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TETRA TECH

Memorandum

To:	**Teresa Rafi (Task Order Leader)**	**Date:**	**June 12, 2014**
	John O'Donnell (QA Officer)	**Subject:**	**Champlain Model QA**
From:	**Dr. Jonathan Butcher, P.H.**	**Proj. No.**	**100-FFX-T29974-08**

Detailed SWAT watershed models have now been completed for the entire Lake Champlain basin. As specified in the Quality Assurance Project Plan (QAPP) for Lake Champlain TMDL Support (April 24, 2012), I am the Watershed Modeling QC Officer for the project. In this role I have undertaken a detailed Quality Assurance (QA) review of the model setup, input data, and parameterization of the SWAT models.

The modeling system for the basin is complex, constituting 13 separate SWAT models. As each SWAT model can have several thousand individual input files, it is not feasible to examine and check every file in the system; however, assuring the quality and integrity of the models is of high importance. The review therefore focuses on (1) examination of model components in which errors are frequently encountered based on past experience with similar models, (2) spot checks of a random subset of model inputs and parameters, and (3) an automated review of model parameters and outputs using the SWAT Error Checker, which is designed to identify and pinpoint errors and anomalies in SWAT models.

Results of the QA review are presented below. A number of relatively minor errors and discrepancies have been identified.

1 Land Use and Subbasins

The SWAT models were first checked for consistency with the project GIS. This review showed:

- Model subbasins are consistent with HUC boundaries.
- Subbasin areas for each model are the same in GIS, in the SWAT input database, and in the SWAT output.std file
- All HRUs present in the input database are present in the model and shown in the output.std file, demonstrating that each intended HRU actually ran.
- Model HRU areas sum to within 0.1% of the total area of each subbasin. This test passed with the exception of Chazy subbasin 5, where the HRUs add up to 99.83% of the subbasin area. This discrepancy is judged minor and appears to be due to round-off error in ArcSWAT's calculation of the slope percentages.

The ArcSWAT calculation of HRUs was also investigated. As noted in the calibration report, thresholds of 5% for land use, 10% for soil, and 5% for slope class were imposed when defining the HRUs; however, developed lands, farmsteads, unpaved roads, paved roads, driveways, pasture land, hay, and corn were exempted from the 5% land use threshold. ArcSWAT automatically reapportions fragments that fall below the threshold values into the more dominant land uses within a subbasin.

As shown in Table 8 in the modeling report, this procedure results in a 12,737 ha (5%) decrease in total agricultural land, decreases in grass/shrub (-35,664 ha or 50%), wetlands (-23,683 ha or 20%), and barren land use (-2,981 ha or 100%) categories, along with a 5.5% increase in forest area and a small increase in water area. Examination of the HRU creation process in several basins shows that agricultural land decreased primarily through elimination of areas classified as soybeans or miscellaneous agriculture, both of which frequently fell below the 5% cutoff and were not exempted. Similarly, the range-grass, and non-forested wetland categories frequently fell below the cutoff. Most of the land area thus eliminated from HRU creation was reassigned to forest as this is the dominant land use in the watershed.

Modeling report Table 8 also implies that pasture area was unchanged by the HRU creation process. This does not appear to be correct. It does appear that the general pasture land use was exempted from the land use threshold; however, the “summer pasture” land use was not exempted. For example, in the Lamoille watershed 2,929.71 ha of pasture are retained, despite occupying only 1.29% of the model area, but 969.2 ha of summer pasture are eliminated.

The HRU creation process with thresholds thus artificially inflates the forest land area while reducing several other categories. This type of biasing is common in the ArcSWAT setup process and cannot be fully avoided unless no land use threshold is applied – which typically results in an unwieldy number of HRUs. Strategies could have been used to mitigate the issue, however, such as lumping all the minor (non-corn) agricultural land uses and exempting them from the threshold, lumping the different wetland and pasture categories together, and/or using a lower threshold.

2 Stream Routing

Stream routing for all models was checked against the NHDPlus coverage in GIS. The following minor errors were found and have been fixed in the newest versions of the models:

- Otter: Reach 14 should flow to reach 11 (not reach 12).
- Rock-Pike: Reach 3 should flow to reach 1 (not reach 2); reach 6 should flow to reach 4 (not 3).

3 Assignment of Reaches to Calibration Files

One error was identified and fixed:

- Chazy: HydroCal for gage 04271500 should access output from subbasin 5 (not subbasin 7).

