Appendix A: WARMF Model Code Revisions to Simulate Several Types of Onsite Wastewater Treatment Systems

Project Title:
Development of Custom Model Code to Simulate Loading from Additional Types of Onsite Wastewater Treatment Systems

Prepared for

Upper Neuse River Basin Association and
the NC Department of Environmental Quality

Sponsor: NC Department of Environmental Quality

Fiscal Year of Grant: 2019
NC-DENR Contract Number: 8192
Contract Period: June 19, 2020 to June 30, 2021
Federal Dollar Amount: $23,500

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Date of Final Report: February 10, 2021

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Prepared for

Upper Neuse River Basin Association, NC

February 10, 2021

Acknowledgements

The Upper Neuse River Basin Association (UNRBA) appreciates the assistance provided by staff at the NC Division of Water Resources (DWR) to acquire funding for this project under an EPA Section 319 Grant. This project benefits the region by furthering the understanding of nutrient loading from onsite wastewater treatment systems in the watershed of Falls Lake, NC. This project expanded and enhanced the capability to simulate on-site wastewater systems in the watershed.

Improving the model simulations of onsite wastewater treatment systems is important to better quantify the significance of this source of nutrient loading to Falls Lake. This effort will support the UNRBA's Re-examination of Stage II of the Falls Lake Rules. The overall UNRBA effort is managed by the UNRBA Executive Director, Forrest Westall. Updates to the model code were performed by Joel Herr at Systech Water Resources, Inc., the owner of the Watershed Analysis Risk Management Framework (WARMF) that is being used by the UNRBA to simulate nutrient loading from the watershed to Falls Lake. The UNRBA is funding development of a watershed model for Falls Lake which includes simulation of loading from onsite wastewater treatment systems. The UNRBA members have provided extensive datasets to further this effort. The UNRBA Modeling Project is managed by Alix Matos at Brown and Caldwell. Additional contributing authors include Lauren Handsel at Brown and Caldwell and Scott Sheeder at Systech Water Resources.

The UNRBA would also like to thank the researchers at the UNC Collaboratory for working through a separate 319 grant to monitor water quality in areas served by onsite wastewater treatment systems in the Falls Lake watershed, to estimate locations of systems where spatial databases are not available, and to assist the UNRBA in developing model inputs for the simulation of different types of systems in the watershed. Together, these two grant-funded projects result in better modeling tools that utilize local data and expert understanding to improve the simulation of nutrient loading from these systems.

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List of Abbreviations

kg N/d	kilograms of nitrogen per day
mg/L	milligrams per liter
N	nitrogen
NC	North Carolina
DWR	Division of Water Resources
QA/QC	Quality Assurance/Quality Control
UNC	University of North Carolina at Chapel Hill
UNRBA	Upper Neuse River Basin Association
WARMF	Watershed Analysis Risk Management Framework

Executive Summary

The Upper Neuse River Basin Association (UNRBA) is sponsoring studies of pollutant loading in the Falls Lake watershed (Figure 1-1). The goal of the studies is to ascertain the sources of pollutants and the effects of those pollutants on the water quality in Falls Lake. One of the tools being used for this study is the Watershed Analysis Risk Management Framework (WARMF).

WARMF version 6.9a includes the option to simulate up to only three types of onsite wastewater treatment systems. The UNRBA and NC Division of Water Resources (DWR) have information about the presence and nutrient loading associated with a greater number of types of onsite wastewater treatment systems in the watershed. Better understanding of the different types and condition of these systems in the watershed will allow more effective evaluation of potential management of these sources. Based on the DWR nutrient crediting documents (draft and final documents for different system types), there are potentially 12 to 15 permutations of types between conventional vs discharging sand filter systems, functional versus failing systems, advanced treatment (TS-II) vs single pass vs recirculating systems, subsurface vs surface discharge, and potential discharge through a wetland.

To simulate these different types of onsite wastewater treatment systems and determine the impact of each on water quality, the UNRBA Modeling Team utilized this funding to upgrade the WARMF graphical user interface and simulation engine (onsite wastewater treatment system subroutine within the WARMF computer model code) to allow for greater flexibility in the simulation of onsite wastewater treatment systems. With these additional system types included, the number of types has been made user-selectable up to 15. The discharge soil layer is now customizable by system type. The WARMF loading output has been expanded to include each type simulated. The Modeling Team has tested the revised model to ensure that the revised code interfaces properly with the full model code. The revised and tested model code, along with this Final Report, is summarized here and submitted to satisfy the funded deliverables specified in the 319 contract.

