Modeling the Production of Multiple Ecosystem Services from Agricultural and Forest Landscapes in Rhode Island

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Appendix

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Calibration and Validation of the SWAT Model

Sensitivity Analysis

Since different watersheds have different hydrologic attributes, a sensitivity analysis is necessary to reduce the uncertainty and also provide overall coarse guidance for the calibration and validation. Based on the ranking of sensitivity analysis, we found that the top five parameters that the SWAT output was particularly sensitive to were soil evaporation coefficient (ESCO), canopy evaporation coefficient (CANMX), the curve number (CN2), evaporation coefficient (threshold watershed depth in the shallow aquifer for "evaporation", REVAPMN), and base flow alpha factor (ALPHA_BF). Similar sensitivity analysis have been found in Reungsang et al. (2007). The soil evaporation coefficient values adjust the depth distribution for evaporation from the soil to account for the effect of capillary action, crusting, and cracking (Neitsch et al. 2005).The curve number determines the partitioning of precipitation between surface runoff and infiltration as a function of soil hydrologic group, land use, and antecedent moisture condition (Kaur et al. 2003).

Several simulations were conducted for each input parameter while holding the other parameter constant. Based on the result, we adjusted the range of the parameters to account for the uncertainty of the soil and land use conditions of that watershed. For example, the soil evaporation coefficient (ESCO), which has a range between 0.0 and 1.0, was changed from default 0.95 to 0.98 in our research. The initial and final values of the selected calibration parameters, as well as ranges for each parameter based on SWAT auto-calibration and the default ranges, were given by Neitsch et al. (2005) listed in Appendix Table 4, such as soil evaporation coefficient (ESCO), canopy holding waters capacity (CANMX), curve number (CN2), threshold depth of water in the shallow aquifer for "revap" or percolation to the deep aquifer to occur (REVAPMIN), and base-flow factor (ALPHA_BF). These parameters were chosen on the basis of the results of the sensitive analysis and they are consistent with previous studies (Reungsang et al. 2007).

Calibration and Validation

Each SWAT simulation was executed for the 1987–2010 to encompass a complete cycle and a three-year "warm up" period (1987–1989) is included. Calibration of SWAT was performed for the years 1990–2000, while the years 2000–2010 were used as validation. The 1990–2010 annual average streamflow was simulated using historical precipitation and temperature records at the Kingston weather station. Average annual streamflow of the calibration period (1990–1999) is 0.540 m^3/s and is lower than the observation of 0.571 m^3/s by 5.44%. Average streamflow in validation period (2000–2010) is 0.616 m^3/s and is slightly higher than the observed 0.613 m^3/s by 0.49%, almost identical (Appendix Figure 5). The following steps were then taken to complete the calibration and validation process of this study based on comparisons between the simulated and measured data at the watershed outlet. (1) Calibrate the long-term average annual streamflow. (2) Calibrate the monthly streamflows. (3) Validate monthly streamflow. (4) Calibrate the seven-day moving average for summer months (from June to August). (5) Validate the seven-day moving average for summer months. For the first step, the annual streamflow was calibrated against measured streamflow at the outlet of the watershed from year 1990 to 2000. This step was performed to check if the simulated water yield from SWAT output is realistic. Once the simulated annual streamflow was within 10% of measured streamflow, the validation from year 2000 to year 2010 was estimated using input parameters determined during the validation step. Then monthly streamflow was calibrated from year 1990 to year 2000. The same validation step followed monthly calibration.

Appendix Table 1: Comparison of the Performance of the Simulated vs. Observed 7 Day Moving Average, Lowest and Highest 5% and 10% (1990–2010)

	R^2	NSE	PBIAS	RSR
7 day moving average lowest 5%	0.99	0.72	5.79	0.53
7 day moving average lowest 10%	0.99	0.80	–3.70	0.44
7 day moving average highest 5%	0.79	–0.10	16.8	1.04
7 day moving average highest 10%	0.88	0.32	14.9	0.83

Notes:
1. The daily simulation from SWAT model was used to calculate the seven-day moving average.
2. Nash-Sutcliffe efficiency (NSE), Percent Bias (PBIAS), Deviation of Measured Data (RSR), Source: Moriasi et al. (2007).

