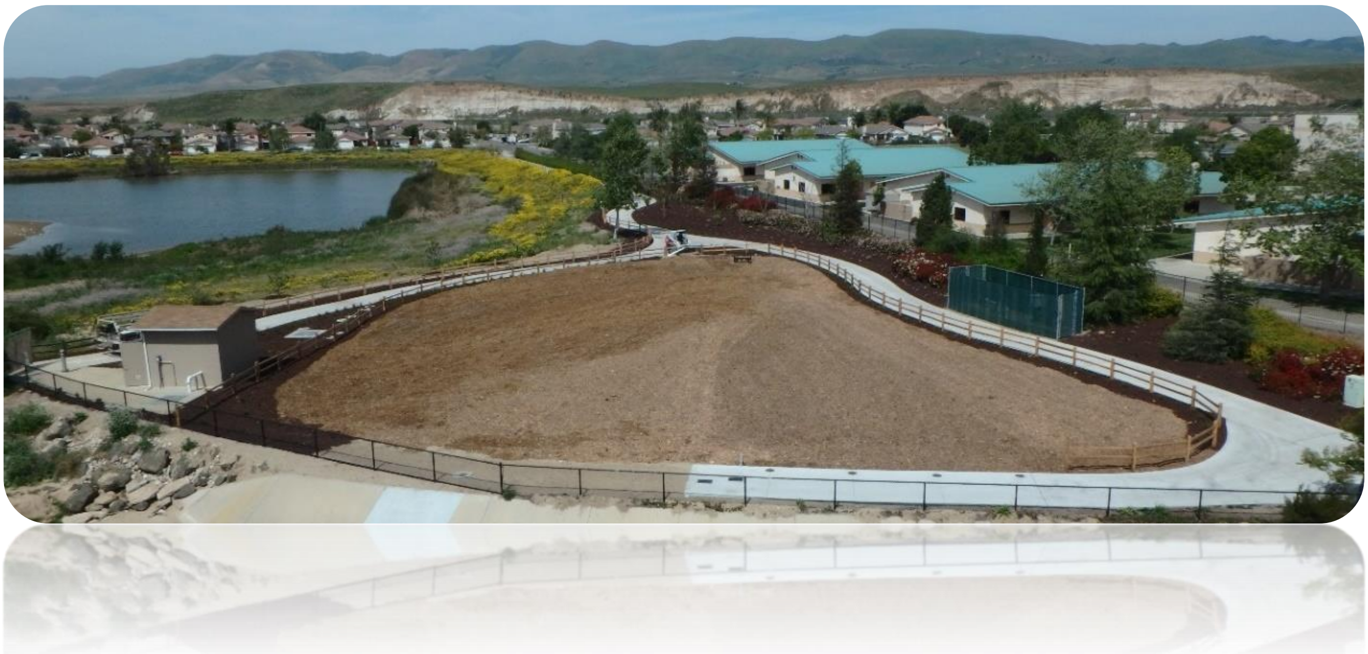
# CENTRAL COAST IRRIGATION AND NUTRIENT MANAGEMENT PROJECT, SANTA MARIA WATERSHED



# FINAL REPORT

PROPOSITION 84
AGRICULTURAL WATER QUALITY GRANT PROGRAM
GRANT AGREEMENT NO. 14-475-553
TOTAL GRANT FUNDS: $1,250,000

October 27, 2017

URBAN & AGRICULTURE
Collaborating for a Better Future

CITY OF SANTA MARIA
Utilities Department
(805) 925-0951 ext. 7270 www.cityofsantamaria.org

PAGE INTENTIONALLY BLANK

# Table of Contents

# Table of Figures

## Acknowledgements

The City of Santa Maria Utilities Department wishes to acknowledge City staff, the Santa Maria City Council, Cachuma Resource Conservation District, Engel & Gray, Inc., MKN, Santa Barbara County Public Works Department Water Resources Division, State Water Resources Control Board, Wallace Group, and Whitaker Construction Group Inc. for their support of the Central Coast Irrigation and Nutrient Management Project, Santa Maria Watershed, also known as the Jim May Park Biofilter Project.

## Project Disclaimer

Funding for this project has been provided in part through a grant agreement with the State Water Resources Control Board. This report has been written as a provision of that grant agreement. The contents of this document do not necessarily reflect the views and policies of the State Water Resources Control Board, nor does mention of trade names or commercial products constitute endorsement or recommendation for use.

# Executive Summary

The City of Santa Maria ("City") received grant funding of $1,250,000 from the State Water Resources Control Board ("State Water Board") under the Proposition 84 Irrigation and Nutrient Management Grant. The project goal was to utilize grant funding and City-match funding to construct a woodchip biofilter downstream of Bradley Channel to treat agricultural runoff from more than 5,000 acres of irrigated farmland to a nitrate level below 10 mg/L-N, the municipal drinking water maximum contaminant level for nitrate.

The project consisted of a woodchip biofilter and included a feasibility study, pilot project, design, construction, and startup and evaluation. Construction for this project was completed in July 2017 and the biofilter became operational in July 2017.

*Figure 1: Completed Project*

# Background

## City of Santa Maria Municipal Water Supply

The City is a full service municipality that provides water supply to a population in excess of 100,000. Current water demand is approximately 12,000 acre-feet (“AF”) per year. The City has two sources of supply: imported State Water and local groundwater from the Santa Maria Valley Groundwater Basin.

### Local Groundwater

The City has sufficient groundwater wells to meet production needs for daily water demand. The local groundwater supply is healthy; in the midst of the latest multiyear drought, there was no shortage of local supply to meet both domestic and agricultural needs within the Santa Maria Valley. Local groundwater is blended with available State Water to maximize supply and optimize water quality.

### Imported State Water

The City began taking deliveries of State Water in the 1990s to maximize its water supply and to help resolve wastewater treatment plant discharge issues associated with total dissolved solids (“TDS”), and salts generated from the use of water softeners. Imported State Water is generally softer, lower in TDS, and lower in nitrate.

The City has an allocation of 16,200 AF of imported State Water. Various factors affect how much imported State Water is available to the City each year, including hydrologic conditions such as Sierra snowpack, environmental conditions such as smelt populations, and water storage conditions such as existing water supply in Oroville Reservoir. Over the course of the last ten years, the availability of State Water has ranged from five percent to 100 percent. In years of low State Water supply, imported water is augmented with local groundwater. In addition, the State Water system is taken out of service for maintenance for two to three weeks each year; during that time, the City relies on local groundwater.

## City of Santa Maria Municipal Water Quality

Water quality issues associated with the City’s local water supply have become increasingly challenging. The local water has high TDS, hardness, and nitrate. Over the years, nitrate concentrations within municipal water supply wells have generally risen. Figure 2 shows nitrate levels in two representative wells in the City. The trend shows increasing nitrate concentrations over time.

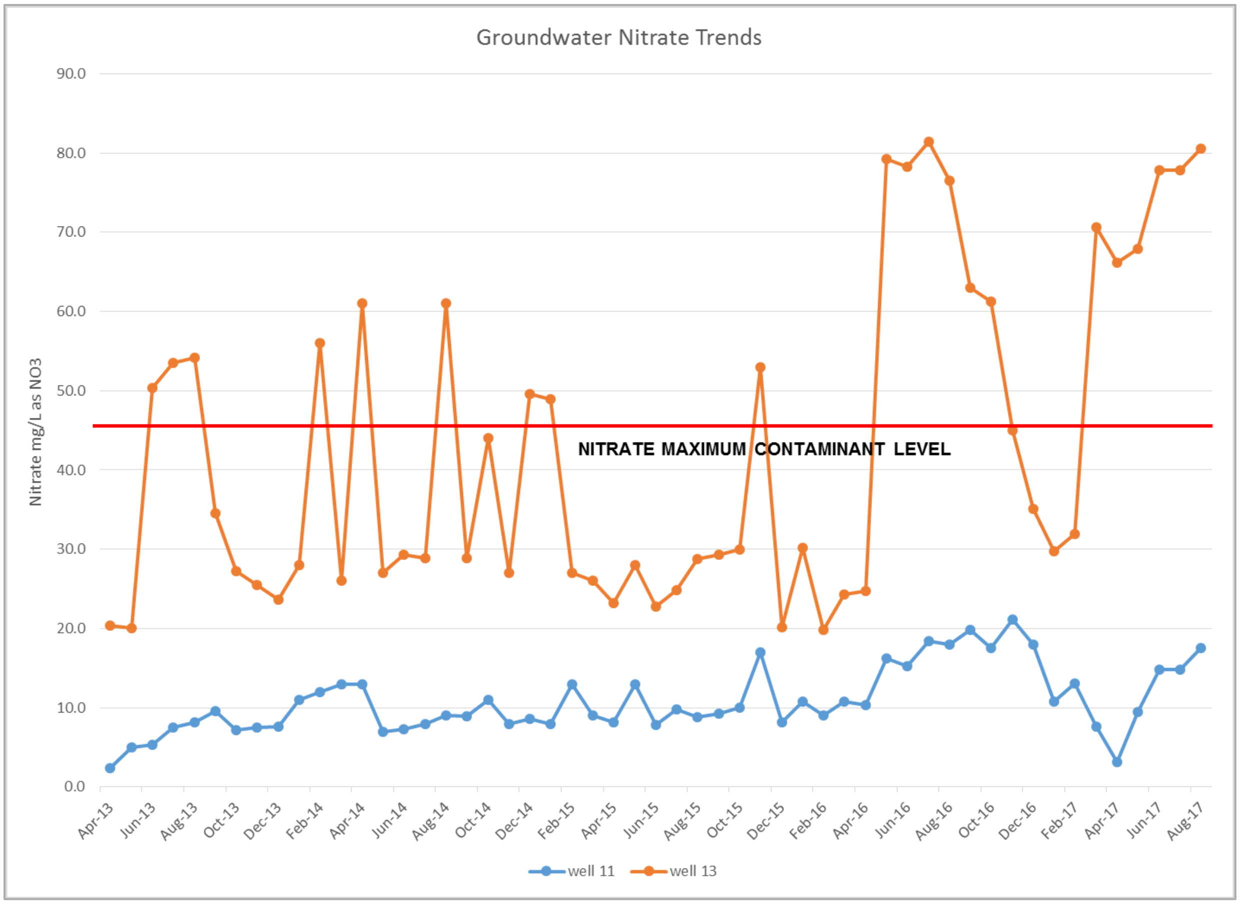



*Figure 2: Historical Nitrate Trends in Representative Municipal Supply Wells*

The City evaluated various ways to address water quality concerns. In 2009, wellhead treatment was studied, but the City determined that such treatment would cost tens of millions of dollars. In 2009, City Municipal Well 14 had nitrate levels exceeding the maximum containment levels (MCL) prescribed by the United States Environmental Protection Agency. However, water produced from an adjacent well with screens starting at 500 feet deep had virtually no nitrate. The City postulated that the lower groundwater basin had lesser nitrate concentrations than the shallower groundwater basin. In 2010, the City installed a packer in City Municipal Well 14 to limit pumping to only the deep aquifer. The packer was installed at a depth of 450 feet to block production from the shallow groundwater table. This resulted in an immediate decrease in nitrate concentration in the water produced from the well, as shown in Figure 3.

Although isolating wells from producing water from the shallow aquifer is a swift and cost-effective way to solve nitrate issues in the municipal water supply in the short-term, it is not believed to be a long-term solution. The groundwater basin's shallow and deep aquifers are connected; it is a common belief that as water is removed from the deeper aquifer, shallow water that is high in nitrate will percolate into the deep aquifer and contaminate it. Unless nitrate is kept from entering the aquifer initially, it will become necessary to remove nitrate through wellhead treatment at substantial cost to the City.

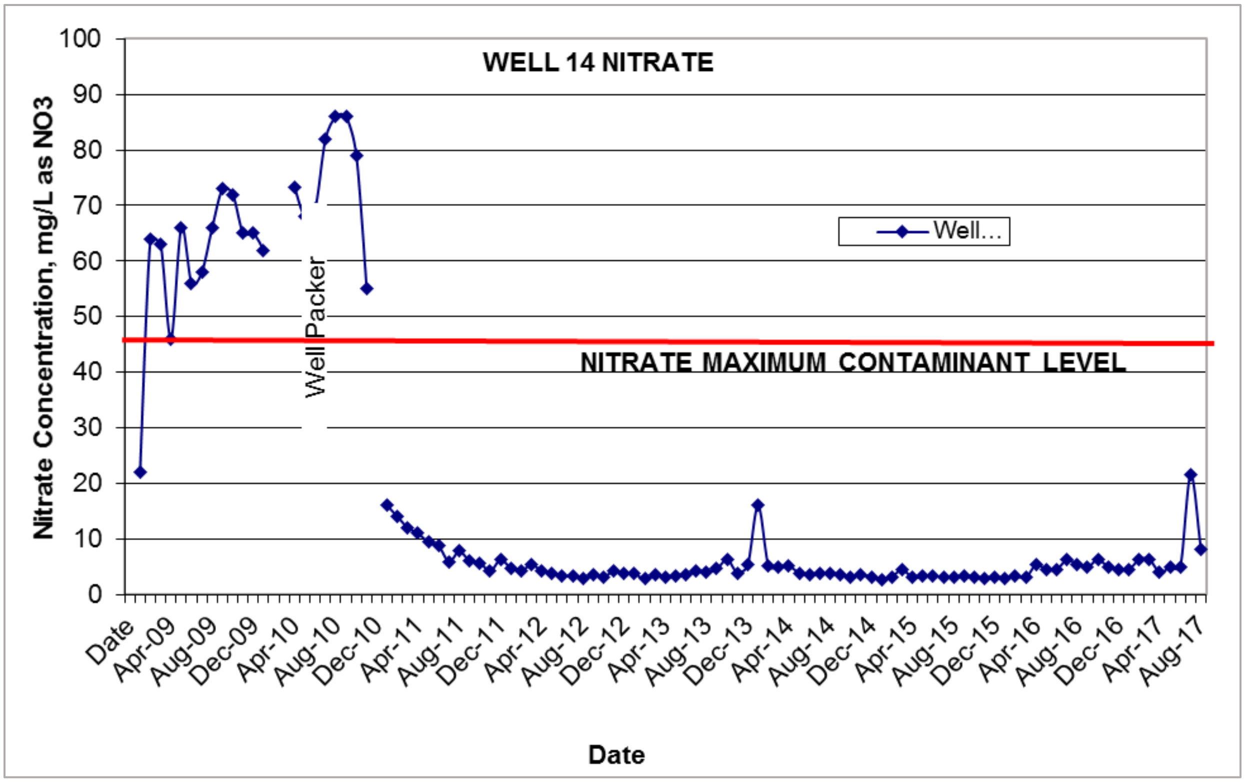



*Figure 3: Impact of Packer on Nitrate Concentrations*

## Santa Maria Valley Groundwater Assessment

In 2012, the Integrated Regional Water Management Program in Santa Barbara County was awarded a planning grant as part of a Proposition 84 Integrated Regional Water Management Plan. A groundwater assessment was prepared to evaluate sources, and transport and fate, of salts and nutrients in surface and groundwater within the Santa Maria Valley. The assessment also helped to support the development of a Salt and Nutrient Management Plan for the Santa Maria Valley.

The assessment was developed using a collaborative process involving stakeholders within the Santa Maria Valley, including water purveyors, wastewater agencies, and local farming interests. Stakeholders evaluated options for reducing nitrogen loading within the Santa Maria Valley. Some of the options considered included nitrification/denitrification at wastewater treatment plants, wellhead treatment at municipal production supply wells using reverse osmosis or electro dialysis reversal, plant uptake, wetlands, or woodchip biofilters. Wastewater treatment plant modification and wellhead treatment are expensive, and plant uptake and wetlands require a significant amount of land. Woodchip biofilters are known to be cost effective and can be built on a small footprint.

The Santa Maria Valley Groundwater Assessment final report[1] included the following relevant conclusions:

---

[1] www.jimmayparkbiofilter.org/downloads/SM_GW_Assessment_SN_Report%2010_10_2013%20Final.pdf

- Salts loading appears to have decreased since 2000;
- Nitrate levels have increased substantially in shallow wells, particularly in the western portion of the Santa Maria Valley; and
- Nitrate levels began increasing in coastal monitoring wells in the mid to late 1980s, suggesting slow response to nitrogen loading that has occurred for decades.

The conclusions of the groundwater assessment support similar findings of higher nitrate concentrations in surface water sampling provided by the Central Coast Ambient Monitoring Program ("CCAMP") performed by the Regional Water Quality Control Board ("Regional Board"), as well as ongoing nitrate monitoring in City Municipal Wells.

