GROUNDWATER NITRATE MITIGATION SYSTEM USING INTERCEPTOR WELLS, IRRIGATION REUSE, AND DENITRIFICATION BIOREACTOR

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Introduction

Anthropogenic activities, such as crop fertilization, livestock operations, and urban/residential landscape fertilization and onsite waste disposal are causing elevated levels of nitrate in groundwater.   Significant efforts have been made to reduce sources of nitrate through the use of best management practices (BMPs) and advanced waste management technologies for urban sources. However, these approaches are limited in the total nitrate reductions that can be achieved before becoming economically unsustainable for landowners. For agriculture, the nutrient related BMPs, like tissue testing, slow release forms of fertilizer, and fertigation, have been very effective, but are limiting as to how much nitrate leaching can be reduced before adversely impacting crop yields and farm income.   Therefore, more advanced technologies are needed that can prevent nitrate contamination of the groundwater while maintaining viable agricultural production.

The hydrogeological characteristics greatly influence what technologies are adaptable to a farming operation or urban sources because they determine whether excess nutrients not adequately reduced through BMPs can be intercepted and treated before impacting downstream resources. Where aquifers are confined resulting in areas with high water tables, most of the discharge will be in the form of surface runoff making additional treatment possible by using onsite tail-water recovery ponds or offsite regional stormwater treatment areas, typically constructed wetlands. Where aquifers are unconfined, water and nitrates leach vertically into the aquifer making it more difficult to intercept and treat prior to the leaving the site. However, new approaches to capturing high nitrate groundwater from under agricultural fields for irrigation reuse and treatment is showing great promise. Therefore, the objective of this paper is to describe how this new nitrate mitigation system works and performance data for four existing systems for removing nitrate that has already entered the groundwater below an agricultural field, but before it has a chance to move offsite. By capturing and treating the groundwater after it has leached to the surficial aquifer means the crop management on the surface above the aquifer would not have to be altered allowing optimal production practices to be maintained.

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Description of Groundwater Nitrate Mitigation System

The nitrate mitigation system (NMS) combines two technologies to ensure a nearly 100% capture of leached nitrate from agriculture fields. The first is an irrigation reuse system where shallow wells and pumps are placed into the high nitrate groundwater under a field which are then used as the primary water supply for the field's irrigation system. Depending on rainfall and crop rotations being used, this system can capture between 50% to 100% of the leached nitrate and place it back onto the field for crop uptake, which will also offset fertilizer requirements by the amount of nitrate extracted. The second technology is similar to contaminant plume mitigation technologies that have been used for groundwater petroleum and other toxic contaminants cleanup, where the contaminated groundwater plume is captured by groundwater wells that bring the contaminated water to the surface for treatment and the treated (cleaned) water is then returned to the groundwater down gradient of the plume. Denitrification bioreactors is a well-documented and accepted technology for agricultural drainage as evidenced by the Natural Resource Conservation Service publishing a Conservation Practice Standard (Code 605) for their use primarily for subsurface tile drainage systems. The denitrification is a biological process that occurs in an anaerobic (no oxygen) environment where microorganisms with use the nitrate as an electron acceptor to metabolize available carbon, which releases CO_2, NO_x and N_2 gases as byproducts. The N_2 gas is the dominate form of nitrogen being released, which is the form of nitrogen that makes up 78% of our atmosphere, so does not have an adverse environmental impact. The denitrification bioreactor system is designed to treat between 25% to 70% of the leached nitrate, which means when the irrigation reuse and the bioreactor systems are both implemented for a field, anywhere from 90% to 120% of the leached nitrate will be kept from leaving the property. Greater than 100% capture of the field's leached nitrate is possible because if the extraction rates exceed infiltration rates, then the system will be treating offsite groundwater, i.e., neighbor's leached nitrates.

The bioreactor uses the same technology as the denitrification wall that was recently demonstrated as being extremely effective in removing nitrate from groundwater at a container nursery within the Santa Fe River watershed. Figure 1 shows a conceptual view of how a series of interceptor wells can capture 100% of the contaminated groundwater and delivery it to either the irrigation system or a denitrification bioreactor where the combined system will be able to consistently remove between 90% to 120% of the nitrate that would have otherwise moved offsite in the groundwater.

