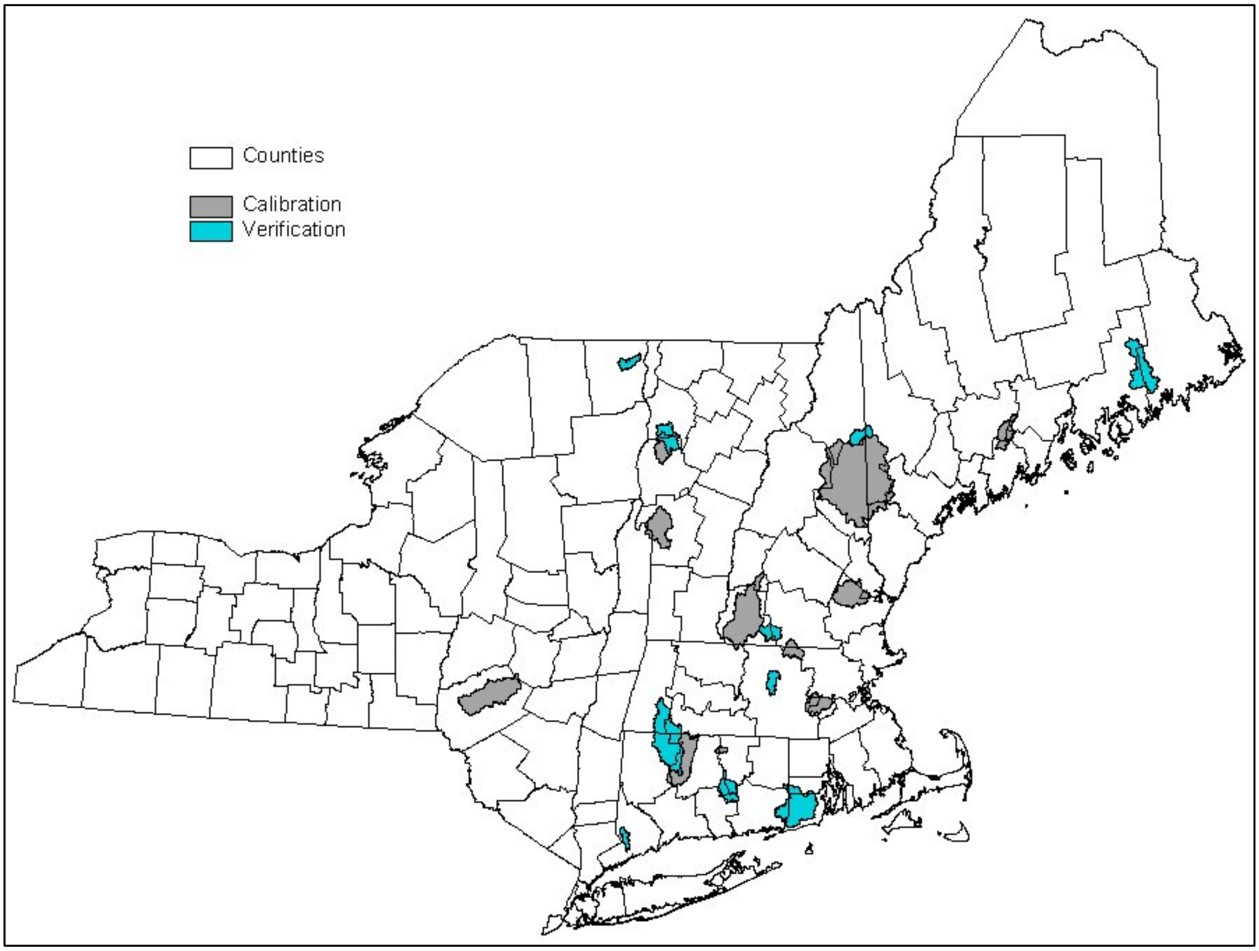
APPENDIX A. AVGWLF MODELING ANALYSIS

Northeast AVGWLF Model

The AVGWLF model was calibrated and validated for the northeast (Evans et al., 2007). AVGWLF requires that calibration watersheds have long-term flow and water quality data. For the northeast model, watershed simulations were performed for twenty-two (22) watersheds throughout New York and New England for the period 1997-2004 (Figure 10). Flow data were obtained directly from the water resource database maintained by the U.S. Geological Survey (USGS). Water quality data were obtained from the New York and New England State agencies. These data sets included in-stream concentrations of nitrogen, phosphorus, and sediment based on periodic sampling.