The Bradley Channel at Magellan Drive ("BCU") has been actively monitored for several constituents including channel flow, nitrogen species, and other constituents, as part of the CCAMP. Samples were collected from 2000 through 2013.[2] BCU, the closest CCAMP sampling location to the Jim May Park Biofilter (312BCU), shows a minimum nitrate of 0.32 mg/L a maximum nitrate of 68 mg/L with an average nitrate of 20 mg/L.

Figure 4 provides nitrate concentrations of samples collected from BCU for the CCAMP program, and shows higher nitrate in more recent years than in previous years. For comparative purposes, the maximum contaminant level for nitrate as nitrogen in drinking water is 10 mg/L, as prescribed by the United States Environmental Protection Agency. This data demonstrates the significant nitrogen-loading contributed from agricultural land adjacent to Bradley Channel.

Annual loads at BCU between 2000 and 2013 were approximately 11,500 pounds per year for wet and dry season loads were approximately 6,000 pounds per year. Based on the sampling data, there is approximately 10,000 pounds of nitrogen available for removal from the Bradley Channel annually at the location of the Jim May Park Biofilter.

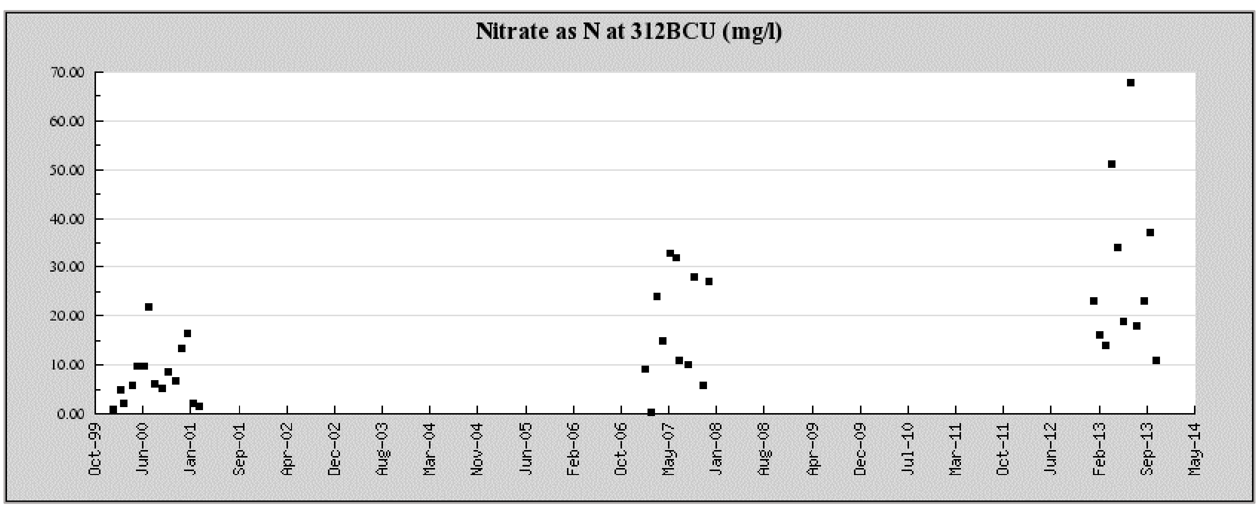



*Figure 4: CCAMP Data for Nitrate as Nitrogen*

[2] Data is available at www.ccamp.org

## Woodchip Biofilter Process Explanation

All plants require nutrients to grow. One of these nutrients is nitrogen. Nitrogen is most readily available to plants in the form of nitrate. Nitrate is usually applied to plants in levels greater than can be taken up by the plants in order to make sure that enough is absorbed. Excess nitrate either runs off the property in agricultural runoff or is absorbed into the ground past the root zone of the plants and into groundwater. Converting nitrate to a less harmful form of nitrogen before it enters the groundwater helps protect the drinking water supply. Once nitrate is in the groundwater, it is expensive to remove.

*Figure 5: Woodchips*

Nitrate can be converted to nitrogen gas by certain kinds of bacteria. These bacteria, called denitrifiers, occur naturally in the environment. Denitrifiers grow when conditions suit them, and prefer warmer temperatures, a source of carbon, and no oxygen. Such conditions are typically found in marshes and bogs or other wetland-like locations.

Woodchip biofilters provide both a carbon source and a place for bacteria to grow to convert nitrate to nitrogen gas. Those conditions encourage the growth of these bacteria and encourage the conversion of nitrate to nitrogen gas. The atmosphere is 80 percent nitrogen gas so this conversion reverts nitrate into a harmless atmospheric gas.

## Funding

The State Water Board awarded Proposition 84 Agricultural Water Quality Grant Program funding to Cachuma Resource Conservation District ("CRCD") to fund a project that reduces water quality pollutants from agricultural sources. The City and CRCD collaborated to develop a project that reduces water quality pollutants, with CRCD acting as the lead and the City performing as a sub-consultant for the project. The CRCD eventually relinquished project control and oversight to the City, and initiated the change with the State Water Board.

To ensure completion of this project, the Santa Maria City Council authorized an agreement with the State Water Board to receive Proposition 84 Agricultural Water Quality Grant Program funding for the Central Coast Irrigation and Nutrient Management Program, Santa Maria Watershed, also known as the Jim May Park Biofilter Project. The Santa Maria City Council also authorized the required expenditure of the funding match. Following approval by all parties, the State Water Board City transferred the grant to the City.

The construction cost of the project was $1,009,591, with professional services costs including design and construction management of $217,482 and match costs of $287,616, for a total capital cost of $1,514,689.

## Project Description

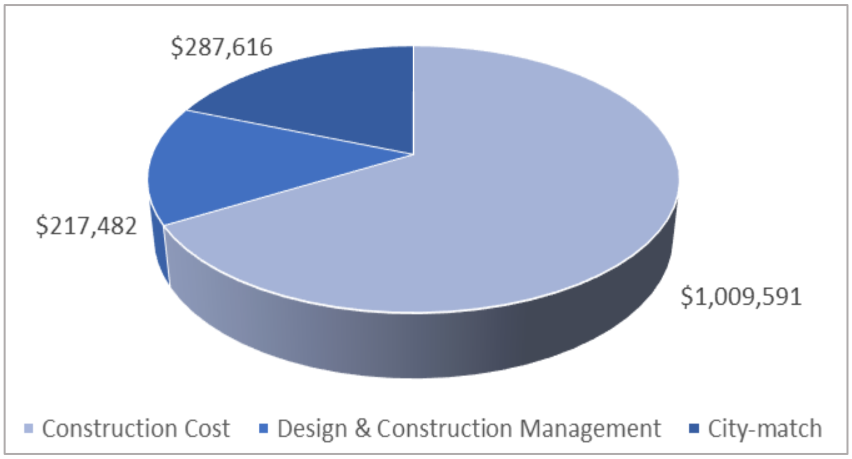



*Figure 6: Capital Construction Costs*

The purpose of the Jim May Park Biofilter Project was to implement an agricultural tailwater denitrification system for the treatment of nutrient rich agricultural flows within Jim May Park and provide pollution prevention and reduction strategies for irrigation and nutrient management in the Santa Maria Watershed. An integrated, regional water management approach was applied for addressing nitrate in agricultural runoff and supporting municipal water supply in a disadvantaged community; a denitrification woodchip biofilter was installed to treat approximately 200 gallons per minute of discharge from over 5,000 acres of irrigated agricultural land that drains into Bradley Channel.

Prior to the installation of this project, water from Bradley Channel discharged into a large waterbody constructed for flood control in Jim May Park. Water from the waterbody overflowed into another channel and a series of flood control basins prior to discharging into the Santa Maria River. Following installation of the woodchip biofilter, flow is intercepted from Bradley Channel via a sump and pumped into the woodchip biofilter. As water travels through the biofilter, a biological process converts the ammonia and nitrate into nitrogen gas. Once the water leaves the biofilter, treated tailwater is returned into the Bradley Channel. This project improves water quality by reducing pollutant loading in waters that typically percolate into the groundwater basin.

## Project Coordination

This project required coordination with the adjacent elementary school, nearby residents, the County of Santa Barbara, regulatory agencies, and other City departments. This project also included several phases, including a feasibility study, pilot project, design, construction, and startup and evaluation. These topics are further discussed below.

## Feasibility Study

In 2012, the City was participating in the development of a Salt and Nutrient Management Plan with other stakeholders in the groundwater basin. The City contracted with Wallace Group, a civil and environmental engineering firm, to develop a Feasibility Study to establish the viability of using wetlands-based denitrification facilities employing woodchips or other organic carbon, as a means of enhancing the water quality of the groundwater basin. This report includes background on the use of woodchip biofilters to remove nitrogen from water, potential locations for the biofilter within the Santa Maria Valley, and size and cost estimates for a location within the city that would provide optimal benefits and accessibility.

Wallace Group's 2012 Feasibility Study was utilized as the basis for the Jim Park Bark biofilter Project. Several different locations were considered, but Jim May Park, directly downstream of the Bradley Channel, was determined to be the location that provided the greatest benefit. Figure 7 provides a map overview of the project site. A copy of the study is included as Appendix A.


*Figure 7: Map Overview*

## Pilot Project

It was important that the woodchips for the biofilter were the most effective to provide the desired results. A pilot project was conducted testing readily available local woodchips. The results of the pilot project are included in Appendix B.

The pilot project involved placing various types of woodchips in a container and replicating the residence time suggested in literature. Tests were conducted for ammonia, nitrate, flow, alkalinity, and temperature of the water entering and leaving the biofilter. Woodchips tested included overs (a byproduct of composting), blonde (from construction demolition), and pine (from local trees that died as a result of the drought). The pilot project determined that overs performed the most consistently over time.

## Design

The City contracted with MKN, a civil and environmental engineering firm, to design the biofilter based on the Wallace Group Feasibility Study. Several factors were considered in the design including flexibility in operation, access for maintenance, and consistency of design elements with the surrounding park. The design was completed in April 2016.

*Figure 8: Design Team*

An important aspect for operations is the use of automated controls. A programmable logic controller ("PLC") was installed and programmed to control the operation of the main pump as well as a local shallow groundwater well. Water from the channel and the groundwater well enter a wet well with level sensors. Data transmitted from the level sensors to the PLC dictate when the groundwater well operates to maintain flow to the biofilter. The level sensors in the wet well also help protect equipment by shutting off the facilities if the wet well level exceed high or low operating ranges.

## Construction

Following design, the project was bid for construction in May 2016, and four bids were received. Whitaker Construction Group, Inc., a construction company based in Paso Robles, was awarded the project on July 11, 2016. Once bonding requirements were met, the Notice to Proceed was issued and a preconstruction meeting was held on August 25, 2016. Construction began in September 2016. The Jim May Park Biofilter Project website contains a time-lapse video of the construction.

*Figure 9: Project Site before Construction*

Engel & Gray, Inc., a construction, trucking, and environmental company, provided the woodchips (overs) for the project at a reduced rate.

Substantial completion of the project occurred in May 2017; however, there were issues with the programming of the site that required additional attention. The biofilter started up via manual operation in July 2017, and automated operation commenced in August 2017.

Pictures of the project site before and after construction are shown in Figures 9 and 10.

## Start Up & Evaluation

A Monitoring Plan ("MP") and Quality Assurance Project Plan ("QAPP") were developed for this project to provide guidance on evaluating operational effectiveness. After startup, samples of ammonia, nitrite, nitrate, and total Kjeldahl nitrogen (TKN) were collected upstream and downstream of the biofilter, from Taylor Well, and from Bradley Channel per the approved MP and QAPP. Figure 11 provides the location of the sampling points. Sampling results are included in Appendix C.

*Figure 10: Project Site after Construction*

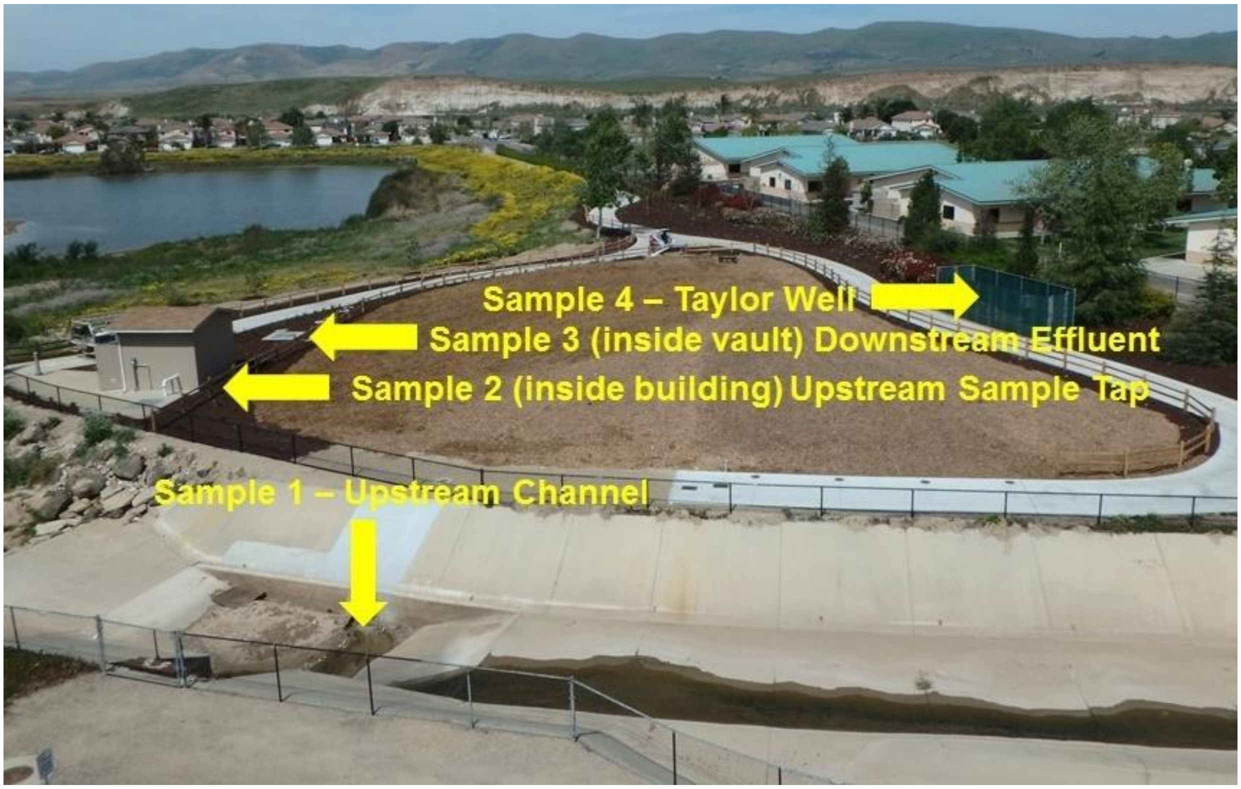



*Figure 11: Sampling Points*

During post-construction sampling, there was low flow in the channel as few growers were irrigating. This was because most fields were in preparation for an upcoming crop cycle, and one of the ditches upstream was undergoing construction work. As such, the biofilter was primarily running groundwater for much of the early sampling. With more contribution from the channel, the biofilter will have a better opportunity to demonstrate greater nitrate removal.

Flow stabilization was a challenge in the beginning weeks of biofilter operation. Early in its operation, the water leaving the biofilter was discolored, foamy, and odiferous. In addition, early sampling results showed an increase rather than a decrease in nitrogen. This was because the biofilter required a seasoning period to allow color and foaming agents to leave the biofilter and bacterial population to develop. Figure 12 shows the appearance of some of the first water to leave the biofilter after startup.

*Figure 12: Initial Effluent Flow*

One of the objectives of the Jim May Park Biofilter Project is to achieve an effluent nitrate of less than 10 mg/L-N. A shallow groundwater well was installed as part of this project to make sure that the biofilter would remain operational even when flow was not available from the channel. At the time the well was established, nitrate in the well was 7 mg/L as nitrogen.

Table 1, shown on the next page, provides the amount of water flow entering the biofilter, contributions from each source water, the average flow, nitrate concentrations in the inflow and outflow, Taylor Well, and Bradley Channel, and the approximate pounds of nitrogen removed. During the first two weeks of sampling, effluent nitrate was non-detect; however, the total nitrogen leaving the biofilter was greater than the total nitrogen entering. As such, there is no estimate of pounds nitrogen removed even though there is no nitrate in the effluent.