The UNRBA Modeling Team will work with the researchers at the UNC Policy Collaboratory to develop the model inputs for the various types of systems after the UNRBA Modeling Team has developed the model code (the UNC Collaboratory researchers were awarded a separate 319 grant for their effort). Model inputs will be based on a combination of water quality data collected in the Falls Lake watershed and review of the subject matter literature, where required. As part of the Collaboratory's 319 grant, the UNRBA Modeling Team will coordinate with researchers on the quality assurance/quality control (QA/QC) of the model output to ensure accurate simulations of the processes associated with loading to surface waters from onsite wastewater treatment systems.

Section 1

Introduction

The Upper Neuse River Basin Association (UNRBA) is sponsoring a comprehensive Re-examination of the Falls Lake Nutrient Management Strategy currently in place under the Falls Lake Rules. This work includes studies of pollutant loading in the Falls Lake watershed (Figure 1-1). The goal of these studies is to ascertain the sources and maginitude of pollutants from land use in the watershed and determine the effects of those pollutants on the water quality in Falls Lake. One of the tools being used for this study is the Watershed Analysis Risk Management Framework (WARMF) model.

WARMF is a comprehensive, physically based watershed model which simulates the flow and water quality within land catchments and the associated impact from these land-based sources on the streams, rivers, and reservoirs within the catchment. These simulations provide pollutant content and loading on a daily or shorter time step. Flow volume is tracked through precipitation, infiltration, evapotranspiration, lateral flow, overland flow, stream flow, reservoirs, and diversions. Reservoirs have many layers, so the model can simulate seasonal stratification. WARMF simulates many water quality parameters including the various forms of nitrogen and phosphorus, major cations and anions, organic carbon, dissolved oxygen, suspended sediment, and phytoplankton. WARMF also simulates processes including atmospheric deposition, uptake by vegetation, litter fall and decay, adsorption to soil and sediment, chemical reactions, and advective transport. Anthropogenic loading sources simulated by WARMF include fertilizer application, point source discharges, and onsite wastewater treatment systems. Mass balance is maintained for each constituent in every land use and soil layer of every catchment, each river segment, and each layer of reservoirs. The algorithms used in the WARMF simulation engine are described in the WARMF Technical Documentation (Systech Water Resources, Inc., 2017).

While WARMF version 6.9a includes simulation of onsite wastewater treatment systems, it is limited to only three types. Based on local data provided by UNRBA members as well as draft and final nutrient crediting documents developed by NC Division of Water Resources (DWR), there are many additional types of systems in the watershed. Because a primary goal of the UNRBA modeling studies is to test nutrient management strategies, the UNRBA and DWR believed that the model's simulation of onsite wastewater treatment systems should be improved. The first required step in providing improved simulation of these systems required modification of the model code to increase the number of system types that can be simulated. This 319 grant was awarded for this task.

