CHAPTER 3
PILOT SCALE MODELS

Background

Prior to the investment of collecting large amounts of data for the full-scale modeling effort of the entire basin, it was decided that SWAT would be tested at a pilot scale level to ensure that the model could meet the goals and expectations of the project. Specifically, the accuracy of SWAT predictions in respect to phosphorus loads needed to be verified.

Pilot watersheds were selected to test and verify the model's capability to accurately predict sediment and phosphorus loads. The criteria for selecting the pilot watersheds included: 1) size (less than 90 square miles), 2) completeness and availability of flow gaging and water quality data, and 3) minimal influences from dams, lakes, and point sources on hydrology and water quality within the watershed. Only three gaging stations within the basin had long-term water quality records: 1) Yahara River at Windsor (USGS Station No. 5427718), 2) Pheasant Branch at Middleton (USGS Station No. 5427948), and 3) Jackson Creek at Mound Rd. near Elkhorn (USGS Station No. 5431016). Of these, it was decided that Pheasant Branch would not be used because of the amount and rate of urbanization within its watershed in recent years. Pilot scale models were created for the remaining two locations:

- <u>Jackson Creek at Petrie Road</u>: 8.96 square miles in size composed of 4% urban, 76.4% agriculture, 8% grassland, 8% forest, and 4% wetlands. This area was modeled as one sub-watershed subdivided into several HRUs representing the smallest unit the Rock River Basin will be subdivided into.

- Yahara River at Windsor: 73.6 square miles in size and is composed of 7% urban, 72.5% agricultural, 7% wetlands, and 9% grasslands. This area was broken down into five sub-watersheds each further subdivided into HRUs.

During the generation of the pilot scale models, *Excel*™ macros (programs within *Microsoft Excel*™) were developed to allow for automated generation of input files. Routines for generation of soil, land use, and pond-wetland files were created. The automated generation of input files allowed for rapid creation of input files from spreadsheets. In turn, the spreadsheets were used to manipulate variables for calibration and sensitivity analysis.

Jackson Creek at Petrie Road:

<u>Data Collection</u>

Jackson Creek at Petrie road was selected as the first area to be modeled because it encompasses one sub-watershed - the smallest scale at which the Rock River Basin will be geographically subdivided (Note: HRUs are the smallest unit, however, HRUs do not have defined geographic boundaries). Jackson Creek has flow data available for 1984 through 1995 and sediment and phosphorus data for 1984 to 1985 and 1994 to 1995. Flow, sediment, and phosphorus data were divided into calibration and validation data sets. The validation data set was then set aside and only used to validate the model. The USGS helped select the calibration and validation periods based on the distribution of high, normal, and low flow years.

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Data collected for Jackson Creek was consistent with the process to be used in the entire basin. The same level of effort was maintained in both the pilot scale and full-scale modeling. A meeting with the Walworth County Land Conservation Department (LCD) was arranged to fill in gaps in the WISCLAND coverage. Due to satellite imagery problems, land use in a portion of Walworth County was only delineated as agricultural, forest, wetland, or urban with a considerable area classified as unknown or barren. This is not consistent with more detailed level of WISCLAND classification available for the rest of the basin. The LCD was able to distinguish the agriculture land use into corn grain (cash crops), corn silage and forage (dairy rotations), and other row crops. Based on this, the sub-watershed was divided into 6 HRUs based on the cropping rotations. Wetlands and ponds were simulated using the "*.pnd" routine within SWAT.

For the pilot areas, HRUs were generated based on cropping practices. For the full-scale modeling, HRUs were also determined by using tillage once the transect survey data became available (see Chapter 4). Based on information provided by the LCD, it was assumed that the cash crop rotations used conservation tillage (simulated with chisel plow) and the dairy rotations used conventional tillage (simulated with moldboard plow). Urban areas were not simulated because of the small percentage of urban present in the sub-watershed (less than 4%). Land classified as urban was distributed among the dominant agricultural land uses.

The beta test version of the AVSWAT interface was used to automate the delineation of sub-watersheds. The AVSWAT delineation was checked against a manual delineation using USGS quads and a second delineation that was provided by the USGS. All three compared well with only slight variances. The AVSWAT interface was not used to generate the HRUs because it could not accurately account for crop rotations in its assessment. HRUs were generated using a series of spreadsheets and based on cropping practices.

Soils data was obtained from the STATSGO database and averaged by sub-watershed. Climate data was obtained from the closest available station, located at Lake Geneva, WI.

