Describing Ecosystem Complexity through Integrated Catchment Modeling Using SWAT

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Abstract: Land use and climate change have been implicated in modifying ecosystem services, i.e., water quality and water yield, biodiversity, and agricultural production. The prediction of ecosystem services expected under future land use decisions and changing climate conditions has become increasingly important. Complex policy and management decisions require the integration of physical, biological, economic, and social data over several scales to assess effects on natural resource availability and use.

Field-based meteorology, hydrology, soil physics, plant production, solute and sediment transport, economic, and social behavioral data were measured. Results from individual local-scale models provide identification of sensitive parameters, which are then incorporated into a large-scale semi-distributed SWAT watershed model. This study illustrates how research can be structured to analyze complex ecosystems and landscapes where cross-disciplinary linkages benefit the end result.

The field-based and modeling framework is applied in scenarios to examine potential impacts of spatial and temporal changes in land use practices and climatic shifts on water quantity, water quality, and sediment transport. An extension of the work will include agricultural production and greenhouse gas emissions. Evaluation of such scenarios will contribute to the understanding of the relationships between individual and policy-driven land management, and the values of that can be sustainably obtained for stakeholders.

Keywords: *climate change; extreme events, Haean Basin, mountainous watersheds, soil erosion, water quality*

1. Introduction

A coupled hydrological and crop production model is an efficient approach to simulate the interactive effects of catchment physical characteristics, agricultural practices, and weather inputs on water yield, biogeochemistry, sediment transport and agricultural economic gains. Crop cover can have a substantial influence on the water balance via influences on precipitation interception, evaporation, transpiration, soil moisture redistribution, and temporal variation in surface runoff associated with crop development. The effects of land use change, including deforestation (Forti et al., 1995), agricultural intensification (Berka et al., 2001), yearly variations in agricultural land use (Tilman et al., 2002), and construction of roads, culverts, and sediment detention ponds (Foirman and Alexander, 1998), on stream discharge and water quality occur at a variety of spatial and temporal scales. Deforestation significantly affects streamflow characteristics (Calder, 1992) by increasing erosion, while decreasing soil moisture and soil nutrient concentrations. Agricultural intensification affects surface runoff by altering infiltration, evaporation, and timing of runoff. These effects are compounded by double cropping systems which substantially change leaf area index, infiltration and runoff patterns (Calder, 1992). As agricultural land use increases, the need for water resources increases, particularly at higher elevations, and water management becomes an increasingly important factor in obtaining desired ecosystem services.

In Haean Catchment in South Korea, surface water flow may be entirely depleted over extended stretches of smaller streams, or a constant pumping is carried out from shallow aquifers. Previous research has indicated that seasonal precipitation as well as individual events influence the hydrologic flushing of organic materials from the land surface (e.g., Park et al., 2010), and are correlated with dilution of dissolved ions in surface water as found for many other locations (cf. Murdoch et al., 2000). Water quality depends as well on erosion processes as a function of topography, land use, and management. To estimate sediment transport, runoff and soil loss from individual crops under particular management practices is critical to understanding sustainable resource use in this mountainous site known for quality vegetable production during summer.

Calibrated simulation models are useful for understanding management practices and evaluating the consequences of land use as well as climate change (Pieri et al., 2007). While understanding temporal and spatial dynamics in nutrient and sediment transport as a function of land use is the goal of this project, water distribution is the primary control on this transport. Several papers in this proceedings discuss nutrient dynamics (cf. Bartsch et al. and Park et al.) and sediment transport (Arnhold et al., 2011). The focus of this paper is on hydrologic processes and catchment-wide simulation modeling of water flows.

2. Study Area

The Haean Catchment study area is located in Yanggu Province, northeastern South Korea along the demilitarized zone (DMZ) between South and North Korea (Figure 1). The 62.7 km^2 catchment is one of the primary areas inputting agricultural runoff to Lake Soyang, which is a major drinking water source for urban areas and the city of Seoul, and ultimately to the Han River. The catchment has unique physiographic characteristics, climate and elevation variation. Elevation ranges between 339 to 1320 m with an average slope of 28.4% and maximum slope of 84%. Geologically, the “punchbowl” shaped basin is composed of Precambrian Gneiss at the higher elevations with Jurassic biotite granite intrusion that was subsequently eroded in the central portion of the catchment (Kwon et al., 1990). The basin has a monsoonal climate with an average temperature of 8.65±0.35˚C and ranging between -26.9˚C in January to 33.4˚C in August. Rainfall is focused during the monsoonal period between the months of June and July with 50% on average and up to 70% of the total annual precipitation. The average annual rainfall over the past 12 years is 1514 mm and ranged between 930 to 2299 mm/yr. Maximum precipitation has been as high as 48.6 mm/hr or up to 223.2 mm/d. The average catchment outlet discharge is 37 m^3/s with an observed maximum of 258 m^3/s in August 2010 and low flow typically around 3 m^3/s.