In addition, the water quality calibration file for Otter includes gaged flows that turn out to be the sum of the two upstream gages, although this is not documented in the file.

4 Weather Data

The weather data for the SWAT model were initially processed in the Fairfax office of Tetra Tech and transferred to the RTP office in August 2012. At that time we instituted a full quality assurance review, checked for anomalous values, and identified and repaired several periods of missing data. That effort was not repeated for this review; however, checks were made to ensure that the data were correctly translated to the SWAT model.

It was first confirmed that weather station assignments to model subbasins were made correctly and as stated in the report. Spot checks were then conducted on the precipitation (pcp) and temperature (tmp) files created by SWAT and used in the model runs for Otter and Saranac. These appear to be constructed correctly and reproduce the original weather data files.

5 Point Sources and Withdrawals

Examining versions of the model it appears that the point sources and water withdrawals were all mistakenly zeroed out in the process of putting additional reservoirs into the model (Table 1). This global error has been at least partially fixed in the most recent version of the model.

Point source discharge data were provided by VT DEC. The calibration report includes only a few sentences on the point sources. Appendix B lists point sources "represented in the Lake Champlain Basin SWAT Model", but does not show the model segment or subbasin number. The PCS coverages of point sources contain many more permits than are shown in Appendix B, primarily because agricultural general permits are not included in the model.

Point source inclusion in the model was checked by cross-referencing a number of different sources:

- VT_PCS_LC.shp: Shapefile of Vermont point sources created by Fairfax office of Tetra Tech.
- NY_PCS_LC.shp: Shapefile of New York point sources created by Fairfax office of Tetra Tech.
- EnvironPollution_ENVPTS2001.shp: Shapefile of EPA-regulated Vermont point sources included in EnviroFacts and based on 2001 information originally supplied by Vermont Agency of Natural Resources.
- MWWTP_VT.shp: Shapefile of Municipal WWTPs in Vermont provided by USEPA Region 1.
- Point source data files for NY and VT facilities provided by Eric Smeltzer (Vermont DEC).
- Appendix B in the draft modeling report.
- SWAT geodatabase links to input files for point sources.

Note that these sources do not cover the Quebec portion of the watershed. A summary tabulation of Quebec point sources provided by VT DEC (Eric Smeltzer) shows 6 point source discharges in the Missisquoi basin, 5 in the Rock and Pike basins, and one discharging direct to the lake. Detailed QA of these sources has not been possible because the Quebec permits and discharge records are not available on line. The Missisquoi point sources are included in the model based on the detailed Stone Environmental SWAT model of this basin. Point sources within the Quebec portion of the Rock and Pike watersheds are not included in the Rock-Pike model at this time.

The complete set of New York and Vermont point sources includes many minor discharges associated with CAFOs, industries, and remedial sites. These are generally not included in the model and do not have discharge monitoring for nutrients available. It is assumed that they are intentionally omitted.

The following point sources had monthly discharge data supplied by VT DEC (Eric Smeltzer), but were not included in the current version of the watershed models:

Table 1. Point Sources Not Included in the Model

Facility Name	NPDES	Watershed	Reach	Notes
Keeseville (V) W P C P	NY0025097	Ausable	1	
Au Sable Forks Comm WWTF	NY0201910	Ausable	3	
Lake Placid (V) W P C P	NY0022187	Ausable	14	
Swanton Village W W T F	VT0100501	Lamoille	1	VT_PCS and MWWTP_VT differ on subbasin; placed in model by VT_PCS
Fairfax W W T F	VT01087	Lamoille	5	
Village of Jeffersonville	VT0101150	Lamoille	8	
Johnson W P C F	VT0100901	Lamoille	10	
Hardwick W W T F	VT0100137	Lamoille	19	VT_PCS and MWWTP_VT differ on subbasin; placed in model by VT_PCS
Morrisville Villlage W T F	VT0100480	Lamoille	19	VT_PCS and MWWTP_VT differ on subbasin; placed in model by VT_PCS
Middlebury W W T F	VT0100188	Otter	9	VT_PCS and MWWTP_VT differ on subbasin; placed in model by VT_PCS
Salisbury Fish Hatchery		Otter	10	
Brandon MTP	VT0100056	Otter	12	VT_PCS and MWWTP_VT differ on subbasin; placed in model by VT_PCS
Otter Valley Union High School		Otter	16	
Pittsford, Town of	VT0100692	Otter	18	VT_PCS and MWWTP_VT differ on subbasin; placed in model by VT_PCS
Proctor Mtp	VT0100528	Otter	18	
Rutland W W T F	VT0100871	Otter	20	VT_PCS and MWWTP_VT differ on subbasin; placed in model by VT_PCS
Pittsford Fish Hatchery		Otter	20	
Wallingford W W T F	VT0100552	Otter	27	
Vergennes	VT0100404	Otter	34	VT_PCS and MWWTP_VT differ on subbasin; placed in model by VT_PCS
Shoreham	?	Otter	?	Discharge records supplied; appears to be for Village of Shoreham; not found in shapefiles, ISIS, or PCS.
West Pawlet	VT0100811	Mettawee	6	Omitted from VT_PCS
Burlington Riverside W W T F	VT0100307	Winooski	1	Smeltzer did not provide a file under this name. Likely supplied as