*Table 1*

| Date | Total Flow, MG | % Flow from Bradley Channel | Bradley Channel mg/L NO3-N | Taylor Well mg/L NO3-N | Biofilter Influent mg/L NO3-N | Biofilter Effluent mg/L NO3-N | Approximate Nitrate-N Removed (in Pounds) |
|---|---|---|---|---|---|---|---|
| 8/10/2017 | | | 6.70 | 3.40 | 6.60 | 0.38 | |
| 8/17/2017 | | | 7.00 | 3.40 | 5.10 | ND | |
| 8/24/2017 | | | 1.70 | 0.88 | 1.30 | ND | |
| 8/31/2017 | 1.30 | 34 | 35.0 | 3.30 | 35.00 | 4.90 | 320 |
| 9/7/2017 | 0.80 | 32 | 0.55 | 2.70 | 1.30 | ND | 8 |
| 9/14/2017 | 0.90 | 17 | 1.40 | 1.30 | 1.60 | ND | 11 |
| 9/21/2017 | 1.00 | 28 | 22.0 | 2.70 | 11.00 | 1.90 | 80 |
| 9/28/2017 | 1.00 | 52 | 25.0 | 3.00 | 7.10 | 1.60 | 46 |
| 10/5/2017 | 0.90 | 64 | 26.0 | 2.90 | 22.00 | 8.80 | 102 |
| 10/12/2017 | 0.90 | 71 | 4.20 | 2.20 | 3.40 | 1.70 | 13 |
| 10/19/2017 | 0.90 | 41 | 2.00 | 2.20 | 1.30 | ND | 7 |
| **TOTALS** | **7.70** | | | | | | **587** |

Using an average of 196 pounds of nitrogen removal per week after biofilter maturation, the biofilter is projected to remove approximately 10,000 pounds of nitrogen annually. With a total construction cost of approximately $1.5-million and a projected 20 year life, the cost of nitrogen removal is $7.50 per pound.

As more channel water is treated and the biofilter continues to mature, the site will continue to optimize; the amount of nitrogen removed annually is anticipated to increase, and likewise the cost per pound of nitrogen removed is expected to decrease.

Another objective of the Jim May Park Biofilter Project is to reduce effluent nitrate to below 10 mg/L NO3-N, the maximum contaminant level (MCL) for nitrate in drinking water. Figure 13 (shown on the next page) demonstrates nitrate removal since the biofilter became automated. Early in its operation, there was little influent nitrate to remove, and the effluent results were non-detect. However, on August 31, 2017, there was substantial nitrate entering the biofilter and the biofilter successfully removed 86 percent of incoming nitrate.

Figure 14 (shown on page 20) demonstrates total nitrogen removal since startup of the biofilter in automatic mode. For the first several weeks, due to the lack of seasoning of the biofilter, there is more nitrogen leaving the biofilter than entering. This is likely due to soluble ammonia and organic nitrogen washing off the woodchips early in the biofilter's operation. It is unclear how this impacts the success of the biofilter; in the last sample, ammonia and organic nitrogen concentrations in the effluent are greater than in the influent. This phenomena is masked because of the substantial reduction in nitrate.

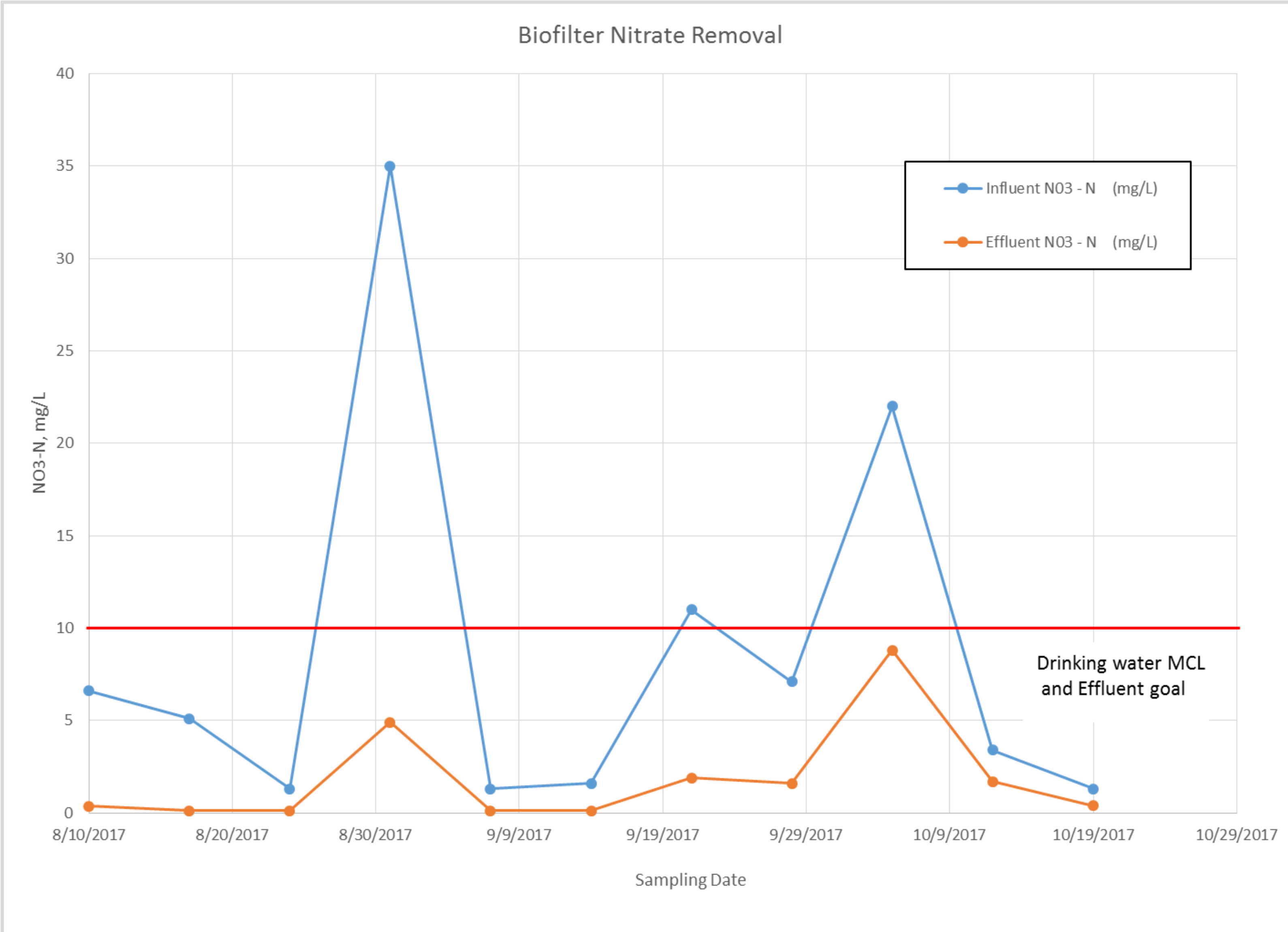



*Figure 13: Graph of Nitrate Removal*

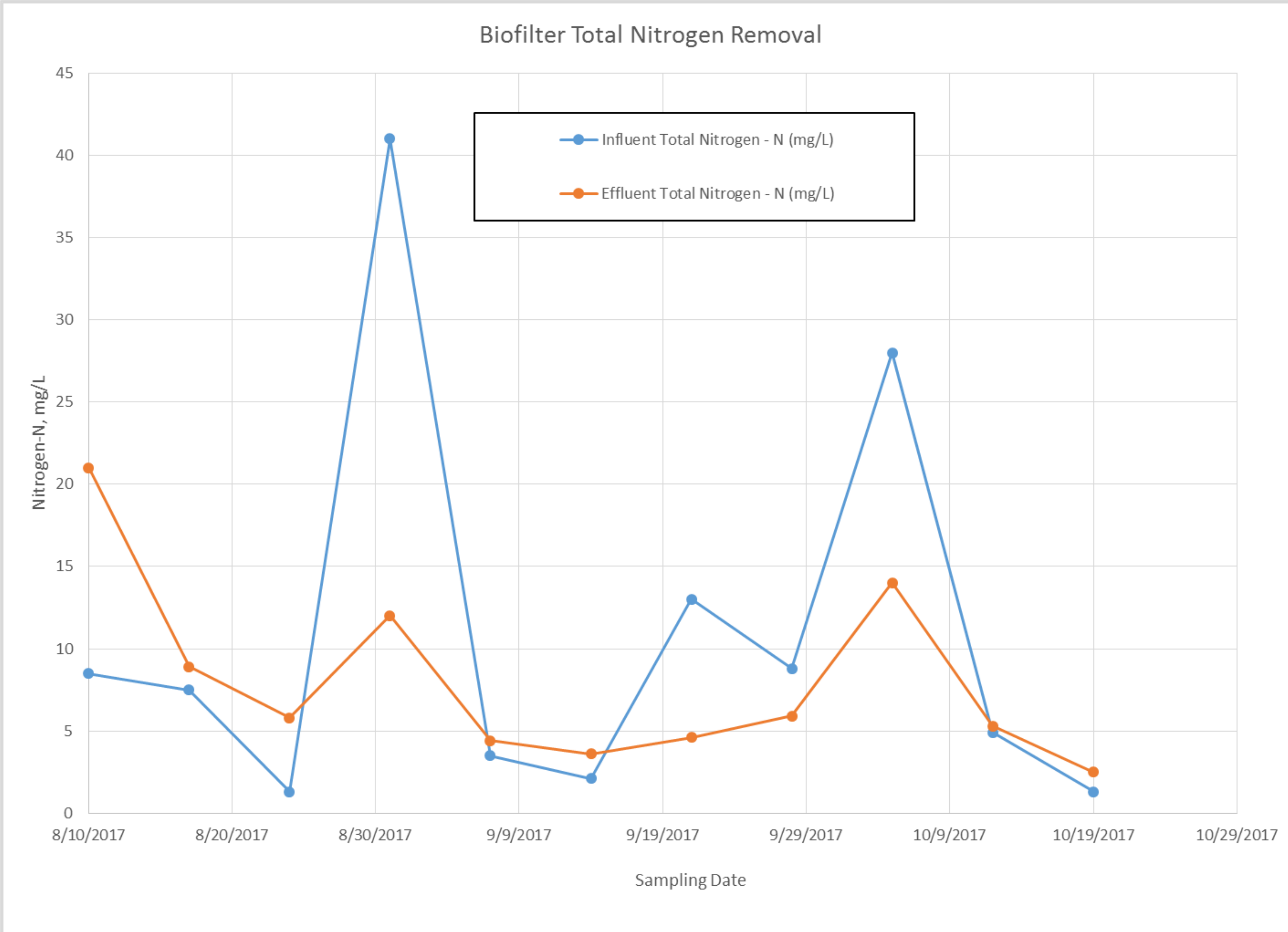



*Figure 14: Graph of Total Nitrogen Removal*

## Lessons Learned

The Jim May Park Biofilter Project was challenging because there were no known biofilters of comparable size after which to model the design. There were numerous lessons throughout the project, including:

- Plywood glue is made of urea. When used in the pilot biofilter, ammonia in effluent increased considerably.
- The type of wood matters. Pine was not as effective at removing nitrogen as the “overs,” or composting leftovers. This may be because pine is naturally antiseptic and may inhibit bacterial growth.
- Removing nitrogen from water with any appreciable biological oxygen demand (BOD) is difficult. The pilot biofilter first started using wastewater effluent, but the carbonaceous bacteria outcompeted the nitrogenous bacteria resulting in no nitrogen removal.
- Nitrification requires alkalinity.
- Flow leaving the biofilter should not be impeded. The biofilter material reduced flow and the material was removed from the effluent piping. A gravel pack around the effluent lines may be a better alternative.
- Building without a baffle may be more efficient and cost-effective. A baffle was necessary for this project because of the shape of the site; however, the baffle caused installation issues and was the primary reason for construction cost overruns.
- Plan for more maintenance access points. Additional cleanouts and sumps were installed after the biofilter was constructed to provide more opportunities for maintenance.
- The biofilter requires start up time to develop bacteria and to season the woodchips. The initial water leaving the biofilter was colored, foamy, and odiferous; it took several weeks for the biofilter to settle in and provide quality results.

## Conclusions

The Jim May Park Biofilter Project demonstrates that nitrate does not have to be limited to discharges from a single operation; it can be removed from agricultural drainage from multiple sites. While the biofilter has been operating for only a few months as of the date of this report, the data is promising that this biofilter will reduce nitrogen loading in the Santa Maria Valley.

Although the system is being operated under specific parameters, it has been built with numerous flexibilities to allow different configurations to optimize its use in the future. Future testing may include programming adjustments that will allow more channel water to be pumped when it is available, as it has significantly more nitrate than the shallow groundwater well. In addition, the City is working with the Department of Pesticide

Regulation for sampling the biofilter for pesticides to test its effectiveness at removing pesticides.

## Community Outreach

Figure 15: Project Logo

The City's grant agreement with the State Water Board included provisions for providing outreach to property owners upstream of the project site and to the public at large. While upstream property owners did not respond to opportunities for free technical assistance, the City undertook a variety of outreach activities throughout the project, including:

- Development of a logo for the project and an online presence, including the design and rollout of a new website and ongoing social media posts;
- An October 6, 2016 letter to growers upstream of the biofilter offering free technical assistance on irrigation and nutrient management;
- Collaboration with Cachuma Resource Conservation District to develop a link on their website promoting free technical assistance on irrigation and nutrient management;
- Development of a poster describing the project, its location, and the agricultural properties upstream of the project;
- Distribution of a September 29, 2016 news release promoting the start of construction of the biofilter project;
- Installation of a temporary sign adjacent to the project during construction;
- Development and distribution of a one page, full-color brochure describing the project;
- An April 13, 2017 letter to growers upstream of the biofilter informing them of an upcoming presentation on the biofilter project at *Strawberry Field Day* in May 2017;
- Availability of outreach funding to technical service providers;
- Installation of a bronze permanent sign on the north side of the biofilter project site; and
- Numerous presentations to diverse stakeholders and the public at large discussing the project and its benefit to the community.

Some of these outreach activities are described in more detail below.

### Logo

As shown in Figure 15, a custom logo for this project was developed to showcase the cooperation between an urban water supplier and agriculture. This logo was included on all project material, including correspondence, presentations, and signage.

This logo can be reused for future projects similar in nature by updating the name of the project in the graphic.

### Website

The City purchased the website domain www.jimmayparkbiofilter.org and developed content to provide a comprehensive project website. The website offered varying degrees of information related to the project. The homepage provided a succinct description and subpages contained more wide-ranging information and technical data. The website also allowed the City to share links to relevant documents associated with the project.

Various analytical data about the website is provided in Appendix D. The Analytical Data User Source chart demonstrates that the majority of visits to the website were from direct URL entry. This means the City's outreach materials, such as the letters, signs, or presentations, generated sufficient interest that resulted in user engagements. This chart also depicts the impact of social media, as the City began showcasing the project on social media in January 2017. As shown in the chart, website activity increased following social media promotions.

### Letters to Upstream Property Owners

Under the grant agreement, the City was required to offer free technical assistance to property owners upstream of the biofilter. In addition to a link on the Cachuma Resource Conservation District website promoting the technical assistance, multiple letters were sent to property owners upstream of the biofilter. One such letter is included as Appendix E. The City did not receive any requests for technical assistance.

Figure 16: Temporary Sign during Construction

### Poster

The City developed a poster for use at various meetings and presentations to illustrate the purpose and location of the project. The City also used this poster as a way to identify property owners upstream of the project. A copy of this poster is included in Appendix F.

### Signs

Two signs were constructed and installed for this project. As shown in Figure 16, a temporary sign was installed at the south end of the project during construction. As shown in Figures 17 and 18, a permanent bronze sign was installed at the north end of the project at the completion of construction.


*Figure 17: Permanent Sign after Construction*


*Figure 18: Close Up of Permanent Sign*

## Presentations

- California Association of Resource Conservation Districts Annual Meeting, November 13, 2014;
- Central Coast Water Board Grant Kick-Off Meeting, March 12, 2015;

- Lunchtime Rotary, March 31, 2015;
- Regional Technical Advisory Committee Meeting for Prop 84 Agricultural Grant Recipients, December 15, 2016;
- Strawberry Field Day, May 10, 2017;
- American Public Works Association Luncheon, September 14, 2017;
- Morning Rotary Club of Santa Maria, September 21, 2017;
- Sanitation Agency Manager's Association Meeting, October 11, 2017;
- Santa Barbara County Water Purveyors Group Meeting, October 12, 2017; and
- Central Coast Water Board Grant Wrap-Up Meeting, October 27, 2017

## Brochure

A full-color brochure that summarizes the project was developed and was distributed at all presentations. This brochure is included in Appendix G.