Figure 2 shows the layout of the bioreactor, where the groundwater from the interceptor wells is pumped into a manifold system at one end of a plastic lined long pond to evenly distribute the water to flow horizontally through the woodchips and exits the other end of the pond via a similar manifold into an infiltration ditch to where the nitrate free water is recharged back to the groundwater. The bioreactor is filled with an organic media, typically woodchips, to provide a

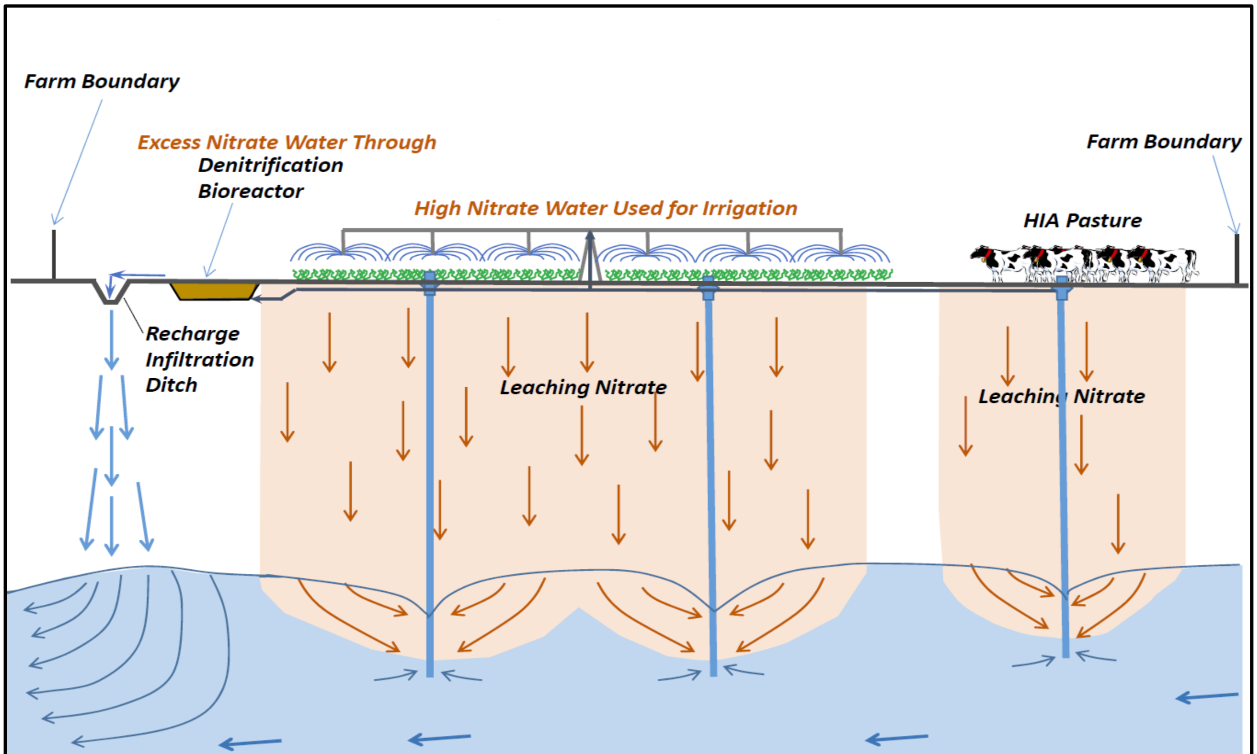

Figure 1. Groundwater Nitrate Mitigation System

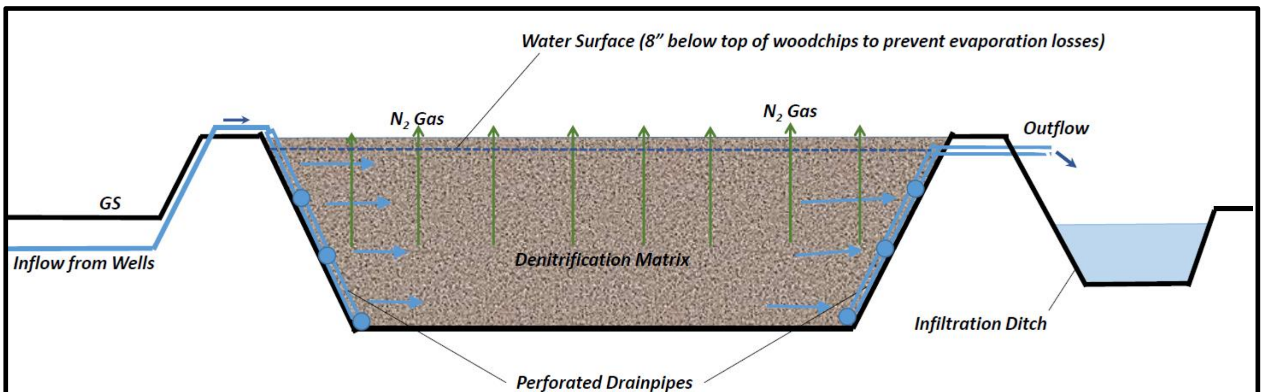

Figure 2. Denitrification Bioreactor

carbon source and media for the denitrification bacteria. The infiltration ditch returns the water to the groundwater downgradient of the nitrate plume. Additional denitrification can occur as the water drains through the soils from the infiltration ditch.

