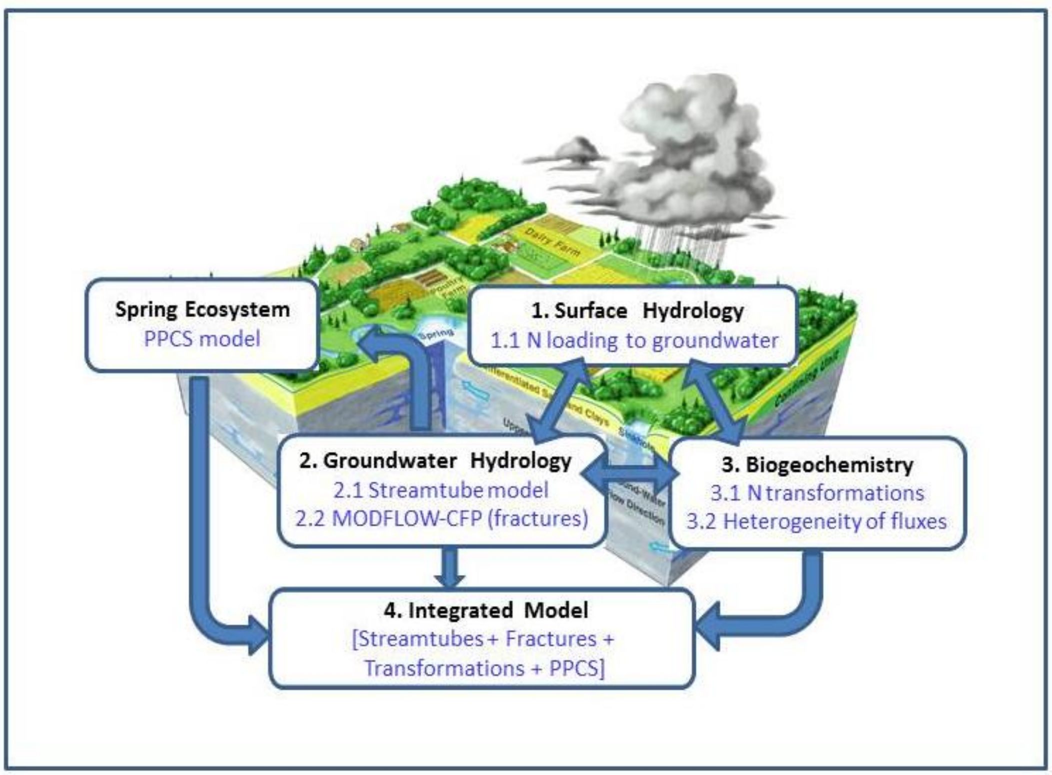
STATEMENT OF WORK
For Springs Protection Initiative:
Springs Protection Initiative Science (SPIS)
GROUNDWATER HYDROLOGY WORK GROUP

I. INTRODUCTION/BACKGROUND

The Floridan aquifer is one of the State of Florida's most significant natural resources. The aquifer is the primary drinking water source for the state and discharges vast quantities from the springs that flow from the aquifer. The water quality and quantity emerging from spring vents critically influence the health of spring ecosystems. Effective management of springs therefore requires an understanding of the factors that control the spatial and temporal variation in the magnitude of water and solute delivery from the aquifer to springs. The Spring Protection Initiative presents a unique opportunity to investigate aquifer characteristics near Silver Springs. The Groundwater Hydrology Work Group in conjunction with the Springshed Super Group has developed an integrated approach to studying the mechanisms that drive flow and solutes through the Floridan aquifer system.

The Springshed Super Group tasks are designed as an integral framework to provide complementary information related to Nitrogen (N) loading in springs. The surface hydrology, groundwater hydrology, and biogeochemistry components all provide interlocking data about how N loaded at the land surface is transformed and transported through the soil and the aquifer



(see **figure** below). The assembled data will provide an integral picture of the spatial heterogeneity of land uses, soil types, lithology, fracture and conduit networks, water flow paths, and solute travel times to the spring outlet.

Overview of the UF Integrated Springshed Project Outline

Project	Total
1. Surface hydrology [Kramer]	$147,114
2. Groundwater hydrology	
2.1 Desktop Risk Model of travel times and N attenuation (ongoing) [Annable]	**$200,000**
2.2 Conduit and fracture flow modeling [Graham]	**$157,867**
3. N biogeochemistry	
3.1 N transformations in the Floridan aquifer [Inglett]	$286,066
3.2 Nitrate fluxes and attenuation: direct measurements [Jawitz]	**$195,000**
TOTAL	$986,047

Task 2.1 (streamtube modeling) was initiated in 2013. The management-level modeling tool from this task will be the core of the springshed portion of the integrated [springshed+ecosystem] intervention model. The coupled model will include feedbacks between both systems. The data collected in the tasks outlined below will inform future model development.