# Appendices

CONTINUED ON NEXT PAGE

Appendix A

Feasibility Study

CONTINUED ON NEXT PAGE

WALLACE GROUP®

CIVIL AND TRANSPORTATION ENGINEERING
CONSTRUCTION MANAGEMENT
LANDSCAPE ARCHITECTURE
MECHANICAL ENGINEERING
PLANNING
PUBLIC WORKS ADMINISTRATION
SURVEYING / GIS SOLUTIONS
WATER RESOURCES

January 25, 2013

Shannon Sweeney
Water Resources Manager
City of Santa Maria
2065 E. Main Street
Santa Maria, CA 93454

Subject: Tailwater Denitrification Feasibility Analysis

Dear Ms. Sweeney:

Wallace Group has been retained to investigate the feasibility of implementing an agricultural tailwater denitrification system for the treatment of flows conveyed within the existing Bradley Channel (see Figure 1). The focus of the study is on the use of low-cost, passive technology that utilizes waste wood chips as the source of carbon for the denitrification process. Wood chip-based denitrification systems have been used successfully by Caltrans for the treatment of wastewater generated at roadside rest stops. Important research on the technology has been performed by UC Davis under the direction of Harold Leverenz PE, PhD, who also assisted in the development of the proposed tailwater treatment process. Appendix A includes a technical report that describes the biological processes, research results, and engineering conclusions.

**Background and Project Purpose**
Surface runoff from farming operations contains a number of contaminants that present a threat to the beneficial uses of both surface and groundwater. Nitrate is a key contaminant of concern, and evidence of existing contamination exists in both the shallow aquifer and in monitored surface water. The Regional Water Quality Control Board (RWQCB) monitors for multiple contaminants, including nitrate, through the Central Coast Ambient Monitoring Program (CCAMP). The Bradley Channel is actively monitored, and historical data was provided for channel flow and nitrate concentration, in addition to other contaminants. The Bradley Channel at the proposed project location is tributary to approximately 5,700 acres of irrigated agriculture.

In 2012, the RWQCB adopted Agricultural Order RB3-2012-0011, which requires agricultural operations to conduct surface and groundwater monitoring, implement best management practices for nutrient and sediment control, and comply with various other monitoring and reporting requirements. The proposed project will provide an important local example of low-cost, passive tailwater treatment for nitrate. The same technology could then be considered as a decentralized treatment solution for individual growers to comply with current and future regulations. In addition to RWQCB regulatory efforts, the City of Santa Maria (City) is currently working with a group of stakeholders to develop and implement a Salt and Nutrient Management Plan, which will consider regulatory, physical, and management solutions to existing and future contamination.

WALLACE GROUP
A California Corporation

612 CLARION CT
SAN LUIS OBISPO
CALIFORNIA 93401

T 805 544-4011
F 805 544-4294

www.wallacegroup.us

WALLACE GROUP®

### Anticipated Flows and Loadings

Monitoring data from the Bradley Channel is provided in graphical form in Appendix B. The channel flows are variable, and the majority of the nutrient loading occurs during the irrigation season. The intent is to treat a substantial portion of the annual nitrogen loading while remaining within the other key project constraints of site area and implementation cost. Based on the performance of other wood chip based systems, nitrate removal rates in excess of 90% are achievable. At a minimum, the intent is to reduce the nitrate concentration to a level below the drinking water Maximum Contaminant Level (MCL) of 10 mg/L as nitrogen. During periods of consistent flow and stable operation, the system may be able to achieve effluent levels that are essentially non-detect for nitrate. The recommended basis of design is summarized in Table 1.

**Table 1: Recommended Basis of Design**

| Parameter | Recommended Design Value |
|---|---|
| System flow for dry weather operation | 200 gal/min (0.29 Mgal/d) |
| Influent nitrate concentration as N | 80 mg/L |
| Hydraulic retention time (HRT) | 2 to 4 days |
| Average effluent nitrate concentration as N | < 10mg/L |

### Facility Sizing and Location Alternatives

In consultation with Dr. Leverenz, a conceptual design for the denitrification system was assembled to meet the parameters indicated in Table 1. The key system parameters are summarized in Table 2:

**Table 2: System Parameters for Wood Chip Denitrification System**

| Parameter | Recommended Value |
|---|---|
| System surface area | 0.65 to 0.75 ac, depending on depth |
| Operating depth of wood chips | 6 to 8 ft, depending on area |
| Hydraulic retention time (HRT) | 4 days |
| Surface plant materials | Bulrush, cattail, reed, calla lily, canna lily, or other species appropriate for a wetland in a park setting |

A reconnaissance-level site investigation of a number of potential project sites was conducted, including the following potential locations:

- the vicinity of the Blosser Basin
- linear portions of the Blosser and/or Bradley Channels, including access frontages
- areas near the outfall to the Santa Maria River
- adjacent to or within Jim May Park, or otherwise near the Bradley Basin

The latter location was determined to be the most viable in terms of cost and function. Jim May Park, which sits on land owned by the County of Santa Barbara but is operated and maintained by the City through a use agreement with the County, also has the advantage of an available upper aquifer well that has been contaminated with nitrate. The well is currently cased, but it has not yet been equipped with electrical power or a pump. If equipped, the well could be utilized in conjunction with the denitrification system for the following purposes:

- Provide a source of winter-period nitrate loading, when the County draws down the Bradley basin for flood control purposes. The County bypasses flow from the Bradley Channel around the basin by opening a valve adjacent to the channel, thereby draining the supply to the biofilter. The availability of an alternate water supply to the biofilter during that time period allows for additional nitrate removal from the shallow groundwater aquifer while not impacting existing flood control practices. It also allows the biofilter to stay alive and working when little to no drainage water is available.
- Provide a low cost source of start-up water for the wetland plants, without depending on consistent flows from the Bradley Channel.
- During the irrigation season, provide a nutrient-rich source of water to the park while reducing the cost of water and applied fertilizers.

In the vicinity of the Bradley Basin, three alternative locations were identified that contained sufficient land area for the system. These areas are summarized in Figure 2. Alternative A was selected as the preferred approach for the following reasons:

- Alternative C results in impacts to open turf play area, while Alternative A minimizes impacts. The area designated for Alternative A is primarily used for pedestrian and bicycle access, which is a function that can be maintained with minor changes to the sidewalk configuration.
- Alternative B is located in an area subject to historical erosion damage, and access to the Bradley Channel and the above-referenced upper aquifer well is more challenging.
- Alternative A has the highest potential for visible and direct educational opportunities for school children, and will be accessible for visitors with disabilities. Instructional displays that convey important information concerning stormwater management and water quality should be included within the final project design.

**Recommended Project**

Figure 2 shows the configuration of the recommended project, including the potential realignment of existing walkways. Key elements of the project are described in the following sections.

Grading: The system will require the excavation of approximately 10,000 cubic yards of material within the project area. Opportunities exist for minimizing the cost of earth moving operations by depositing the excavated material on the low-lying vacant areas to the north of the Bradley Basin, or making arrangements with other property owners in need of fill material. Trucking costs have been included in the project estimate.

Sidewalk Demolition and Repair: Prior to excavation, the existing walkways and underlying irrigation system will require demolition, while maintaining service to the surrounding park. The walkways can be realigned to maintain the existing circulation patterns, as indicated in Figure 2.

Impermeable Liner: A clay or synthetic impermeable liner will be required to maintain a continuous subsurface water level in the wood chip bed. High density polyethylene and polypropylene are potential alternatives. Internal synthetic baffles, comprised of the same liner material, may also be required to improve the hydraulics of the system and prevent short circuiting.

Intake Pumping System: Water will be withdrawn directly from a new 4' x 4' sump constructed in the bottom of the Bradley Channel as shown in Figure 2. A single self-priming pump (approx. 5 horsepower) will be utilized to withdraw the water from the channel and convey it to the system inlet. The pumping system will require a source of electrical power, which can be implemented concurrently with the shallow well project as described below. The estimated annual power cost is $11 per day, or approximately $3,000 per year assuming no use during the winter months. The turbidity of the tailwater is highly variable. Given the high porosity of the wood chip media, and for the purpose of this study, it is assumed that pre-treatment will not be required. If necessary, a slow sand filter forebay or equivalent mechanical system could be added to reduce turbidity, but this will increase both the capital and operating cost of the system. Another alternative would be to design the inlet of the bioreactor for maintenance and/or replacement.

Yard piping: Inlet and outlet works will be included in the system to uniformly distribute the flow over the wood chip bed. Other operating systems have utilized chamber-type infiltration units common in septic systems for flow distribution. The yard piping should also provide flexibility to withdraw effluent at intermediate points within the system, primarily to limit the hydraulic retention time (HRT) during periods of low flow or loading. If an excessively long HRT is maintained, all of the nitrate may be consumed, and sufficient additional time may be available for the subsequent reduction of sulfate, which would increase the potential for the formation of odors. The bacteria present in the system will preferentially utilize nitrate first, and therefore HRT control should be an effective means of mitigating odor potential.

Wood Chips: As described in Appendix A, a number of different wood chip materials have been tested, with the conclusion that many types of chips will provide acceptable performance. As the local solid waste handler, the City is well-positioned to identify and stockpile a cost effective source of wood chips. The unit price assigned in the project cost estimate assumes a typical wood chip cost consistent with recent Caltrans projects.

Planting Materials: Wood chip wetlands are often planted with typical wetland species such as cattails and bulrushes, and occasionally with decorative species such as calla lily, with a preference for native materials. Given the park setting, a blend of functional and decorative species would be appropriate. The plants utilize both the water and nutrients present in the wood chip bed, while also assisting to limit chip compaction and thereby maintain the porosity of the system through root growth (see Appendix A). Given that the plants require a source of nitrogen for successful growth, an established system will tend to have more robust growth near the inlet, where nitrate levels are highest, and some amount of plant die-off near the outlet, where nitrate concentrations are minimal. This phenomenon can be seen in the following photographs (Figure 3) of an existing system:


**Figure 3**
**Views of anoxic wetland bioreactors in El Centro, Ca**

Well Equipment and Electrical Power: As indicated previously, the equipping and use of the existing upper aquifer well will provide a benefit to the proposed system, the groundwater basin, and the adjacent park. The well pump will be selected to match the irrigation demands of the park while providing a source of supplemental water to the woodchip wetlands. The estimated pump size is 20 horsepower. Suitable three phase power will also be required for efficient operation of the well and system inlet pump. The City has worked closely with the local electrical utility (PG&E) to identify the cost of extending three phase power to the site, including the installation of approximately 800 feet of underground conduit and wire from the intersection of Carlotti and Stanford Drives. The annual electrical cost to operate the well for irrigation purposes is estimated at $2,300, based on an annual park demand of 46 acre-ft per year. If used continuously during the winter months to provide a source of high-nitrate water to the bioreactor, the well will generate an additional winter-period electrical cost of $3,900 per year.

**Estimated Draft Project Budget**

A conceptual project cost estimate has been developed for budgeting purposes as summarized in Table 3, consistent with the assumptions previously described. The estimate was developed based on 2012 costs, and can be indexed for inflation based on an Engineering News Record (ENR) Construction Cost Index (20 City Average) of 9413. Some adjustments in the project scope may be required during design to bring

| Table 3a: Conceptual Estimate for Construction-Related Costs | | | | |
|---|---|---|---|---|
| **Item Description** | **Units** | **Approx. Quantity** | **Unit Price** | **Total Price** |
| Grading | cu yds | 10,000 | $20.00 | $200,000 |
| Liner | sq ft | 40,000 | $1.50 | $60,000 |
| Wood Chips | cu yds | 8,000 | $15.00 | $120,000 |
| Yard Piping | LS | 1 | $95,000 | $95,000 |
| Wetlands Planting | LS | 1 | $30,000 | $30,000 |
| Storm Water Pump and Intake | LS | 1 | $150,000 | $150,000 |
| Shallow Well Equipment | LS | 1 | $28,000 | $28,000 |
| Sidewalk Demo and Repair | sq ft | 5000 | $15 | $75,000 |
| Three Phase Power to Site | LS | 1 | $60,000 | $60,000 |
| **Subtotal** | | | | **$818,000** |
| Construction Contingency (20%) | | | | $163,600 |
| Design and Construction Management (25%) | | | | $204,500 |
| **Total Conceptual Cost Estimate for Construction-Related Items** | | | | **$1,186,100** |

Notes:
1. Wetlands planting assumes bulrush/cattail, with spacing for future grow-in.
2. Three phase power estimate assumes selection of 50% PG&E discount option.
3. Yard piping includes the repair of impacted irrigation facilities.

| Table 3b: Conceptual Estimate for Non-Construction Costs | |
|---|---|
| **Item Description** | **Total Price** |
| Monitoring, Education, Outreach, and Program Administration | $312,000 |
| **Total Conceptual Cost Estimate for Non-Construction Items** | **$312,000** |

Appendix A

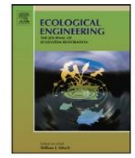
Anoxic Treatment Wetlands for Denitrification

Ecological Engineering 36 (2010) 1544–1551

Contents lists available at ScienceDirect

Ecological Engineering

journal homepage: www.elsevier.com/locate/ecoleng




# Anoxic treatment wetlands for denitrification

Harold L. Leverenz[a], Kristine Haunschild[b], Guy Hopes[a], George Tchobanoglous[a], Jeannie L. Darby[a,*]

[a] Department of Civil and Environmental Engineering, University of California Davis, One Shields Avenue, Davis, CA 95616, USA
[b] US Army Corps of Engineers, Sacramento, CA 95814, USA

ARTICLE INFO

*Article history:*
Received 19 November 2009
Received in revised form 27 March 2010
Accepted 28 March 2010

*Keywords:*
Anoxic constructed wetland
Subsurface flow
Woodchips
Denitrification
Decentralized wastewater management
Nitrate removal

ABSTRACT

Anoxic subsurface flow (SSF) constructed wetlands were evaluated for denitrification using nitrified wastewater. The treatment wetlands utilized a readily available organic woodchip-media packing to create the anoxic conditions. After 2 years in operation, nitrate removal was found to be best described by first-order kinetics. Removal rate constants at 20 °C ($k_{20}$) were determined to be 1.41–1.30 $d^{-1}$, with temperature coefficients ($\theta$) of 1.10 and 1.17, for planted and unplanted experimental woodchip-media SSF wetlands, respectively. First-order removal rate constants decreased as length of operation increased; however, a longer-term study is needed to establish the steady-state values. The hydraulic conductivity in the planted woodchip-media SSF wetlands, 0.13–0.15 m/s, was similar to that measured in an unplanted gravel-media SSF control system.



## 1. Introduction

Nitrate has been identified as a constituent of concern for many wastewater systems that disperse effluent to the soil because of potential impacts on groundwater. In some aquifers, nitrate concentrations above the drinking water limit have been found to extend more than 100 m from septic systems (Robertson et al., 1991). Elevated concentrations of nitrate in drinking water have been linked to methemoglobinemia in infants, a medical condition that interferes with the oxygen-carrying capacity of blood (U.S. EPA, 2002). Due to this health concern, the U.S. EPA and other regulatory agencies have set the maximum contaminant level for nitrate in drinking water at 10 mg N/L. Currently, there are limited options available for decentralized wastewater systems for the removal of nitrogen. The lack of cost-effective decentralized treatment options for nitrogen has resulted in the installation of capital intensive centralized collection and treatment systems in some communities. Therefore, an effective and inexpensive denitrification process for use in decentralized wastewater management applications is needed (Oakley et al., 2010).

* Corresponding author. Tel.: +1 530 752 5670.
*E-mail address:* jdarby@ucdavis.edu (J.L. Darby).

0925-8574/$ – see front matter © 2010 Elsevier B.V. All rights reserved.
doi:10.1016/j.ecoleng.2010.03.014

### 1.1. Onsite wastewater systems

Onsite wastewater management for an individual home consists typically of a septic tank and effluent dispersal system. The septic tank provides primary treatment for the wastewater and acts as an anaerobic digester for the organic waste that settles out of the water. Effluent from the septic tank contains nitrogen that is primarily in the ammonium form. A commonly used effluent dispersal system uses perforated subsurface pipes to infiltrate septic tank effluent into the soil by gravity. In the soil, the septic tank effluent undergoes additional treatment as the wastewater is exposed to oxygen and soil bacteria, resulting in the conversion of ammonium to nitrate. The wastewater nitrate then percolates through the soil matrix and may accumulate in groundwater aquifers and contaminate surface waters (Kellogg et al., 2010; U.S. Geological Survey, 2004).