Description and Findings from Five Existing Systems

Five interceptor-well denitrification systems have been installed in Florida. The first one (Figure 3) was installed in November, 2015 at Watson Dairy to address high groundwater nitrate concentrations observed near a 25-acre field that was being used as a dairy heifer pasture, but had previously received large amounts of biosolids in the form of yard waste that is suspected to be the primary source of the nitrate. Due to the change of land management, this system is no longer being managed, but was heavily studied for two years by the University of Florida (UF) Department of Soil and Water Science. It was found the upflow design was problematic due to gas entrapment and short circuiting, which lead to a major redesign that was described above. In spite of the significant short circuiting the system the bioreactor was providing a steady 40% removal of the nitrate (Figure 4).

Figure 3. Watson Interceptor Wells and Bioreactor

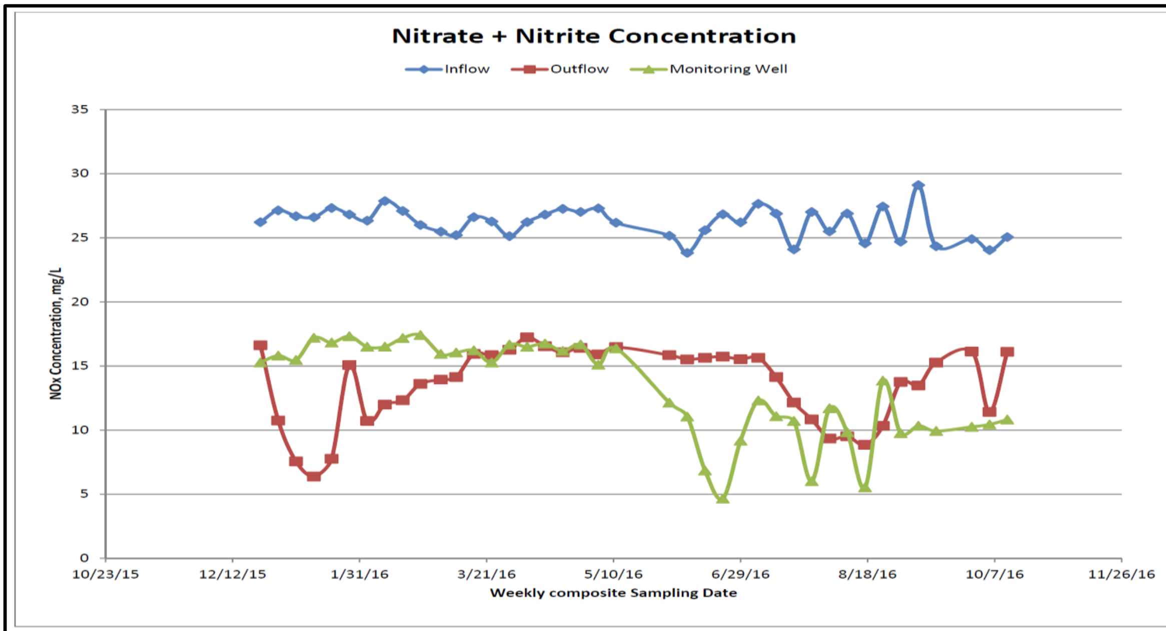

Figure 4. Nitrate Removal Results for Watson Bioreactor

The layout of a second system located at a dairy in Gilchrist County and is shown in Figure 5. This project was installed just after the Watson Dairy system and therefore it also has the less efficient up-flow design. However, it has fifteen interceptor wells under the 280-acre center pivot to capture the nitrate ladened water reaching groundwater and reuse it for irrigation. The 4-inch diameter interceptor wells are installed to a depth of about 60 feet, which are approximately thirty-five feet below the average water table. Each well has an electric submersible pump with a capacity of about 30 gpm, which allows when running all interceptor wells a significant water supply for irrigation of about 450 gpm. Because the interceptor wells provide less flow than the 1200 gpm required by the pivot, a variable rate controller was installed on the existing irrigation well pump to properly balance the flowrate to the pivot.

