Appendix A
SWAT Model Setup Process

1 Overview

This memorandum describes a methodology to ensure an efficient and consistent model setup process to implement the SWAT model for the non-pilot study areas.

Modeling in this study addresses large study areas, with an emphasis on relative change for future conditions. A simplified approach is used for land use and soils coverages to the extent possible to make this efficient. SWAT setup and calibration starts from a common land use platform representing current (calibration) conditions.

Simplifying principles include the following:

- Optimize for automated processing, taking advantage of features already built into ArcSWAT.
- Calibrate first for one 8-digit HUC, then extend to whole study area. The calibration HUC should be selected in an area with the greatest availability of hydrology and water quality calibration data. Avoid selecting a calibration HUC8 with complicating features, such as large reservoirs.
- SWAT is set up in the usual way, using an HRU overlay of land use and STATSGO soils.
- Use only weather stations already processed for BASINS 4 and supplied to the team. Account for sparse coverage by using elevation bands in areas of high relief.
- Existing impervious area is identified based on NLCD products

2 Processing Steps

2.1 Initial Setup

Initial GIS processing has been performed by Tt in ArcGIS for the whole study area. Processed GIS inputs are then used in ArcSWAT (which runs as an extension in ArcGIS).

Watershed Boundaries and Reach Hydrography

Subbasin boundaries and reach hydrography have been created from NHDPlus. In general these delineations should be sufficient for application and isolation of appropriate calibration points. Note that many river "basins" have multiple outlets, notably those adjacent to the Great Lakes or ocean shorelines.

DEM

Mosaic-ed DEMs are supplied for the full extent of the model watershed area. ArcSWAT will create a slope grid during model setup. For some of the study areas (notably those with significant shoreline adjacent to an ocean or Great Lake), the DEM extent does not fully overlap the subbasin extent, due to differences in shoreline representation in the parent spatial files. If the study area has shoreline, or if the SWAT "subbasin delineation" process fails, we recommend the following ArcGIS procedure to fill the DEM NoData "holes".

- In the Single Output Map Algebra tool, use the following statement:
  con(*grid*>0,*grid*,0)
  where *grid* is the name of the DEM.
- Before executing the tool, in the Environments section set the extent to the subbasin shapefile.
- The procedure will replace NoData cells with 0 inside the subbasin extent, but not beyond. The error associated with using 0 is likely to be minimal and not adversely affect model setup.

Land Cover and Soils

1. Clipped NLCD 2001 Land Cover is provided for the extent of the model watershed area. The grid files have been modified to include four reclassified cells in each subbasin. These cells and their values are used as placeholders for updating developed land cover in future scenarios. You must use the land cover grid ending in "*_sw*" for SWAT applications.
2. NLCD 2001 Urban Imperviousness bas been analyzed to calculate developed class impervious area. This is provided in an Excel spreadsheet.
3. STATSGO soils grids are provided with ArcSWAT.

Other Data Provided

4. BASINS4 weather stations in proximity of model watersheds. Weather stations from this set must be used to enable climate updates for the scenarios. The locations are provided within the SWAT precipitation and air temperature input files on the project FTP site. ArcSWAT will create shapefiles for the weather stations during model setup.
5. Locations of major point sources are provided in an Excel file.
6. Shapefiles with locations of long-term gaging stations and water quality monitoring stations.
7. Area-averaged nitrogen wet atmospheric deposition concentration (mg/L as N) for the study area.
8. Area-averaged percent impervious values for each of the NLCD developed classes. The values were developed from an analysis specific to each study area. Both total (FIMP) and directly connected (FCIMP) values are provided.

Other Setup Tasks (to be undertaken by modeler)

1. Identify locations and characteristics of any major reservoirs. Reservoirs included in the model should be kept to the essential minimum of those that are sufficiently significant to the water balance of the simulated area (at the HUC-8 scale or greater) to include explicitly.
2. Identify locations and characteristics of any major features of the watershed affecting water balance (e.g., diversions, upstream areas not modeled, reaches that lose flow to groundwater). Some of these features may best be represented with observed flow series as boundary conditions. Irrigation should be explicitly considered only where needed as a significant part of the basin-scale water balance, e.g. Rio Grande.