### 1.2. Nitrate removal from wastewater

In conventional activated sludge type wastewater treatment plants, a small amount of nitrogen is removed through the production and wasting of biomass. High levels of nitrogen removal require the application of specialized biological nutrient removal processes. Conventional biological nutrient removal processes convert the organic and ammonia nitrogen to nitrate in an aerobic environment (nitrification) and then reduce the nitrate to nitrogen gas in an anoxic environment (denitrification). The denitrification process involves the anoxic biological oxidation of organic substrates in wastewater using nitrate as the electron acceptor (Tchobanoglous et al., 2003).

In wastewater treatment plants designed for nitrogen removal, nitrification and denitrification are typically integrated processes that utilize anoxic zones either before or after aerobic treatment. In processes that utilize anoxic zones before aerobic treatment, nitrates and biomass are returned from aerobic treatment to the anoxic zone where influent organics are utilized as the carbon source in the denitrification reaction. A common pre-anoxic denitrification method is the Modified Ludzack-Ettinger process (MLE) that achieves nitrate removal through an internal recycle step (Tchobanoglous et al., 2003). However, processes such as the MLE are not well suited for decentralized wastewater systems with stringent nitrogen limits because the variability in the loading conditions experienced in these small systems can lead to unreliable performance. For example, a number of decentralized wastewater systems recirculate nitrified effluent to the septic tank for denitrification but can only achieve total nitrogen removal rates around 50–60% reliably (Oakley et al., 2010).

In processes that utilize anoxic zones after aerobic treatment, the influent wastewater carbon is oxidized in the aeration and nitrification process and is no longer available for denitrification. Therefore, an external carbon source must be added to supply energy to the nitrifying organisms (Tchobanoglous et al., 2003). Several proprietary post-anoxic denitrification methods have been developed to overcome this limitation, including the use of both liquid carbon feed systems and solid phase carbon filters (Oakley et al., 2010; Schipper et al., 2010). For decentralized wastewater systems, liquid carbon feed systems can pose problems because the chemical source needs to be replenished on a regular basis and there is difficulty in applying the correct chemical dose to wastewater with varying characteristics (Leverenz et al., 2007).

### 1.3. Nitrogen removal in constructed wetlands

Natural wetlands have been shown to be a simple and energy-efficient method of removing nutrients (i.e., phosphorous and nitrogen) from wastewater (Nichols, 1983). Nichols (1983) concluded that while natural wetlands are good at removing phosphorous, nitrogen removal was dependent on the organic content of the wetland soils. Artificial open water wetlands have also been shown to be effective for the removal of nitrogen from wastewater (Gersberg et al., 1983, 1984). These results are explained by plant assimilation, the presence of microscopic anoxic zones that occur in bacterial films, and, over time, the presence of decaying plant material that provide carbon for denitrifying bacteria. Nitrate disappearance in open water constructed wetlands has been modeled as a volume-based first-order reaction (Kadlec and Knight, 1996).

Another alternative treatment wetland technology is the subsurface flow (SSF) constructed wetland, which is well suited for onsite wastewater applications because they provide odor and vector control and mitigate public access issues (U.S. EPA, 1993). Artificial SSF wetlands are typically designed with an inert rock medium and can be either planted or unplanted, and are designed so that the water flows below the surface of the wetlands through the packed-bed porous medium. The rock medium provides a surface area for the growth of bacterial films but inhibits the carbon cycling from plant debris because the packing material impedes the plant debris from reaching the water. As a result, conventional subsurface wetlands are only marginally successful at removing nitrogen from wastewater and generally require a prenitrification step to enhance denitrification capacity, however, these systems remain carbon limited (U.S. EPA, 1999). The nitrogen removal that does occur in rock medium SSF wetlands is the result of plant assimilation and microbial denitrification that utilizes any remaining carbon source in the influent and from rhizosphere plant decay (Kadlec and Knight, 1996). Thus, an alternative carbon source is required to increase the denitrification performance, assuming that nitrification has already taken place. For example, Gersberg et al. (1983) demonstrated that the addition of carbon, in the form of methanol, stimulated bacterial denitrification and increased nitrate removal efficiencies to 95%. However, the use of liquid carbon feed systems in small wastewater systems are subject to the limitations noted in Section 1.2.

### 1.4. Nitrogen removal in anoxic filters

Based on previous research reported in the literature, it has been found that a variety of organic solids can be used simultaneously as media and as a carbon source to support the denitrification process. These include plant biomass (Gersberg et al., 1983), cotton burr and mulch compost (Su and Puls, 2007), wheat straw (Aslan and Turkman, 2003), sawdust (Robertson and Cherry, 1995; Schipper and Vojvodic-Vukovic, 1998), and woodchips (Healy et al., 2006; Robertson and Merkley, 2009). Schipper and Vojvodic-Vukovic (1998) demonstrated that porous groundwater treatment walls amended with sawdust were successful in removing nitrate from contaminated groundwater. Schipper et al. (2010), also employed woodchip-based denitrification bioreactors to reduce end-of-pipe losses from agricultural drainage systems. Robertson et al. (2005) demonstrated that the Nitrex filters, which utilize a proprietary nitrate reactive material, produced septic tank effluent nitrate removal rates of up to 96%, remaining effective for at least 5 years, but removal rates were diminished during the winter months. However, the use of a readily available organic medium in a subsurface flow constructed wetland as a method for denitrification of nitrified septic tank effluent has not been investigated.

### 1.5. Purpose of study

The purpose of this research was to evaluate the use of constructed subsurface flow wetlands filled with an organic woodchip-media for denitrification of wastewater. The specific objectives were to assess the effect that aquatic plants, temperature, length of operation, hydraulic performance properties, and nitrate concentration had on nitrate removal performance. The results were used to determine nitrate removal rates and temperature coefficients that can be used for the preliminary design of constructed wetlands using organic woodchip-media.

## 2. Materials and methods

The pilot facility used in this study consisted of a septic tank, a packed-bed nitrification system, and experimental subsurface flow wetland units. Details of the experimental system and operational parameters are presented below.

### 2.1. Pretreatment system

Wastewater used in the study was diverted from the influent to the University of California Davis Wastewater Treatment Plant (UCD WWTP). The septic tank was a conventional design with a nominal volume of 7.6 $m^3$ and retention time of about 2 d. The packed-bed nitrification system consisted of three parallel single-pass units that utilized a synthetic textile media (Orenco Systems, Inc., Sutherlin, OR) and employed natural ventilation the perforated section at mid-depth, and samples were withdrawn using a hand pump.

### 2.4. Porosity measurements

The porosity of the media contained in the unplanted woodchip SSF wetland units was measured by volumetric displacement to evaluate degradation of the woodchip-media over time. Media samples were obtained from 0.3 m below the water surface and at several locations along the length of the basin. The porosity values were compared to gravel and unused woodchips.

### 2.5. Hydraulic conductivity measurements

Hydraulic conductivities of SSF media were measured using a permeameter test procedure (Crites et al., 2006). The permeameter testing was conducted directly in the SSF wetland unit basins by measuring headloss across a section of the system during loading at a constant flow rate. Darcy's Law of laminar flow through porous media was then used to determine the hydraulic conductivity value.

During the test procedure, the influent wastewater supply pump was turned off and a perforated pipe was inserted next to the influent pipe. Potable water was distributed through the perforated pipe at a constant flow as determined from volumetric testing. Piezometers installed 0.2 m from the inlet and outlet on basin sides were monitored and the head difference was recorded after steady-state conditions were obtained. Following the measurements, the Reynolds number through porous media was determined to ensure laminar regime assumptions were accurate. The limit of the laminar regime within porous media holds when the associated Reynolds's numbers are less than 10 (Charbeneau, 2000).

### 2.6. Tracer study

Tracer testing was performed in May 2009 using sodium chloride (NaCl). The effluent electrical conductivity was measured using a handheld conductivity meter (Myron L Ultrameter). For purposes of the study, 7.5 L of NaCl solution at a concentration of 20 g/L was added to the influent feed to each wetland system. An effluent composite sample and grab sample were obtained every 4 h during the study, which lasted for a total of 100 h. After the 100 h testing period, the effluent conductivity values had been observed to return to the baseline conditions, indicating that the tracer had been flushed from the system.

## 3. Results and discussion

The experimental results are presented and discussed in this section, including performance characteristics of the pretreatment system, overall nitrate removal performance, nitrate removal profiles, nitrate removal rates, effluent biochemical oxygen demand, hydraulic characteristics of SSF wetlands, and effects of plants on the system operation.

### 3.1. Performance of pretreatment system

Packed-bed filters were used to pretreat the wastewater prior to treatment in the wetland systems. The effluent $BOD_5$ concentrations from the pretreatment system were consistently less than 2 mg/L throughout the study. Effluent grab samples from the pretreatment system were also analyzed for ammonium and organic nitrogen. Average warm season ammonium and organic nitrogen concentration were 0.2 and 0.8 mg/L, respectively. Average cool season ammonium and organic nitrogen concentration were 1.4 and 1.2 mg/L, respectively. The pretreatment system effluent nitrite concentrations were non-detectable throughout the study. Based on the ammonium nitrogen and nitrite data, near complete nitrification was occurring throughout the study.

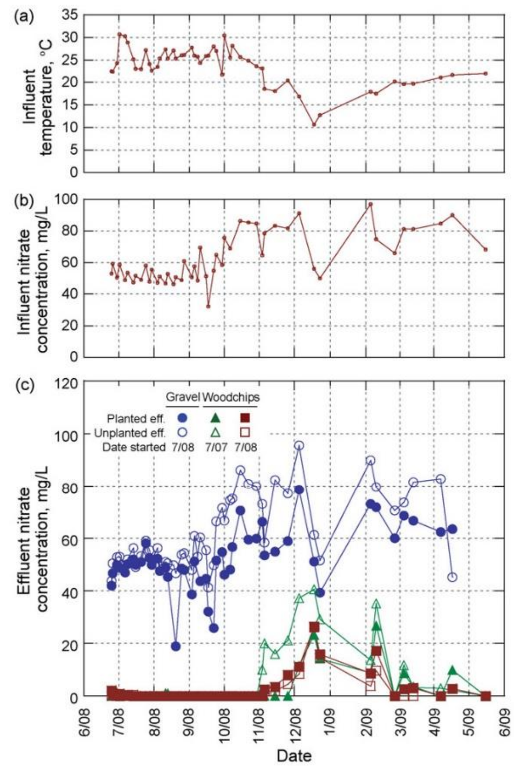



**Fig. 3.** Summary of SSF wetland performance (a) influent temperature, (b) influent nitrate concentration for all systems, and (c) effluent nitrate concentrations.

### 3.2. Nitrate removal performance

The influent temperature profile, shown in Fig. 3a, varied from 22 to 30 °C during the first 4 months of operation. In November, the influent temperature began to decrease reaching a low of 11 °C. The influent concentration of nitrate to the constructed wetlands is shown in Fig. 3b. For the first 4 months of operation, the influent concentrations averaged 53 mg/L, after which the influent concentration increased to an average of 82 mg/L when the student population increased at the start of the academic year.

The effluent concentration of nitrate from each wetland is presented in Fig. 3c. Nitrate removal in the unplanted gravel wetland (G, UP, 08) was negligible throughout the study. The nitrate concentration in the planted gravel (G, P, 08) wetland was reduced by an average value of 10 mg/L. On an area basis, this equates to a removal rate of 0.74 g N/m$^2$ d. Other researchers have observed values in the same range; for example, Lin et al. (2008) reported maximum nitrogen removal rates in SSF wetlands of 1.161 g N/m$^2$ d. While the observed nitrate reduction in the planted gravel SSF wetland is associated with plant growth, the specific removal mechanism has not been determined.

Reductions in the nitrate concentrations were observed in all of the woodchip wetlands throughout the study, with removals ranging from 60 to 100 mg/L. For the first 5 months of operation the woodchip wetlands removed an average of 99.7% of the influent nitrate, which ranged from 45 to 80 mg/L. However, beginning in November, the effluent nitrate concentration from the wetlands began to rise as the influent water temperature dropped. The reduced performance is attributed to decreased bacterial activity at lower temperatures (Sawyer et al., 1994). On an area basis, the nitrogen removal rate is estimated to be about 5.9 g N/m$^2$ d at temperatures above 15 °C, or 8 times higher than in the gravel-based SSF wetland system.

As shown in Fig. 3c, there was not a significant difference in the effluent nitrate concentrations between the 2008 planted and unplanted woodchip wetlands (W, P, 08 and W, UP, 08), which indicates that the availability of carbon from the woodchips was not rate limiting in these wetlands during this period. Similarly, for the first 4 months of operation there was no significant difference in the effluent concentrations between the planted and unplanted woodchip wetlands constructed in 2007 (W, P, 07 and W, UP, 07). However, in November when the temperatures began to decline, the unplanted woodchip wetland constructed in 2007 (W, UP, 07) exhibited higher effluent nitrate concentrations than the planted woodchip wetland constructed in 2007 (W, P, 07), with an average increase in concentration of 20 mg/L. The difference between the planted and unplanted systems is attributed to plant assimilation or synergistic effects between the plant roots and microbial community.

### 3.3. Nitrate profiles

Nitrate profile data collected at varying influent nitrate concentrations and temperatures are presented in Fig. 4. In each profile data set, nitrate removal in the unplanted gravel wetland (G, UP, 08) did not occur. Planting the gravel wetland (G, P, 08) consistently improved nitrate removal, but only slightly. This observation is consistent with the low overall nitrate removal for the planted and unplanted gravel wetlands (G, P, 08 and G, UP, 08) as shown in Fig. 3. The effect of temperature variation is evident when the profiles presented in Fig. 4a, b, and c are compared. The profile data reflects a decline in the nitrate removal rate with declining temperature. This temperature dependent removal relationship is consistent with lower bacterial activity that would be associated with lower temperatures.

### 3.4. Nitrate removal rates

The results of nitrate profile measurements, along with retention time in the wetland units as determined with a tracer study (see Table 2), were used to assess nitrate removal kinetics of the woodchip SSF wetlands. The profile data was best described with a first-order removal rate model (Tchobanoglous and Schroeder, 1985). A number of other researchers have described denitrification reactions in packed-beds as zero order (Robertson et al., 2000; Van Driel et al., 2006). However, it is proposed that while most field-scale systems are well approximated assuming zero order reaction kinetics, at low nitrate concentrations and at reduced temperatures, first-order kinetics may provide a better fit. Additional controlled studies are recommended to further characterize the nitrate removal kinetics.

The first-order removal constants, calculated for a temperature of 20 °C are summarized in Table 3. As shown in Table 3, the reaction rate decreases as the woodchip packing ages. In addition, the presence of plants resulted in a slight increase in the observed reaction rate, possibly due to combined effects of denitrification and plant uptake. The temperature coefficient, $\theta$, was calculated to be 1.10 and 1.17 for the planted and unplanted systems, respectively (Benefield et al., 1982). The temperature coefficient can be used to calculate the reaction rate at temperatures ranging from 11 to 20 °C, as shown in the following equation:

$$k_T = k_{20}\theta^{(T-20)}$$

where $k_{20}$ = removal rate constants at 20 °C; $k_T$ = removal rate constant at temperature $T$; $\theta$ = temperature coefficient.

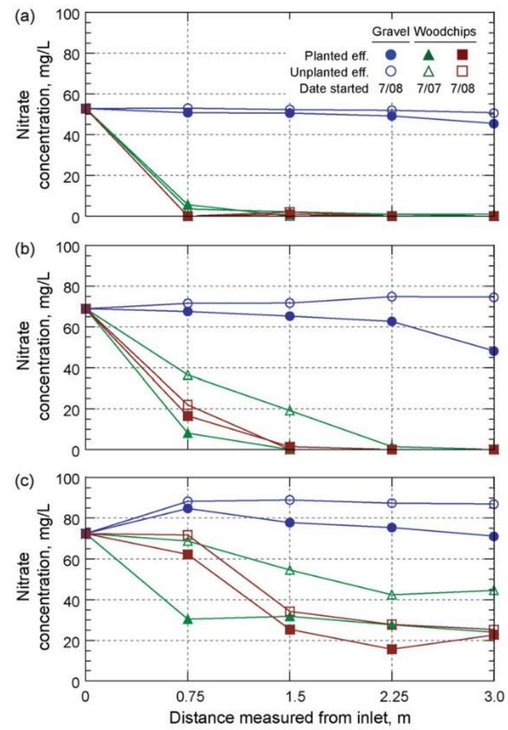



**Fig. 4.** Nitrate profile along the length of the wetland on (a) 8/13/08, 25 °C; (b) 2/26/09, 19 °C; and (c) 12/12/08, 11 °C.