Facility Name	NPDES	Watershed	Reach	Notes
				"Burlington East", which does not appear in shape files.
South Burlington Airport Pkwy	VT0100366	Winooski	1	
Winooski WPCF	VT0100510	Winooski	1	VT_PCS and MWWTP_VT differ on subbasin; placed in model by VT_PCS
Essex Junction MTP	VT0100111	Winooski	2	VT_PCS and MWWTP_VT differ on subbasin; placed in model by VT_PCS
IBM Corporation	VT0000400	Winooski	2	
Richmond W W T F	VT0100617	Winooski	3	
Burlington North End W W T F	VT0100226	Winooski	4	
Stowe W W T F	VT0100455	Winooski	6	
Village of Waterbury W W T F	VT0100463	Winooski	7	
Marshfield WWTF	VT0100471	Winooski	15	
Plainfield W W T F	VT0100781	Winooski	15	
Cabot, Town of	VT0101257	Winooski	16	
Barre W W T F	VT0100889	Winooski	18	
Williamstown WTF	VT0100722	Winooski	21	
Montpelier W W T F	VT0100196	Winooski	22	
Northfield MTP	VT0100242	Winooski	23	
South Burlington MTP (Bartlett)	VT0100358	Winooski	33	
Shelburne WWTF #2	VT0100820	Winooski	34	

One important issue revealed by the previous table is that the VT_PCS_LC and MWWTP_VT shapefiles frequently differ on the subbasin receiving a discharge. Currently, all Vermont discharges have been located in the watershed models using the VT_PCS_LC shapefile. This appears to be derived from old and less accurate PCS information and it is likely that the location of all Vermont dischargers should be checked and revised to that shown by MWWTP_VT.

The following additional dischargers were apparently intentionally omitted from the watershed models because they fall within the direct drainage area and are supposed to be represented directly in the lake model. Note that they are included in Appendix B despite not being in the watershed model.

Table 2. Point Sources in Direct Drainage Area

Facility Name	NPDES	Watershed	Notes
Alburg Village W W T F	VT0100005	DD	
Brown Ledge Camp	VT0021008	DD	
Burlington Elec-Moran Plant	VT0000531	DD	
Burlington Electric-McNeil	VT0020401	DD	
Champlain Park SD W W T P	NY0020834	DD	
Crown Point SD#1 W W T F	NY0239844	DD	
Essex SD No. 1 W W T P	NY0256471	DD	No discharge file provided. Is the omission intentional?
International Paper Company	NY0004413	DD	
Northwest State Correctional		DD	
Orwell W W T P	VT0100676	DD	
Plattsburgh (C) W P C P	NY0026018	DD	
Rouses Point (V) W W T P	NY0021831	DD	
Ticonderoga SD#5 W P C P	NY0036706	DD	
Valcour SD W W T F	NY0183636	DD	
Weed Fish Culture Station		DD	
Westport SD#1 W W T P	NY0020222	DD	
Wyeth Pharmaceuticals	NY0033421	DD	

Finally, there appear to be a number of errors in the list of dischargers included in Appendix B. The appendix includes the following, which are neither currently included nor intended to be included in the model:

Table 3. Other Point Source Model/Appendix B Discrepancies

Name	NPDES	Notes
Agrimark	Multiple (VT)	Modeler: Stopped discharging in 1991, should be removed from Appendix B
PBM Nutritionals, LLC.	VT0020702	Modeler: Aka Wyeth PBM Nutritionals – It is in the Missisquoi model