Appendix Table 2: Percentage of Land Use across Different Scenarios after HRU Definition Unit: Percent

Land Use	Scenario 1: Baseline	Scenario 2: Conventional Agriculture	Scenario 3: BMP Agriculture	Scenario 4: Biofuel	Scenario 5: Suburban Medium Density	Scenario 6: Suburban Medium Low Density
Medium Density Residential (1 to 1/4 acre lots)	0.43	0.55	0.55	0.55	54.41	0.43
Medium Low Density Residential(1 to 2 acre lots)	0	0	0	0	0	57.64
Developed Recreation	0.01	0.01	0.01	0.01	0.01	0.01
Cropland (tillable)	0.87	16.62	16.62	16.62	0.87	0.87
Deciduous Forest (>80% hardwood)	69.27	63.44	63.44	63.44	31.11	31.65
Softwood Forest (>80% softwood)	8.75	4.94	4.94	4.94	2.82	2.82
Mixed Forest	19.18	12.94	12.94	12.94	3.37	3.5
Wetland	1.05	1.05	1.05	1.05	1.07	1.06
Septic Systems*	0.46	0.45	0.45	0.45	6.34	2.02

Note: Land use maps were created based on 2003/2004 land use and land cover data (RIGIS). The percentage of land uses were calculated after the HRUs were defined using a 10% minimum threshold and thus there are a subtle difference in the percentage of area because of this threshold. A GIS layer for septic systems was created as a new land use type in our study.

Appendix Table 3: Days below the Requirement of RI ABF in Each Month 1990–2010 (20 years)
Unit: Days

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Scenario 1: Baseline	137	241	156	153	286	391	262	230	132	62	63	69
Scenario 2: Conventional Agriculture	139	244	173	161	301	418	273	239	154	72	69	80
Scenario 3: BMP Agriculture	149	245	175	164	320	409	267	234	153	68	70	83
Scenario 4: Biofuel	137	245	169	161	296	402	264	233	151	73	69	80
Scenario 5: Suburban Medium Density	162	241	148	123	214	276	177	107	72	36	49	81
Scenario 6: Suburban Medium Low Density	126	216	123	118	201	296	208	176	115	54	64	76

Note: Days below RI ABF threshold in each month of the 20-year period. For example, in January, there is 137 days below RI ABF threshold in the 620 days of 20 January from 1990 to 2010(31*20=620).

Appendix Table 4: Initial and Final Values of the Calibration Parameters and Possible Ranges

Parameters	Range	Initial Value	Final Calibrated Value
1.Soil evaporation coefficient (ESCO)	0.1–1.0	0.95	0.98
2.Maximum Canopy Storage (CANMX)	0–6	0	1.89
3.Initial SCS runoff curve number for moisture condition (CN2)	25/35–98	–	Multiply by 0.4
4.Threshold depth of water in the shallow aquifer for "revap" or percolation to the deep aquifer to occur (REVAPMIN)	0–500	1	85.59
5.Baseflow alpha factor, days(ALPHA_BF)	0.1–1.0	0.025	0.0224

Notes:
1.The ranges are based on recommendations given in the *SWAT User's Manual* (Neitsch et al. 2005); the curve number range was selected arbitrarily.
2. The base flow separation analysis yielded a subsurface contribution of 64%, based on values of 0.0224 and 102.46 days for the base-flow alpha factor. The base-flow alpha factor was one of the parameters selected for calibrating SWAT.

Appendix Table 5: Days below the Requirement of New England ABF
Unit: Days

	Summer	Fall/Winter	Spring
Scenario 1: Baseline	194	17	0
Scenario 2: Conventional Agriculture	211	15	0
Scenario 3: BMP Agriculture	205	16	0
Scenario 4: Biofuel	202	15	0
Scenario 5: Suburban Medium Density	13	9	0
Scenario 6: Suburban Medium Low Density	116	11	0