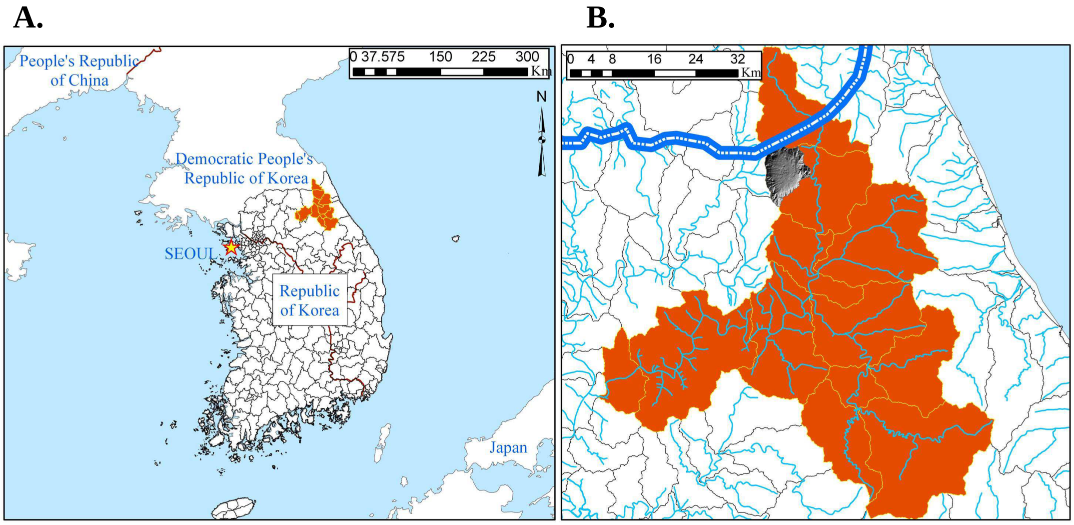

Figure 1. A. Soyang Lake Watershed location. B. Haean Catchment as a contributing area in the Soyang Lake Watershed (gray area) in northeastern South Korea just along the border with North Korea (DMZ shown in blue)

The Haean Catchment was selected for intensive survey due to intensive agricultural land use and high levels of non-point source export of nutrients and sediments. Agricultural production has substantially encroached on the surrounding higher elevation oak dominated forests. With the loss of upper elevation forests, coupled with soil additions during farm management procedures, considerable sediment transport and elevated erosion rates occur. Additionally, nutrient additions, flow management, and construction activities have significantly altered the hydrology and nutrient loading characteristics of the catchment.

3. SWAT Hydrological Modeling

3.1 Model Description

SWAT is a physical, process-based, continuous time, semi-distributed model designed to assess the long term impact of land management on water balance, sediment transport, and non-point sources of pollution in large river basins (Arnold et al., 1998). The basic model inputs are rainfall, maximum and minimum temperature, radiation, wind speed, relative humidity, land cover, soil distribution and elevation (DEM). SWAT input and pre-processing is simplified with the ArcSWAT interface. The spatial unit is the sub-catchment and the Haean watershed is subdivided into 121 sub-catchments. Sub-catchments are further divided into 2515 smaller hydrologic response units (HRU) that are representative of individual land use, soil type, and slope characteristic units. Most soil and aquifer computations are completed at the HRU scale but not spatially referenced (semi-distributed model). In-stream nutrient transformations, adapted from QUAL2E, are simulated in SWAT. The discharge, nutrient fluxes, and sediment fluxes from each HRU are accumulated within each sub-basin and allocated to the main reach of the sub-basin. Discharge and other fluxes are routed through the Muskingum river routing method within the stream network from one sub-basin to another and ultimately to the catchment outlet.

This project attempts to link fluid flow, water quality, sediment transport, ecosystem variability, plant production, agricultural yield, land management, and economic incentives through a common system. The SWAT modeling components include: weather inputs, hydrologic patterns, erosion and sedimentation, soil temperature, plant growth, nutrient transport, pesticide distribution, and land management. Because fluid flow controls sediment and nutrient transport and provides habitat required for different ecosystems, accurate parameterization of the hydrologic components may be the most critical requirements for successful simulation studies.