**Table 2**
Characteristics of wetland systems.

| Wetland unit | Retention time (d)[a] | Hydraulic conductivity (m/s)[b] | Media porosity[b] |
|---|---|---|---|
| Planted | | | |
| G, 08 | 1.0 | 0.34 | – |
| W, 07 | 1.9 | 0.15 | – |
| W, 08 | 1.8 | 0.13 | – |
| Unplanted | | | |
| G, 08 | 2.2 | 0.14 | 0.37 |
| W, 07 | 2.0 | 0.54 | 0.58 |
| W, 08 | 1.2 | 0.36 | 0.59 |

[c] Unused woodchip porosity was 0.65.
[a] Measurements made in May 2009.
[b] Measurements made in August 2009 for unplanted systems only.

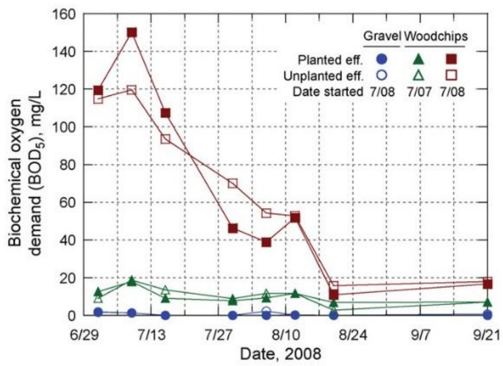



**Fig. 5.** Effluent $BOD_5$ concentration for each of the wetlands (influent $BOD_5$ was consistently less than 2 mg/L).

While a preliminary assessment of the impacts of temperature is presented in this paper, additional research is needed to evaluate the effects of temperature over a wider range. However, it is apparent that temperature effects should be taken into consideration for systems that must meet a regulatory limit. As shown in Table 3, the planted systems had a lower temperature coefficient than the corresponding unplanted systems. The smaller $\theta$ value is a result of being less sensitive to temperature fluctuations, particularly at low temperatures. It is therefore possible that the plants buffered the microbial community somewhat from the effects of temperature.

### 3.5. Biochemical oxygen demand

Effluent concentrations of biochemical oxygen demand ($BOD_5$) for each wetland are shown in Fig. 5. The influent $BOD_5$ concentration to all systems and the effluent $BOD_5$ concentrations of the planted and unplanted gravel wetlands (G, P, 08 and G, UP, 08) remained below 2 mg/L for the duration of the experiment. For the SSF woodchip wetlands constructed in 2008, the effluent $BOD_5$ concentrations were high (e.g., 120 mg/L) during the first month of operation, reflecting a significant release of carbon from the new woodchips. The effluent BOD for the systems started in 2007 were also high for the first few months after startup, however, quantitative measurements were not made at the time. The elevated effluent $BOD_5$ concentrations associated with the release of carbon was also observed by Robertson et al. (2005) for the Nitrex system. Following the first month of operation, the effluent $BOD_5$ concentration decreased to less than 20 mg/L. The effluent $BOD_5$ concentrations in both the planted and unplanted woodchip wetlands constructed in 2007 (W, P, 07 and W, UP, 07) increased from the influent concentration of 2 mg/L to effluent values ranging from 10 to 20 mg/L.

The high initial effluent BOD could be a problem in areas where there are strict effluent limitations that need to be observed. In these cases, the initial flow can be discharged to alternate location or treated in an aerobic process to remove the residual organic matter until satisfactory levels are attained. Another option would be to bypass and blend a portion of the nitrified influent with the high carbon effluent in a separate post-anoxic denitrification process. It should be noted that the effluent BOD is almost completely derived from the woodchips and not from wastewater.

**Table 3**
Summary of first-order reaction rate and temperature coefficients for woodchip wetlands.

| Wetland unit | $k_{20}$ ($d^{-1}$) | $\theta$[a] |
|---|---|---|
| W, P, 07 | 1.41 | 1.10 |
| W, P, 08 | 2.61 | |
| W, UP, 07 | 1.30 | 1.17 |
| W, UP, 08 | 2.28 | |

[a] Valid from 11 to 20 °C (Sawyer et al., 1994).

### 3.6. Wetland hydraulic characteristics

Hydraulic conductivity measurements were made in August 2009, approximately 25 months and 13 months after the startup of the systems initiated in July 2007 and July 2008, respectively. Porosity for the woodchip SSF wetland systems was also measured in August 2009, following the hydraulic conductivity testing. The characteristics of the gravel and woodchip SSF systems are presented in Table 2.

In the planted woodchip SSF systems, the hydraulic conductivity values were similar, 0.15 and 0.13 m/s for the 2007 and 2008 systems, respectively. The similar values could be an indication that after 1 year of service, the root growth in the planted systems had reached an equilibrium status. By comparison, the unplanted woodchip SSF systems had much higher conductivity values of 0.54 and 0.36 m/s for the 2007 and 2008 systems, respectively. It is expected that plant root growth is the cause of the reduced conductivity values in the planted systems, however, it is not clear why there is an increase in the conductivity value for the older unplanted woodchip SSF. One reason for the increase could be the degradation of small woodchip particles and/or the development of preferential flow paths. As reported in Table 2, there was little change in porosity between woodchip samples that were unused as compared to after use in the wetlands.

In the planted and unplanted gravel SSF wetlands, an increased conductivity of 0.34 m/s was measured in the planted system compared to 0.14 m/s measured in the unplanted system. While the growth of plants was expected to decrease the hydraulic conductivity, other researchers have reported a similar phenomenon (Grismer et al., 2001). It is proposed that the presence of plant roots may create preferential flow paths through the gravel bed where the smaller porosity inhibits flow. Alternatively, the growth of plant roots may expand the gravel bed and increase the effective porosity. However, these concepts remain to be tested in a controlled study.

### 3.7. Effects of plants

During the course of the study, plants were found to have several specific impacts in addition to the minor performance effects described in Sections 3.2 and 3.3. For example, it was noted that the unplanted systems were subject to media settling, which occurred mostly in the first year and equal to about 0.1 m of settlement. In contrast, due to root growth, the planted systems did not experience settlement and the woodchip-media was even slightly expanded. Plants in the woodchip SSF wetlands had robust growth on the inlet side (0–1.5 m) of the system and stunted growth on the outlet side (1.5–3.0 m) of the system. The stunted growth was correlated with the lack of nitrogen and resulted in significantly reduced growth, shorter plants, and yellowed vegetation color. On the outlet side of the wetland, plant growth only occurred near the edges of the basin, perhaps in response to preferential flow paths at the sidewalls. In this case, plants could be used as a visual indicator of nitrate progression through the anoxic reactor. An example of the variation in plant growth in the woodchip SSF compared to the gravel SSF is shown in Fig. 6. In the long-term, there is a possibility

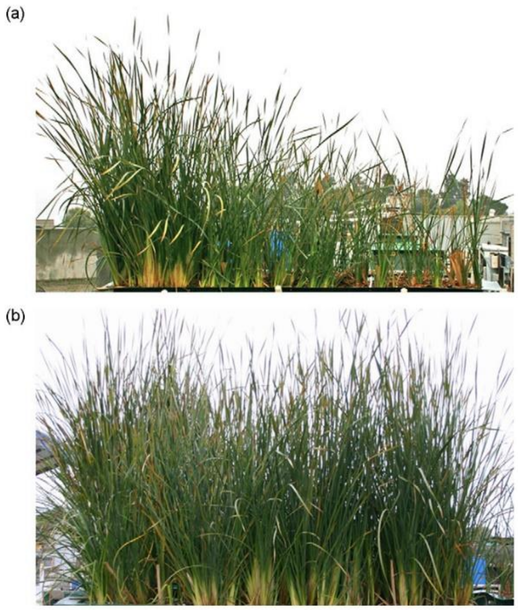


Fig. 6. Views of plant growth in (a) woodchip SSF wetland and (b) gravel SSF wetland. Inlet is on the left side and outlet is on the right side. Photographs taken on the same day, for systems of same age (8 months after startup), with identical loading.

that plants could contribute additional carbon to the system due to decay of plant material.

## 4. Findings

The purpose of this research was to evaluate the use of subsurface wetlands constructed with a readily obtained organic medium for the denitrification of wastewater. Nitrate removal performance and the effects of temperature, length of operation, and aquatic plants were assessed, as summarized below.

- Readily available woodchips were an effective source of the carbon for denitrification of nitrified septic tank effluent. Waste woodchips are available at a fraction of the cost compared to gravel and thus may be an economically viable alternative media in subsurface flow wetlands.
- The observed nitrate removal performance in subsurface flow wetlands constructed with woodchips can be described with first-order reaction rate kinetics with rate constants at 20 °C ($k_{20}$) that varied from 1.41 to 1.30 $d^{-1}$ for planted and unplanted systems, respectively, after 2 year in operation. Corresponding temperature coefficients for planted and unplanted systems were 1.10 and 1.17, respectively. Additional research is needed to further characterize the nature of the reaction kinetics and establish the temperature effects over a wider range.
- Longer operation times for the woodchip wetlands resulted in lower first-order removal rate coefficients and temperature coefficients. However, steady-state was not reached and no estimate of the long-term removal rate can be determined.
- The presence of plants in the woodchip SSF systems resulted in the decrease of the hydraulic conductivity to the same range as measured in an unplanted gravel SSF system (0.14 m/s).
- Porosities of the woodchips did not change significantly over the course of the study.
- Plants were found to have several beneficial effects, including buffering against low temperature effects, prevention of woodchip-media settling, and visual indicator of nitrate removal.

## Acknowledgments

This research was supported by the Water Environment Research Foundation Contract # DEC13U06 and the California Department of Transportation. The content is solely the responsibility of the authors and does not necessarily represent the official views of the funding agencies. Woodchips were provided by Waste Management, Inc. (WMCR/K&M, Sacramento, CA). The septic tank, nitrification filters, and SSF basins were provided by Orenco Systems Inc. (Sutherlin, OR).

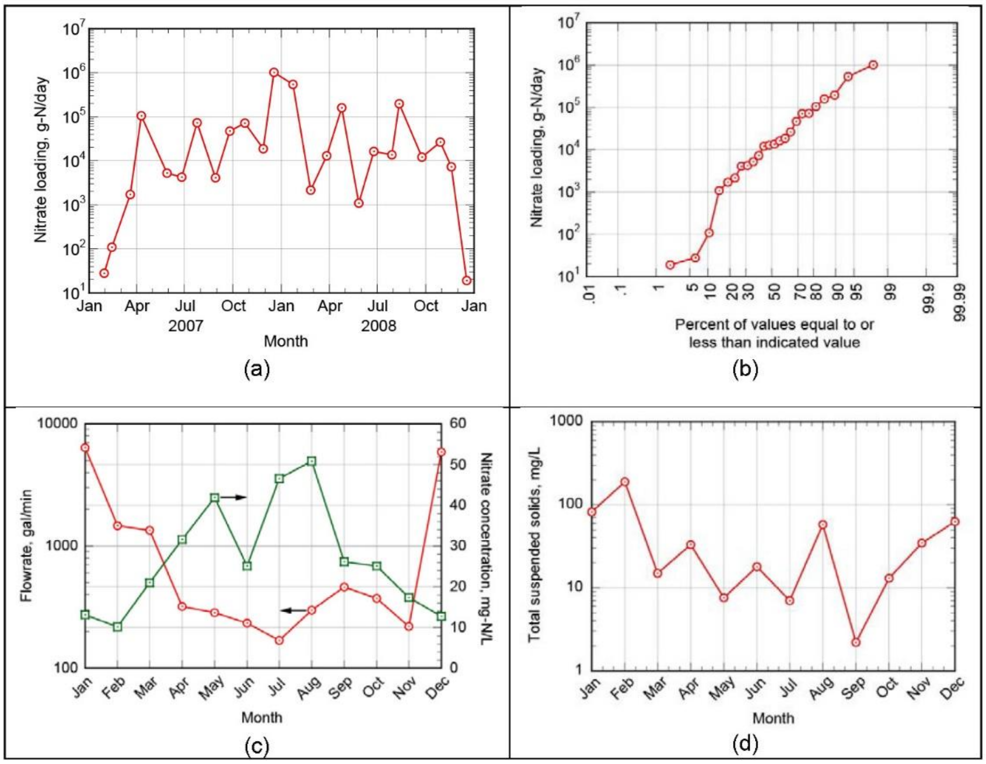
## References

Aslan, S., Turkman, A., 2003. Biological denitrification of drinking water using various natural organic solid substrates. Water Sci. Technol. 48 (11–12), 489–495.
Benefield, Judkins, J.F., Weand, B.L., 1982. Process Chemistry for Water and Wastewater Treatment. Prentice-Hall.
Charbeneau, R.J., 2000. Groundwater Hydraulics and Pollutant Transport. Waveland Press, Inc.
Crites, R.W., Middlebrooks, E.J., Reed, S.C., 2006. Natural Wastewater Treatment Systems. CRC.
Gersberg, R.M., Elkins, B.V., Goldman, C.R., 1983. Nitrogen removal in artificial wetlands. Water Res. 17 (9), 1009–1014.
Gersberg, R.M., Elkins, B.V., Goldman, C.R., 1984. Use of artificial wetlands to remove nitrogen from wastewater. J. Water Pollut. Control 56 (2), 152–156.
Grismer, M.E., Tausendschoen, M., Sheperd, H.L., 2001. Hydraulic characteristics of a subsurface constructed wetland for winery effluent treatment. Water Environ. Res. 73 (4), 466–477.
Healy, M.G., Rodgers, M., Mulqueen, J., 2006. Denitrification of a nitrate-rich synthetic wastewater using various wood-based media and materials. J. Environ. Sci. Health 41, 779–788.
Kadlec, R.H., Knight, R.L., 1996. Treatment Wetlands. CRC, Boca Raton.
Kellogg, D.Q., Gold, A.J., Cox, S., Addy, K., August, P.V., 2010. In review. A geospatial approach for assessing denitrification sinks at the local level. Ecol. Eng. 36, 1596–1606.
Leverenz, H.L., Darby, J., Tchobanoglous, G., 2007. Comparison of a commercially available chlorine and an ultraviolet disinfection unit for onsite wastewater systems. Small Flows Magazine 8 (2), 11–21.
Leverenz, H., Ruppe, L., Tchobanoglous, G., Darby, J., 2001. Evaluation of high porosity media for the treatment of onsite treatment of wastewater. Small Flows J. 2 (2).
Lin, Y.F., Jing, S.R., Lee, D.Y., Chang, Y.F., Shih, K.C., 2008. Nitrate removal from groundwater using constructed wetlands under various hydraulic loading rates. Bioresource Technol. 99 (2008), 7504–7513.
Nichols, D.S., 1983. Capacity of natural wetlands to remove nutrients from wastewater. Water Pollut. Control Federation 55 (5), 495–504.
Oakley, S., Gold, A.J., Oczkowski, A.J., 2010. In review. Nitrogen control through decentralized wastewater treatment: process performance and alternative management strategies. Ecol. Eng. 36, 1520–1531.
Robertson, W.D., Merkley, L.C., 2009. In-stream bioreactor for agricultural nitrate treatment. J. Environ. Qual. 38, 230–237.
Robertson, W.D., Blowes, D.W., Ptacek, C.J., Cherry, J.A., 2000. Long-term performance of in situ reactive barriers for nitrate remediation. Ground Water 38 (5), 689–695.
Robertson, W.D., Cherry, J.A., Sudicky, E.A., 1991. Ground-water contamination from two small septic systems on sand aquifers. Ground Water 29, 82–92.
Robertson, W.D., Cherry, J.A., 1995. In-situ denitrification of septic-system nitrate using reactive porous media barriers: field trials. Ground Water 33 (1), 99–111.
Robertson, W.D., Ford, G.I., Lombardo, P.S., 2005. Wood-based filter for nitrate removal in septic systems. Trans. ASAE 48 (1), 121–128.
Sawyer, C.N., McCarty, P.L., Parkin, G.F., 1994. Chemistry for Environmental Engineering, 4th Edition. McGraw Hill, New York.
Schipper, L.A., Robertson, W., Gold, A.J., Jaynes, D.B., Cameron, S.C., 2010. Denitrifying bioreactors—an approach for reducing nitrate loads to receiving waters. Ecol. Eng. 36, 1532–1543.
Schipper, L.A., Vojvodic-Vukovic, M., 1998. Nitrate removal from groundwater and denitrification rates in a porous treatment wall amended with sawdust. Ecol. Eng. 14, 269–278.
Clesceri, L.S., Greenberg, A.E., Eaton, A.D. (Eds.), 1998. Standard Methods for the Examination of Water and Wastewater, 20th edition. American Public Health Association, Washington, DC.
Su, C., Puls, R.W., 2007. Removal of added nitrate in cotton burr compost, mulch compost, and peat: mechanisms and potential use for groundwater nitrate remediation. Chemosphere 66, 91–98.