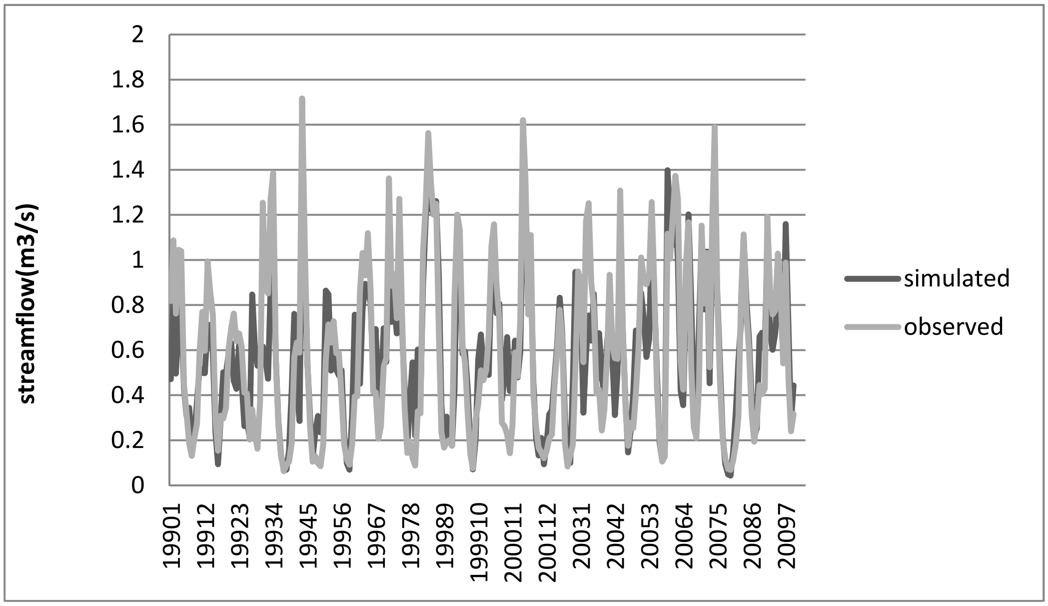
Note: Based on the New England ABF method, the streamflow for August is assumed to represent the month of greatest stress for aquatic organisms in the summer. The streamflow for fall and winter seasons was determined by averaging the medians of the monthly mean flows for twenty February months. The streamflow for spring was determined from an average of the April and May for the medians of the monthly mean flows for 20 years(Armstrong et al. 2004). The number of days below the threshold during different seasons was then calculated.

Appendix Table 6: Percent below the Requirement of New England ABF
Unit: Percent

	Summer	Fall/Winter	Spring
Scenario 1: Baseline	31.3%	3.0%	0.0%
Scenario 2: Conventional Agriculture	34.0%	2.7%	0.0%
Scenario 3: BMP Agriculture	33.1%	2.9%	0.0%
Scenario 4: Biofuel	32.6%	2.7%	0.0%
Scenario 5: Suburban Medium Density	2.1%	1.6%	0.0%
Scenario 6: Suburban Medium Low Density	18.7%	2.0%	0.0%

Note: Based on the New England ABF method, the streamflow for August is assumed to represent the month of greatest stress for aquatic organisms in the summer. The streamflow for fall and winter seasons was determined by averaging the medians of the monthly mean flows for twenty February months.; The streamflow for spring was determined from an average of the April and May for the medians of the monthly mean flows for 20 years(Armstrong et al. 2004). The percent of days below the threshold during different seasons was then calculated.

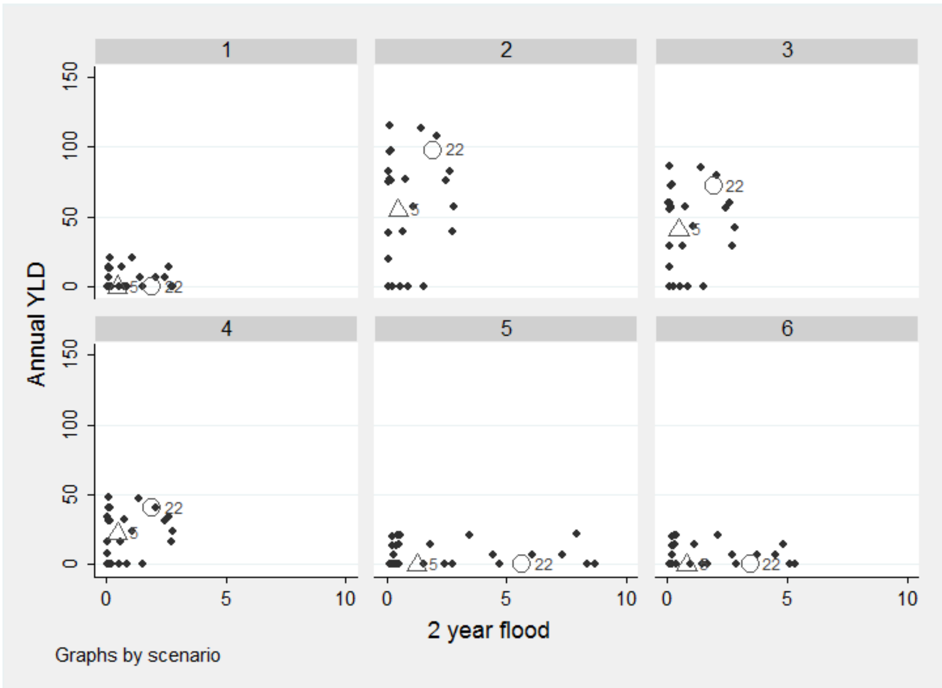
Appendix Figure 1. Annual Simulated vs. Observed Streamflow during the Calibration Period (1990–2000) and Validation Period (2001–2010)