II. OBJECTIVES

The Groundwater Hydrology Work Group under the Springshed Super Group are conducting an array of investigations to explore issues with numerical modeling of karst systems and understanding water quality transport in these systems. The work focuses on three main components:

a) Conduct numerical modeling exercises to test the significance of conduit flow in the Floridan aquifer near Silver Springs
b) Collect data to determine groundwater flow characteristics and natural attenuation rates of N loads in the Upper Floridan Aquifer (UFA).
c) Develop a Desktop Risk Model to assess travel time and attenuation of nutrients flowing within the UFA and discharging at Silver Springs.

III. SCOPE OF WORK

The scopes of these projects are discussed in the sequence presented in Section II, Objectives, above.

A. Project 1/UF Project 2.2 – Conduit and fracture flow modeling.

The purpose of this project is to incorporate representative realizations of conduits and fractures into the local-scale Silver Springshed equivalent porous media model to systematically explore the relative importance of conduit/fracture geometry and porous matrix properties on predicting the sources, fluxes, travel paths and travel times of water and solutes to Silver Springs.

Project 1 - This project will answer the following questions:

1) How much do piezometric heads and the magnitude and timing of springflows change when a representative system of conduits and fractures is incorporated into the calibrated local-scale Silver Springshed model using MODFLOW-CFP?
2) What characteristics of the conduit/fracture network (e.g. density/diameter/roughness) and porous media properties (e.g. porosity/specific storage/hydraulic conductivity), contribute the most uncertainty to the prediction of piezometric head and the magnitude and timing of streamflow using the Silver Springshed MODFLOW-CFP model?
3) Is the actual spatial configuration of conduits important to predicting the magnitude and timing of spring flow, or is springflow consistent among aquifer realizations generated using the same probability density functions for conduit and porous media properties?
4) Can improved (unbiased, lower uncertainty) predictions of piezometric head and spring discharge be obtained by assimilating observations of hydraulic conductivity, head and springflow into the Silver Springshed MODFLOW-CFP using an Ensemble Kalman Filter or Ensemble Smoother with Multiple Data Assimilation (Emerick and Reynolds, 2013; Tavakoli et al, 2013)?
5) What characteristics of the conduit/fracture network (density/diameter/roughness) and porous media properties (spatial distribution of porosity/specific storage/hydraulic conductivty), contribute most uncertainty to the prediction of spring vent solute breakthrough curves when solutes are introduced as conservative tracer pulses over the entire springshed?
6) Is the actual spatial configuration of conduits important to predicting spring vent breakthrough curves for conservative tracers introduced as pulses over the entire springshed, or is tracer breakthrough curve behavior consistent among aquifer realization configurations generated using the same probability density functions for conduit and porous matrix properties?
7) Do vulnerable areas of the springshed (i.e. those with fastest travel times for conservative solutes) depend on actual spatial configuration of conduits or are vulnerable regions consistent among conduit configurations generated using the same probability density functions for conduit and porous matrix properties?

Project 1 - Results of this project will:

1) Determine whether the contributions of conduit flow processes to water and solute delivery to springs can be captured using "effective" statistical conduit properties, or whether actual spatial configurations of the conduit system are important.
2) Determine the relative importance of local-scale conduit/porous media properties versus large-scale springshed boundary/confinement characteristics for predicting locations of highest risk for contamination of the spring vent from surface activities.

3) Determine whether is it feasible for the SJRWMD to develop a calibrated model for the Silver Springshed that incorporates conduits and fractures, and whether it is important to do so in order to effectively manage the quality and quantity of water flowing from Silver Springs.
4) Help define travel time for use in the Nutrient Loading/Spring Concentration Desktop Tool currently being developed by the SJRWMD.