Shoreham		Reviewer: Input data supplied but could not be located. May be in Otter. Modeler: Estimated location in the Otter Creek watershed based upon the location of the town
Troy/Jay		Reviewer: Apparently should be N. Troy, in Missisquoi model. Modeler: Troy/Jay and N. Troy are two separate facilities, both are in the MIssisquoi model
Wood Group Pratt & Whitney Industrial Turbine Services Llc - Test Cell	NYR00E475	Modeler: this facility is not listed in Appendix B and is not modeled.
Central VT P.S.-Milton	VT0000671	Modeler: this is in the Lamoille model

The point sources are supplied to the SWAT model in three forms, as constants (RECCNST), yearly records (RECYEAR), and monthly records (RECMON). RECCNST files are used primarily for place-holder files with zero flows. The New York dischargers are represented by RECYEAR and the Vermont dischargers by RECMON files. The three file types do not have the same format, as there are two extra columns (for month and year) in the RECMON files, and one extra column (for year) in the RECYEAR files relative to the presentation in RECCNST files. This caused a problem in the Poultney SWAT model as the point sources were supplied as RECMON files, but described to the model as RECCNST files. As a result, year is read as flow, flow is read as solids load, organic P is read as ammonium load, and mineral P is read as a DO load. The Poultney model thus did not represent any P load from WWTPs. This error is being fixed in a new version of the model.

The point source files provide flows and loads of phosphorus (metric tons and kg/day, respectively). Where Tetra Tech calculated the loads from reported flow and concentration the unit conversions appear correct. Nitrogen loads are not assigned to the WWTP discharges. While the primary interest of the model is phosphorus, it would be advisable to include N loads because these interact with P to determine algal uptake of both nutrients during stream transport. (Note, however, that the model is not currently simulating algal growth, as discussed in Section 10.)

It is also worth noting that the dischargers located within the direct drainage area to Lake Champlain are not included in the SWAT model – despite the fact that they are listed in Appendix B.

In sum, the point source representation needs further QC, but this is not readily feasible with the materials in hand.

Water withdrawals are listed in Table 11 in the model report, but again the locations are not identified, making QA difficult. The version of the model that I reviewed had no withdrawals specified. According to the model developer, this was an error that occurred when additional reservoirs were added and is being corrected.

6 Hydrology Parameterization

Hydrology parameters and model performance were examined using SWAT Error Checker version 1.1.14. This generated a number of warnings and some potentially questionable parameter values, but no obvious errors.

- The ratio of evapotranspiration (ET) to precipitation and baseflow to total flow varies among model areas as shown in the following table. Values are reasonably consistent across watersheds. The baseflow fraction of total flow is expected to be in the 40-50% range for this part of the county and appears reasonable. The ET fraction of precipitation appears low in most subbasins as it is more typically found to be in the 60-80% range. This may explain why the calibrated models tend to over-predict summer runoff. Results for the Direct Drainage (not calibrated) differ significantly from the other basins, with 81% of precipitation returned as ET.

Table 4. Ratio of Evapotranspiration (ET) to Precipitation and Baseflow to Total Flow

	Ausable	Boquet	Chazy	Direct Drainage	Lamoille	Mettawee	Missisquoi	Otter	Poultney	Rock-Pike	Saranac	Winooski	Winooski 31-44
ET/precip	52%	54%	60%	81%	43%	55%	45%	49%	54%	60%	50%	45%	52%
Baseflow/ Total Flow	57%	58%	51%	38%	45%	40%	46%	44%	35%	48%	58%	46%	40%

- "Water yield may be excessive" warnings were generated for all models except the Direct Drainage and Rock-Pike. This reflects the ET/precipitation ratios of < 60% in these subbasins.
- Individual land uses (averaged over soils and slope ranges) generated a number of hydrology warnings, as summarized below.

Table 5. SWAT Error Check Hydrology Warnings Generated for Individual Landuses

	Ausable	Boquet	Chazy	Direct Drainage	Lamoille	Mettawee	Missisquoi	Otter	Poultney	Rock-Pike	Saranac	Winooski	Winooski 31-44
Surface runoff may be excessive	FRSE FRST	BLUG RNGB	BLUG RNGB	BLUG RNGB	BLUG FRSD FRST WWHT	BLUG FRSD WWHT CSIL	BLUG FRSD CSIL FRST FRSE AGRR	BLUG FRSD CSIL FRST RNGB	BLUG FRSD RNGB WETF CSIL FRST	BLUG	BLUG FRSD WETF	BLUG FRSD CSIL	BLUG
Surface runoff may be too low			PAST										
>69% of water yield as baseflow	BLUG			FRST						FRSE RNGB	HAY RNGE RNGB		
<22% of water yield as baseflow	WWHT	WWHT	WWHT	WWHT HAY CSIL	CSIL	CSIL	CSIL	CSIL	CSIL	WWHT CSIL		CSIL	BLUG

These warnings do not necessarily represent errors, but are flags for further investigation. The warnings regarding "surface runoff may be excessive" are apparently set off by a combination of low ET in combination with low simulated biomass in certain land uses such as BLUG (the cover code used for urban grass). The other warnings do not appear consequential and may also be related to biomass simulation issues.