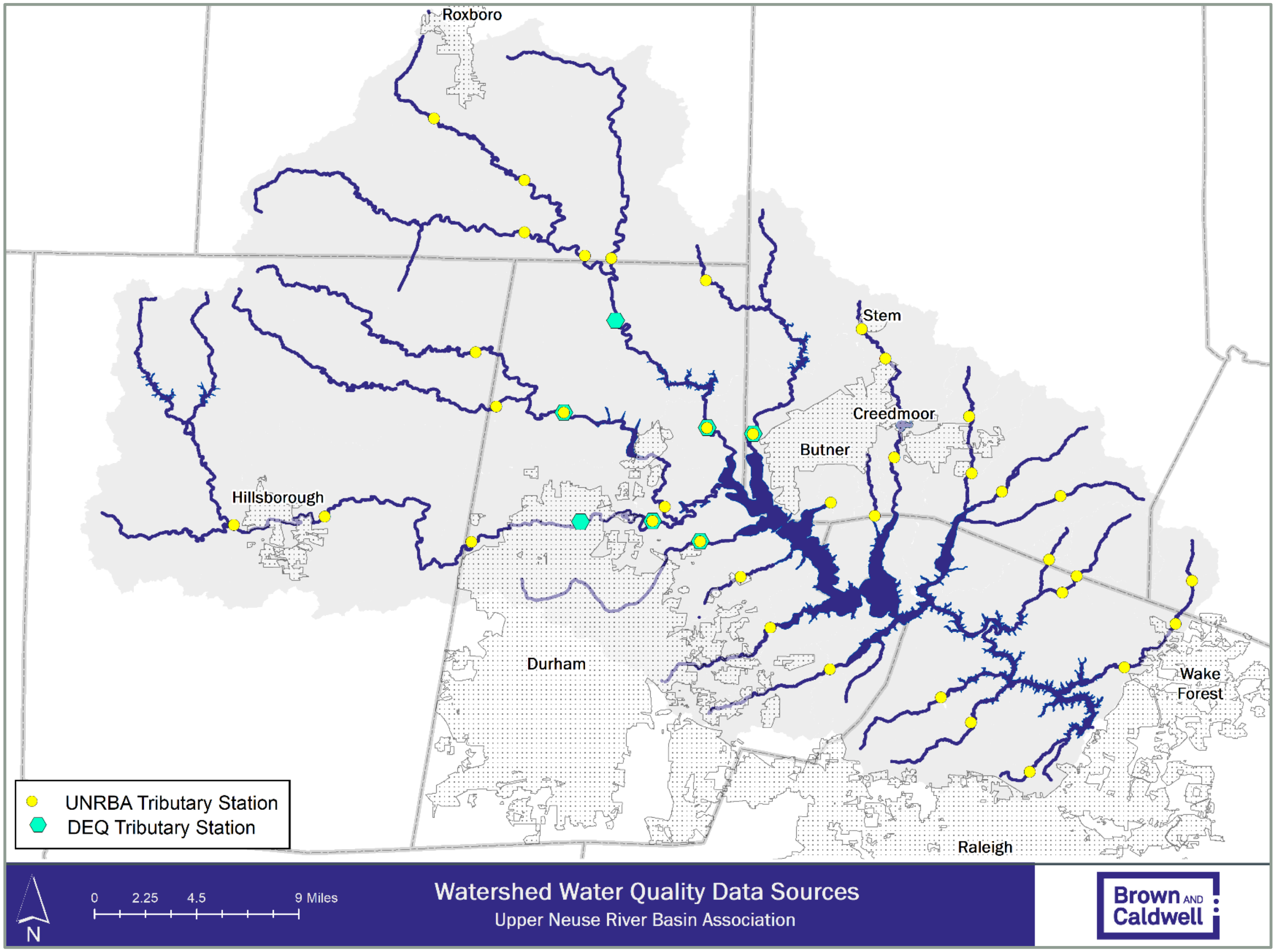

Figure 1-1. Falls Lake Watershed and Historic Monitoring Stations
(no additional monitoring was associated with this project)

Section 2

Goals and Objectives

WARMF version 6.9a is being developed to simulate nutrient loading to Falls Lake in NC. This version originally included the option to simulate up to three types of onsite wastewater treatment systems, and the modeler defines the discharge quality associated with each type. The original model can set the soil layer receiving the discharge in the model by catchment but is the same for each system type. The loading from each type is tracked through the watershed so the portions of pollutants attributable to each type of system can be determined for any surface water body in the watershed.

The UNRBA and DWR have some existing information about the presence and nutrient credits associated with various types of onsite wastewater treatment systems in the watershed. Based on the DWR nutrient crediting documents (draft and final), there are many permutations of types between conventional vs discharging sand filter, TS-II vs single pass vs recirculating, subsurface vs surface discharge, and potential discharge through a wetland.

The goal of this project was to modify the WARMF model code to represent a user-specified number of onsite wastewater treatment systems and better account for nutrient loading from this source. Table 2-1 provides preliminary estimates of the number of systems in the Falls Lake watershed by system type (the UNRBA Modeling Team is continuing to compile data from State and local entities). The availability of existing data and that being collected by the Collaboratory researchers looking at this issue will be used for input data and for calibrating output to loading from the catchments.

Code modification will allow for better accounting of nutrient loading from onsite wastewater treatment systems in the Falls Lake watershed. This improvement to the model will provide an expanded set of model scenarios related to nutrient management to identify feasible options for improving water quality in Falls Lake.