Hydrologic components of SWAT include precipitation, canopy storage, surface runoff, infiltration, soil moisture redistribution, evapotranspiration, subsurface flows, tributary channels, and groundwater return flow.

- Precipitation - Hourly precipitation is provided as an input from the spatially distributed meteorological stations located throughout the catchment.
- Canopy storage - The maximum canopy storage at any time in the land use growth cycle can be computed as a function of the leaf area index. Water moving to the atmosphere is removed first by evaporation from canopy storage and then via evapotranspiration.
- Evapotranspiration - Evapotranspiration in SWAT is based on Penman-Monteith potential evapotranspiration (PET). Actual ET is calculated from PET after plant canopy intercepted rainfall is evaporated, the maximum amount of transpiration is removed, and soil evaporation is estimated. PET is limited by evaluation of the leaf area index specified for an individual HRU. Estimated ET for the Haean deciduous forest type is shown in Figure 2.

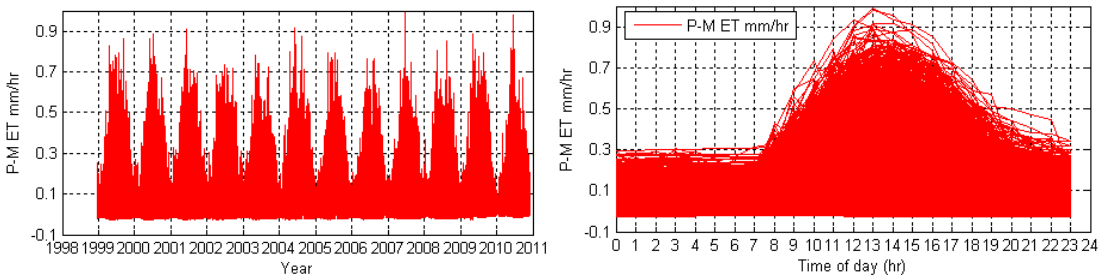

Figure 2. Representative estimates of ET using the Penman Monteith method for the deciduous forest, which encompasses nearly 60% of the Haean Catchment. Average hourly ET was 0.1 mm/hr or 2.0 mm/d throughout the13 year period.

- Infiltration – The Green and Ampt (1911) infiltration method can be used to directly model infiltration or the modified SCS Curve number method (USDA-SCS, 1972) can be used where infiltration is the calculated difference between rainfall and runoff.
- Soil moisture - Lateral flows are estimated via a kinematic storage model applied over an elevation gradient.
- Lateral subsurface flow - Water that infiltrates the soil follows several pathways including plant uptake, evaporation, percolation to recharge the shallow aquifer, and lateral flow contributing to stream discharge. Infiltration or percolation through soil layer profiles is calculated via a storage routing methodology.
- Return flow from groundwater - Aquifer flow between sub-basins is computed based on a hydrological gradient in SWAT and is dependent on the water table and baseflow recession constant defined for each sub-basin. Groundwater in SWAT is separated into shallow and deep aquifers. The shallow aquifer water balance includes recharge to the aquifer, lateral groundwater flow, main channel baseflow return, return to the soil zone due to water deficiencies, and water removed due to pumping. The deep aquifer includes percolation from the shallow aquifer and deep groundwater pumping.
- Surface runoff – In the land phase of the hydrologic cycle, surface runoff is predicted separately for each HRU using the modified SCS curve number method, which is a function of soil permeability, land use, and antecedent moisture condition.
- Tributaries - Tributaries drain a portion of the subbasin and are routed to the subbasin main channel. Transmission losses can be simulated in tributaries, although groundwater inputs are not routed into tributaries.
- Channel routing – The Manning equation for uniform flow is used to calculate the flowrate and velocity in each sub-basin reach for a given time step. SWAT then routes streamflow downstream using the Muskingum

river routing method (Chow et al., 1998), which is a variation of the kinematic wave model. Routing in the stream channel is divided into water, sediment, nutrients, and organic chemical routing (Neitsch et al., 2002). In flow routing, SWAT accounts for losses due to soil moisture redistribution, evaporation, streambed transmission loss, and diversions and additions from main channel precipitation and point sources discharges.

- Soil erosion –SWAT uses the Modified Universal Soil Loss Equations (MUSLE) to compute soil erosion in individual HRUs. It uses the runoff energy to detach and subsequently transport sediment (Williams and Berndt, 1977).

