterial growth. The reactor is designed to reduce the dissolved oxygen concentration from saturation down to a concentration of 0.5-1.0 ppm. This is the optimum concentration for either denitrification or perchlorate remediation. If the dissolved oxygen concentration rises above one ppm, the remediation is ineffective, and if it drops to near-anaerobic concentrations, the threat of sulfate attack arises. Hydrogen sulfide can be injurious to the bacteria, stopping the remediation activity. Although the bacteria can be revived very easily by restarting the process, time is wasted if oxygen levels are not monitored.

From the bottom of the deaeration reactor, water is then drawn into the bottom of the Hall reactor. This patented reactor is the key element of EcoMat's process. It is designed to hold a mass of floating media and maintain continuous circulation of the media along with the water in the reactor. This mixing is attained without any internal moving parts, but rather, by external pump re-circulation (as shown in Figure 4-2 of the ITER). Continuous circulation is extremely important as it provides for uniform, low concentrations of the contaminant under ALL influent contaminant concentrations. This factor is key to EcoMat's success in both denitrification as well as perchlorate remediation as it puts no upper limit on the allowable inlet concentrations.

At this point we must say more about the EcoLink media (see ITER cover). This is a polyurethane-based sponge that is cut into one-centimeter cubes. The media last for a very long time-- up to several years. They are kept reasonably clean and capable of supporting bacteria colonies by virtue of their gentle collisions with each other and with the walls of the reactor. When functioning to produce a gas, as in denitrification, the size of the interstitial spaces within the sponge is designed to permit passage of gas out, as well as passage of water into, these spaces. At the same time, the surface area involved is sufficiently great to provide for large bacteria concentrations and high interaction efficiency.

The overflow from the Hall reactor is recycled back into the deaeration reactor during the startup period to form colonies of bacteria. In normal operation the effluent is discharged from the system. In cases where drinking water purity is desired, a post-treatment system can be added to the process to control the small amount of biosolids that leaves the system. This is the only residual stream that results from the process. In case of upset conditions, water can be returned to the Baker tanks.

Both reactors require feed of a carbon source (electron donor) to feed the bacteria. EcoMat has studied a variety of available sources and we find that the best one is methanol. Methanol residual of less than 2 ppm is

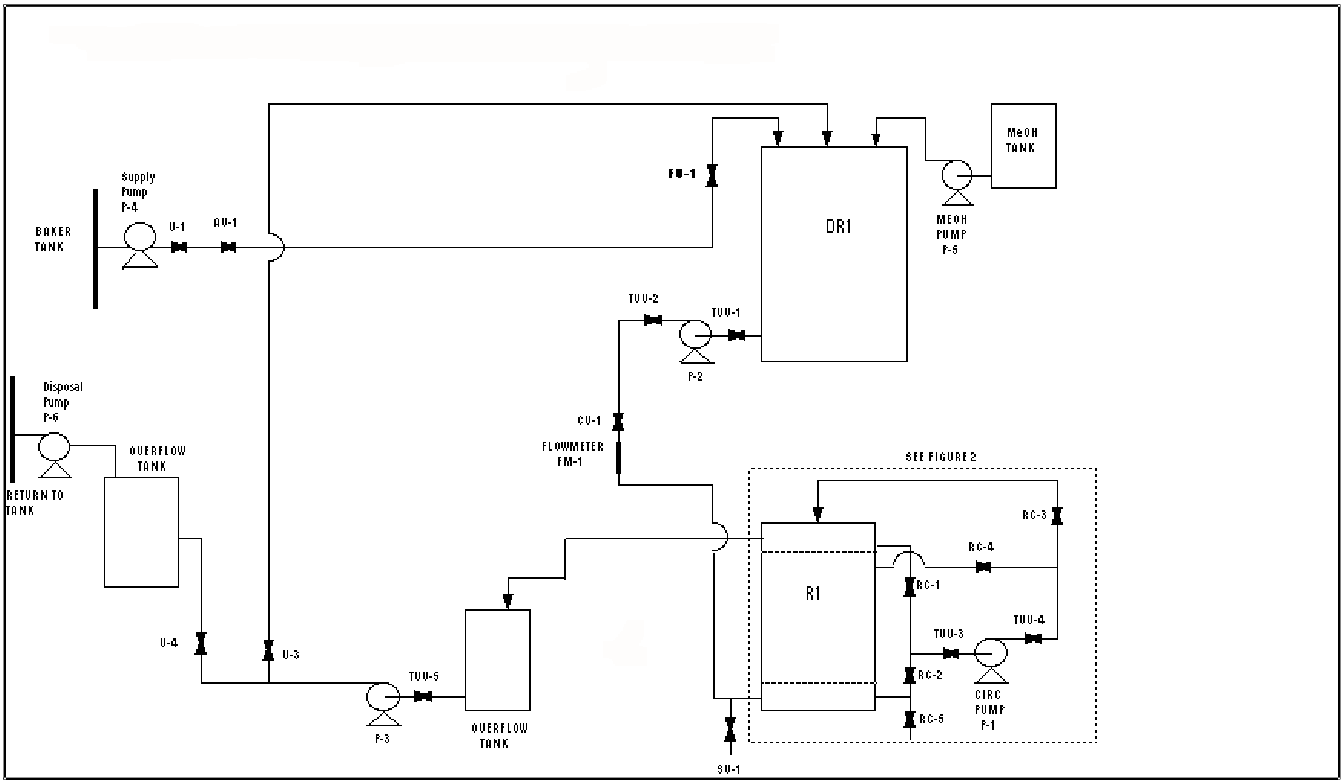

Figure A-1. EcoMat Perchlorate Removal System.