Unlike the Watson system, about 80% of the captured groundwater under the pivot will be reused for irrigation where the crops get a second chance to utilize the nitrogen that had been lost to the groundwater. To ensure 100% capture of the nitrate in the groundwater, approximately 30 gpm is continuously pumped into the bottom of a woodchip bioreactor that has a similar design

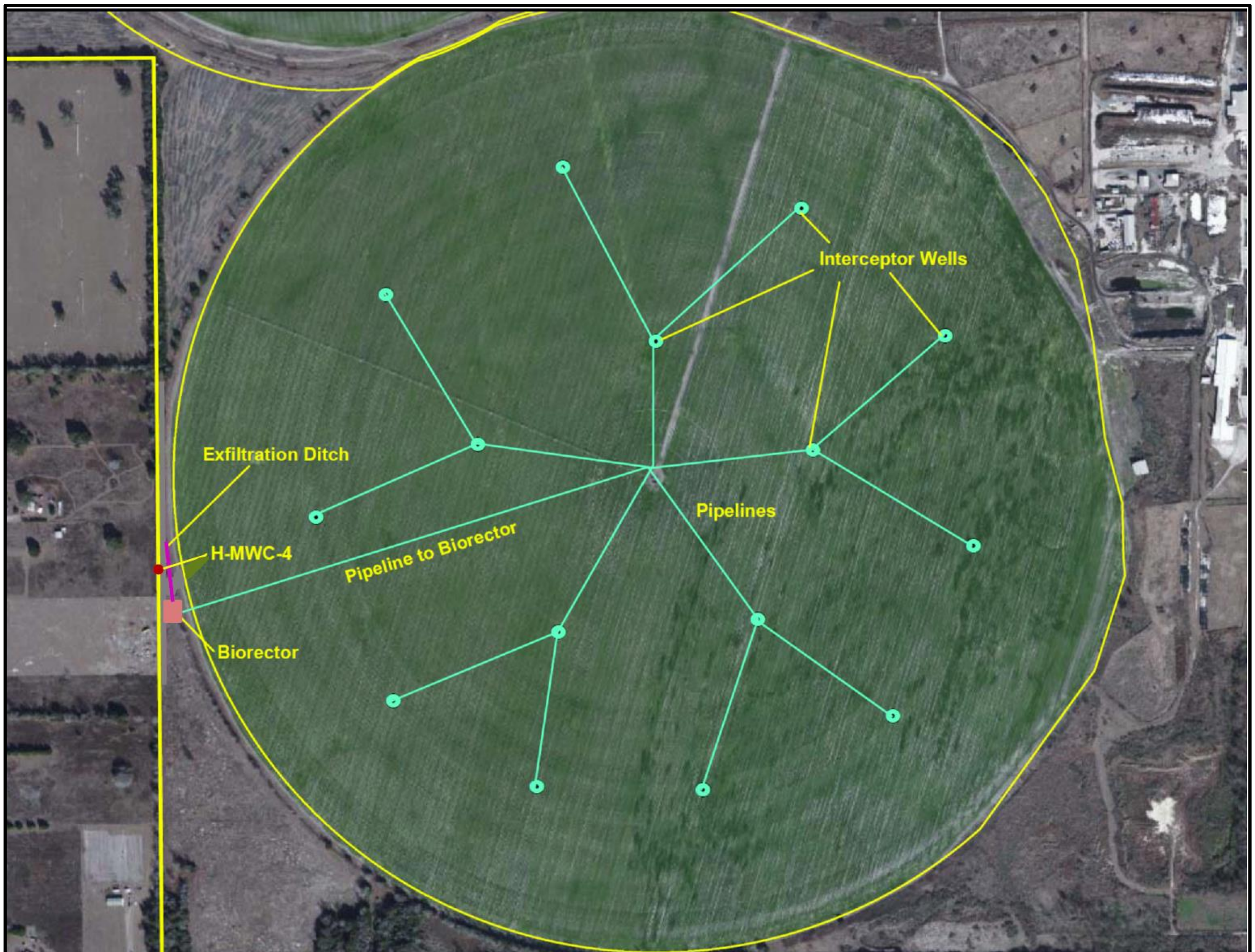

Figure 5. Interceptor Wells and Bioreactor at Alliance Dairies 280-acre Pivot 18.

to the above Watson described bioreactor. The discharge from the top of the bioreactor again discharges via an overflow pipe into the infiltration ditch that recharges the water back to the groundwater.

In 2018 to two more NMS projects were completed in Lafayette and Suwannee Counties. These systems have unique irrigation reuse designs and were constructed with the new horizontal flow bioreactor design. The Lafayette County system (Figure 6) has a large irrigation pond to allow storage of extracted groundwater during non-irrigation periods from the low flow wells in order to maximize their withdrawal capacity. The stored water is then used to irrigate row crop fields and to offset commercial fertilizer use. The Suwannee County system (Figure 7) runs all six of extraction wells continuously with five of them supplying the dairy with freshwater while one supplies the bioreactor. The extracted well water is safe for all dairy water needs as long as it remains below 30 mg-N/l nitrate, which is the safe drinking water limit for dairy cows, and therefore should only be used for flushwater if nitrate level exceed this limit. Ultimately the extracted groundwater going to the dairy ends up in the wastewater storage pond where 100% of its nitrate is denitrified to N_2 gas before the water is pumped to one of nineteen center pivot irrigation systems that have vegetables and other row crops.