3.2 SWAT Input Data Sources

3.2.1 Weather and Climatological Datasets

Meteorologic data was collected from a station operated by the Korean Meteorological Agency (KMA) that has been in operation since 1998 near the center of the catchment. Weather data was also collected at up to 15 TERRECO maintained meteorological weather stations located throughout the watershed since 2009 and 2 individual eddy flux towers installed in 2010 (Figure 3). Rainfall monitored with a tipping bucket was provided at each station. The only subdaily weather data available in SWAT is precipitation, which is then used to simulate hourly peak flow rates. The remainder of the micro-meteorologic data collected includes temperature (maximum and minimum), solar radiation, relative humidity and wind speed and is input into the model on a daily time step.

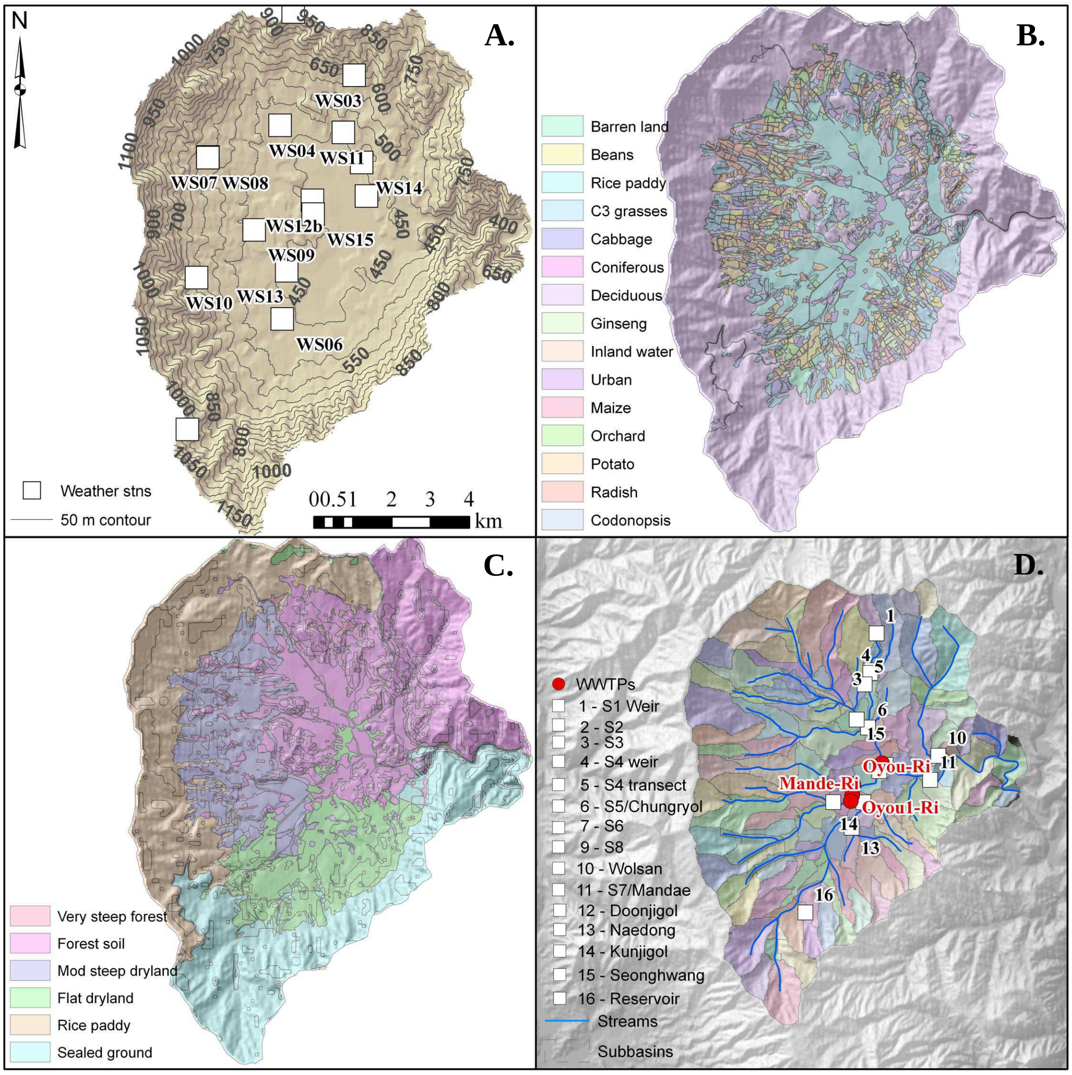

Figure 3. A. DEM with TERRECO weather station locations, B. 2009 land use, C. 2009 soil types, and D. sub-basin discretization, river network, waste water treatment plant locations (WWTP), and surface water monitoring locations