Appendix Figure 2: Median Monthly Average Daily Flow (20 Years), Baseline Flow vs. Climate Change, *Scenario 7*.

Appendix Figure 3. Tradeoff between Crop Yield (vertical axis, annual yield of crop, unit Tons/ha) and Flood Risk (horizontal axis, 2 year flood, unit Cubic meter per second) in Different Scenarios.

Tons/ha

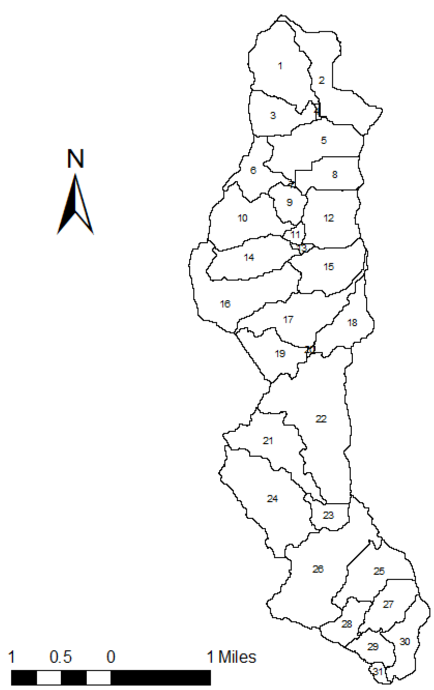


Scenarios: (1) Baseline, (2) Conventional Agriculture, (3) BMP Agriculture, (4) Biofuel, (5) Suburban Medium Density, and (6) Suburban Medium Low Density.

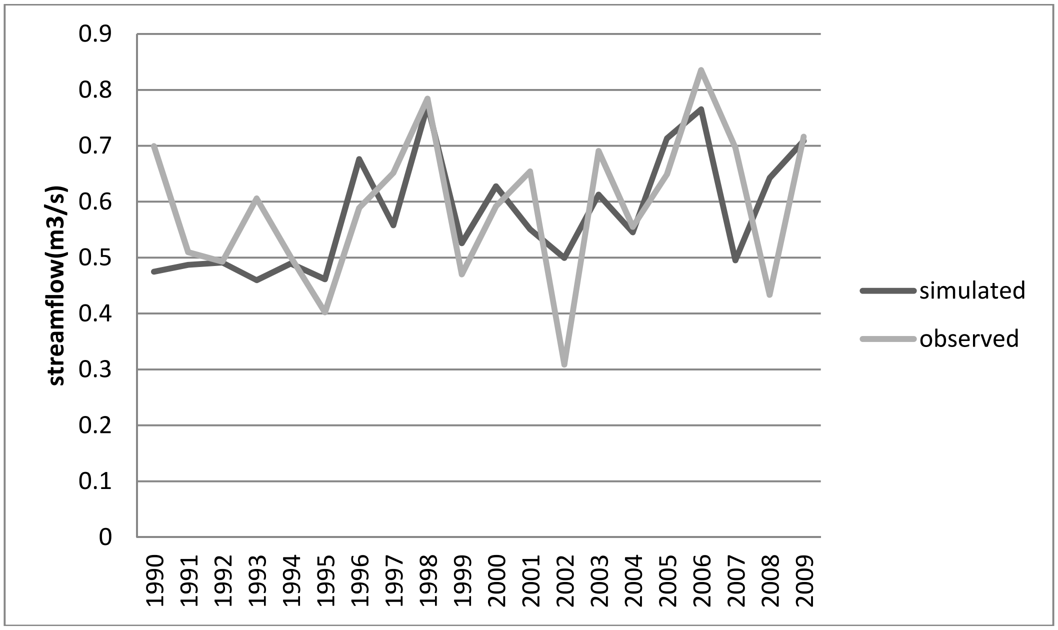
Cubic meter per

Note: Each point represents a unique subbasin.