In 2019 a fifth NMS was installed on another Gilchrist dairy. The system has fifteen groundwater 40 gpm extraction wells that are connected to two pivots for irrigation reuse, see Figure 8. Again, a variable speed pump controller is used to optimize water mixing to the two pivots. The woodchip bioreactor receives 40 gpm of flow continuous.

Monitoring

All of the above systems have monitoring data for estimating nitrate removal. This section details the monitoring protocol to be followed to properly manage and verify the systems' effectiveness for groundwater nitrate mitigation. The total amount of water pumped from the interceptor wells is needed to verify the capture rate of the nitrate plume. Each well's discharge line should have a sampling port/valve so that water samples can be periodically collected and tested for nitrate levels, which allows the nitrate distribution in the groundwater under the field to be evaluated and groundwater nitrate capture optimized. The net flow rate to the irrigation system and into bioreactor can be measured using flowmeters. Water samples should be collected quarterly at the bioreactor inflow and outflow points until the treatment efficiencies can be verified at which time the sampling interval can be extended to semi-annually or even annually. The inflow volume and nitrate concentrations measured at the bioreactor inflow and outflow points will allow a precise measurement of the amount of nitrate being removed by the bioreactor, which then needs to be added to the amount of nitrate (irrigation volume times the bioreactor inflow nitrate concentration) being captured and irrigated back onto the crops and any additional denitrification losses in the infiltration ditch in order to provide the total nitrate removal performance of the system. The additional denitrification in the infiltration ditch can be determined by installing a monitoring well in the surficial aquifer below the ditch. The nitrate