3.2.2 DEM, Land Use, and Soil Classes

A 30 m^2 DEM provided by the Korean Ministry of Development was used to delineate 121 sub-basins in Haean and provide the stream network. A subsequent stream network was used to refine the actual stream network which does not agree with the elevation based DEM (Figure 3). This is reasonable in highly managed catchments similar to Haean and improves hydrologic segmentation and boundary delineation.

Extensive field-based classification of up to 100 classes was observed for each year between 2009 and 2011 in Haean Catchment (Seo et al.). The 2009 SWAT model land use is based on 16 LULC classes obtained by reduction of the field-based survey (Figure 3). The catchment area is divided into the following percentages: deciduous forest (56%), rice paddy (14%), C3 grasses and barren land (9%), cabbage (5%), potato (4%), radish (3%), beans (3%), urban and residential (2%), orchard (1%), and ginseng (1%), while the remaining 2% includes corn, *Codonopsis*, coniferous forest, and inland water.

Soil data was originally obtained from the development ministry at 1:25000 scale and based on a single layer. This data was coupled with extensive field-based soil profiles collected throughout the catchment in 2009 through 2011 to capture higher spatial resolution heterogeneity and depth dependant variability. Soil samples were discretized in up to 5 individual layers for 6 individual soil types and include estimates of soil bulk density, available water content, hydraulic conductivity, clay, silt, sand and rock fractions, soil albedo, and USLE K values. The USLE K value was calculated after Williams (1995) and based on soil texture and organic carbon content. The hydraulic conductivity of the rice paddy and other hydrological soil group profiles was predicted by the Rosetta model based on soil texture and bulk density information (Figure 3).

3.2.3 Monitoring Sites, Management and WWTPs

Discharge data was collected at up to 14 catchment locations (Figure 3) at different times from 2003 up to 2011. The contributing drainage areas range from 0.1 km^2 to the entire 64 km^2. Measured discharge has included: in-stream flow, solute tracers, acoustic Doppler current profiles (ADCP), timed volume and velocity methods, manning calculations, and installed weirs. At each location, multiple methods have been used and compared to create weighted discharge relationships for each location. At each location, a pressure transducer was also installed to continuously monitor the river stage. Subsequent stage/discharge rating curves have been produced for continuous estimates of discharge. These same monitoring sites have been used to collect nutrient and sediment samples since 2003. Figure 4 presents a series of example hydrographs that increase with elevation through the catchment and a 5 min “closeup” of the peak hydrograph correlation for an example storm on August 13, 2010.

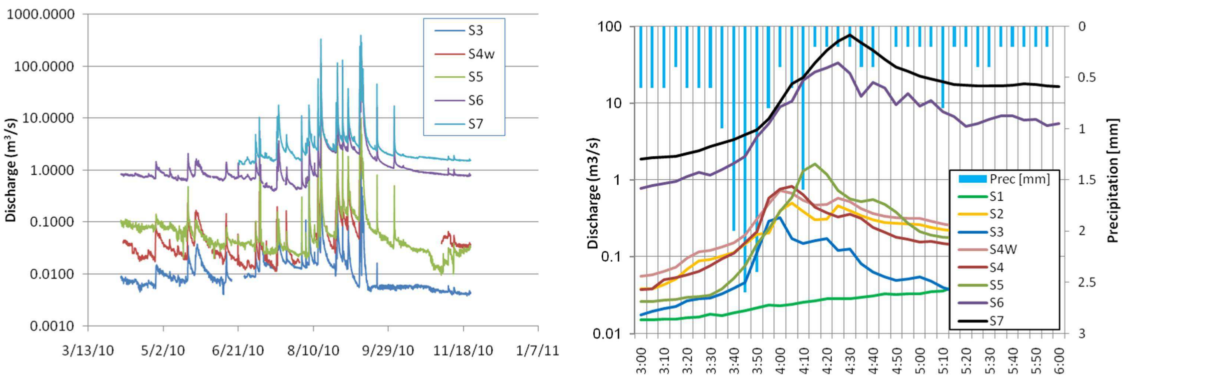

Figure 4. Continuous discharge collected along an elevation gradient throughout the catchment and 5 min continuous hydrograph data collected during a peak event on 13 August, 2010