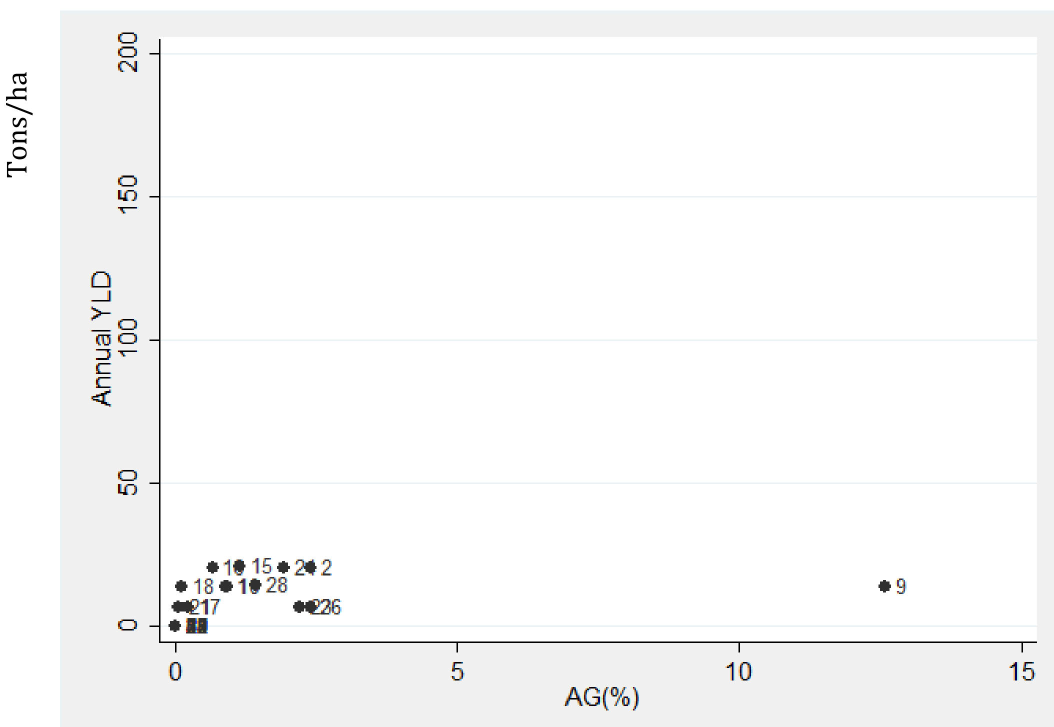
Appendix Figure 4. Subbasin Map of the Beaver River Watershed, RI



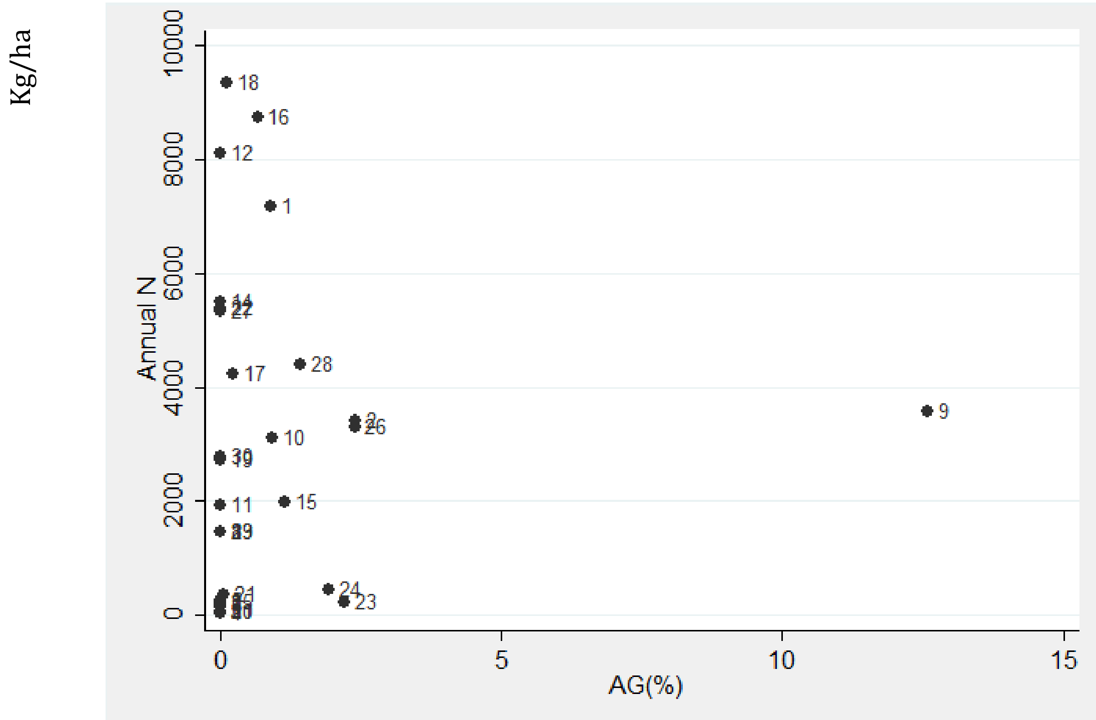
Appendix Figure 5. Annual Simulated vs. Observed Streamflow during the Calibration Period (1990–1999)