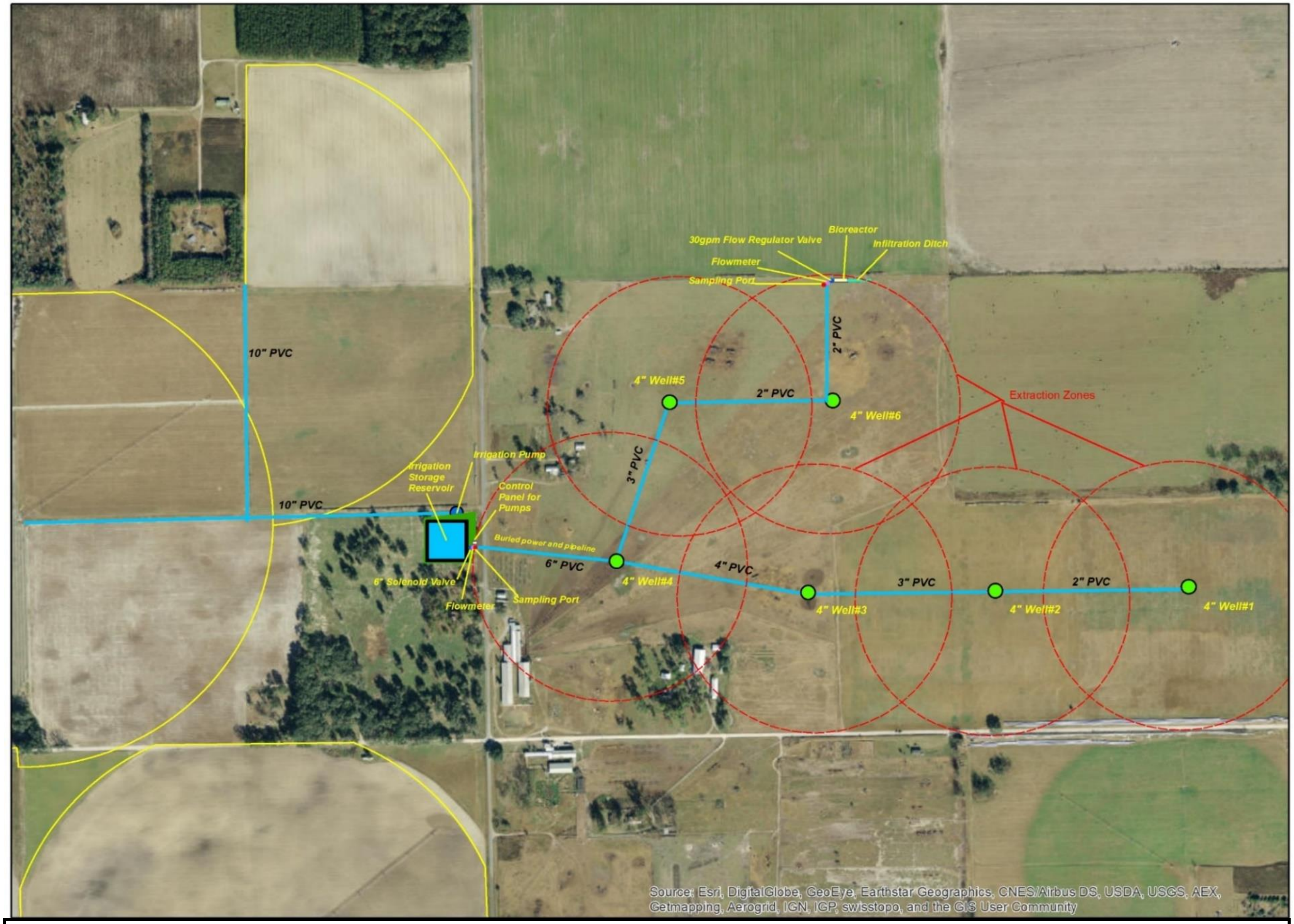

Figure 6. Interceptor Wells and Bioreactor at Lafayette County Dairy.

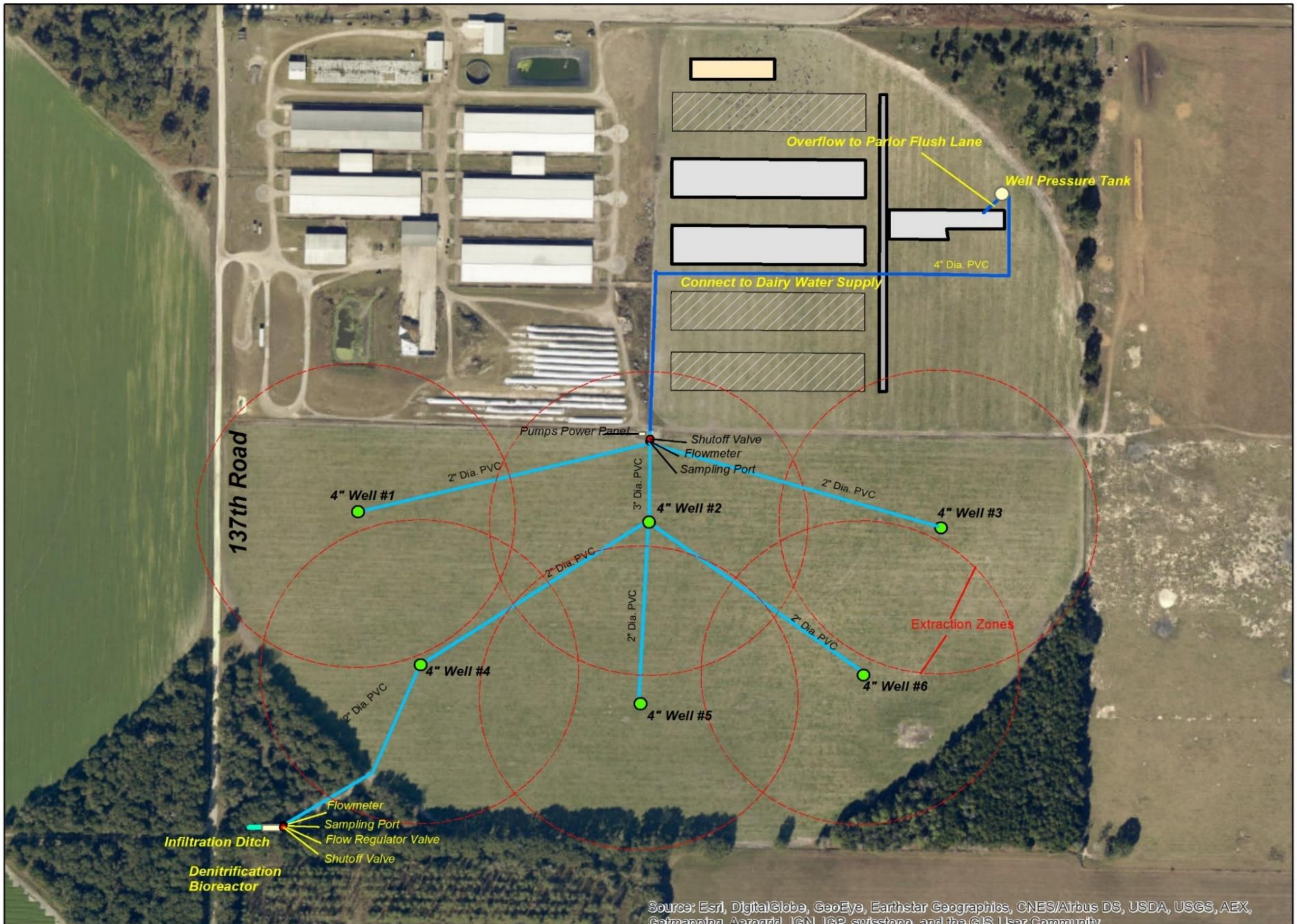

Figure 7. Interceptor Wells and Bioreactor at Suwannee County Dairy.