Agricultural practices in the Haean Catchment have been surveyed between 2009 through 2011 by farmer interviews, field observations, regulatory agency information, and published literature. Agriculture management information required for simulations includes the timing and intensity for: sowing, tillage, irrigation, fertilizer application, crop harvest. The temporal schedule of management has been converted and is based on heat units. The inputs used in the model are presented in Appendix A. Irrigation practices are only observed for orchard crops and rice paddy fields. While every attempt has been made to characterize the management practices, observations suggest that irrigation and fertilizer amounts vary widely between crops, over different years, and between farmers. Some uncertainties remain, particularly regarding the dates of fertilizer applications and management between plots. Four waste water treatment plants are currently operational in Haean and are indicated in Figure 2.

4. Modelling Results and Discussion

4.1 Parameter Sensitivity Analysis

After model construction was completed, parameter sensitivity was carried out to guide the subsequent calibration procedure. The sensitivity analysis is used to explain how variations in model output can be attributed to and weighted through model inputs. A suite of parameter variables controlling hydrological conditions were individually analyzed by comparing the effect on simulated discharge. Several parameters were found to be sensitive relative to in-stream discharge; however, only the 10 most sensitive parameters are given in Table 4.

Table 4. SWAT parameter sensitivity analysis

Rank	Parameter	Description	Default	Lower Bound	Upper Bound	Mean Modeled
1	ALPHA_BF	baseflow recession constant (days)	0.048	0	1	1.27
2	CH_K2	effective hydraulic conductivity in the main chanel alluvium (mm/hr)	0.000	0	150	0.27
3	CH_N2	mannings "n" value for the main channel	0.050	0	1	0.21
4	GWQMN	threshold depth of water in the shallow aquifer required for return flow (mm H2O)	0.000	-1000	1000	0.20
5	SOL_Z	depth from soil surface to bottom of layer (mm)	user	-25	25	0.06
6	ESCO	soil evaporation compensation factor due to capillary action, crusting, and cracks (watershed or hru level)	0.000 / 0.950	0.01	1	0.05
7	CN2	initial SCS runoff curve number for moisture condition II	user	30	98	82.00
8	CANMX	maximum canopy storage (mm H2O)	0.000	0	10	0.02
9	REVAPMN	threshold depth of water in the shallow aquifer required for "revap" or percolation to the deep aquifer (mm H2O)	1.000	-100	100	0.02
10	BLAI	maximum potential leaf area index	user	0	1	0.02

4.2 Calibration

Model calibration was completed under both baseflow and peak discharge conditions for 3 years (2008-2010) with the first year used for initialization in order to assure that the model state variables have stabilized (Kirchner, 2009). Hourly weather input data and observed discharge data used for calibration was for the period of 2009. Calibration is being conducted at each monitoring location for multiple spatial scales, although the primary gauging stations used for calibration were the S1 weir in the forested headwaters and the S7 Mandae Stream outlet. Model performance was evaluated using a number of metrics including the coefficient of determination (R2), the Nash-Sutcliffe coefficient of efficiency (ENS), and the root mean square error (RMSE). The goodness of fit between observed and simulated stream flow at S7 was assessed and the R^2 was found to be 0.24 and the NSE was 0.46 (Figure 3). While the goodness of fit at this time is relatively poor, the calibration procedures provide additional information on the spatial water balance and peak discharge time of concentrations. In general, shorter time steps display worse goodness of fit than longer time steps (Moriasi et al., 2007).

