Innovative subsurface drip irrigation (SDI) alternatives for on-site wastewater disposal in the Alabama Black Belt

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Abstract: More than 75% of the Blackland Prairie area of Alabama is unsuitable for conventional septic systems due to high clay content. An innovated integrated soil moisture controlled subsurface drip irrigation (SDI) is proposed as an alternative to conventional septic systems. This study evaluates the ability of an integrated treatment/disposal system to increase the hydraulic disposal rate of primary septic tank effluent on a Blackland Prairie soil to maintain favorable aeration for nutrient removal. Other objectives of the study include GIS evaluation of existing soils in the region and modification of an existing SDI system to dose wastewater based on volumetric soil moisture. A lab scale SDI prototype has been assembled for field evaluation in summer 2006. Results can be used to provide design information for alternative wastewater treatment and disposal in heavy clay soils in Alabama and elsewhere.

Introduction

Decentralized wastewater treatment methods are used where connecting isolated households to the existing sewer system is not practical and/or economical (Viraraghavan, 1986), or when expansion of the current municipal WWTP serving area is too costly. In the US, about thirty percent of households are using onsite sewage disposal, while in Alabama this number is 47 percent (Alabama Onsite Wastewater Association, 2005).

Conventional septic systems collect raw sewage from individual homes. The sewage goes through primary settling and biological reaction during its retention in a septic tank. Upon reaching a preset overflow level, the supernatant from the septic tank is disposed by gravity to a drain field where percolation through an unsaturated soil zone provides advanced aerobic treatment of the effluent. The environmental challenge for conventional onsite treatment is the system's almost complete reliance on soil properties (Oron, 1996). Overload to the drain field is a common cause of onsite system failure (U.S.EPA., 2002). Conventional onsite septic systems are a significant contributor of non-point source pollution. (Carroll and Goonetilleke, 2005; Charles et al., 2005; Lipp et al., 2001; Shaviv and Sinai, 2004; U.S.EPA., 2002). Therefore, a carefully scheduled dosing strategy becomes important in controlling the hydraulic and nutrient impact to the environment (Cote, 2003).

Pradhan (2004) reported the average nitrogen concentration of septic tank effluent to be 40-80mg/L, among which 75 percent is ammonium nitrogen and 25 percent is organic nitrogen. Average phosphorous concentration was reported to be 3 to 20 mg/L, with about 85 percent as orthophosphate. An extensive septic effluent field survey in Australia (Charles et al., 2005) compared published regulations in Australia and the United States, and recommended that the 80^{th} percentile (250 mg TN/L and 36 mg TP/L) of effluent survey values should be adopted as design guideline by new regulations to minimize drain field overloading. Lipp (2001) demonstrated the pathogen impact from onsite sewage systems to the coastal community. Carroll (2005) confirmed that a high system density (290 units/sq.km) can significantly impact shallow groundwater systems. Incidences of poor management of onsite systems, particular conventional septic systems, are quite common (Carroll and Goonetilleke, 2005). In Alabama the average onsite system failure rate is 20 percent (U.S.EPA., 2002).

Background Analysis

A series of Geographic Information System (GIS) analyses were conducted to evaluate the environmental risks associated with conventional onsite septic systems in the Alabama Black Belt area (Figure 1). Results indicate that approximately 77 percent of the study area is rated as unsuitable for conventional onsite septic systems due to high clay content soils. According to the 2000 US census, about 12 percent of the rural census block groups have an average system density larger than 15 units/sq.km, with a maximum of 212 units/sq.km (Figure 2). Approximately 99 percent of the rural census block groups have an average system size smaller than 3 persons/unit (Figure 2). As to 2000, more than 97 percent of the rural census block groups had a weighed average system age of more than 20 years (Figure 3). GIS ranking analysis (Figure 4) revealed several census block groups close to cities with a comparatively high environmental risk. The GIS analysis revealed that not only are the majority of soils in the Black Belt area unsuitable for conventional onsite systems, but that high system density in certain areas is also responsible for high environmental risk. Therefore, for areas with high system density, small community based onsite systems are a potential alternative technology. For areas with low system density but poor soil properties, improving the management (dosing strategy) and/or upgrading existing systems is more practical.