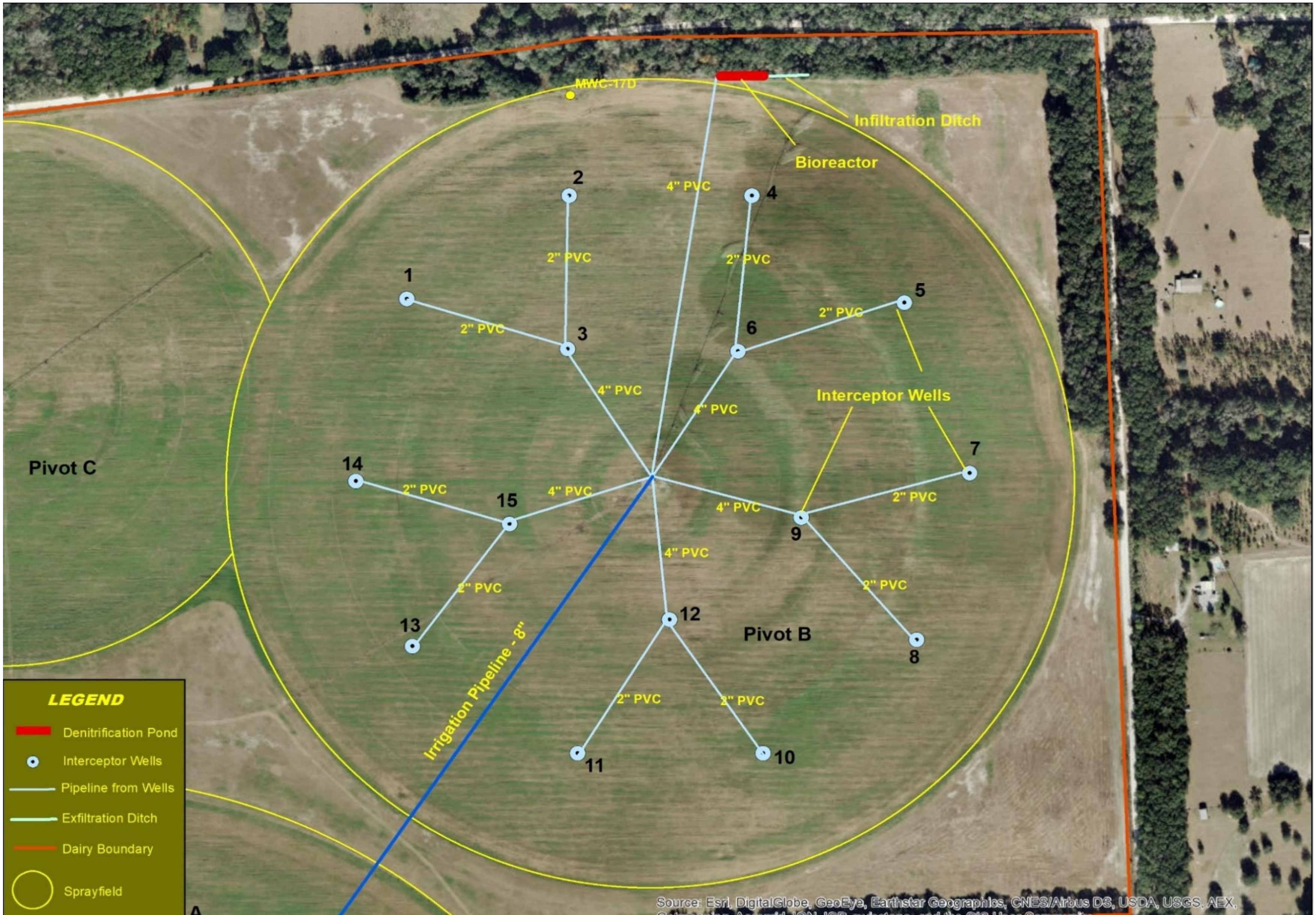

Figure 8. Interceptor Wells and Bioreactor at Gilchrist County Dairy.

concentration difference between the well and the bioreactor outflow times the outflow rate will provide a direct measure of this nitrate loss.

Findings and Lessons Learned from existing NMS.