<u>Calibration and Sensitivity Analysis</u>:

Once the model input was generated for Jackson Creek, calibration in conjunction with sensitivity analysis was performed. Earth Tech performed sensitivity analysis for model parameters indicated as being "critical" or sensitive by Paul Baumgart's work on the Fox-Wolf Basin in Wisconsin and based on advice from Dr. Arnold (the SWAT developer).

<u>Evapotranspiration</u>

Initial sensitivity analysis was performed on the evapotranspiration (ET) routines. SWAT allows for the user to select between three ET routines: (1) Penman-Monteith, (2) Hargeaves and Samani, and (3) Priestly-Taylor. The Penman –Monteith method requires solar radiation, air temperature, wind speed, and relative humidity. The Priestly-Taylor method requires solar radiation and air temperature as input, while the Hargreaves method requires air temperature only. SWAT generates values for solar radiation, wind speed, and relative humidity using statistical data from the weather generator input file (*.wgn file). Several variables in the ET equations were evaluated. These variables include ESCO (controls soil evaporation), EPCO (controls plant uptake of moisture to account for root density), and ETCO (controls extent from which water can be drawn from the soil based on wilting point). All three of these variables influence the amount of water available for runoff or lost due to ET. The higher the amount of water lost to ET, the less there is available for runoff and vice versa.

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In addition to the specific parameters, the three ET options within SWAT (Priestly-Taylor, Penman-Monteith, and Hargreaves) each produced a different result for the same given inputs. Earth Tech originally selected Hargreaves because of its reliance on only temperature as input. Hargreaves seemed to produce good results. Paul Baumgart reported problems when he tried to utilize it around the Green Bay area, however the Hargreaves method seemed to be generating adequate results for southern Wisconsin and was thus utilized for the Rock River Basin. Results of the ET analysis are summarized in Appendix B.

Groundwater influences in Jackson Creek seemed minimal, thus not a great deal of effort was spent on groundwater parameters. Most of the effort was spent on the ET variables and fine tuning the land use management files. Default soils values from the STATSGO coverage were also utilized.

Jackson Creek at Petrie Road Calibration Results

Earth Tech calibrated and validated to flow, sediment, and nutrient data for the Jackson Creek. Calibration data is presented in Table 3.1 and the validation data is presented in Table 3.2. Relative error is calculated based on the absolute value of (predicted minus measured) divided by measured times 100 to generate a percentage. Calibration and validation data for Jackson Creek at Petrie Road is summarized in Appendix C.

Table 3.1
Calibration Data
Jackson Creek at Petrie Road

Year	Runoff (inches)			Sediment (tons)			Phosphorus (lbs.)		
	SWAT	USGS	Rel. Error	SWAT	USGS	Rel. Error	SWAT	USGS	Rel. Error
1984	11.05	6.62	67%	1400	305	359%	2,307	2,587	11%
1985	8.89	6.66	34%	129	206	37%	1,394	2,341	40%
1986	12.25	13.25	8%	----	----	----	----	----	----
1987	6.67	5.21	28%	----	----	----	----	----	----
1988	6.18	3.76	65%	----	----	----	----	----	----
1989	5.67	2.86	98%	----	----	----	----	----	----
1990	8.12	5.72	42%	----	----	----	----	----	----
Totals:	**58.83**	**44.07**	**33%**	**1529**	**511**	**199%**	**3,701**	**4,928**	**-25%**

For Flow: R SQ. of 0.78 and COE of 0.31.
For Sediment: R SQ. of ---- and COE of –1.64.
For Phosphorus: R SQ. of ---- and COE of 0.01.

Table 3.2
Validation Data
Jackson Creek at Petrie Road

	Runoff (inches)			Sediment (tons)			Phosphorus (lbs.)		
Year	SWAT	USGS	Rel. Error	SWAT	USGS	Rel. Error	SWAT	USGS	Rel. Error
1991	6.31	4.88	29%	----	----	----	----	----	----
1992	8.09	7.78	4%	----	----	----	----	----	----
1993	12.31	17.82	31%	----	----	----	----	----	----

1994	2.82	4.39	36%	16.66	455.08	96%	314	2,683	88%
1995	5.03	4.62	9%	252.52	132.23	91%	2,186	1,232	77%
Totals:	**34.55**	**39.51**	**13%**	**269**	**587**	**54%**	**2,500**	**3,915**	**36%**

For Flow: R SQ. of 0.86 and COE of 0.41.
For Sediment: R SQ. of ---- and COE of -1.64.
For Phosphorus: R SQ. of ---- and COE of -1.37.