Integrating drain field conditions with a more uniform temporal water distribution increases the drain field utilization rate while reducing the environmental risk of overload. The system proposed in this study adopts real-time drain field soil moisture content into the dosing strategy, along with an integrated seasonal cropping system for optimum moisture and nutrient uptake. Subsurface drip irrigation (SDI) is used to distribute the wastewater more evenly in the drain field. By integrating the two components together, the innovative system overcomes the shortcomings of conventional onsite systems and is better suited to high clay soil areas. Plant uptake in the drain field is optimized to increase the water and nutrient uptake during different seasons, utilizing wastewater as a natural fertilizer for plants in the drain field.

Objectives

The purpose of this research is to optimize the onsite wastewater dosing rate in a selected high clay soil in Alabama Black Belt area through an innovative onsite system which integrates agronomic water and nutrient uptake with soil-moisture based dosing of pre-filtered septic effluent. The goal of this research is not necessarily to maximize waste disposal, rather to develop an innovative treatment and beneficial reuse of effluent using environmentally friendly plant uptake systems at sustainable loading rates in marginal clay soils. Results can be used to provide design information for alternative onsite wastewater treatment and disposal systems in heavy clay soils in Alabama and similar areas. Although the cost of these integrated seasonal cropped systems may be prohibitive for single home owners, this research may provide a viable option for decentralized sewage system managers, or existing community systems looking for increased treatment and disposal capacity.

Methods

Soil Moisture Control Interface

A data logger controller (DeltaT, UK) and a sanitary drip irrigation control unit (Geoflow, CA) were modified and integrated to add soil moisture based dosing control to an existing drip irrigation control unit. The data logger/controller receives input from two soil moisture sensors and uses the feedbacks to control an external circuit (Figure 5). The external circuit controls an intermediate relay which is wired in series to the tank low water float switch. When the soil moisture feedback is below a preset threshold, the external circuit will close the intermediate relay and the existing irrigation control system will response as long as there is sufficient water in the 350-gallon test tank. If there is enough water in the tank, the SDI dosing pump will operate at a preset sequence. If there is not enough water in the tank, the dosing pump will not be activated. When soil moisture feedback is above a preset threshold, the external circuit will break the intermediate relay and the in-series the low water level float circuit, cutting irrigation just as if there was not enough water in the tank. At this circuit interruption, the dosing pump is set to off. As described, the soil moisture sensor works in tandem with the low water float switch to control irrigation dosing to turn off the dosing pump temporally when the drain field is near a preset moisture level or there is not enough water in the tank. The preset moisture level in this study, which uses a synthetic secondary-treated wastewater effluent, is set to approximate field capacity.

Field Experiment

The SDI application in this study is conceived to be for a small community-based system. The design flow rate is set to 1022 liters/day/household (270 gpd/household). A test site at the Black Belt Research and Extension Station in Marion Junction, Alabama was selected for the field experiment. Soil sampling was conducted at the field site in December, 2005 at the site. The soil in the proposed drain field is Houston clay. Textural soil properties are listed in Table 1, below.

Table 1. Soil properties of Houston soil, Black Belt Research and Extension Station, Marion Junction, Alabama

Horizon	Lower Depth	Particle Size Distribution		
		Sand	Silt	Clay
	cm	%		
Ap1	23	7.09	39.63	53.28
Ap2	42	8.26	38.04	53.70
BA	63	10.17	33.38	56.45
Bkss1	88	3.50	35.93	60.57
Bkss2	152	3.10	25.80	71.10

* Source: Auburn University Pedology Laboratory

The designed hydraulic loading rate applied to the drain field was set to 2.04 liter/m^2/day (0.05 gal/sq.ft/day). A 3.78 m^3 (1000 gallon) tank was used in the field as the water reservoir. A 0.37 KW (1/2 horse power) submersible pump working at 1.26 liters/sec (20 gpm) supplies water from the tank to a $18.3m \times 27.4m$ ($60' \times 90'$) SDI drain field (Figure 6). Ryegrass (cool season) and Sorghum (warm season) are planted over the drain field to increase water and nutrient uptake. The drain field is divided into two subplots, a clean water subplot and a nutrient subplot. Each subplot has 15 drip laterals at 2 feet spacing. The clean water subplot in this study accepts clean water and regular surface-applied fertilizer, and the nutrient subplot accepts synthetic wastewater (250 mg TN/L and 36 mg TP/L) only. An open field beside the drain field study area is also planted with ryegrass and sorghum as a control plot, but no irrigation is carried out except for regular fertilizer. Two soil moisture sensors are buried in the middle of the drain field to monitor the real-time drain field soil moisture content. The data logger/controller, located beside the drain field, is pre-programmed to control the pump run time sequence based on soil moisture sensor feedback. With the exception of the nutrient injection pump, the entire system has been installed at the experimental site (Figure 7). Since the experimental system is currently operating with clean water, initial comparisons will be made between the clean water subplots and the open field control.