Experience and monitoring data from the five NMSs described above have shown the great potential that these systems have for mitigating nitrate from groundwater, but also they have also shown that there are still significant challenges for optimizing peak and sustained performance, particularly the bioreactor media. In general, the irrigation reuse components of these NMSs have performed as designed with thousands of pounds of nitrate having been documented as being extracted from the groundwater for irrigation and crop uptake, which is between 60% to 80% of the nitrate that had been leached to groundwater. However, the denitrification bioreactors have been more problematic in that the existing mill-grade woodchips, which are currently being used because they are readily available, have not performed well over time, i.e., nitrate denitrification rates have slowly dropped from an initial 95% to 100% to 30% to 40%. Therefore, additional research is currently being proposed with the University of Florida to further evaluate various design criteria for optimal performance including flowrates, organic media sources and particle sizes, and physical configurations.

Summary of lessons learned to date:

- Irrigation reuse directly from the extraction wells should be integrated into all systems as much as possible because its effectiveness has been well documented.
- The interceptor wells should be used as the dairy's freshwater supply, particularly for flush water because this water will ultimately end up in the dairy's wastewater pond where 100% of the nitrate will be denitrified. Note, if nitrate concentrations exceed 30 mg-N/l then caution is recommended for using extracted water for watering the animals.
- The number and location of the interceptor wells to extract the underlying nitrate plume will depend on the site-specific conditions, but typically between 5 to 15 are recommended and optimally placed within or just at the edge of the field being irrigated. Wells placed within the field are optimal, but create logistical problems for the farmer's field equipment. Therefore, it is currently recommended that either the well heads be buried, which introduces additional maintenance issues, or mostly placed at the center of the pivot with only a few being placed on the down gradient side of the field.
- All interceptor wells shall use a screen casing once the top of the surficial aquifer is encountered.
- For at least the first well installation at a site, well production tests must be run as the interceptor well is being drilled to ensure they are drilled no deeper than necessary to supply the recommended amount of flow.

- When possible, interceptor wells should collectively have the capacity to operate the entire irrigation system, but when this is not possible, then a variable speed controller will be needed to blend existing wells water supply with the interceptor wells water supply.
- Backflow preventers are needed on all wells.
- Horizonal flow with a 4:1 length to width ratio is recommended over the older vertical flow bioreactor design.
- No fiber cloth, sand, or gravel layers should be used in the bioreactor.
- The organic media (compost, wood chips, chopped hay, etc.) needs to be very uniform with significant hydraulic conductivity to allow flow through the media and gases to escape. Use more biodegradable wood or organic tissue sources.
- Use of sugars or other soluble organic carbon sources may to useful for increasing denitrification rates of existing bioreactors.
- Open infiltration ditches or basins are recommended over buried exfiltration tile lines.
- It recommended to till in about 3” of sawdust into the infiltration ditch or basin to provide for some additional denitrification polishing of the effluent from the bioreactor.
- The denitrification gases that build up in the bioreactor matrix have been found to limit flow and/or can cause preferential flow paths through the matrix reducing surface contact between water and wood chips thus reducing denitrification rates. Therefore, significant pore spaces associated with higher conductivity media is recommended to allow gases to escape.
- There should be no exposed open water in the bioreactor to limit evaporative losses, which is accomplished by filling the bioreactor to the top of its containment berm.
- Floating Styrofoam balls or chips can be used to minimize evaporative losses from the infiltration ditch or basin.

Summary and Costs

NMSs are adaptable to any land use activity that will result in nitrate leaching to groundwater, which includes virtually all lands on well drained soils where fertilizer, biosolids, and human or animal wastes are applied. However, this technology will be most cost effective where irrigation reuse is available, but is not a requirement. Example land uses that could benefit from this technology includes row crops, residential septic tanks, managed landscapes like golf courses, livestock facilities, and municipal waste treatment sprayfields. This NMS technology with or without irrigation reuse provides the most feasible option for farmers and homeowners to maintain their existing land practices while meeting regional nitrate reduction targets for groundwater that are currently not achievable under best management practices (BMP) programs alone.

The initial capital cost for the described system for an irrigated agricultural field will be about $1000/acre, which can be broken down between the interceptor wells and irrigation reuse portion of the system at about $700/acre and the bioreactor at about $300/acre. However, when costs are calculated in terms of the dollars spent per pound of nitrogen removed over the life-time of the project, the cost efficiency of the NMS in terms of dollars spent per pound of nitrate as nitrogen will be about $1.00/lb-N if the extracted nitrate concentration is about 30 mg-N/l. Note the cost effectiveness improves proportional as nitrate concentrations increase. Therefore, it is strongly recommended that the highest nitrate sources be a priority focus of any NMS program.