Table 2-1. Estimates of the Number of Onsite Wastewater Treatment System Types in the Falls Lake Watershed							
Category	Durham	Orange	Person	Granville	Franklin	Wake	Total
Privy	1	7	-	-	-	1	9
Conventional, functioning, subsurface discharge	7,102	11,585	5,671	4,181	1,790	14,094	44,423
Conventional, malfunctioning, subsurface or discharge	708	763	634	278	93	1,057	3,533
Advanced treatment, functioning subsurface discharge, single family	631	235	-	-	-	163	1,029
Advanced treatment, malfunctioning subsurface discharge, single family	114	14	-	-	-	12	140
Advanced treatment, subsurface discharge, >3000 gallons per day	4	-	-	-	-	2	6
Single pass, sand filter discharging to land surface	-	26	-	-	-	-	26
Single pass, sand filter discharging to stream	996	60	8	4	-	2	1,070
Recirculating sand filter discharging to stream	2	-	-	-	-	-	2
Total	**9,558**	**12,690**	**6,313**	**4,463**	**1,883**	**15,331**	**50,238**

Section 3

Deliverables

The following bullets summarize the deliverables developed by the project and specified in the 319 contract. Sub-bullets provide additional information regarding the completion of each deliverable.

- Revised model code related to the simulation of up to 15 types of onsite wastewater treatment systems for the Falls Lake watershed application of WARMF
  - The WARMF model code has been updated and tested by Systech Water Resources, Inc.
  - Simulation results for model testing are provided in Section 5 of this report.
  - Researchers at the UNC Collaboratory will review these results providing an additional level of the quality assurance/quality control (QA/QC) as part of their separate 319 grant contract to provide further review of model input and output.
- Brief report (2-3 pages) describing the development of the model code
  - This report satisfies this deliverable.

Section 4

Methodology

To simulate these different types of onsite wastewater treatment systems and determine the impact of each on surface water quality, the UNRBA Modeling Team upgraded the WARMF graphical user interface and model code to allow for greater flexibility in the simulation of onsite wastewater treatment systems. The number of types has been made user-selectable up to 15. The discharge soil layer has been made customizable by system type, and the WARMF loading output has also been expanded to include all system types. The Modeling Team has tested the revised model to ensure that the revised code interfaces properly with the full model code.

The original WARMF onsite wastewater treatment system simulation algorithm within WARMF allowed for three types of systems, each with their own discharge quality. The discharge soil layer for all system types and the percentages of each type were specified for each modeling catchment. The revised code developed under this 319 grant allows for up to 15 different system types with the discharge soil layer set by catchment and system type.

Table 4-1. Changes to WARMF Simulation of Onsite Wastewater Treatment Systems

	Old WARMF Formulation (version 6.9a)	New WARMF Formulation (version 6.9b)
Number of System Types	3	Up to 15, user specified
Discharge Flow	One flow for all system types	Flow specified for each system type
Discharge Quality	Specified for each system type	Specified for each system type
Discharge Soil Layer	Specified for each catchment for all system types	Specified for each catchment and system type
Loading from each system type	Flow x concentration x population on each system type x fraction of each system type	Flow x concentration x population on each system type x fraction of each system type

Changes were made to the WARMF graphical user interface to enter the new coefficients and to the simulation engine to use the new coefficients. The actual simulation algorithms did not need to be revised, but the variables for the number of system types, discharge flow, and discharge soil layer were expanded to match the new flexibility in the graphical user interface.

Section 5

Results of Testing Revised Model Code

Accurate accounting of nutrient loading to Falls Lake from onsite wastewater treatment systems in the watershed is an important component of developing recommendations for a revised nutrient management strategy. The current model framework allows up to three types of systems to be simulated. In the Falls basin, there are many types of systems and different potential upgrade approaches to systems contributing loading. The modified model is important in developing potential water quality benefit and the cost of these actions. This onsite reduction component of potential actions must be considered in the development of an updated nutrient management strategy. This 319 grant-funded project improves the ability of the UNRBA to simulate a more accurate overall level of nutrient loading to Falls Lake and to understand how much this source of the load impacts overall lake loading. The results of the modeling studies on Falls and the ultimate goal of a revised nutrient management strategy should also benefit other Piedmont watersheds and reservoirs as lessons learned here will provide insight elsewhere. As demonstrated in Sections 5.1 through 5.3, the revised model code effectively and accurately generates expected concentrations and nutrient loads as the previous model code when the same flow rates and nutrient concentrations are assumed across system types. This QA/QC process provides a high level of confidence that the modified code is performing as designed and intended

The UNRBA Modeling Team will continue to work with the researchers at the UNC Policy Collaboratory under the separate 319 grant-funded project to develop the model inputs for the various types of systems. Model inputs will be based on a combination of water quality data collected in the Falls Lake watershed and literature review. The UNRBA Modeling Team will also coordinate with researchers at the Collaboratory as part of their separate contract on additional QA/QC of the model output and test simulations to ensure the model accurately simulates loading from onsite wastewater treatment systems.