The field data, including plant water uptake, soil moisture content, rainfall, soil temperature, pumping rate and volume, dosing frequency and dosing time, will be continuously logged at 15-minute intervals. Crops will be harvested during the end of each growth season to quantify the nutrient uptake from the drain field.

HYDRUS-2D, developed by U.S. Salinity Laboratory, U.S. Department of Agriculture, will be used to simulate the seasonal water and nutrient profile in the drain field using collected field data as input.

Expected Results

The recorded dosing time and flow rate of the SDI system will be used to quantify the seasonal average dosing rate and the total mass of nutrients entering the drain field. The nutrient mass in the harvested plant will be used to quantify nutrient uptake. The difference between nutrient input and uptake approximates the amount of nutrients remaining in the drain field, lost due to runoff, leaching, de-nitrification or other transformations. Environmental risk to the nearby water bodies from surface runoff and leaching should be minimized by soil-moisture based dosing. The mechanism by which this functions is to reduce the potential of wastewater overdosing during saturated field conditions. HYDRUS-2D will be used to simulate seasonal water and nutrient profile in the drain field, including plant uptake. Results from HYDRUS-2D will be used to assess the environmental impact from nutrient and water, optimize the field seasonal dosing rate for different seasonal conditions, and provide optimized hydraulic dosing rates and dosing strategies. The differences between the three treatments (nutrient subplot, clean water subplot, and open field) will be statistically evaluated in terms of plant growth through ANOVA.

Conclusion

The pilot system evaluated in this study overcomes the shortcomings of conventional onsite systems and focuses on sustainable hydraulic loading rates on the high clay soils. The system integrates real-time drain field soil moisture content into a dosing control strategy and utilizes select crop species capable of maintaining consistently high seasonal water and nutrient uptake. Since the system is based on real-time field conditions, the reliability of the control strategy must be evaluated through multi-year field tests. The proposed system can be used as the basis for 1) an alternative to conventional decentralized secondary treatment systems; 2) a supplement to existing decentralized secondary treatment systems; or 3) a supplement to an existing municipal WWTP.

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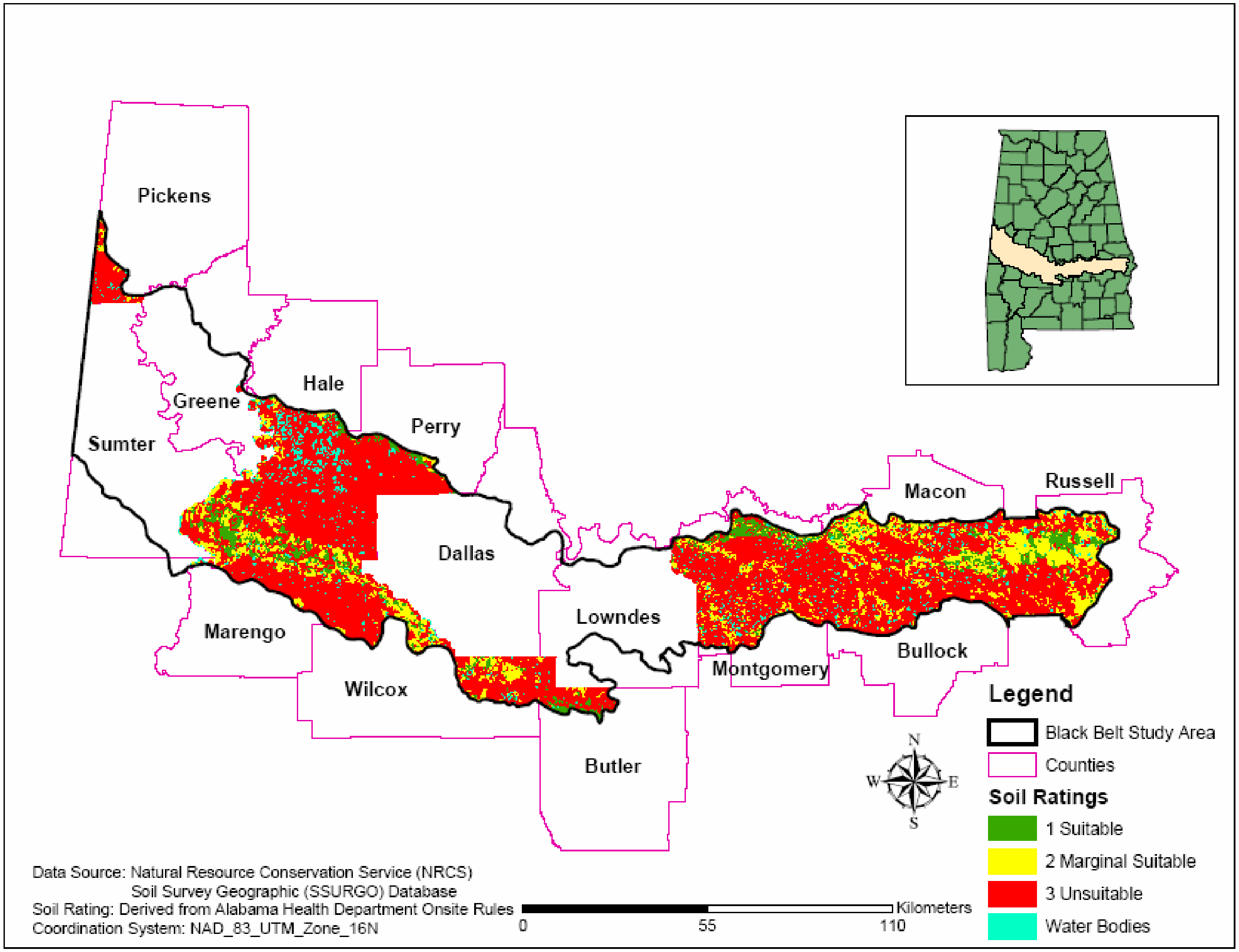