B. Project 2/UF Project 3.2 - Nitrate fluxes and attenuation

The goal of this project is to determine groundwater flow characteristics and natural attenuation rates of N loads in the UFA. Groundwater velocities, ages, nitrate fluxes, and denitrification rates will be measured at a network of wells using a suite of monitoring techniques. The data from this project will be used directly in the springshed models. The specific objectives and associated tasks are:

1. **Modify borehole dilution and passive flux meter methods for application in a) matrix flow in the upper Floridan, b) flow through zones with fractures, and c) flow through karst cavities.**
2. **Develop push-pull tracer test methods for applications in complex karst aquifers.**
3. **Use flux meters to quantify groundwater flow and N fluxes at multiple depths in approximately 30 wells.**
4. **Quantify denitrification rates through push pull tracer tests in selected wells.**
5. **Age dating of groundwater samples from selected locations using environmental tracers.**

Simplified ("lumped parameter") models may be an efficient way to describe the dynamic behavior of the UFA within the Silver Springs springshed in terms of hydraulic and nitrate transport responses. These models are based on analyses of time series of aquifer input (i.e., recharge and nitrate loading) and output (i.e., spring discharge and nitrate concentration or discharge) over extended periods of time. Thus, the most fundamental aquifer dynamics may be captured and used for future predictions under different input scenarios related to particular aquifer management strategies. Geologic information on confining layers, sink holes, fault zones, predominant fracture orientation and submerged cave systems may provide additional insight for differentiating input zones throughout the springshed with individual dynamic response characteristics. However, more relevant information may be obtained from direct hydrodynamic measurements of flow, transport and nitrate reactions.

Due to the heterogeneity of the UFA within the Silver Springs region, the interplay of slow matrix flow and fast fracture/conduit flow may result in highly complex flow and transport conditions. Hydraulic and reactive properties of the aquifer will be measured using four approaches:

1. Borehole dilution tests
2. Passive Flux Meters
3. Push-pull tracer tests
4. Groundwater age dating tracers

Borehole dilution tests involve isolating a section of a borehole intersected by fractures or bedding plane features using inflatable packers. Water flow in fracture features is estimated using an electrical conductivity contrast between water in the borehole and ambient water in the aquifer. Groundwater flow is interpreted from a change in the electrical conductivity of water in the borehole as water from the fracture displaces water originally in the borehole. Borehole dilution tests will be modified and used to characterize vertical groundwater velocity distribution in selected wells and in critical regions of the springshed (Task 1). This data provides an initial assessment of the hydraulically active regions of the aquifer and a measure of the relative importance of fracture and karst features in the springshed. The borehole dilution program will guide the next phase of higher resolution special data collection including design aspects of the sampling plan.

Passive flux meters (PFMs) provide local flux measurements of groundwater, as well as nitrate and its degradation products. The method uses sorbents and tracers placed in the well bore for a specified period of time to determine water flow and nutrient flux (Hatfield et al., 2004; Annable et al., 2005) Flow and transport in conduits and/or cavities intercepted by wells will be characterized by modifying passive flux meter techniques developed for surface water systems to borehole applications (Task 1) (Klammler et al., 2007; Padowski et al., 2009). Flux data becomes available as depth profiles within monitoring wells, which allows characterization of several important features: (1) Vertical heterogeneity of flow and transport as produced by spatial variability of input sources and aquifer characteristics. This type of information is fundamental for assessing the internal dispersion and mixing behavior of the UFA as well as for the interpretation of point measurements. (2) Vertical trends in flow and transport as produced by the large scale boundary conditions of the UFA. This may help define the hydraulically active upper portion of the aquifer from a possibly stagnant lower part. The size of the active aquifer is directly related to the mean nitrate travel time towards the spring and stagnant parts of the aquifer may act as additional nitrate reservoirs, with nitrate uptake and release by diffusion from / into the active aquifer. (3) The spatial distribution of well averaged groundwater and nitrate fluxes may contribute to identifying larger scale flow, transport and reaction patterns between recharge locations and the spring. Comparing depth averaged fluxes of nitrate and its degradation products, for example, at different distances from the spring allows conclusions about nitrate reaction behavior at the transport scale. (4) Temporal variations in measured fluxes (e.g., between rainy and dry seasons) may be used to validate assumptions involved in the simplified aquifer response models (Task 3).

Push-pull tests provide in-situ measurements of groundwater velocity, effective porosity, dispersivity, retardation factors and nitrate degradation rates (Task 2) (Kim et al., 2005). These measurements may again be obtained as depth profiles over monitoring wells and may serve for: (1) Mutual validation of PFM and push-pull results for groundwater flux. (2) Assessment of reservoir size (i.e., aquifer storage and mean travel time) by combining PFM observed active aquifer depth with measurements of spatially variable effective porosity. (3) Local scale dispersivity is again fundamental for small scale nitrate mixing before reaching the spring, while (4) retardation and degradation are first order parameters influencing mean travel time and the aquifer's natural nitrate attenuation capacity (Task 4). The latter is of great interest for achieving long term aquifer restoration goals, as it is a tool to distinguish nitrate degradation from nitrate storage in hydraulically stagnant parts of the aquifer, which may be released again over longer time scales. Consequently, direct observations of nitrate degradation rates are essential complements to overall nitrate input-output balances.