considered non-hazardous and EcoMat's systems normally run at undetectable concentrations (below 0.5 ppm). Methanol is not only the lowest cost commercially available carbon source but it also maintains the lowest level of biosolids. Alternative carbon sources, such as ethanol, tend to “gum up” the works. The major requirement for methanol is for removal of dissolved oxygen in the deaeration reactor, as oxygen levels are so much greater than perchlorate levels in the first stage of the process. For fire safety reasons, the methanol is dissolved in water (generally 50%). The rate of feed of methanol is so small that even if it were to exit unused, the concentration would not reach hazardous levels.

It should be noted that while the bacteria involved in denitrification are hardy, best operations are realized when temperatures are controlled between limits of 8 ^{o}C and 35 ^{o}C. During normal flow, the influent water maintains adequate temperature control. During startup, when recirculation is 100% care should be taken to turn on the circulation pump in the Hall reactor for a relatively small time period each day.

The way the system works is that the bacteria can “eat” a constant rate of contaminant. Thus, the flow rate of water through the system isn’t a significant parameter in the design. The most significant system size factor, which determines the basic system size, is the total amount of material that is to be removed per day. This number is the product of the flow times the concentration. For example, for a system that will remediate 1000 gpm of water having a concentration of 10 ppm, the amount of contaminant to be removed is 120 pounds per day. For this example, EcoMat estimates that it can build, own and operate this system, at the currently demonstrated sizing criteria, at total cost to the customer of $.50 per thousand gallons.

A.1.3 Operations

The system was built on a skid that is four feet by four feet in size. Startup operations involve continuously recycling the water through the reactors while feeding methanol and assuring that there is adequate perchlorate in the water. This recirculation need not be constant, and in warm weather, when the bacteria might overheat, it is best to circulate for no more than a few hours per day. Periodic measurements are made of the dissolved oxygen levels leaving the de-aeration reactor. When the dissolved oxygen level is below 1.0 ppm the system can be opened in stages, until it is wide open. After start-up, operations remain continuous, and it is only necessary to check the system once daily to be sure that no spurious upset has taken place. The methanol source only needs to be replenished every few weeks.

At this DOD site there were a number of upsets, particularly during the early operating days. First, someone driving by pulled the main power plug! A few days passed before the operators realized that there was something wrong. During that time, the bacteria used up all of the oxygen and perchlorate and started producing hydrogen sulfide. The system turned black and smelled characteristically of that material. The system was re-started and within a few days it returned to normal operation.

Importantly, Earth Tech (the contractor using EcoMat's system at the site) was not concerned with optimizing the time for performing the remediation of the water from the Baker tanks. With a retention time of one half-hour, the remediation proceeded sufficiently rapidly. However, based upon EcoMat's denitrification experience, much shorter retention times may be feasible for perchlorate remediation, further reducing the cost of new systems. EcoMat is pursuing this possibility.

A.1.4 Results

Measurements were made by Earth Tech on a regular basis. As a result of the "closed loop" feature, it was possible to control the outlet so that only when the effluent perchlorate concentrations were below the allowable level (ND) would water be discharged to a cleaned water baker tank. Initial results during the startup period were as follows in **Table A-1** (in micrograms per liter):

Table A-1

DATE	INLET	OUTLET
2/17	350	210
2/18	390	160
2/21	390	410 *
3/06	350	ND
3/07	370	ND
3/08	340	9
3/09	320	ND
3/10	320	19
3/15	260	24 **
3/23	300	ND

* Power loss
** New Tank. When the Baker tanks were emptied, the system was moved to another location at the DOD site, where it is presently in operation.

A.1.5 Future Plans

Reactors 15 times the size of the subject reactor are currently in operation, and EcoMat has designed reactors as large as 100 cubic meters. The reactors may be ganged together to provide adequate volume for any flow rate. EcoMat plans to offer its perchlorate remediation process to customers as a build-own-operate package, with pricing in the range of $.50/1,000 gallons.

A.1.6 Conclusions

It appears to EcoMat that this system is one of the most inexpensive ways to remediate perchlorate from water. For very large systems it would be cost effective to implement on-line measurement capabilities with SCADA systems to transmit data to a remote operations center, facilitating satisfactory operations.