Figure 1: The study area and the soil ratings

Note: Soil survey data not currently available for Sumter, Greene, and Lowndes Counties.

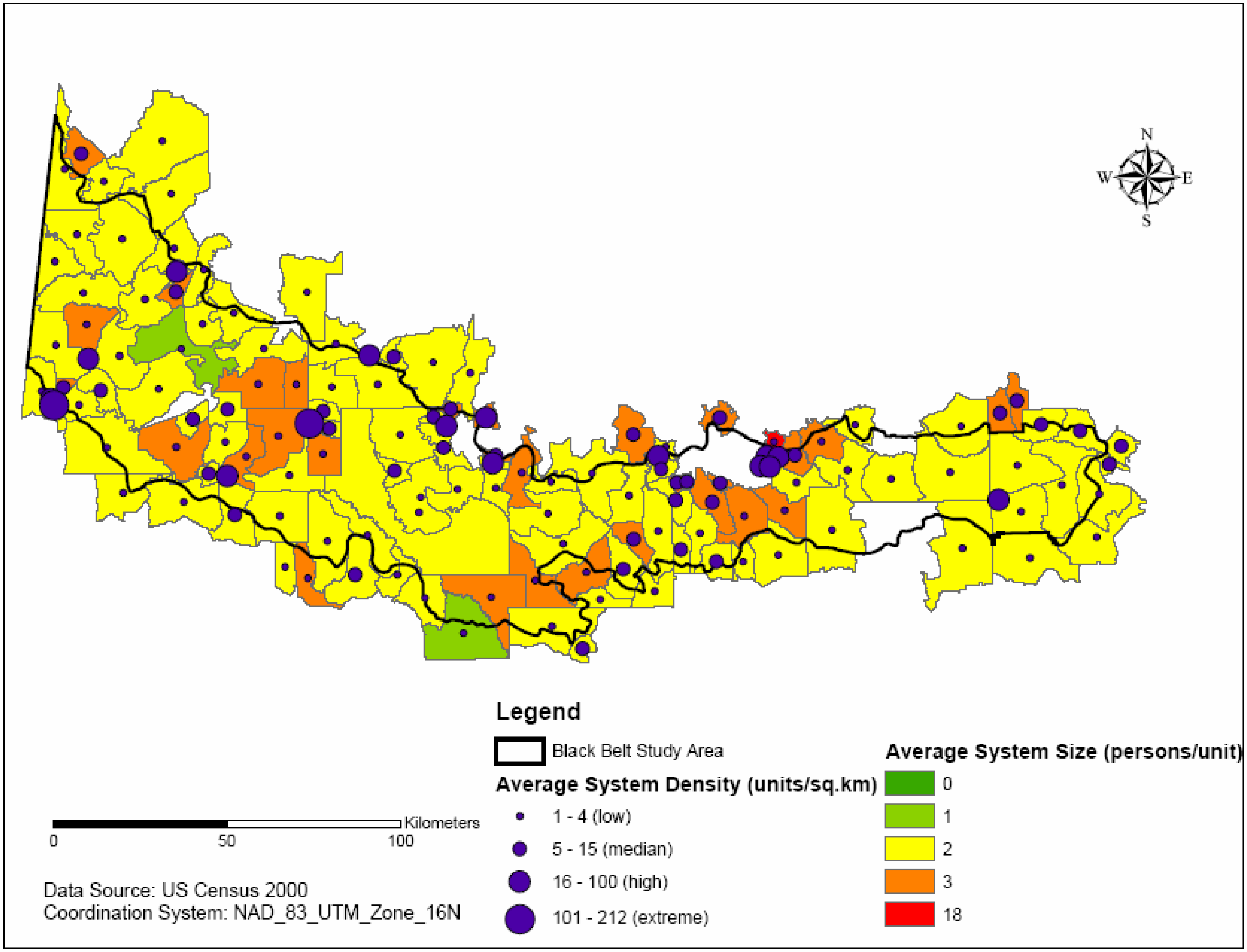

Figure 2: Onsite system density and size in rural areas of the Alabama Black Belt by census block group