The age of groundwater at the Silver Springs vents and in wells throughout the springshed can provide critical information on spatial contributions of N loads (Task 5). The data acquired through deployments of borehole dilution and passive flux meters will identify regions of the aquifer where groundwater age data will provide valuable information. Those locations will be sampled for environmental tracers such as tritium, cesium, CFCs, SF6 or carbon. The samples will be submitted for laboratory analysis externally. The results will provide a measure of local groundwater age distribution with area and groundwater depth to refine our understanding of the travel time from areas of the springshed to the Silver Springs discharge.

C. Project 3/UF Project 2.1 - Desktop Risk Model

The University of Florida (University) shall perform four tasks over a period of 24 months, which will include 1) data and literature review; 2) nutrient selection and development of conceptual model; 3) calibration and testing; 4) application of the model. The tasks are described in the Task Identification section of this Statement of Work. The University shall perform the following tasks to accomplish the scope of this project.

Task 1 – Data and Literature Review

The data required for model development and calibration can be divided into three categories: (1) hydrogeologic and topographic; (2) climatic; and (3) land-use. Category (1) includes information about fundamental local watershed and aquifer properties, such as stream network, retention capacities, hydraulic conductivities, aquifer confinement, and spring potentiometric surface/flow/nutrient measurements. Category (2) is rainfall and evapotranspiration temporal and spatial distribution as primary drivers of temporal variability in spring discharge. Category (3) includes anthropogenic effects, such as crop cultivation, fertilization, pumping, irrigation and point and non-point wastewater release, which may be variable in space and time. Primary data will be assembled from the District, US Geological Survey (USGS), Florida Department of Environmental Protection (FDEP), and all other identifiable sources. Literature review will start with the *Fifty-Year Retrospective Study of the Ecology of Silver Springs* [SJRWMD, 2006] and will include all existing articles and reports related to Florida springs as well as scientific publications related to simplified (preferentially analytic) watershed models for the scale of the present problem and existing and potential limiting nutrients (nitrate, phosphate, iron, etc.).

Task 2 – Conceptual Model Development

The first step in the development of a conceptual model will be the geographic definition of the model domain by delimiting the surface and subsurface watersheds based on topographic and UFA potentiometric surface information. The spring discharge data will further be used to determine spring base flow and respective nutrient (nitrate, phosphate, iron, etc.) base discharge. In order to capture both spatial and temporal variability in the system, while keeping the approach easily tractable for simplified application, a travel time based method appears appropriate. That is, simple analytic transfer functions will be devised to describe the travel times of water and nutrient particles between a location in the watershed and the spring. These transfer functions will depend on a minimum number of relevant parameters and surface and subsurface pathways may be considered separately (fast surface runoff versus somewhat delayed subsurface flow). Formulations are flexible and robust to account for both nonreactive and reactive transport. Due to data limitations and for simplicity, the watershed may be divided into a number of zones or elements (e.g., 10 to 20), each of which possess internally similar properties (e.g., same land-use, overlying confined or unconfined aquifer portions, etc.) or representing point sources and/or sinks for water and/or nutrient (e.g., pumping wells, wastewater release points, etc.). For a given point in time, the contributions of each zone or element to water and nutrient discharge at the spring is expressed by the respective transfer function. The individual contributions may then be integrated to predict total spring discharge.

Task 3 – Model Calibration and Testing

Available data will be used to test different transfer functions and to optimize and quantify their predictive performance. This is done by selecting parameter values corresponding to zone properties (e.g., larger nutrient intake where and when fertilizer is applied) and by adjusting uncertain parameters within their plausible ranges. Inspection of time series of water and nutrient discharges at the spring may be helpful in this process and in determining potential nutrient sources. For example, strong correlation between water and nutrient discharges indicates proportionality and the persistence of a relatively constant nutrient concentration in the spring water. This condition results from solute sources of insignificant variability over the time scale of interest and of rapid mass transfer between source and dissolved phase. This is commonly found for natural “geogenic” constituents that are ubiquitous in the watershed, or more recently from persistent anthropogenic loads of solutes in managed or “impacted” watersheds. In contrast, weaker correlation implies temporal variability in solute concentrations between rainfall events potentially indicating contributions of spatially or temporally discontinuous sources (e.g., localized hot spots, or seasonal fertilization). Additional data, such as discharges and/or concentrations of other dissolved constituents in the spring water, may assist in improving the understanding of the spatial and temporal dynamics of the watershed. This includes isotope data of nitrogen (indicative of the types of nitrate sources present) as well as other nutrients, i.e., phosphate and/or iron and oxygen (indicative of groundwater age, i.e., subsurface travel time).