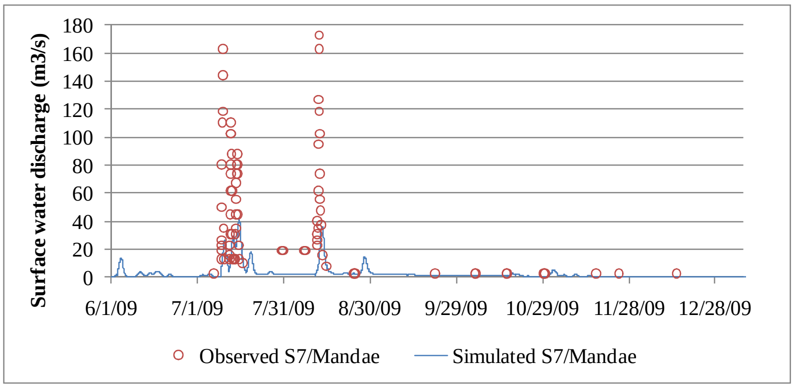

Figure 3. Observed and simulated discharge at S7/Mandae Stream outlet

4.3 Baseflow Separation

Hourly surface water discharge data at S1 and S7 were examined to estimate the baseflow contribution during both 2009 and 2010. The baseflow alpha factor or recession constant reflects the groundwater flow response to changes in recharge. The baseflow days are the number of days for the baseflow recession to decline through one log cycle and ranges from less than 1 hr to more than 16 days. The fraction of streamflow contributed by baseflow for locations S1 (0.35 km^2 drainage) and S7 (52.1 km^2 drainage) was approximately 44% and 16%, respectively. The estimated alpha factor ranges between 0.16 to 0.26 for Haean.

4.4 Validation

To determine whether the calibrated model could be used in within the Haean Catchment, the model must also have a validation period. This is achieved by using a different input and observational data than that used for calibration. In July 2011, an intensive hydrological campaign was performed to quantify temporally varying discharge and in-stream water quality at 15 spatial locations. While the observational data appears to be high quality, it has not yet been incorporated into the SWAT model for validation purposes.

4.5 Implementation of the Haean SWAT Model

Substantial difficulties are evident in the collection of representative parameter inputs such as weather, plant functions, and soil moisture. However, detailed and comprehensive field experiments coupled with a multiple method data collection approach across a range of disciplines provides a robust and comprehensive database that is being examined. Several tasks are being completed to better understand the Haean Catchment system.

- We are using synoptic water quality, water level and stage, and isotopic analysis throughout the catchment during 2011 to examine recharge components during peak precipitation events to better conceptualize our hydrologic understanding of the catchment.
- Although the project has extensive weather inputs, the uncertainty associated with location, instrumentation, and temporal variations are being explored. Spatially distributed algorithms to estimate parameters with elevation and aspect as well as, data gap filling is examined.
- Discharge uncertainty between different years is being examined to quantify and compare continuous head measurements to estimate continuous discharge.
- We are examining how the model performs over short hourly timesteps to capture peak event based discharge response on and the expected nutrient transport and sediment loading under different land use scenarios.
- The relationship between land use/ cover change and stream discharge and water quality appears to be significant in the Haean watershed and will be spatially and temporally investigated.
- We are investigating the role of constructed roads, culverts, sedimentation ponds, and reservoirs in hydrologic responses and their nutrient and sediment retention and transport capacities. It appears that roads and culverts control a significant portion of surface runoff, decrease infiltration, route flow out of subbasins, change nutrient transport, and alter sediment erosion.

5. Conclusions and Recommendations

The calibrated and validated SWAT model can simulate stream discharge, nutrient loadings, and sediment transport within the Haean Catchment; however, model performance varies depending on the available observational data. Land use change and the effect on stream discharge and water quality appears to be significant in the Haean watershed and will be spatially and temporally investigated. While the focus of this manuscript has primarily been on hydrological flow, the potential of SWAT for sediment transport, agricultural chemical and crop yields, quantification of ecosystem services, and economic and power scenarios are considerable and are being explored.

Anthropogenic influences and a highly managed watershed lead to difficulties in modelling calibration and future scenarios. However, coupled physical process observations, farmer and management interviews, and cause and effect investigations are leading to significant progress in minimizing management uncertainty throughout the watershed and increasing the utility of the SWAT model to integrate many of the watershed characteristics.