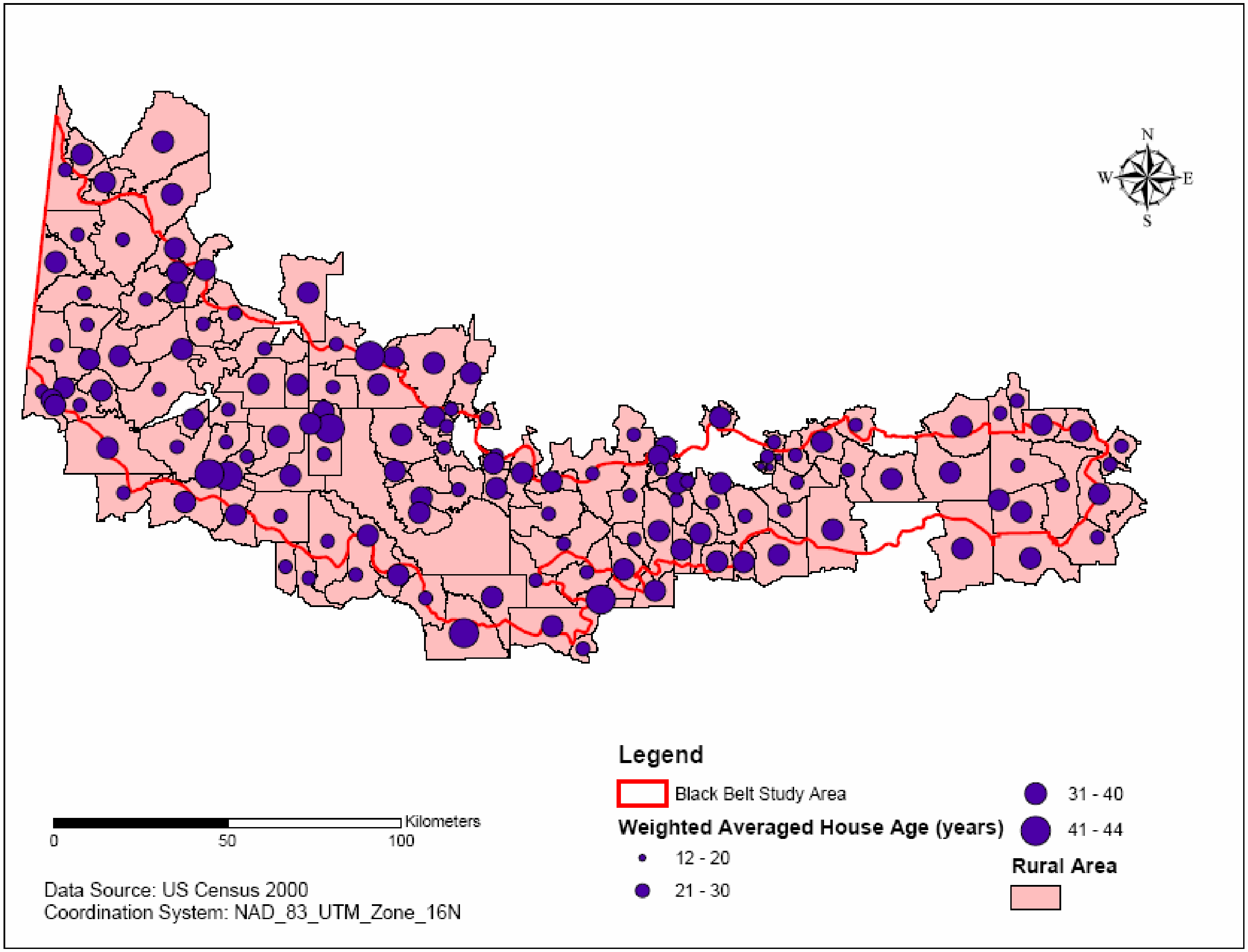

Figure 3: Weighted average house age in rural areas of the Alabama Black Belt by census block group

Note: Soil survey data not currently available for Sumter, Greene, and Lowndes Counties.