Task 4 – Model Application
Once a model is implemented and tested to satisfaction using historic time series flow and nutrient data, it will be used to illustrate its potential to enhance the management of the Silver Springs watershed. This includes the prediction of nutrient discharge under different management scenarios and may result in an optimized set of recommended actions to potentially decrease nutrient discharge in the future (e.g., through elimination or mitigation of most contributing anthropogenic sources). Recommendations will also be given with regard to what additional information may be most valuable to further improve the predictive performance of the developed watershed model.

IV. TASK IDENTIFICATION – BUDGET & TIMEFRAMES

Detailed Task Description:

<u>Project 1/UF Project 2.2 – Conduit and fracture flow modeling</u>

Task	**Responsible Party**	**Time**	**Estimated Cost**	**Estimated Delivery Date**
Task 1: Flow Simulation Experiments				
1. SJRWMD delivers transient, high resolution Silver Springshed MODFLOW-2005 model to UF	Burger		-	?
2. UF adapts de Rooij's existing random 3-D fracture generator to generate 2-D conduit systems with random density, orientations, size and roughness, in appropriate format for direct incorporation into MODFLOW-CFP	de Rooij	1 mo	$6365[1]	1 month after project execution
3. UF develops algorithm to calculate spatially distributed conduit-matrix exchange parameters for input into MODFLOW-CFP using local MODFLOW grid-cell discretization and local hydraulic conductivity and conduit diameter values in the Peaceman well-index method (de Rooij et al, 2013).	de Rooij	2 mo	$6365	2 months after project execution
4. UF meets with SJRWMD to develop "representative" conduit network system based on the WRA/SDII Global photolineament analysis (WRA, 2005) and to discuss range of random	Burger, Johnson, Graham, de Rooij,	-	-	At Springshed model delivery

porous media properties and random conduit properties to include in Silver Springshed MODFLOW-CFP experiments	Henson			
5. UF incorporates representative conduit system into Silver Springshed MODFLOW-2005 model using MODFLOW-CFP	Henson	2 mo	$7,956[1]	2 months after Springshed model delivery
6. UF conducts an analysis of representative conduit network system to determine influence of horizontal and vertical MODFLOW grid-cell discretization on conduit-matrix exchange and spring discharge for both a steady state and transient representative tropical storm using the Silver Springshed MODFLOW-CFP	Henson	2 mo	$7,956	4 months after Springshed model delivery
7. UF meets with SJRWMD to discuss results of representative conduit network simulation and plan Monte Carlo Simulations	Burger, Johnson, Graham, de Rooij, Henson		-	At completion of Task 1.6
8. UF develops unconditional Monte Carlo simulation to quantify uncertainty associated with unknown porous media and conduit geometry properties on piezometric head and spring discharge hydrographs for 1) steady state simulation and 2) representative storm	Henson, Graham	4 mo	$15,912	1 year after Springshed model delivery
Total Cost Task 1			$44,554	1 year after model delivery
Task 2 Data Assimilation/Parameter Estimation Experiments				
1. UF meets with SJRWMD to discuss results of Monte Carlo Simulations and plan Ensemble Kalman Filter (or Ensemble Smoother with multiple data assimilation (ES-MDA) experiment	Burger, Johnson, Graham, de Rooij, Henson		-	At completion of Task 1.8
2. UF develops an Ensemble Kalman Filter (EnKF) or Ensemble Smoother with multiple data assimilation (ES-MDA) to assimilate synthetic head and springflow observations (from a randomly selected "true system") into the Silver Springshed MODFLOW-CFP model to optimally	Henson, de Rooij, Graham	6 mo	$62,393	1 year after completion of Task 1