Earth Tech used two methods for evaluation of model predictions during the calibration and validation periods: 1) linear regression (R SQ.) and 2) the Nash-Sutcliffe coefficient of efficiency (COE). The COE measures the comparison of the actual fit to the line of perfect fit (the 1:1 line) and measures how well the measured and simulated flows correspond. Regression line slopes and R SQ. values near unity indicate a close relationship between predicted and measured yields. Predicted and measured yields were compared on an average annual basis. Negative COE values indicate that the predicted value is less than the arithmetic mean of the data set.

The calibration data set for flow produced a COE of 0.31 and the validation data set produced a COE of 0.41. The calibration data set produced an R SQ. of 0.78 and the validation data set produced an R SQ. of 0.86. The total predicted water yield for the calibration period is within 33% of the measured yield while the total predicted yield for the validation period is within 13% of the measured yield. However, the R SQ. and COE provide a better indication of the accuracy of the predicted to measured values.

An examination of the calibration and validation data indicates that for the years with high runoff, SWAT is less accurate (i.e. 1993 and 1986). The yield for other years tended to be overestimated by the model in order to obtain the best fit between high and low runoff years. Removal of 1993 (the highest runoff year) from the calibration data set improves the COE to a value of 0.53. However this same change slightly reduces the R SQ. to 0.74.

To analyze the discrepancies during high precipitation years between predicted and measured yields, Earth Tech evaluated the SWAT routines. It was found that adjustment of the "revap" coefficient significantly increased the COE of the calibration data set by increasing the surface yield. The revap coefficient controls the amount of ET. Decreasing the amount of ET increases the surface yield. Examination of 1993 revealed that the crop growth model allowed vegetation to grow at normal rates and produced inflated ET values in response to the increased precipitation. In reality, because of the wet spring, farmers were forced to plant their crops later in the growing season. This, coupled with excess moisture throughout the growing season resulted in extremely low yields corresponding to poor plant growth. This in turn produced lower ET rates and reduced vegetative cover, which increased surface yield. Earth Tech also ran additional SWAT runs for 1993 and adjusted the planting dates back to reflect the delayed planting that occurred that year. This however had little effect on the predicted yields because the model did not stunt the plant growth rate due to excess water.

Earth Tech discussed these results with Dr. Arnold (principal creator of SWAT, USDA-ARS at the Grassland, Soil and Water Research Laboratory in Temple, Texas, USA). Dr. Arnold ran into similar problems with the 1993 data while recently modeling a watershed in Iowa. Dr. Arnold also noted the model's predicted ET values were much higher than appropriate. Dr. Arnold stated that SWAT currently does not have a subroutine to reduce plant growth with water stress stemming from too much water. Dr. Arnold has been working on a subroutine to address this problem. The goal is to be able to predict within 20-30% of monitored values for wet years.

Earth Tech sent a copy of the Jackson Creek model to Dr. Arnold so that the new subroutines to reduce the ET to account for plant stress could be added.

Yahara River at Windsor:

The Yahara River at Windsor gaging site allowed for a test of the urban routines and routing routines. The calibrated model constructed for Jackson Creek was applied on the Yahara River with little or no adjustment of parameters except for slope factors, land use and associated management files, and soils. The initial results for the application of the Jackson Creek model to the Yahara River at Windsor watershed were poor. Table 3.3 provides a summary of the flows and sediment predictions for the "uncalibrated" Yahara River at Windsor watershed model generated by using the calibration parameters from Jackson Creek.

Table 3.3
"Uncalibrated" Results
Yahara River at Windsor

Year	Runoff (inches)			Sediment (tons)		
	SWAT	USGS	Rel. Error	SWAT	USGS	Rel. Error
1989	1.30	2.94	56%	----	----	----
1990	2.91	2.45	19%	----	----	----
1991	2.26	2.98	24%	33,852	1,222	2669%
1992	7.60	6.98	9%	140,614	8,539	1547%
1993	1.71	5.74	70%	37,178	2,410	1442%
1994	1.14	4.02	72%	21,986	1,135	1838%
1995	----	----	----	157,298	1,980	7843%
Totals:	**16.91**	**25.11**	**33%**	**390,927**	**15,286**	2457%

For Flow: R SQ. of 0.43 and COE of 0.30.
For Sediment: R SQ. of 0.34 and COE of 0.03.