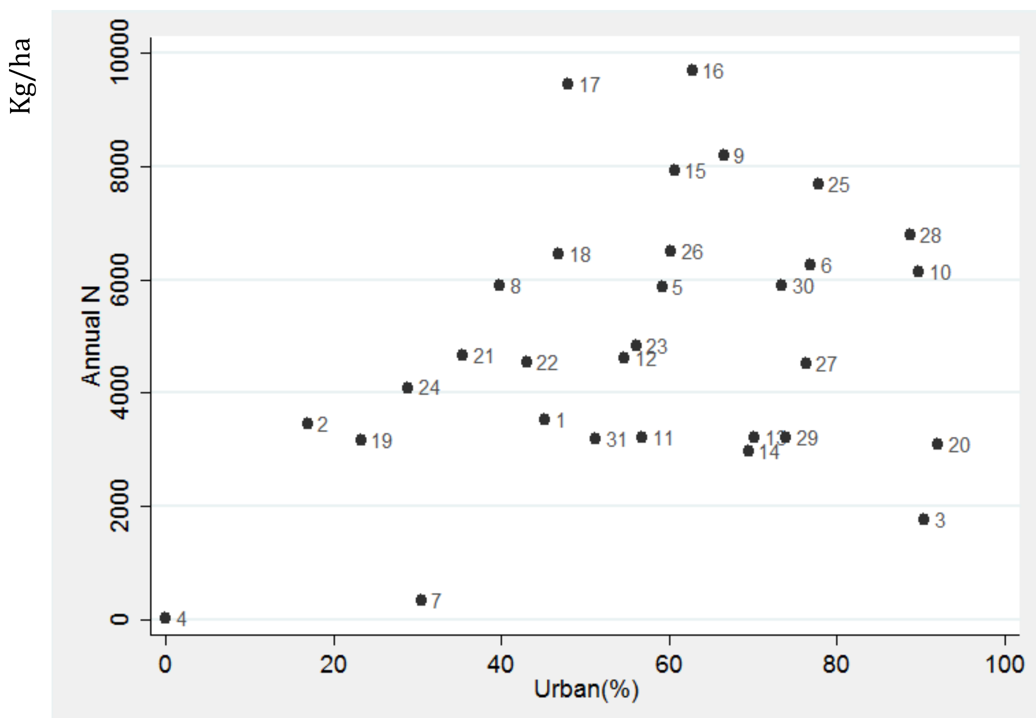
Appendix Figure 6. Annual Crop Yield (vertical axis, annual yield of crop, unit Tons/ha) vs. Percentage of Agricultural Land under Baseline *(Scenario 1)*



Appendix Figure 7. Annual Nitrogen Loading (vertical axis, annual N, unit Kg/ha) vs. Percentage of Agricultural Land under Agricultural Scenarios (Scenario 2–4: Conventional Agriculture, BMP Agriculture, and Biofuel respectively)



Appendix Figure 8. Annual N Loading (vertical axis, annual N, unit Kg/ha) vs. Percentage of Urban under Suburban Medium Density Residential Scenario (Scenario *5*).



Appendix Figure 9. Annual P Loading (vertical axis, Annual P, unit kg/ha) vs. Percentage of Urban under Suburban Medium Density Residential Scenario (Scenario *5*).