Notes for specific study areas

1. Cook Inlet Alaska:
    a. The projection is different from the one used for the lower 48 states. Be sure that all input data used in building the model is in the same projection as the DEM and land cover grid.
    b. The DEM is in meters, not cm.
    c. No wet atmospheric deposition rates for nitrogen were available, so it can be omitted from the model.
    d. The SWAT soils database does not include Alaska, so the user will need to obtain appropriate STATSGO data for the extent of the model area.
2. Illinois River:
    a. The Chicago region has a complex history of drainage – areas that drained to Lake Michigan were diverted to flow into the Des Plaines River. Flow from Chicago River and Calumet River now includes surface runoff, point source flow (including combined sewer areas), and inflow from Lake Michigan itself.
    b. Flow and pollutant loads from the Chicago region should be represented as a “point source”, using flow series from USGS and loads derived from long term monitoring data.

c. The Chicago River and Calumet River drainages should still be included in the model for understanding the impact of climate change in an ultra-urban environment. Flow from these systems should not be connected to the main model but evaluated separately.

2.2 SWAT MODEL SETUP

SWAT model setup follows directly from the initial setup, using the ArcSWAT extension in ArcGIS. The following items should be noted and/or followed during SWAT model setup:

Watershed Delineation

Use the Automatic Watershed Delineation option with the following steps:

1. Open the Watershed Delineation window.
2. Import the DEM for the watershed and choose the z unit as cm.
3. Select the option for using user defined watersheds.
4. Import the subbasin and reach shapefiles subsequently. Create outlets.
5. Click the calculate subbasin parameters button. Please check "Skip Longest flow path calculation" option before calculating subbasin parameters.
6. Once the subbasin parameters have been calculated, add reservoirs, if any. It is desirable to avoid inclusion of reservoirs where possible due to the difficulty in representing operating rules adequately. Therefore, only include significant/major reservoirs that have a major impact on flows. If a reservoir is at the terminus of the model area it may be ignored so that the model represents input to, rather than output from the terminal reservoir.
7. For point sources, only those identified as majors and supplied by Tt are included in the model. Create a GIS coverage of the point sources in the subbasin from the list of majors supplied by Tetra Tech. Bring in the point sources layer to aid manual addition of point sources using the ArcSWAT interface. Define the major point sources at this stage. For some watersheds it will also be necessary to define an upstream boundary condition "point source".
8. Run Watershed Topographic Report for later use.

HRU Analysis

Start with the Land Use/Soils/Slope Definition

1. Save the model often, and make complete backups as you finish major tasks.
2. Use SWAT to classify the slopes into two categories with a breakpoint at 10%.
3. Bring in STATSGO soils with the MUID option.
4. NLCD 2001 land use coverage that is supplied can be loaded directly into ArcSWAT without modification. The default NLCD class to SWAT class mapping is appropriate for most areas; however, there are added future urban land uses (codes 121, 122, 123, and 124). Use the supplied *luc.txt* file to ensure correct mapping. Adjustments to the land use assignment can be made during cover setup, or parameters for SWAT classes adjusted at a later time. The clipped grids distributed for a project include a nominal representation of **all** potential future developed classes in each subwatershed, with near-zero area (e.g., 0.001 ha). This will provide a basis for ready modification to address future land use scenarios.
5. Assign impervious percentage to developed land use classes in the SWAT urban database using the values provided for the study area. The same assumptions must be applied for the future

developed land use classes UFRL, UFRM, UFRH, and UFHI, i.e., the future classes will have the same total and connected impervious fractions as the corresponding URLD, URMD, URHD, and UIDU urban land uses. Within ArcSWAT, the impervious values are saved to the main program geodatabase at C:\Program Files\SWAT\SWAT2005.mdb. The corresponding urban.dat file is regenerated from the geodatabase each time the model is run from the ArcGIS interface. This has another important implication: If a given model is ported to a different machine, the SWAT2005.mdb file must also be ported.