Tchobanoglous, G., Burton, F.L., Stensel, H.D., 2003. Wastewater Engineering. McGraw-Hill, New York.
Tchobanoglous, G., Schroeder, E., 1985. Water Quality. Addison-Wesley, Massachusetts.
U.S. EPA, 1993. Subsurface Flow Constructed Wetlands for Wastewater Treatment: A Technology Assessment, United States Environmental Protection Agency, EPA 832-R-93-008.
U.S. EPA, 1999. Constructed Wetlands Treatment of Municipal Wastewater, United States Environmental Protection Agency, EPA 625-R-99-010.
U.S. EPA, 2002. Onsite Wastewater Treatment Systems, United States Environmental Protection Agency, EPA 600-R-00-008.
U.S. Geological Survey, 2004. Is Septic Waste Affecting Drinking Water from Shallow Domestic Wells Along the Platte River in Eastern Nebraska, Factsheet 072-03.
Van Driel, P.W., Robertson, W.D., Merkley, L.C., 2006. Denitrification of agricultural drainage using wood based reactors. Am. Soc. Agric. Biol. Eng. 49 (2), 565–573.

Appendix B

Bradley Channel Data




**Appendix B**

Summary of data for Bradley Channel: (a) time-series of nitrate-N loading, (b) probability distribution of nitrate-N loading, (c) average monthly flowrate and nitrate-N concentration, and (d) average monthly total suspended solids concentration.

Appendix B

Pilot Project Results

CONTINUED ON NEXT PAGE

| Date | Taylor Well | | | | | Bradley Channel | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | $NH_3$ - N (mg/L) | $N0_3$ - N (mg/L) | $NO_2$ - N (mg/L) | TKN (mg/L) | Total Nitrogen - N | $NH_3$ - N (mg/L) | $N0_3$ - N (mg/L) | $NO_2$ - N (mg/L) | TKN (mg/L) | Total Nitrogen - N |
| 8/10/2017 | ND | 3.4 | ND | ND | 3.4 | 0.15 | 6.7 | 0.57 | 1.3 | 8.5 |
| 8/17/2017 | ND | 3.40 | ND | ND | 3.40 | 0.55 | 7 | 0.89 | 2.4 | 10.00 |
| 8/24/2017 | ND | 0.88 | ND | ND | 0.88 | ND | 1.7 | ND | ND | 1.70 |
| 8/31/2017 | ND | 3.30 | ND | ND | 3.30 | 2.2 | 35 | 1.4 | 4.2 | 40.00 |
| 9/7/2017 | ND | 2.70 | ND | ND | 2.70 | 4.10 | 0.55 | 0.19 | 7.30 | 8.10 |
| 9/14/2017 | ND | 1.30 | ND | ND | 1.30 | ND | 1.4 | ND | 0.51 | 1.90 |
| 9/21/2017 | ND | 2.70 | ND | ND | 2.70 | 3.2 | 22 | 1.7 | 4.8 | 28.0 |
| 9/28/2017 | ND | 3 | ND | ND | 3 | 3.3 | 25 | 1.2 | 4.6 | 31 |
| 10/5/2017 | ND | 2.90 | ND | ND | 2.90 | 4.2 | 26 | 1.5 | 4.8 | 33.00 |
| 10/12/2017 | ND | 2.2 | ND | ND | 2.2 | 0.38 | 4.2 | 0.3 | 1.6 | 6.1 |
| 10/19/2017 | ND | 2.20 | ND | ND | 2.20 | ND | 2 | ND | ND | 2.00 |

| Date | Biofilter Influent | | | | | Biofilter Effluent | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | $NH_3$ - N (mg/L) | Influent $N0_3$ - N (mg/L) | $NO_2$ - N (mg/L) | TKN (mg/L) | Influent Total Nitrogen - N (mg/L) | $NH_3$ - N (mg/L) | Effluent $N0_3$ - N (mg/L) | $NO_2$ - N (mg/L) | TKN (mg/L) | Effluent Total Nitrogen - N (mg/L) | % Removal $NO_3$ - N | Removal Total Nitrogen - N | Flow, MG | Lbs nitrogen removed | Lbs nitrate removed |
| 8/10/2017 | ND | 6.6 | 0.51 | 1.4 | 8.5 | 15 | 0.38 | ND | 21 | 21 | 94.2 | -147.1 | | **NA** | |
| 8/17/2017 | 0.27 | 5.10 | 0.60 | 1.80 | 7.50 | 5.6 | 0.12 | ND | 8.9 | 8.90 | 97.6 | -18.7 | | NA | |
| 8/24/2017 | 0.24 | 1.30 | ND | ND | 1.30 | 2.3 | 0.12 | ND | 5.8 | 5.80 | 90.8 | -346.2 | | NA | |
| 8/31/2017 | 2.3 | 35.00 | 1.40 | 4.20 | 41.00 | 3.8 | 4.9 | 0.17 | 7.3 | 12.00 | 86.0 | 70.7 | 1.3 | 308.3 | 320.0 |
| 9/7/2017 | 0.81 | 1.30 | 0.16 | 2.10 | 3.50 | 2.10 | 0.12 | ND | 4.40 | 4.40 | 90.8 | -25.7 | 0.8 | NA | 8.0 |
| 9/14/2017 | ND | 1.60 | ND | 0.49 | 2.10 | 4 | 0.12 | ND | 3.6 | 3.60 | 92.5 | -71.4 | 0.9 | NA | 10.9 |
| 9/21/2017 | 0.53 | 11.00 | 0.69 | 1.90 | 13.00 | 0.81 | 1.9 | ND | 2.7 | 4.6 | 82.7 | 64.6 | 1.0 | 73.4 | 79.5 |
| 9/28/2017 | ND | 7.1 | ND | 1.7 | 8.8 | 2.6 | 1.6 | ND | 4.3 | 5.9 | 77.5 | 33.0 | 1.0 | 24.4 | 46.2 |
| 10/5/2017 | 4.4 | 22.00 | 1.20 | 4.70 | 28.00 | 3.5 | 8.8 | 0.57 | 4.5 | 14.00 | 60.0 | 50.0 | 0.9 | 108.0 | 101.8 |
| 10/12/2017 | ND | 3.4 | 0.22 | 1.3 | 4.9 | 1.9 | 1.7 | 0.2 | 3.4 | 5.3 | 50.0 | -8.2 | 0.9 | NA | 12.9 |
| 10/19/2017 | ND | 1.30 | ND | ND | 1.30 | 1 | 0.4 | ND | 2.5 | 2.50 | 69.2 | -92.3 | 0.9 | NA | 6.7 |

Values in red were non-detect, so the value shown is the Minimum Detection Limit.

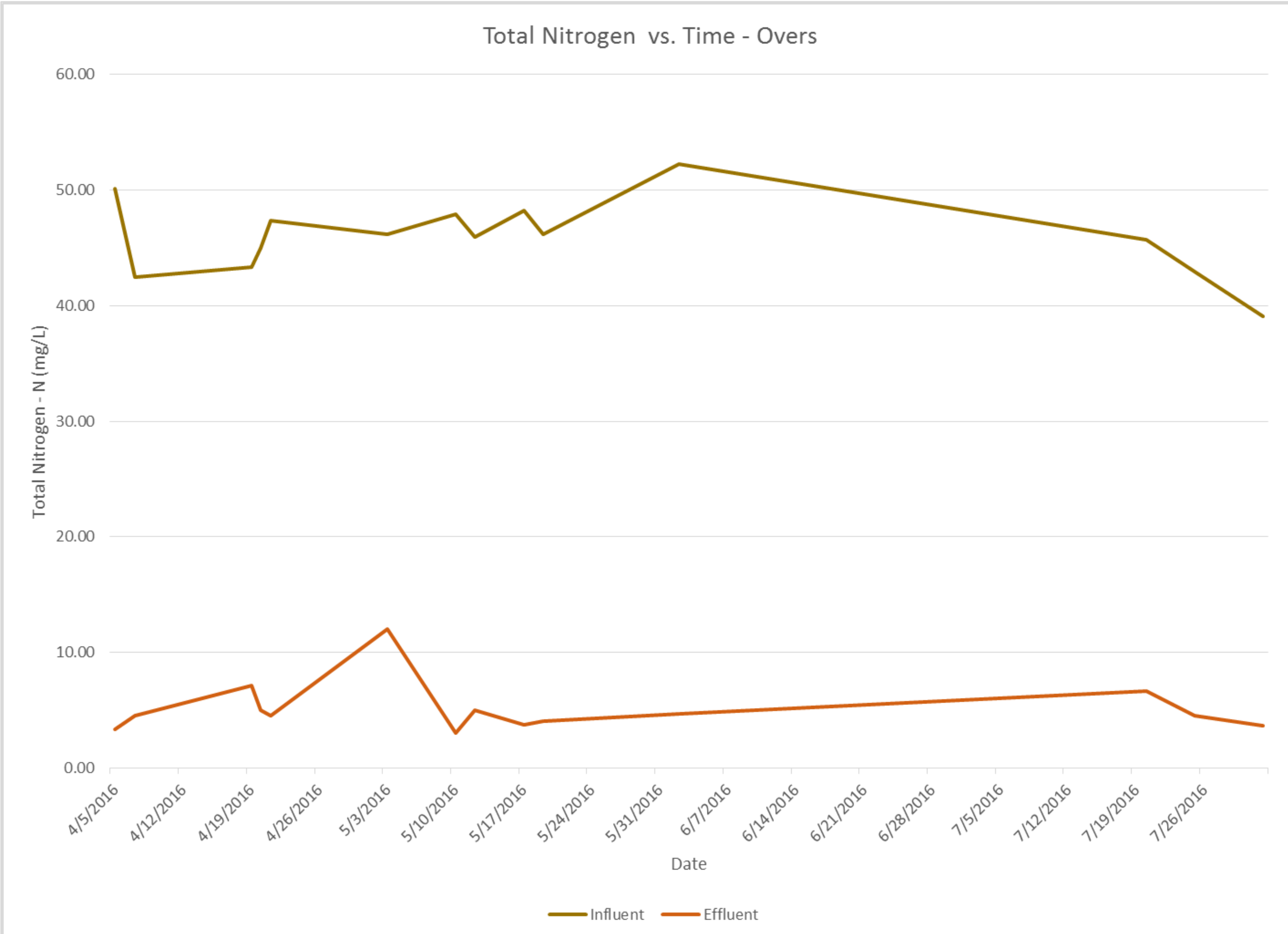
Appendix C

Sampling Results

CONTINUED ON NEXT PAGE

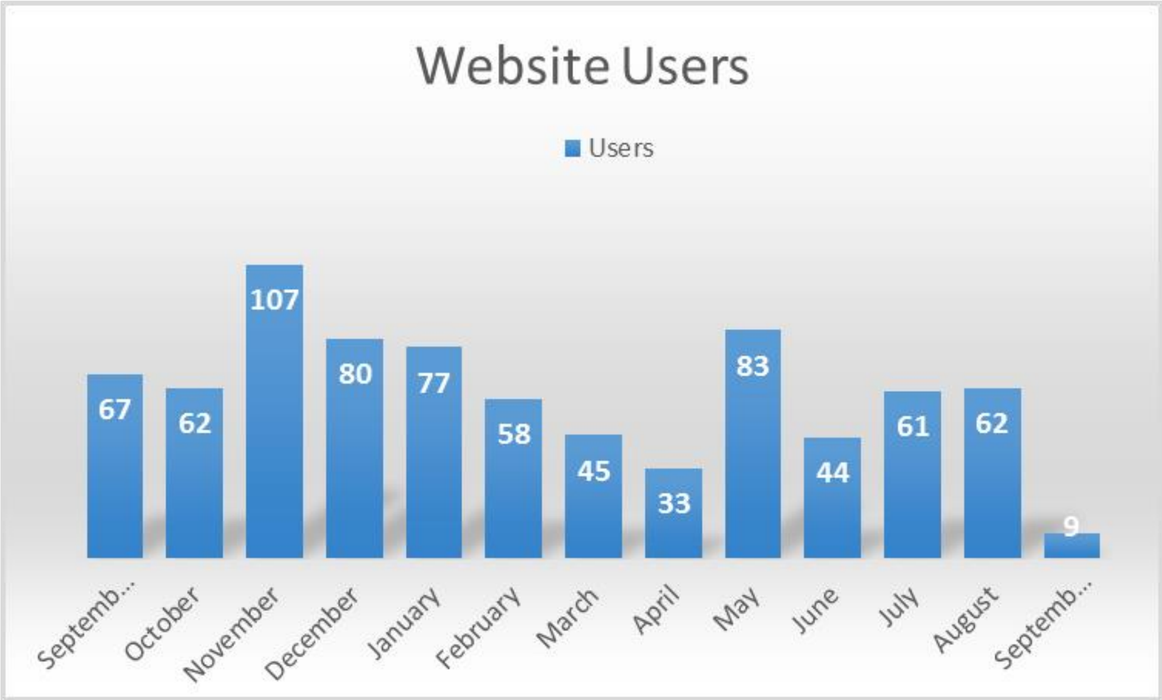
| | Influent | | | | Effluent | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| Date | Temp (°C) | $NO_3$ - N (mg/L) | $NH_3$ - N (mg/L) | Total Nitrogen - N | Temp (°C) | $N0_3$ - N (mg/L) | $NH_3$ - N (mg/L) | Total Nitrogen - N | % Removal $NO_3$ - N | % Removal Total Nitrogen - N |
| 4/5/2016 | 21.6 | 49.8 | 0.30 | 50.10 | 23.3 | 2.47 | 0.92 | 3.39 | 95.0 | 93.2 |
| 4/7/2016 | 23.0 | 41.7 | 0.75 | 42.45 | 25.2 | 3.27 | 1.25 | 4.52 | 92.2 | 89.4 |
| 4/19/2016 | 23.9 | 42.6 | 0.75 | 43.35 | 24.5 | 6.22 | 0.95 | 7.17 | 85.4 | 83.5 |
| 4/20/2016 | 7.30 | 44.3 | 0.65 | 44.95 | 7.40 | 3.91 | 1.10 | 5.01 | 91.2 | 88.9 |
| 4/21/2016 | 20.8 | 46.7 | 0.60 | 47.30 | 22.2 | 2.82 | 1.75 | 4.57 | 94.0 | 90.3 |
| 5/3/2016 | 20.5 | 45.5 | 0.65 | 46.15 | 19.7 | 11.4 | 0.65 | 12.1 | 74.9 | 73.9 |
| 5/10/2016 | 18.5 | 47.4 | 0.46 | 47.86 | 19.7 | 2.73 | 0.32 | 3.05 | 94.2 | 93.6 |
| 5/12/2016 | 18.4 | 45.5 | 0.42 | 45.92 | 18.7 | 4.67 | 0.36 | 5.03 | 89.7 | 89.0 |
| 5/17/2016 | 23.4 | 47.7 | 0.5 | 48.2 | 21.3 | 3.58 | 0.22 | 3.8 | 92.5 | 92.1 |
| 5/19/2016 | 18.4 | 46.1 | 0.08 | 46.18 | 18.5 | 3.86 | 0.24 | 4.10 | 91.6 | 91.1 |
| 6/2/2016 | 22.4 | 52.1 | 0.11 | 52.21 | 21.8 | 4.47 | 0.24 | 4.71 | 91.4 | 91.0 |
| 7/20/2016 | 22.5 | 45.5 | 0.15 | 45.65 | 23.0 | 6.51 | 0.15 | 6.66 | 85.7 | 85.4 |
| 7/25/2016 | 19.9 | 42.6 | 0.3 | 42.9 | 20.2 | 4.32 | 0.25 | 4.57 | 89.9 | 89.3 |
| 8/1/2016 | 20.7 | 38.1 | 0.95 | 39.05 | 22.2 | 3.45 | 0.25 | 3.70 | 90.9 | 90.5 |
| | | | | | | | | | | |
| | | | | | | | | **Average** | **89.9** | **88.7** |