estimate parameter distributions and evaluate reduction in model prediction uncertainty. *Note: Tavakoli et al (2013) showed that the EnKF and ES-MDA methods produced similar results to the Null Space Monte Carlo Method (NSMC) developed by Tonkin and Dougherty (2009) with similar computation times.)*				
Total Cost Task 2			$62,393	2 years after model delivery
Task 3 Transport Simulation Experiments				
1. UF meets with SJRWMD to plan Transport Simulation Experiments	Burger, Johnson, Graham, de Rooij, Henson		-	After completion of Task 1.6
2. UF duplicates MODFLOW-CFP Springshed representative flow simulations using DisCO for representative conduit network system.	de Rooij	2 mo	$12,730	2 months after completion of Task 1.6 (~6 mo after Springshed model delivery
3. UF develops a series of synthetic tracer test experiments across 1) the entire the Silver Springshed, and 2) sub-regions of the domain to determine travel times and travel paths for solute transport to SilverSpings the springshed for "representative" conduit network system under 1) steady flow and 2) representative storm	de Rooij, Graham	2 mo	$12,730	1 year after Springshed model delivery
4. UF conducts unconditional Monte Carlo simulation to quantify uncertainty associated with unknown porous media and conduit geometry properties on solute travel times and travel paths from the springshed for 1) steady state simulation and 2) representative storm.	de Rooij, Graham	4 mo	$25,460	2 years after Springshed model delivery
5. UF meets with SJRWMD to discuss results of transport simulation experiments, particularly with respect to travel time distributions that may be	Burger, Johnson, Graham,		-	After completion of Task

useful for incorporation into the Nutrient Loading/Spring Concentration Desktop Model	de Rooij, Henson			1.6
Total Cost Task 3			$50,920	2 years after model delivery
Total Project Cost			$157,867	2 years after model delivery

Project 2/UF Project 3.2 - Nitrate Fluxes and Attenuation

TRANSPORT AND LOSS OF NITROGEN WITHIN THE UPPER FLORIDAN AQUIFER IN THE SILVER SPRINGS SPRINGSHED (TASK 1 - Springshed supergroup N-transport-Jawitz)

Task	Period	Estimated cost
Task 1. Modify borehole dilution and passive flux meter methods for application in a) matrix flow in the upper Floridan, b) flow through zones with fractures, and c) flow through karst cavities.	Year 1 and 2	$35,000
Task 2. Develop push-pull tracer test methods for applications in complex karst aquifers.	Year 1 and 2	$25,000
Task 3. Use flux meters to quantify groundwater flow and N fluxes at multiple depths in approximately 30 wells.	Year 2 and 3	$70,000
Task 4. Quantify denitrification rates through push pull tracer tests in selected wells.	Year 2 and 3	$30,000
Task 5. Age dating of groundwater samples from selected locations using environmental tracers.	Year 2 and 3	$30,000
Task 6. Final Report	End of Year 3	$5,000
Total		$195,000

Project 3/UF Project 2.1 - Desktop Risk Model

This project will be completed for a total cost of $200,000. University shall invoice the District by percent of tasks completed. The amount budgeted for each fiscal year (FY) is as follows:

$40,000 FY 2013 – From contract execution through September 30, 2013
$100,000 FY 2014 – October 1, 2013 – September 30, 2014
$60,000 FY 2015 – October 1, 2014 – June 30, 2015 (Expiration date of Agreement)

V. TIME FRAMES & DELIVERABLES

	FY2013				FY2014				FY2015			
	Q1	Q2	Q3	Q4	Q1	Q2	Q3	Q4	Q1	Q2	Q3	Q4
Project 1: Conduit and Fracture Flow Modeling												
Task 1: Flow Simulation Experiments	■	■	■	■								
Task 2: Data Assmiilation/Parameter Estimation Experiments					■	■	■	■				
Task 3: Transport Silumation Experiments					■	■	■	■				
Project 2: Nitrate Fluxes and Attenuation												
Task 1: Borehole dilution and Passive Flux Meter Methodology modifications	■	■	■	■	■	■	■	■				
Task 2: Push-Pull Tracer Test Development	■	■	■	■	■	■	■	■				
Taske 3: Deployment of Flux Meters and Data Collection					■	■	■	■	■	■	■	■
Task 4: Quantify Denitrification Rates Through Push-Pull Test					■	■	■	■	■	■	■	■
Task 5: Age Dating of Groundwater Samples					■	■	■	■	■	■	■	■
Task 6: Final Report									■	■	■	■
Project 3: Desktop Risk Model												
Task 1: Data and Literature Review	■											
Task 2: Conceptual Model Development	■	■	■	■								
Task 3: Model Calibration and Testing					■	■	■					
Task 4: Model Application							■	■				