6. Proceed to the HRU Definition tab. Create HRUs by overlaying land use, soil, and slope at appropriate cutoff tolerance levels (usually 5% for land use, 10% for soil, and 5% for slope). BE SURE to EXCLUDE all 8 urban land use classes (URLD, URMD, URHD, UIDU, UFRL, UFRM, URFH, and UFHI) from the threshold criteria. This is done on the Land Use Refinement tab.
7. Proceed with standard SWAT model generation ("Write Input Tables") using met data provided on the project FTP site (processed weather series and station locations files). Precipitation and temperature use observed series; other weather data are simulated with the weather generator. It is advisable to screen the precipitation and air temperature files for any gross errors during the simulation time period. While errors are uncommon in the BASINS dataset from which these were derived, they do occur. Outliers and periods of flatlined values have been discovered in the pilot phase of the project, and the met data should be corrected and/or stations removed if gross errors are found.
8. Specify PET option as 1 (Penman/Monteith) in General Watershed Parameters.
9. Turn on elevation bands if necessary to account for orographic effects in areas with a sparse precipitation network and significant elevation changes. This will generally be appropriate where elevations within subbasins span a range of 250 m or more (see Watershed Topographic Report).
10. Assign management operations. The simulation option IURBAN in the mgt files associated with urban land use classes should be left at the default value of 1 (use USGS regression equations).
11. Set instream water quality options; IWQ = 1, and start with program defaults.
12. Use (daily) Curve Number hydrology with observed precipitation and air temperature. Remaining meteorological variables are simulated using the weather generator.
13. Specify atmospheric N wet deposition concentrations.
14. The time period for simulation should be 31 water years. The first year will be dropped from analysis to account for model spinup. The remaining 30 years span a period for which the supplied weather data are complete and include the year 2000 (with the exception of Central Nebraska). Time periods for complete weather data for each study area are shown in the following table (based on overlapping periods-of-record for available weather stations). Note that the start of simulation is one year prior to the complete weather data period. For this spinup year, some weather stations may be absent, but SWAT will fill in the missing records using the weather generator.

Non-Pilot Site	Complete Weather Period	Start Date for Simulation
Albemarle-Pamlico	10/1/1972 - 9/30/2002	10/1/1971
Central Nebraska	10/1/1969 - 9/30/1999	10/1/1968
Coastal Southern California	10/1/1971 - 9/30/2001	10/1/1970
Cook Inlet, AK	10/1/1971 - 9/30/2001	10/1/1970
Erie-St. Clair	10/1/1970 - 9/30/2000	10/1/1969

Non-Pilot Site	Complete Weather Period	Start Date for Simulation
Georgia-Florida Coastal	10/1/1972 - 9/30/2002	10/1/1971
Illinois River	10/1/1971 - 9/30/2001	10/1/1970
New England Coastal	10/1/1973 - 9/30/2003	10/1/1972
Lake Pontchartrain	10/1/1974 - 9/30/2004	10/1/1973
Rio Grande	10/1/1973 - 9/30/2003	10/1/1972
Sacramento	10/1/1971 - 9/30/2001	10/1/1970
South Platte	10/1/1970 - 9/30/2000	10/1/1969
Trinity	10/1/1971 - 9/30/2001	10/1/1970
Upper Colorado	10/1/1972 - 9/30/2002	10/1/1971
Yellowstone	10/1/1973 - 9/30/2003	10/1/1972

Save and backup the model at this point.

15. Run the model for the full 31 year period. Due to spin up effects and interaction with the weather generator random number processing, ***all*** model runs (calibration, validation, and scenario application) should use the entire model network and the entire simulation time period. (Initial testing can be done on a subset of the model or a reduced time period; however, it is necessary to run the full model extent and time period to obtain valid final results.)

16. Undertake calibration for target HUC8. After calibration, repeat for remainder of study area. Calibration should first be performed for hydrology, then sediment, then nutrients. Calibration spreadsheet templates are distributed for Hydrology and Water Quality, as described in the next section.