5.1 Testing of the New System Simulation

There were two stages of testing for the new WARMF graphical user interface and simulation engine. The first step was to ensure that the new code would produce the same output as the old code given the same model coefficients (i.e., that the simulation engine still provided the same results for the previous three types of systems), and the second step was to ensure that implementation of the new features would produce correct results. Two types of output were tested: 1) standard time series output of flow and 2) water quality constituents over time for a specific location and loading output, where the loading from a section of the watershed is traced back to its original source.

The watershed used for testing was the South Carolina portion of the Catawba River watershed using an existing WARMF model. That watershed is similar to the Falls Lake watershed in that it includes simulation of onsite wastewater treatment systems, has a mix of urban and rural land uses, and includes several reservoirs. Time series results for a two-year simulation were checked for two locations: a tributary called Cane Creek whose watershed has 2,785 people using onsite wastewater treatment systems (to have a location with a high concentration of systems) and the most downstream segment of Lake Wateree at the terminus of the Catawba River watershed (to see if there were any simulation differences in parts of the watershed that should not be affected). The parameters tested were flow and ammonia nitrogen. The baseline scenario's system coefficients had 165 liters per capita per day with an ammonia concentration of 58 milligrams per liter (mg/L) as nitrogen (N).

5.2 Test 1: Run Old Coefficients with New Simulator

A baseline simulation was run using WARMF version 6.9a prior to upgrading the septic system simulation. The baseline scenario was then opened in WARMF version 6.9b with the septic system upgrade and run with the upgraded simulation engine. The test simulation should produce the same time series and loading output results as the baseline. The simulations were compared for each day of the simulation and the minimum, maximum, and average deviations were calculated. The results of the two scenarios were identical as shown in Table 5-1. The loading output was also identical between the Test 1 scenario and the baseline.

Table 5-1. Daily Simulation Result Differences: Test 1 Scenario minus Baseline

	Flow Difference, m3/s			Ammonia Difference, mg/L N		
	Minimum	Maximum	Average	Minimum	Maximum	Average
Cane Creek	0	0	0	0	0	0
Lake Wateree	N/A			0	0	0

5.3 Test 2A: Run with 15 Identical Septic System Types

The baseline scenario was modified in WARMF version 6.9b to use 15 different septic system types (Test 2A). All septic system types were parameterized to be identical to each other, with 165 L/capita/day flow rate and 58 mg/L N of ammonia, so the load should be the same regardless of what type of system is assigned. Each catchment was assigned the same percentages of each of the 15 septic system types for Test 2A: 40%, 20%, 15%, 8%, 4%, 3%, 2%, 1%, 1%, 1%, 1%, 1%, 1%, 1%, and 1%. For baseline, all systems are Type 1. To ensure the revised model code is working properly, the baseline and Test 2A outputs were compared to confirm the following:

- The test simulation should produce time series output results that are identical to the baseline.
- The overall amount of loading should be the same between Test 2A and the baseline, but the loading output should show the distribution between the septic system types in proportion to the fraction of each type in the catchments.

The simulations were compared for each day of the simulation and the minimum, maximum, and average differences were calculated. The results of the two scenarios were identical for Cane Creek as shown in Table 5-2. The Test 2A simulation results from Lake Wateree had minor rounding errors, but very little net difference with the baseline.

The loading output was also identical between the Test 2A scenario and the baseline other than the difference in septic system types contributing to the load. Table 5-3 shows that the apportioning of load varies between the baseline (three types) and Test 2A (15 types), but the total load is the same.