The failure of the Jackson Creek model parameters to successfully predict flows for the Yahara illustrates that all of the parameters must be properly balanced and may not be uniformly applicable across the basin. In addition, the above results illustrate that a calibrated model does not necessarily mean it is correct. The model could be over predicting surface runoff but still predict an accurate yearly total flow because baseflow or some other parameter is being under predicted or vice versa. Errors like this can greatly affect predicted sediment and phosphorus loads and can be difficult to address without adequate data. In other words, the failure of the Jackson Creek calibrated parameters to work in the Yahara River at Windsor watershed may indicate "errors" in the calibration of the Jackson Creek model. Earth Tech began evaluating the two models by taking a closer look at the parameters and physical characteristics of the Yahara River at Windsor watershed.

Examination started with the delineation of the sub-watersheds. As with Jackson Creek, the Yahara River at Windsor watershed was delineated using the AVSWAT interface. During delineation of the Yahara River at Windsor watershed, Earth Tech noted discrepancies between the drainage area reported by the USGS and the actual area contributing to surface water flow. In some cases, USGS records indicate the size of the noncontributing areas, however, this is not always the case. The total water yields reported by the USGS in the Annual Water Resource Reports are based on the total drainage area and often include internally drained areas. In the model, inclusion of the internally drained areas produces excess runoff and exclusion of internally drained areas reduces groundwater base flow. Examination of the Yahara River at Windsor watershed revealed the presence of several large internally drained areas. These areas were not present in Jackson Creek and thus were not an issue at that location.

To identify internally drained areas, Earth Tech used a temporary coverage created by the AVSWAT interface while "filling" the sink areas. Contributing areas had to be manually verified and delineated using the DRGs (the scanned USGS quad maps). Individual sub-watersheds were delineated for large internally drained areas (i.e. the Goose Lake internally drained area located within the Yahara River at Windsor watershed). The SWAT pond/wetland function was utilized to address runoff and pollutant contribution from these discrete internally drained areas. In this manner, surface flows could be better approximated through matching actual contributing areas while allowing for increased groundwater and base flow contributions.

After identification of the internally drained areas, it became apparent that groundwater files would be critical to account for base flow, verses overland runoff. One of the shortcomings of SWAT is that water percolating to the deep aquifer is lost from the system. This is not necessarily always the case. In many cases, groundwater initially considered lost from a sub-watershed or system will re-enter at a different location. This can occur through springs or seepage. The resources do not exist to identify all spring fed water bodies and determine the contribution to flow.

During calibration of the Yahara River at Windsor watershed, sensitivity analysis was performed on the groundwater files. All parameters were evaluated with particular attention to the "critical" parameters: alpha baseflow factor, groundwater delay, and groundwater revaporation. Model documentation stated that adjustment of the alpha factor and the groundwater delay modifies only the shape of the hydrographs and not the total water yield, however, it was found adjustment of these variables did have some impact on the total yield. A starting point for adjustment of these factors was provided in the output of the baseflow separation model explained in Chapter 4.

In the Yahara River at Windsor watershed, adjustment of the groundwater files and identification of the internally drained areas allowed for a decrease in surface flow and an increase in baseflow that better matched the gaging data at Windsor. Additional adjustment of the ET equations was needed, as was adjustment of soil parameters.

The STATSGO soil coverage provides a summary of soils by association with dominant soil series summarized for each association. Thus, the variables are generalized and may require modification. A discussion of the adjustment of soil parameters is included in Chapter 4. Once soil, groundwater, and ET equations were adjusted for the Yahara River at Windsor watershed, a much better fit to gaging data was obtained. Table 3.4 summarizes the calibrated results for the Yahara River at Windsor watershed. Due to lack of data, a validation period was not possible. Individual hydrographs are included in Appendix D.

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Table 3.4
Calibrated Results
Yahara River at Windsor Watershed - Windsor Gaging Site

	Runoff (inches)			Sediment (tons)			Phosphorus (lbs.)		
Year	**SWAT**	**USGS**	**Rel. Error**	**SWAT**	**USGS**	**Rel. Error**	**SWAT**	**USGS**	**Rel. Error**
1989	2.38	2.94	19%	----	----	----	----	----	----
1990	3.74	2.45	53%	----	----	----	----	----	----
1991	3.53	2.98	18%	3,581	567	532%	17,349	6,321	64%
1992	6.65	6.98	5%	1,231	1,222	1%	15,915	7,391	54%
1993	4.61	5.74	20%	8,067	8,539	6%	29,980	38,673	22%
1994	3.15	4.02	22%	2,694	2,410	12%	20,594	21,284	3%
1995	----	----	----	1,133	1,135	0%	14,078	6,633	53%
Totals:	**24.06**	**25.11**	**4%**	**16,707**	**13,873**	**20%**	**97,915**	**80,303**	**22%**

For Flow: R SQ. of 0.74 and COE of 0.61.
For Sediment: R SQ. of 0.82 and COE of 0.75.
For Phosphorus: R SQ. of 0.95 and COE of 0.07.