    NOTE: When pursuing calibration through the ArcSWAT interface be sure to use the option to REwrite SWAT input files (and not "Write Input Files"). The latter option will cause default parameters to be reloaded from the geodatabase.

3 Calibration and Reporting Procedures

Calibration will be pursued for flow, TSS, TN, and TP sequentially. The water quality calibration focuses on replicating inferred monthly loads, although some attention must be paid to the calibration of concentration as well.

As noted above, calibration starts with a single HUC8. Parameters derived for this site are then extended to the remainder of the watershed. However, experience is that this procedure alone is not adequate to provide reasonable results for the entire study area. Therefore, secondary calibration adjustments should be made at 2-3 additional stations in the watershed, at least one of which should be at a larger spatial scale than HUC8 (if available).

The time period for calibration should generally be the last 10 water years of the simulation. Validation will be applied to the preceding 10 water years (for which fit may be less good due to changes in land use and management relative to the 2001 NLCD). Adjustments can be made based on data availability if necessary.

The hydrologic calibration uses the Hydrocal spreadsheet. A version of this spreadsheet will be provided for the assigned non-pilot study areas. The spreadsheet is already loaded with a list of USGS gages with sufficiently long periods of record. The spreadsheet will automatically download USGS flows from NWIS and will load SWAT simulated flows from the program output. Note that this spreadsheet should be opened in Excel 2003 to ensure proper operation. Most of the functions can be run in Excel 2007 if

needed, but, if so, it should be saved in compatibility mode for Excel 2003. The program uses macros, and macro security will need to be set to "Medium" for the program to operate.

User controls for the Hydrocal spreadsheet are located on the Data Management tab. Key results are provided on the Analysis tab. In general, the user should strive to meet the "Recommended Criteria" on the Analysis tab.

Water quality calibration uses the WQUAL-GCRP spreadsheet. This program also uses macros and is now designed for Excel 2007. The water quality calibration takes place at stations for which there are both flow and concentration data and comes pre-loaded with a list of USGS gaging stations. Note that one spreadsheet covers both the calibration and validation periods.

The modeler is responsible for preparing and loading observed water quality data for TSS, TN, and TP on the "Obs" tab. At a minimum use the data available on the USGS NWIS system. (In some cases, previous studies have resulted in creation of more extensive, QA'd data sets that may be used instead.) Pre-processing is required. Duplicate observations on the same day should be pre-averaged. The "TSS" column can be used to store both SSED and TSS data; when both are present on a given day use the SSED results preferentially. A special note is required regarding TN. TN is a calculated value, and USGS reports it directly only in some years. In many other cases the user can construct TN observations by adding TKN plus NO2+NO3 observations. Note that the "Obs" tab contains a column for denoting samples below detection limit (using symbol "<") for each parameter. For TN, observations should be flagged as non-detect only when both TKN and NO2+NO3 are non-detect. If only one of these is non-detect use one-half the detection limit to create the sum.

After entering the observed data, the main user controls are on the "Interface" tab. After running the macros, key results are shown on the GCRP tab at BH22+. The key interest of EPA is in the prediction of loads. Loads are, of course, not observed, but are estimated using a stratified regression (TSS, TP) or an averaging estimator (TN). The first objective of calibration is to reduce the relative percent deviation between simulated and estimated loads – to below 25% if possible. (This will sometimes not be possible.) However, the user should also examine the diagnostic plots on the TSS, TP, and TN worksheets.

4 Implementing Future Scenarios

Both climate and land use scenarios will be implemented by working directly with the model input files, rather than returning to the GIS interface.

4.1 Climate Scenarios

In both HSPF and SWAT, climate scenarios are readily implemented simply by substituting new meteorological series. We will not assume any feedback between climate changes and HSPF parameters.

4.2 Land Use Scenarios

ICLUS will be used to estimate a change table by subwatershed. In SWAT, the HRU fractions in each HRU file are changed using automation scripts.