- Curve Numbers: The surface runoff portion of the hydrologic simulation is driven by specification of curve numbers, specifically the average condition CN2. The CN2 values are reasonably associated with soil hydrologic group and are relatively consistent for specific land uses between models. They are also mostly consistent with SWAT guidelines for curve number calibration. The Error Checker did flag several instances where the CN2 is less than 35 (all on A soils). These are false warnings relative to CSIL and HAY, as these crops are part of rotations in which the CN2 is reset in the management operations file, although the CN2 may be too low during the first winter of simulation (which is, however, part of the spin up year not reported in output).

  Other CN2 values on A soils also appear quite low. The CN2 for FRSE on A soils of 25 is at the minimum of the SWAT recommended range. Of greater concern is the CN2 specified for the pervious fraction of urban land use classes (UIDU, URHD, URLD, and URMD). These are set at 31, 59, 72, and 79 for hydrologic soil group A, B, C, and D soils, respectively, which corresponds to one point above the minimum guidance for perennial grasses. Perennial grass curve numbers are generally not appropriate for urban lands, where the soils are often compacted. The SWAT minimum guidelines for CN2 on urban lands are 46, 65, 77, and 82 for A, B, C, and D soils, respectively. (Note that for urban lands SWAT internally computes a composite curve number based on the pervious and impervious fractions.)

7 Sediment Simulation

Several cases were flagged where sediment yield from individual HRUs exceeded 50 MT/ha. In most cases the average annual load was just above 50 MT/ha, but in one case it is as high as 486 MT/ha. These high values reflect the interaction of the MUSLE approach with specific soil characteristics and parameters, and the occurrence of individual HRUs with very high sediment loads is commonly found in SWAT. I found no clear evidence of errors in parameters, but it worth reviewing the HRUs with the largest unit sediment loads (only those over 50 MT/ha) in each sub-model.

- Ausable HRU 321 in subbasin 9. This is land cover WWHT (in winter wheat – corn silage rotation) on soil S1969. The HRU has a very small available water capacity (AWC) of 18.3 mm, combined with a very large USLE length-slope (LS) factor of 20.69, resulting in an annual load of 486 MT/ha.
- Boquet HRU 1271 in subbasin 24. This is land cover WWHT on soil S1714, with an extremely low AWC of 2.5 mm and a moderately high LS factor of 5.08, resulting in an annual load of 68.6 MT/ha.
- Lamoille HRU 628 in subbasin 6. This is land cover CSIL (again, winter wheat – corn silage rotation, but starting with CSIL) on soil S0560. The AWC is in the typical range (185 mm) and LS factor is 2.02, with an USLE K factor of 0.49 (high range, but not extreme), resulting in an annual load of 74.1 MT/ha.
- Missisquoi HRU 2395 in subbasin 22. This is land cover HAY on soil S0561, resulting in 52.2 MT/ha. This also has reasonable parameters of LS = 2.42 and K = 0.49, with AWC of 182 mm.
- Otter HRU 796 in subbasin 6. This is land cover CSIL on soil S0193, resulting in 58.1 MT/ha. The LS factor is quite high at 9.10.
- Poultney HRU 112 in subbasin 1. This is land cover CSIL on soil S0850, generating 76.5 MT/ha. This has an LS of 1.89 combined with K = 0.49.
- Rock-Pike HRU 277 in subbasin 7. This is land cover AGRR on soil S2312, generating 55.4 MT/ha. LS = 2.44.
- Saranac HRU 456 in subbasin 10. This is land cover CSIL on soil S1928, generating 52.36 MT/ha. LS = 2.58.
- Winooski HRU 382 in subbasin 4. This is land cover HAY on soil S0972, generating 208 MT/ha. AWC is low (55.6 mm), and LS is extremely high at 16.88.