The application of the Jackson Creek model to the Yahara required significant modifications. However, once modified, the sum of the annual results for 1989 to 1995 where within 4% of USGS measured values for flow, 20% for sediment, and 22% for phosphorus, however, again the R SQ. and COE should be used to assess the fit of measured and predicted values.

After the successful calibration of the Yahara River at Windsor watershed model, the model was re-applied to Jackson Creek. With slight modifications to the groundwater file, the new model generated the results similar to those of the original Jackson Creek model. Table 3.5 provides a summary of the results from the Yahara River at Windsor watershed model being applied to Jackson Creek. Note that results are not identical to the previous results for Jackson Creek (Table 3.1). Because of the need to globalize some parameters, predictions will not be as accurate as if calibrated for each individual watershed.

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Table 3.5
Calibration Results
Application of Yahara River at Windsor Model on
Jackson Creek at Petrie Road

	Runoff (inches)			Sediment (tons)			Phosphorus (lbs.)		
Year	**SWAT**	**USGS**	**Rel. Error**	**SWAT**	**USGS**	**Rel. Error**	**SWAT**	**USGS**	**Rel. Error**
1984	11.05	6.62	67%	1400	305	359%	2,307	2,587	11%
1985	8.89	6.66	34%	129	206	37%	1,394	2,341	40%
1986	12.25	13.25	8%	----	----	----	----	----	----
1987	6.67	5.21	28%	----	----	----	----	----	----
1988	6.18	3.76	65%	----	----	----	----	----	----
1989	5.67	2.86	98%	----	----	----	----	----	----
1990	8.12	5.72	42%	----	----	----	----	----	----
Totals:	**58.83**	**44.07**	**33%**	**1529**	**511**	**199%**	**3,701**	**4,928**	**25%**

For Flow: R SQ. of 0.78 and COE of 0.31.
For Sediment: R SQ. of ---- and COE of 0.09.
For Phosphorus: R SQ. of ---- and COE of 0.01.

Variations across the basin including land use, geology, and soils will all contribute to determining the hydrologic response. These variations may sometimes be subtle or immediately apparent, however, in any case, due to the lack of detailed monitoring and input data, all of these variations can not be captured by the model. Thus, the model will predict flows in some areas better (that is, closer to the monitored values) than others.

A summary of the calibration parameters adjusted for flows are included in Table 3.6. These parameters represent global variables that can be adjusted for the calibration of watersheds based on available data.

TABLE 3.6
SUMMARY CALIBRATION PARAMETERS FOR FLOW
PILOT SCALE WATERSHEDS

Input Files	Calibrated Yahara	Original Jackson	Test Jackson	Calibrated Jackson
Groundwater File (*.gw)				
Alpha Factor	0.029	0.850	0.116	0.116
Specific Yield	0.400	0.200	0.400	0.400
Groundwater Delay	500	3	500	3.0
Revaporation	0.00	0.02	0.00	0.05
Deep Aquifer Percolation	0.00	0.30	0.00	0.30
COD File (*.cod)				
ESCO1 (Soil evaporation)	1.00	0.80	1.00	1.00
EPCO1 (Plant evaporation)	0.04	0.30	0.04	0.04
ETCO1 (Evapotranspiration)	1.00	0.60	1.00	1.00
CN Adjustment	0.92	1.00	0.92	0.92
Available Water Capacity	0.95	1.00	0.95	1.00
Basin File (*.bsn)				
SMTMP (base snowmelt temp)	0.50	0.50	0.50	0.50
SMFMX (max. snow melt factor)	4.50	0.70	4.50	4.50
SMFMIN (min snow melt factor)	2.00	0.40	2.00	2.00
TIMP (snow cover temp lag time)	0.40	0.50	0.40	0.40
Albedo (soil)	0.25	0.80	0.25	0.25
Lag Time (lag time in surface flow)	4.00	12.00	4.00	4.00
Routing File (*.rte)				
Effective Conductivity	0.00	-0.10	0.00	0.00

Calibrated Yahara: The Yahara and Mendota Watershed calibrated after trying touse parameters from originally calibrated Jackson Creek model.

Original Jackson: The "original" Jackson Creek watershed calibrated and verified.

Test Jackson: The Jackson Creek watershed using "global" parameters from the Yahara modified with specific parameters determined by the baseflow separation.

Calibrated Jackson: The Jackson Creek watershed modeled by modifying mostly parameters in groundwater file.

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