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		Land Use / Land Classification	barren land	beans	rice paddy	C3 grasses	cabbage	conif forest	decid forest	ginseng	inland water	urban	maize	orchard	potato	radish	codonopsis
		Total heat units to reach maturity	2912	1710	2736	2912	2159	2896	2896	3065		2912	2999	3163	2381	1631	2833
		Baseline CN2 value for runoff estimation	98	70.3	78	98	71	53	50.5	71.5	92	76.1	69.7	58.6	71.8	71.3	40.7
Planting/Growing Season		Date	15-May	15-May	18-May	15-May	20-May	22-Apr	22-Apr	3-May		26-May	5-May	30-Apr	25-Apr	1-Jun	30-Apr
		Heat Units	(607)	(607)	(645)	(607)	(681)	(309)	(309)	(414)		(437)	(447)	(372)	(329)	(870)	(372)
		Initial age of trees (yrs)						40	40					10			
		Initial LAI			0.2			0.75	0					0			
		initial dry wt biomass (kg/ha)			50			342	342					100			
		fraction biomass->residue						0.05	0.05	0.05				0.05			0
Auto Irrigation		Initial Date			19-May									5-May			
		Initial Heat Units			(663)									(400)			
		auto irrigation based on:			SW Content									plant water demand			
		when irrigation is initiated			< 1.0 (constant)									< 0.68			
Fertilizer	1	Date (2d before plant)		13-May	16-May		18-May			1-May			3-May	28-Apr	23-Apr	30-May	30-Apr
		Heat Units (2d before plant)		(577)	(619)		(645)			(386)			(414)	(350)	(315)	(839)	(372)
		Fertilizer (N-P2O5-K2O) ratio		(3-3-3.2)	7.2-7.7-6.5)		(8.3-3-3.9)			(6-9.6-7.9)			(8-7.1-4.5)	(2-3.5-1)	3.7-3.3-11.	(8.8-3-3.4)	(4.2-6-6)
		Fert_KG (kg/ha)		3450	2300		3600			4680			3160	2870	3300	3400	~3200
	2	Date (manure 2d before plant)		13-May	5-Jun		18-May			1-May			3-May	28-Apr	23-Apr	30-May	30-Apr
		Heat Units (manure 2d before plant)		(577)	(941)		(645)			(386)			(414)	(350)	(315)	(839)	(372)
		Fertilizer ID (dairy fresh manure)		yes	*(1.8-0-0)		yes			yes			yes	yes	yes	yes	yes
		Fert_KG (kg/ha)		12000	200		15000			12000			10000	10000	10000	15000	15000
	3	Date (35d after plant)			18-Jun		20-Jun									1-Jul	15-Jun
		Heat Units (35d after plant)			(1160)		(1201)									(1443)	(1107)
		Fertilizer (N-P2O5-K2O) ratio			(1.8-0-0)		(15.5-0-3.2)									(16.4-0-3.4	(1.8-0-0)
		Fert_KG (kg/ha)			200		720									1500	~1500
	4	Date (35d after plant)			30-Jun												
		Heat Units (35d after plant)			(1422)												
		Fertilizer (N-P2O5-K2O) ratio			(1.8-0-2.8)												
		Fert_KG (kg/ha)			500												
	5	Date (35d after plant)			12-Jul												
		Heat Units (35d after plant)			(1663)												
		Fertilizer (N-P2O5-K2O) ratio			(1.8-0-2.8)												
		Fert_KG (kg/ha)			500												
Tillage	1	Date (14d before plant)		1-May	4-May		6-May			19-Apr			21-Apr	16-Apr	11-Apr	16-May	
		Heat Units (14d before plant)		(386)	(431)		(463)			(286)			(304)	(251)	(211)	(619)	
		Tillage ID (Rotary Hoe 15-25cm)		Rotary Hoe	Rotary Hoe		Rotary Hoe			Rotary Hoe			Rotary Hoe	Rotary Hoe	Rotary Hoe	Rotary Hoe	
		CN2 value due to tilling		70.3	78		71			71.5			69.7	58.6	71.8	71.3	
	2	Date (2d before plant w/ fert)		13-May	16-Jun		18-May			1-May			3-May	28-Apr	23-Apr	30-May	
		Heat Units (2d before plant w/ fert)		(577)	(620)		(645)			(386)			(414)	(350)	(315)	(839)	
		Till ID (furrow-out cultivator 15-25cm)		Cultivator	Roller		Cultivator			Cultivator			Cultivator	Cultivator	Cultivator	Cultivator	
		CN2 value due to tilling		70.3	78		71			71.5			69.7	58.6	71.8	71.3	
Harvest only leave residue		Date		12-Aug	15-Oct		20-Jul			25-Oct			22-Oct	30-Oct	31-Aug	20-Aug	
		Heat Units		(2317)	(3381)		(1840)			(3479)			(3446)	(3535)	(2710)	(2501)	
		CN2 value due to harvesting		70.3	78		71			71.5			69.7	58.6	71.8	71.3	
		Harvest yield as percentage of biomass		0.31	0.5		0.8			0.55			0.5	0.1	0.95	2	
Harvest biomass only		Date HUSC															3-Nov
		Date															(3205)
		Heat Units															1.13
End of growing season		Date	31-Oct			31-Oct		28-Oct	28-Oct			28-Oct					
		Heat Units	(3519)			(3519)		(3494)	(3494)			(3494)					

each land use/crop type is modeled as a single crop throughout the year and not a double cropping system.
all time variable management operations are modeled as the same for each of 12 years

Shope – SWAT Model