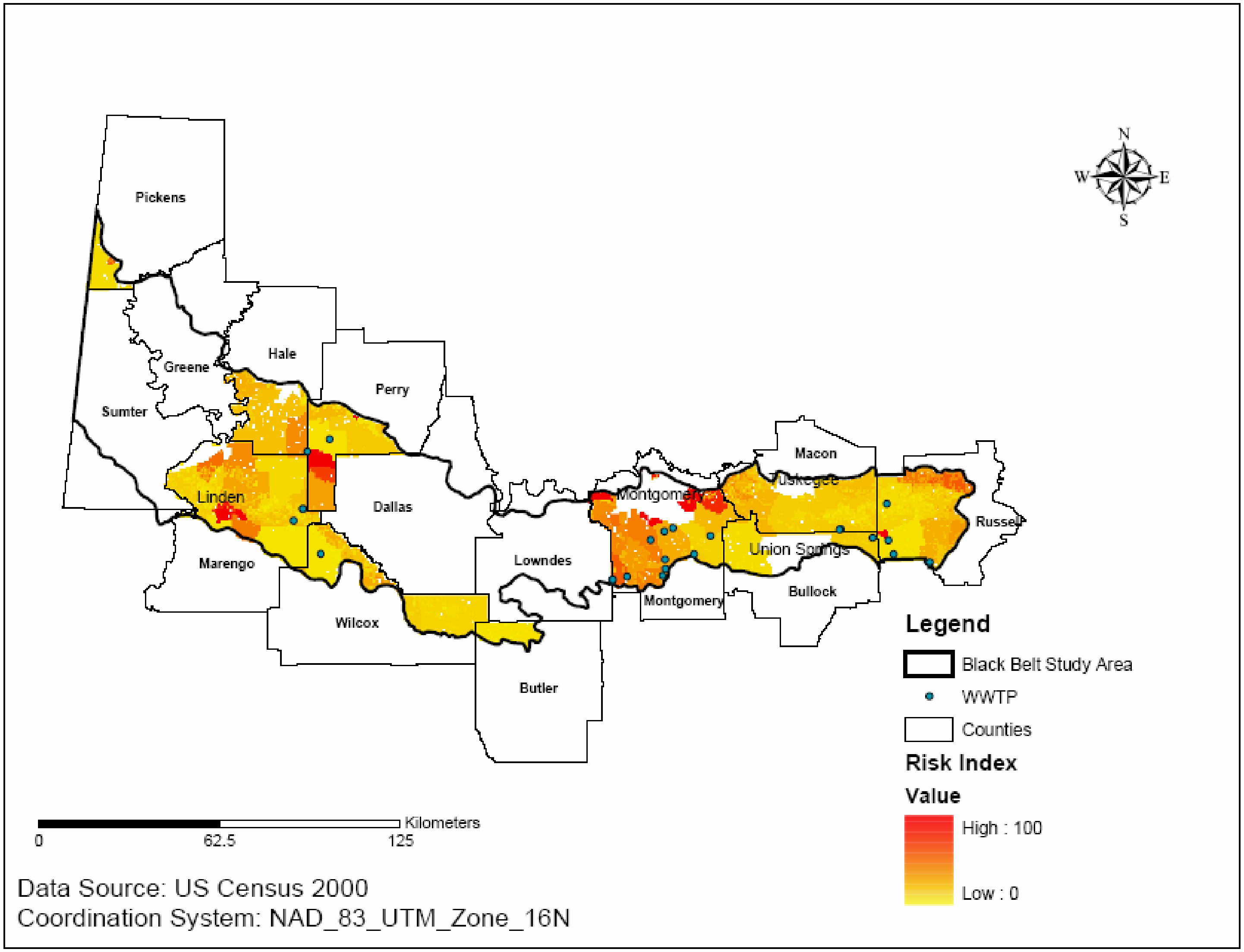

Figure 4: Environmental risk from conventional septic systems in the rural Black Belt area

Note: Soil survey data not currently available for Sumter, Greene, and Lowndes Counties.