Note that the land covers CSIL (corn silage), WWHT (winter wheat), and HAY are all parts of several crop rotations and not equivalent to the HRU land use name. The Error Checker labels these HRUs by their initial land cover; however, the sediment yield results are averages over the full rotation.

A number of different factors appear to contribute to these high sediment yields. In most cases they seem to combine high LS factors with high erodibility (K). The LS factor depends on slope and slope length. The calculation is automated in SWAT, but is prone to anomalies associated with too long a slope length and failure to account for the effects of irregular and concave slopes. One common problem is that a DEM grid may suggest a high slope when the actual landscape pattern is a step pattern in which the major land use is on a small plateau of relatively flat land between two steep slopes. For instance, an LS factor of 16.88 would be associated, for example, with a constant 30% slope and a slope length of around 100 m – which seems unlikely for an active hay field. It might be advisable to restrict or validate the calculation of excessive LS values for agricultural land uses.

Other cases are associated with low AWC, which causes excessive surface runoff. Very low AWC values are likely a mismatch for any agricultural land uses. In the Ausable model, several soils (including S1969) have zero for AWC in each layer, which causes SWAT to revert to a default minimum AWC of 0.01. The same circumstances apply in the Boquet model. It appears that the “soils” with zero AWC in SSURGO are characterized as rock outcrops, water, or pits. As crops don’t grow on bare rock or water, the HRUs with crops on soil with very low AWC reflects minor discrepancies in the spatial extents of the soils and land cover grids. Finally, elevated sediment loads also appear to be associated with under-prediction of crop biomass on some HRUs, as described below.

In general, these anomalies in individual HRU sediment loading rates average out and do not have much effect on the basin scale simulation. However, they do indicate the need for caution in any use of the model to identify most sensitive individual land units based on HRU-level output.

8 Upland Nutrient Cycling

A properly configured SWAT model should exhibit relatively stable pools of nutrients within the soil profile. On agricultural lands, fertilization should balance nutrient removal in harvest – unless there is an intention to simulate the effects of over- or under-application of fertilizers.

Phosphorus is the primary focus of the model and the phosphorus content of soil (both mineral and organic P) is generally stable over the course of the simulation, with consistent and reasonable estimates of both species.

The nitrogen balance is more problematic. The Error Checker reports declines of the spatially averaged nitrate-N concentration over the course of the simulation from around 55 kg/ha to less than 5 kg/ha. This, however, is misleading. It appears to be in large part due to the default SWAT initialization of nitrate-N which assigns concentrations based on depth in the soil profile as an exponentially declining function of depth. This initial mass can drain out rapidly, resulting in an apparent but artificial decline over the course of the simulation, as well as warnings regarding excessive N leaching. This problem could be avoided by manually specifying the initial nitrate concentrations; however, this step is not necessary because the problem resolves itself during the model spin up year.

There are, however, other issues with the N balance. First, the Error Checker reports greater than 100 days of nitrogen stress in most basins. Further investigation suggests that this is not an area-weighted average and the high N stress is confined to a few land uses, where reduced biomass is predicted due to N limitation (see below). N stress occurs for typically only a few weeks per year in the major agricultural land covers.

Only some land uses in the model are simulated as fertilized. The basic urban land uses have auto-fertilization specified, occurring at an N stress of 0.75. Calendar-based fertilization is specified for the various corn rotations and the HAY land cover. This fertilization is specified in terms of mass of mineral N and mineral and organic P. Note that many fields receive manure application, but this has been converted to equivalent amounts of N and P, apparently at the direction of the client. The representation of N fertilization is potentially inaccurate in manured areas because all of the input is specified as inorganic nitrate N, whereas a significant portion is actually likely to be organic N. However, it is unlikely that this introduces any significant errors into the phosphorus simulation.

In addition to fertilizer, inorganic N load from atmospheric deposition is simulated. There is no N fixation input as no legume cover is simulated in any of the rotations. The WWHT land cover is not fertilized, but is always part of crop rotations that are fertilized. No fertilization is simulated for pasture, range, forest, or the road-related urban land uses, so these receive N input only from atmospheric deposition.

9 Plant Biomass

One of SWAT's strengths is the inclusion of a plant growth model that simulates the interactions of plant growth, soil nutrients, residue cover, and erosion. The plant growth model can, however, also be a pitfall if the model fails to simulate sufficient growth, resulting in excess erosion (due to lack of cover) and nutrient export. It is therefore important to check the plant biomass simulation.