Table 5-2. Daily Simulation Result Differences: Test 2A Scenario minus Baseline						
	Flow Difference, m3/s			Ammonia Difference, mg/L N		
	Minimum	Maximum	Average	Minimum	Maximum	Average
Cane Creek	0	0	0	0	0	0
Lake Wateree	N/A			-0.0009	0.008	-2x10-5

Table 5-3. Loading Output for Ammonia (kg/d): Test 2A Scenario vs Baseline Scenario				
	Cane Creek		Lake Wateree	
	Baseline	Test 2A	Baseline	Test 2A
Septic Type 1	0.0398	0.0159	8.45	3.38
Septic Type 2	0	0.00796	0	1.69
Septic Type 3	0	0.00597	0	1.27
Septic Type 4	N/A	0.00318	N/A	0.676
Septic Type 5	N/A	0.00159	N/A	0.338
Septic Type 6	N/A	0.00119	N/A	0.254
Septic Type 7	N/A	0.000796	N/A	0.169
Septic Type 8	N/A	0.000398	N/A	0.0845
Septic Type 9	N/A	0.000398	N/A	0.0845
Septic Type 10	N/A	0.000398	N/A	0.0845
Septic Type 11	N/A	0.000398	N/A	0.0845
Septic Type 12	N/A	0.000398	N/A	0.0845
Septic Type 13	N/A	0.000398	N/A	0.0845
Septic Type 14	N/A	0.000398	N/A	0.0845
Septic Type 15	N/A	0.000398	N/A	0.0845
TOTAL	**0.0398**	**0.0398**	**8.45**	**8.45**

5.4 Test 2B: Setting the Discharge Layer to Soil Layer 2

The baseline scenario, Test1, and Test 2A all had discharge to the top soil layer ("layer 1") for all septic system types and all catchments. Test 2B was modified so that for one catchment, discharge from all septic systems went to the second soil layer ("layer 2"). While the load from septic systems to the catchment is the same regardless of the soil layer to which it is applied, the concentration of ammonia and other constituents in septic discharge within the pore water of each soil layer is dependent upon which soil layer receives the discharge. This test checks the WARMF tracking of loading into the catchment and the relative concentrations of ammonia within the top two soil layers.

WARMF time series output for the top two soil layers within the test catchment from the Catawba WARMF model is summarized in Table 5-4. As expected, concentrations are higher in a particular soil layer when septic systems discharge to that layer. (Note that loading from this source is not the only contributing factor to pore water concentration.) The WARMF loading output had identical ammonia loading between Test 2A and Test 2B: 13.3 kilograms nitrogen per day (kg N/d). This loading is also in agreement with the manual calculation of loading based on 165 liters/capita/day times 58 mg N/L ammonia concentration in discharge times 1389 people on septic systems in the test catchment times the appropriate conversion factors.

Table 5-4. Daily Simulation Result Differences: Test 2A Scenario minus Baseline

	Test 2A Scenario (discharge to Soil Layer 1)			Test 2B Scenario (discharge to Soil Layer 2)		
	Minimum	Maximum	Average	Minimum	Maximum	Average
Soil Layer 1	0.072	0.512	0.221	0.071	0.484	0.212
Soil Layer 2	0.0258	0.0538	0.0377	0.0267	0.0538	0.0382

Section 6

Conclusions

Internal testing by Systech Water Resources, Inc. has found that the upgrade to WARMF's septic system simulation has been completed successfully. Based on the testing and evaluation of the code performance, the number of system types and their characteristics can be simulated effectively based on the inputs to WARMF through the graphical user interface. Test simulations found that the new system simulation produces the same simulation output as the old system simulation given the same inputs. The new features of the upgraded onsite wastewater treatment system engine have been tested and found to work as planned. The upgraded WARMF version 6.9b is available for review and will be used for the Falls Lake watershed. In addition to the high degree of confidence provided by model testing and as referenced in this report, the researchers providing data on these type systems in the watershed will also be reviewing input and output results of the model to add an additional level of QA/QC.

Section 7

Budget

The 319 grant award for this project is $23,500. The members of the UNRBA provided matching funds of $43,584 as the original contracted amount of Phase 321 of the UNRBA FY2020 Modeling and Regulatory Support and Communications project managed by Brown and Caldwell. The total budget amount of the contract with Brown and Caldwell was modified to $67,084 ($43,584+$23,500). The final invoice for the UNRBA FY2020 Modeling and Regulatory Support and Communications project shows the total invoiced amount of $67,084 for Phase 321 reflecting the Phase 321 budget of $23,500 associated with the 319 grant funding to modify the WARMF model code as authorized by Amendment #2 to the UNRBA FY2020 Modeling and Regulatory Support and Communications contract.

Section 8

References

Systech Water Resources, Inc., 2017. Watershed Analysis Risk Management Framework (WARMF): Technical Model Documentation. Walnut Creek, CA.