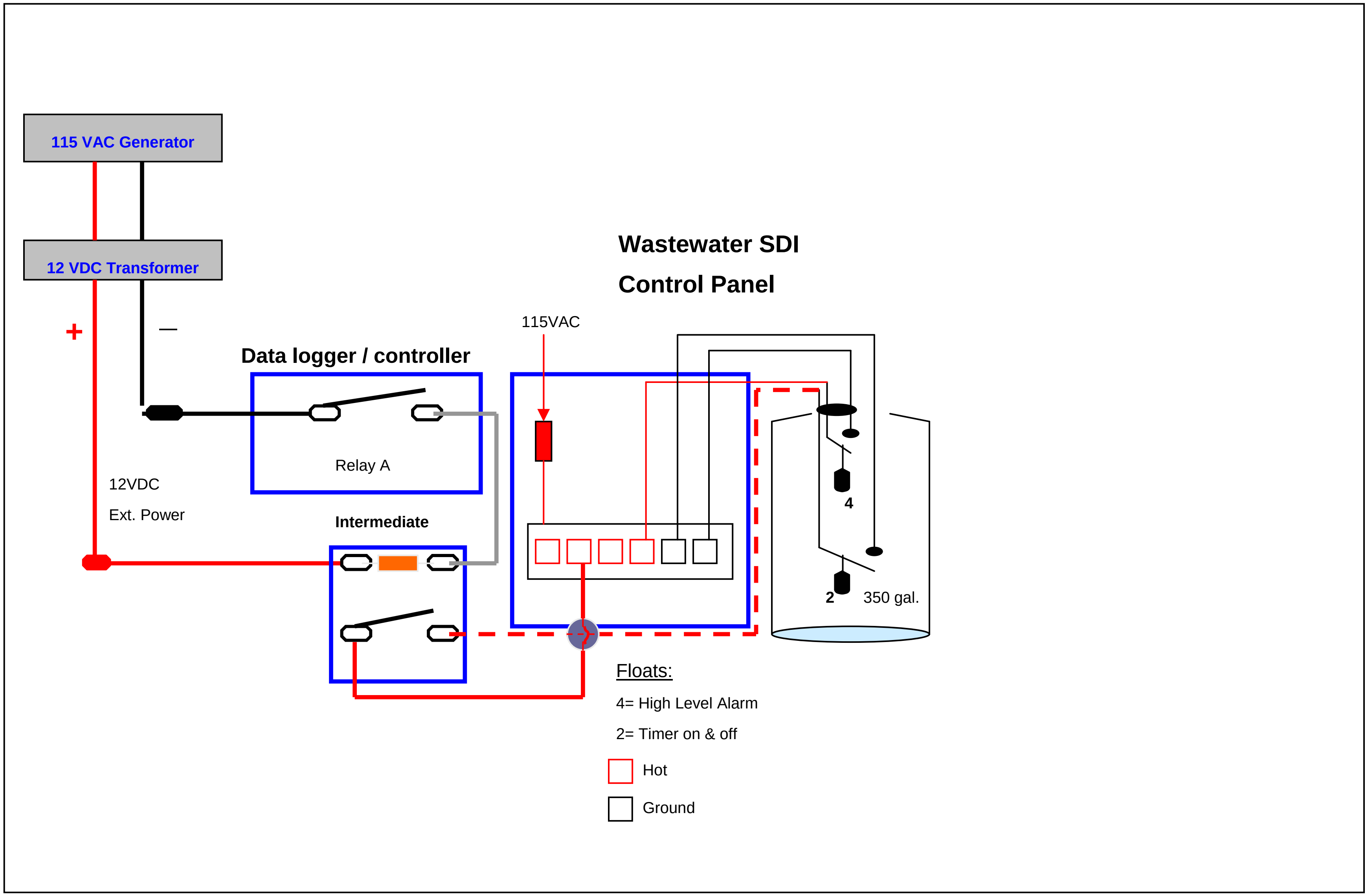

Figure 5. Electric connection diagram illustrating interface of soil moisture sensors and control to existing float / irrigation dosing system. (Adapted from Dynamax, Inc. and Geoflow, Inc.)