The SWAT Error Checker flags cases in which the average biomass for a given land cover is less than 1 MT/ha and identifies the following:

Table 6. SWAT Error Checker Flags for Potential Biomass Errors

	Ausable	Boquet	Chazy	Direct Drainage	Lamoille	Mettawee	Missisquoi	Otter	Poultney	Rock-Pike	Saranac	Winooski	Winooski 31-44
Biomass < 1 MT/ha	BLUG, RNGE	BLUG, RNGB	BLUG, RNGB, PAST	BLUG, RNGB, PAST	BLUG, PAST, WETN	BLUG, PAST, RNGB	BLUG, PAST, WETN	BLUG, PAST, RNGB	BLUG, PAST, RNGB	BLUG, PAST, RNGB	BLUG, RNGB, RNGE	BLUG, PAST	BLUG, PAST, RNGB

These warnings apply to a consistent set of land covers: BLUG (bluegrass, used to simulate urban pervious grass cover), PAST (pasture), RNGB ("range-brush", used for shrubland), RNGE ("range-grasses", used for unspecified grassland herbaceous), and WETN (wetlands – non-forested).

For the pasture, range, and wetlands categories, examination of output for individual HRUs shows that biomass declines over time. For instance, Mettawee HRU 58 (PAST) predicts a biomass of 0.80 MT/ha during the first year of simulation and only 0.23 MT/ha in the final year. The reduction is apparently due to accumulated depletion of N because the pasture, range, and wetland categories receive no N fertilization. This representation is perhaps okay for the minor "range" categories. Pasture, however, should receive N input from manure, but does not. (The draft modeling report states that "The amount of manure application on pasture land was determined according to the total number of animals…"; however, only P is accounted for in the manure.) Nonetheless, this is also a rather minor component of the overall watershed area.

The forest land uses do not show a consistent decrease in biomass over time; however, this is mostly due to the way that perennial vegetation is simulated by the model. Most of the forest HRUs do show greater than 100 days per year of N stress, and the simulated biomass (in the range of 6 MT/ha) appears low. This may bias the simulation of nutrient uptake and transformation in forest. It would also tend to under-estimate ET losses and residue protection against erosion, although these tendencies are likely compensated for by other assumptions in the model.

The results for BLUG are more complex. This is the code for Kentucky bluegrass, which was selected from the SWAT default land covers to represent grass growing on urban land. Note that this selection by itself may be problematic as bluegrass is a warm season grass that has a base temperature to start growth of 12 °C and an optimal temperature of 25 °C. In contrast, cool season grasses start growth around 1 °C. Given the Vermont climate, the selection of bluegrass as representative cover delays and shortens the growth period for urban grass, which may lead to spring and fall biases and reduction in total biomass. On the other hand, no cutting and removal of urban grass is simulated.

For the major urban land covers (UIDU, URLD, URMD, URHD), auto-fertilization of BLUG is simulated and the biomass predictions are stable over time. The biomass does, however, appear rather low, on the order of 0.8 MT/has, whereas I would expect to see a biomass (or biomass plus harvest yield) more in the range of 2 MT/ha or more for bluegrass (see, for instance, Z.G. Davies et al., 2011, Mapping an urban ecosystem service: Quantifying above-ground carbon storage at a city-wide scale, *Journal of Applied Ecology*, 48:1125; or C.W. Russell and W.J. Johnson, 1996, Kentucky Bluegrass Post-harvest Straw-based Particleboard, report to the Washington State Dept. of Ecology).

BLUG is also assigned as the land cover to the small pervious fraction of road and driveway land uses (RDPV, RDDT, and DRWY, which are identified only for the Vermont portion of the watershed). In these HRUs auto-fertilization is not turned on. As a result, nitrogen is rapidly depleted and the biomass simulation goes to zero by the end of the simulation. Because these land uses are specified as 98 percent impervious it is unlikely that this discrepancy has a major effect on the results.

In sum, there are a series of minor inconsistencies in the simulation of plant growth and biomass on land covers other than agriculture. The net impacts on the results are, however, likely to be relatively small.

10 Reach Water Quality

The instream water quality simulation largely uses default parameters with the exception of the channel scour components. Interestingly, while algal simulation is turned on, the model produces no instream algae. This is apparently related to undocumented changes in v. 582 of SWAT2009, in which the "seed" load of algae from the upland input is calculated as a function of sediment-bound organic N and the surface washoff of nitrate, multiplied by a factor *chla_subco*. In the Champlain model, *chla_subco* is set to the minimum allowed value of 0.5. This, together with the issues regarding N simulation, appears to result in chlorophyll *a* seed "loads" that are sufficiently low that algal concentration is adjusted to zero in model subroutine watqual.f. Thus, effects of algae on phosphorus speciation and transport in streams are not being simulated in the model.