*Nitrite and Total Kjeldahl Nitrogen levels minimal

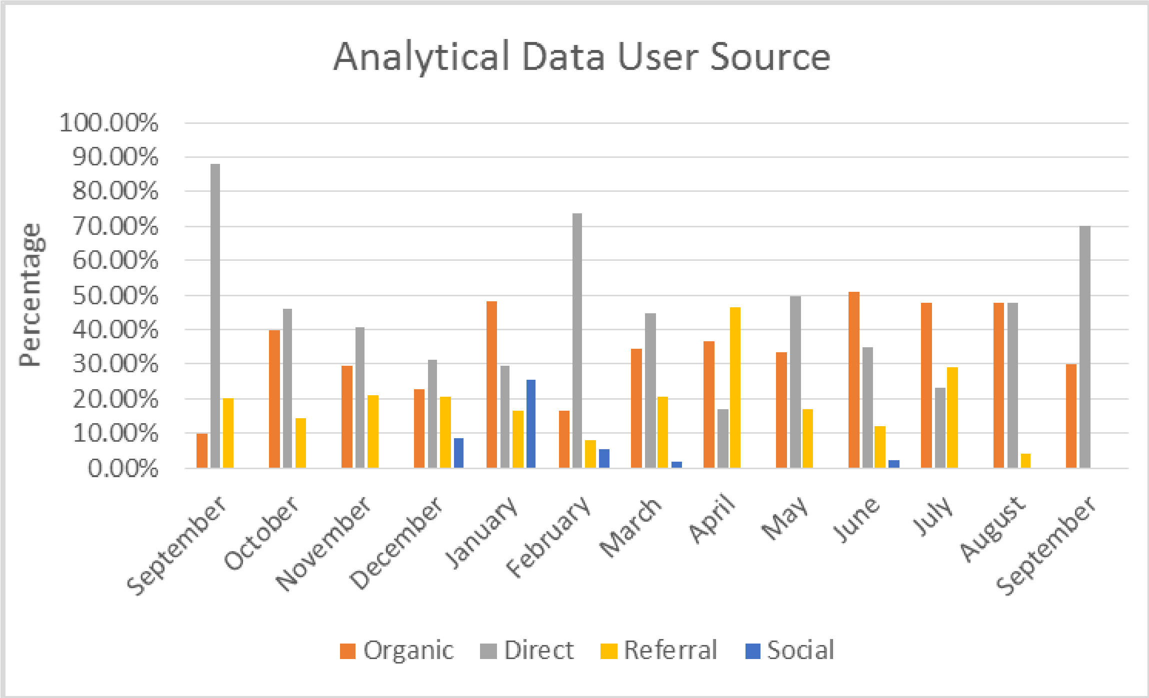

Total Nitrogen vs. Time - Overs
60.00
50.00
40.00
30.00
20.00
10.00
0.00
Total Nitrogen - N (mg/L)
4/5/2016
4/12/2016
4/19/2016
4/26/2016
5/3/2016
5/10/2016
5/17/2016
5/24/2016
5/31/2016
6/7/2016
6/14/2016
6/21/2016
6/28/2016
7/5/2016
7/12/2016
7/19/2016
7/26/2016
Date
Influent
Effluent

Appendix D
Website Analytical Data

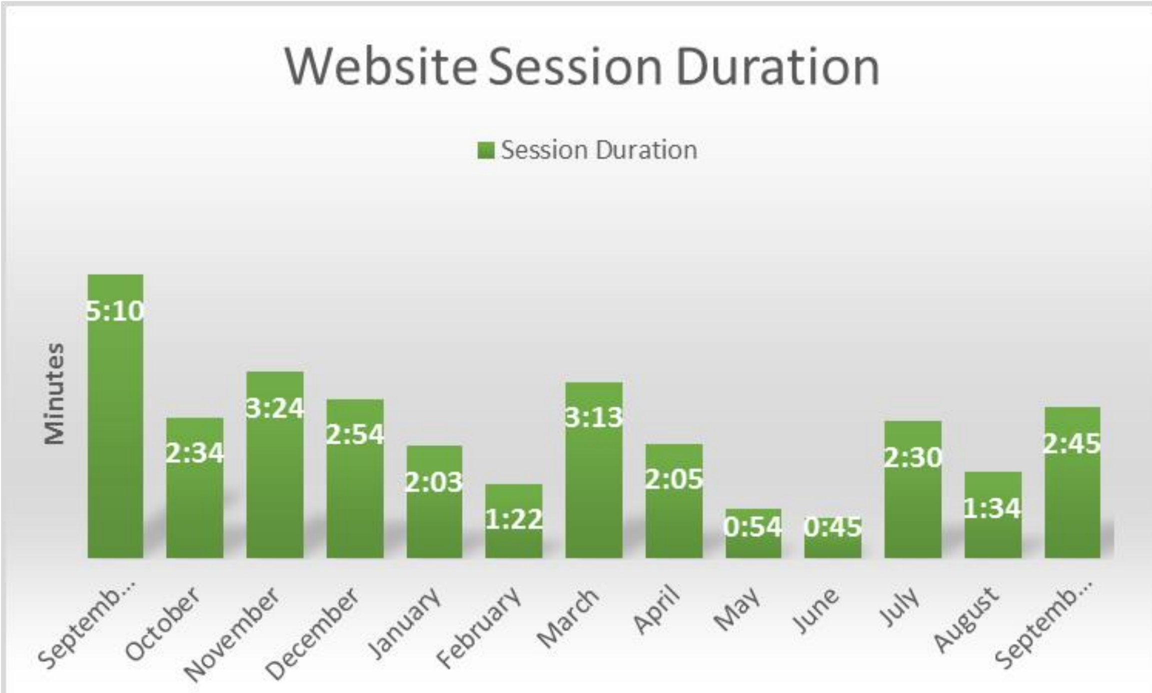
*Graph: Number of Website Users by Month (September 2016 – September 2017)*




*Graph: Data User Source by Month (September 2016 – September 2017)*



*Graph: Duration of Stay on Website by Month (September 2016 – September 2017)*



# Appendix E
## Letters to Upstream Property Owners

CONTINUED ON NEXT PAGE

CITY OF SANTA MARIA
UTILITIES DEPARTMENT
Business Services • Regulatory Compliance
Solid Waste Services • Water Resources

2065 EAST MAIN STREET • SANTA MARIA, CALIFORNIA 93454-8026 • 805-925-0951 EXT. 7270 • FAX 805-928-7240

October 3, 2016

URBAN & AGRICULTURE
Collaborating for a Better Future

RE: Irrigation and Nutrient Management Technical Assistance Available

Dear Grower,

You are receiving this letter because your property is upstream of the Bradley Channel. As you are aware, agricultural runoff is an important topic in California right now. The City of Santa Maria is very excited about a project designed for the denitrification of agricultural tailwater. This project is designed to biologically remove nitrate in the drainage water from Bradley Channel, which drains approximately 5,700 acres of irrigated farmland to groundwater and surface water in the Santa Maria Valley.

The City was awarded a grant in the amount of $1.25 million from the State Water Resources Control Board to design and construct this project. Construction started at Jim May Park this month, and is anticipated to continue until completion in January 2017.

Although the grant project is designed to remove nitrate in agricultural tailwater from Bradley Channel, the project does not alleviate any regulatory requirements growers might be under to minimize nitrate transport from agricultural fields. One of the components of the grant is to provide some on-farm technical assistance regarding irrigation and nutrient management to growers who are upstream of this project. The City is contracting with the Cachuma Resource Conservation District to provide free assistance on a first come first served basis.

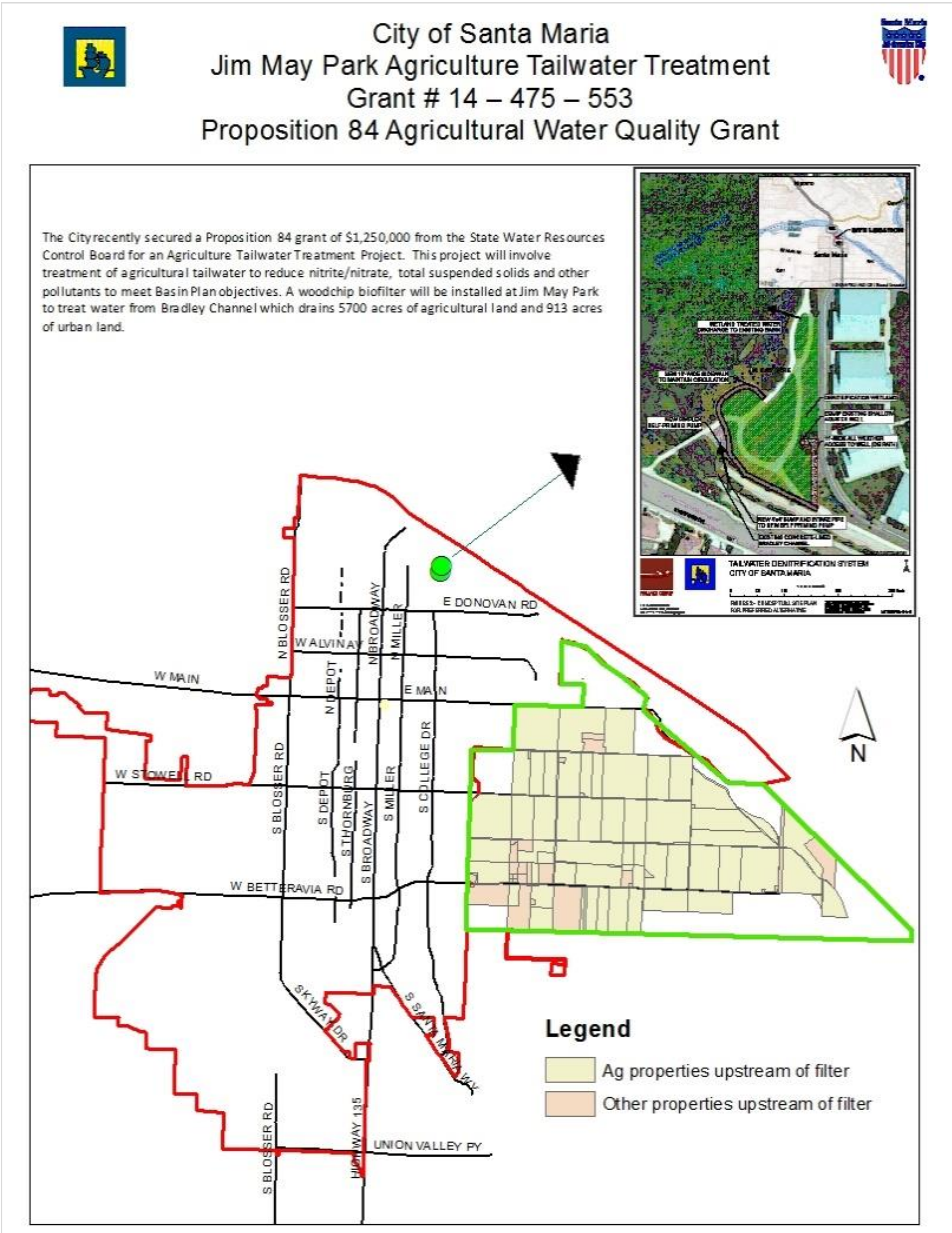
If you have any questions about this project, or would be interested in free technical assistance for irrigation and nutrient management, please contact me via phone or email as indicated below before December 31, 2016 so that I can assist you with any questions you may have about types of assistance and or eligibility requirements. For more information about the Jim May Park biofilter project, please visit: http://jimmayparkbiofilter.org/

We look forward to being able to provide any assistance you may need in this area at no cost to you.

Sincerely,

*Lisa Long*
***Utilities Business Manager***
City of Santa Maria, Utilities Department | 2065 East Main Street Santa Maria, CA 93454
805.925.0951 ext. 7219 | Fax 805.928.7240 | Mobile 805.714.3294
www.cityofsantamaria.org
*Our Mission - "To provide the highest quality service in the most efficient, cost-effective and courteous manner."*

Appendix F
Project Poster



Appendix G
Brochure

# Jim May Park Biofilter Project

URBAN & AGRICULTURE
Collaborating for a Better Future

## Description

The Jim May Park biofilter is a wood chip biofilter located in the City of Santa Maria. It has been designed to convert nitrate from drainage water from Bradley Ditch into harmless nitrogen gas. Nitrate comes from nitrogen fertilizer and is often found in agriculture runoff. Bradley Ditch drains approximately 5,600 acres of agricultural lands that includes approximately 60 different farms. Water drains by gravity from Bradley Ditch into a deep wet well located next to the biofilter. Water is pumped out of the wet well and into a 0.75 acre, 6-foot deep wood chip biofilter that also supports wetland plants. This biofilter will help protect and restore the water quality in the groundwater basin by reducing nitrate.

## Water Quality Issues

Nitrate concentration documented in Bradley Ditch range between 3-78 milligrams per liter nitrate. High levels can affect groundwater quality and are harmful for the downstream aquatic habitat. The regulatory limit for nitrate in drinking water is 10 mg/L nitrate. This regional treatment facility will benefit from a more constant supply of water than would be available from just one individual farm. This constant supply will help keep the biofilter alive and actively treating water throughout the year.

## Partnerships

Many different agencies worked together to make this project happen. The Cachuma Resource Conservation District secured the initial grant. The City of Santa Maria managed the grant, the design and construction of the project, and will monitor effectiveness after construction. The County of Santa Barbara granted approval to build the facility on county property. Engel and Gray, a local compost company, provided the discounted wood chips. Wallace Group developed the initial feasibility study. Michael K. Nunley & Associates designed the project and it was constructed by Whitaker Construction.

## Prop 84 Grant Funding

State Water Resources Control Board Proposition 84 Agricultural Water Quality Grant provided funding for this treatment system. Matching funds and in-kind labor were provided by the City of Santa Maria, and matching funds in the form of discounted woodchips were provided by Engel and Gray.

Construction Costs: not yet available.
Matching Costs: not yet available.

## Construction

*Biofilter construction at Jim May Park.*

## Monitoring Results

Data results from a pilot biofilter indicated that up to 90% of the nitrate was removed. As the project progresses, the City will monitor nitrogen removed from the biofilter. The data will be used to help calibrate the biofilter to maximize its efficiency, and will be shared with the public to help celebrate the anticipated success.

| | Influent | | | | Effluent | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| Date | Temp (°C) | $NO_3$ - N (mg/L) | $NH_3$ - N (mg/L) | Total Nitrogen - N | Temp (°C) | $N0_3$ - N (mg/L) | $NH_3$ - N (mg/L) | Total Nitrogen - N | % Removal $NO_3$ - N | % Removal Total Nitrogen - N |
| 4/5/2016 | 21.6 | 49.8 | 0.30 | 50.10 | 23.3 | 2.47 | 0.92 | 3.39 | 95.0 | 93.2 |
| 4/7/2016 | 23.0 | 41.7 | 0.75 | 42.45 | 25.2 | 3.27 | 1.25 | 4.52 | 92.2 | 89.4 |
| 4/19/2016 | 23.9 | 42.6 | 0.75 | 43.35 | 24.5 | 6.22 | 0.95 | 7.17 | 85.4 | 83.5 |
| 4/20/2016 | 7.30 | 44.3 | 0.65 | 44.95 | 7.40 | 3.91 | 1.10 | 5.01 | 91.2 | 88.9 |
| 4/21/2016 | 20.8 | 46.7 | 0.60 | 47.30 | 22.2 | 2.82 | 1.75 | 4.57 | 94.0 | 90.3 |
| 5/3/2016 | 20.5 | 45.5 | 0.65 | 46.15 | 19.7 | 11.4 | 0.65 | 12.1 | 74.9 | 73.9 |
| 5/10/2016 | 18.5 | 47.4 | 0.46 | 47.86 | 19.7 | 2.73 | 0.32 | 3.05 | 94.2 | 93.6 |
| 5/12/2016 | 18.4 | 45.5 | 0.42 | 45.92 | 18.7 | 4.67 | 0.36 | 5.03 | 89.7 | 89.0 |
| 5/17/2016 | 23.4 | 47.7 | 0.5 | 48.2 | 21.3 | 3.58 | 0.22 | 3.8 | 92.5 | 92.1 |
| 5/19/2016 | 18.4 | 46.1 | 0.08 | 46.18 | 18.5 | 3.86 | 0.24 | 4.10 | 91.6 | 91.1 |
| 6/2/2016 | 22.4 | 52.1 | 0.11 | 52.21 | 21.8 | 4.47 | 0.24 | 4.71 | 91.4 | 91.0 |
| 7/20/2016 | 22.5 | 45.5 | 0.15 | 45.65 | 23.0 | 6.51 | 0.15 | 6.66 | 85.7 | 85.4 |
| 7/25/2016 | 19.9 | 42.6 | 0.3 | 42.9 | 20.2 | 4.32 | 0.25 | 4.57 | 89.9 | 89.3 |
| 8/1/2016 | 20.7 | 38.1 | 0.95 | 39.05 | 22.2 | 3.45 | 0.25 | 3.70 | 90.9 | 90.5 |
| | | | | | | | | **Average** | **89.9** | **88.7** |

## For More Information

jimmayparkbiofilter.org

Shannon Sweeney, Water Resources Manager
City of Santa Maria Utilities Department
ssweeney@cityofsantamaria.org
(805) 925 – 0951, extension 7270