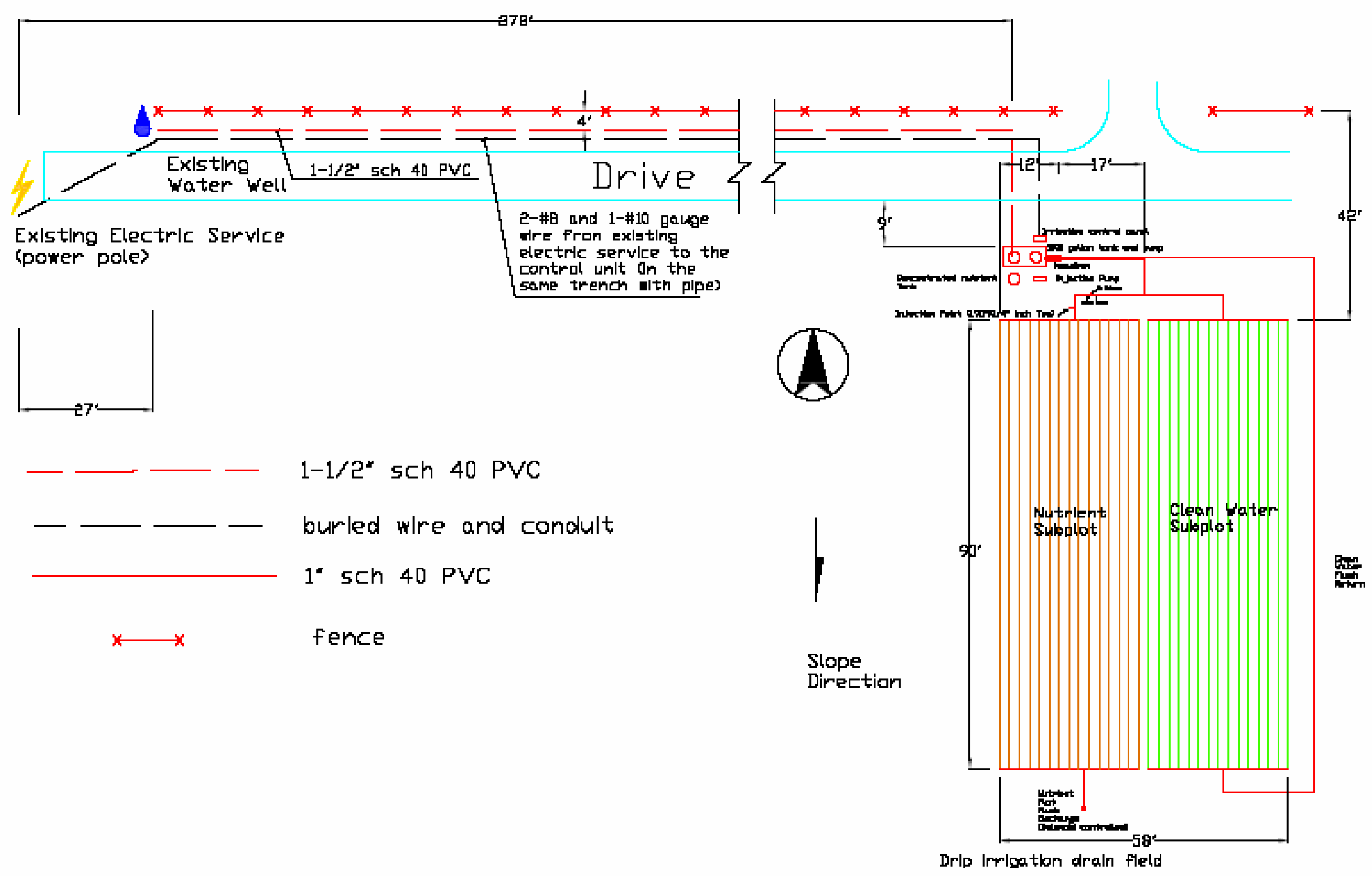

Figure 6. Field sketch of the proposed field experiment at Black Belt Research and Extension Station, Marion Junction, Dallas County, Alabama.

Figure 7. Finished field experimental system (Datalogger and Control box) at Black Belt Research and Extension Station, Marion Junction, Dallas County, Alabama.