The instream sediment simulation uses modified code supplied by Stone Environmental to represent channel erosion based on excess shear stress and susceptibility ratings. I have not reviewed the modified code, although the simulation results appear generally reasonable in terms of observed concentrations and inferred loads at calibration stations. The user should be aware, however, that the procedure results in large scour predictions in some reaches – up to tenfold in Ausable reach 17.

The increased channel sediment erosion simulated by the model also results in increased phosphorus loads due to an organic P concentration (*ch_opco*) associated with channel sediment in the rte file. The values of *ch_opco* are set by reach in the Missisquoi, while other models have constant values. These values are highly variable, ranging from zero to 600 ppm, and look to have been used as calibration parameters. *Ch_opco* values and the identity of the reach with largest channel increases in TSS and TP load are summarized below. The more extreme increases may merit further investigation.

Table 7. Reach with Largest Gains in TSS and TP Loads from Channel Erosion in Each Model

	Ausable	Boquet	Chazy	Direct Drainage	Lamoille	Mettawee	Missisquoi	Otter	Poultney	Rock-Pike	Saranac	Winooski	Winooski 31-44
Max TSS (reach)	1033% (17)	279% (8)	279% (10)	181% (11)	348% (14)	115% (2)	242% (23)	300% (20)	122% (6)	112% (8)	417% (9)	620% (19)	144% (6)
Max TP (reach)	403% (20)	125% (4)	102% (3)	99.7% (1)	105% (15)	117% (18)	143% (11)	128% (15)	102% (13)	113% (5)	101% (9)	176% (12)	112% (6)

Ch_opco (ppm)	350	500	50	0	25	100	33-308 by rch	300	250	300	0	600	200, 600

11 Ponds/Reservoirs

Several of the models include ponds or reservoirs. Table 14 in the modeling report lists 15 reservoirs "represented explicitly in the SWAT model"; however, examination of the modeling files shows that 16 reservoirs are now included after recent updates. Reservoir names are not included in the SWAT geodatabase, and the table in the modeling report does not identify model subbasin, so it was not possible to check the cited storage and surface area data against the model.

Reservoirs are expected to provide trapping of sediment and phosphorus, as well as likely reducing total N loads. The SWAT Error Checker identifies many of the reservoirs in the simulation as having negative load reductions (i.e., increases in net load) over the period of simulation. Negative trap efficiencies are reported for at least one reservoir-constituent combination in all the sub-models that have more than one reservoir specified (Lamoille, Otter, Saranac, and Winooski). The reasons for this are somewhat obscure as the reservoir setup specifies typical deposition rates and no initial concentrations for solids and nutrients. Reported trap efficiencies for TSS range from -51% to +97%. Those for TP range from -19% to +41%, and for TN from -32% to +24%.

These results are based on output after a one-year model spin up period specified by an NSKP value of 1 relative to the start year of 1980. It appears, however, that a one-year spin up is not sufficient to stabilize the reservoir nutrient simulations (the SWAT2009 I/O document contains warnings about providing a sufficient spin up period). For example, the Otter watershed contains two reservoirs. Over the model reporting period these are simulated as having retention rates of (+98, +41, +23%) and (+78, -19, -19%) for TSS, TP, and TN respectively based on output beginning in 1981. Reservoir two has a longer retention time, and thus does not equilibrate as quickly to stresses imposed on initial conditions. Inspection of the output reveals that the negative retention rates reported for reservoir 2 are due almost entirely to large organic nutrient outputs simulated in the first year of reporting. The SWAT2009 guidance suggests a need to perform several years of simulation to obtain equilibration in the reservoir simulation, but the exact reasons for this discrepancy are not fully understood. Nevertheless, analysis of the results from reservoir 2 from 1981 on provide more typical results with a retention rate of +31% for TP and +19% for TN. This is generally more comparable to retention rates simulated in the Otter watershed with one reservoir (+42% for TP and +8% for TN). It is suspected that there are some errors in the SWAT v.582 code that create difficulties for equilibration of the reservoir nutrient simulation, although specific causes have not been identified at this stage. It does appear that trap efficiencies simulated in later years are more realistic. It is thus recommended to continue to begin the model simulations in 1980, but to focus on 21st century model output in the evaluation of scenarios.