Figure 10. Location of Calibration and Verification Watersheds for the Northeast AVGWLF Model



Initial model calibration was performed on half of the 22 watersheds for the period 1997-2004. During this step, adjustments were iteratively made in various model parameters until a “best fit” was achieved between simulated and observed stream flow, and sediment and nutrient loads. Based on the calibration results, revisions were made in various AVGWLF routines to alter the manner in which model input parameters were estimated. To check the reliability of these revised routines, follow-up verification runs were made on the remaining eleven watersheds for the same time period. Finally, statistical evaluations of the accuracy of flow and load predictions were made.

To derive historical nutrient loads, relatively standard mass balance techniques were used. First, the in-stream nutrient concentration data and corresponding flow rate data were used to develop load (mass) versus flow relationships for each watershed for the period in which historical water quality data were obtained. Using the daily stream flow data obtained from USGS, daily nutrient loads for the 1997-2004 time period were subsequently computed for each watershed using the appropriate load versus flow relationship (i.e., "rating curves"). Loads computed in this fashion were used as the "observed" loads against which model-simulated loads were compared.

During this process, adjustments were made to various model input parameters for the purpose of obtaining a "best fit" between the observed and simulated data. With respect to stream flow, adjustments were made that increased or decreased the amount of the calculated evapotranspiration and/or "lag time" (i.e., groundwater recession rate) for sub-surface flow. With respect to nutrient loads, changes were made to the estimates for sub-surface nitrogen and phosphorus concentrations. In regard to both sediment and nutrients, adjustments were made to the estimate for the "C" factor for cropland in the USLE equation, as well as to the sediment "a" factor used to calculate sediment loss due to stream bank erosion. Finally, revisions were also made to the default retention coefficients used by AVGWLF for estimating sediment and nutrient retention in lakes and wetlands.

Based upon an evaluation of the changes made to the input files for each of the calibration watersheds, revisions were made to routines within AVGWLF to modify the way in which selected model parameters were automatically estimated. The AVGWLF software application was originally developed for use in Pennsylvania, and based on the calibration results, it appeared that certain routines were calculating values for some model parameters that were either too high or too low. Consequently, it was necessary to make modifications to various algorithms in AVGWLF to better reflect conditions in the Northeast. A summary of the algorithm changes made to AVGWLF is provided below.

- **ET**: A revision was made to increase the amount of ET calculated automatically by AVGWLF by a factor of 1.54 (in the "Pennsylvania" version of AVGWLF, the adjustment factor used is 1.16). This has the effect of decreasing simulated stream flow.

- **GWR:** The default value for the groundwater recession rate was changed from 0.1 (as used in Pennsylvania) to 0.03. This has the effect of "flattening" the hydrograph within a given area.

- **GWN:** The algorithm used to estimate "groundwater" (sub-surface) nitrogen concentration was changed to calculate a lower value than provided by the "Pennsylvania" version.

- **Sediment "a" Factor:** The current algorithm was changed to reduce estimated stream bank-derived sediment by a factor of 90%. The streambank routine in AVGWLF was originally developed using Pennsylvania data and was consistently producing sediment estimates that were too high based on the in-stream sample data for the calibration sites in the Northeast. While the exact reason for this is not known, it's like that the glaciated terrain in the Northeast is less erodible than the highly erodible soils in Pennsylvania. Also, it is likely that the relative abundance of lakes, ponds and wetlands in the Northeast have an effect on flow velocities and sediment transport.

- **Lake/Wetland Retention Coefficients:** The default retention coefficients for sediment, nitrogen and phosphorus should be set to 0.90, 0.12 and 0.25, respectively.

To assess the correlation between observed and predicted values, two different statistical measures were utilized: 1) the Pearson product-moment correlation (R^2) coefficient and 2) the Nash-Sutcliffe coefficient. The R^2 value is a measure of the degree of linear association between two variables, and represents the amount of variability that is explained by another variable (in this case, the model-simulated values). Depending on the strength of the linear relationship, the R^2 can vary from 0 to 1, with 1 indicating a perfect fit between observed and predicted values. Like the R^2 measure, the Nash-Sutcliffe coefficient is an indicator of "goodness of fit," and has been recommended by the American Society of Civil Engineers for use in hydrological studies (ASCE, 1993). With this coefficient, values equal to 1 indicate a perfect fit between observed and predicted data, and values equal to 0 indicate that the model is predicting no better than using the average of the observed data. Therefore, any positive value above 0 suggests that the model has some utility, with higher values indicating better model performance. In practice, this coefficient tends to be lower than R^2 for the same data being evaluated.

Adjustments were made to the various input parameters for the purpose of obtaining a "best fit" between the observed and simulated data. One of the challenges in calibrating a model is to optimize the results across all model outputs (in the case of AVGWLF, stream flows, as well as sediment, nitrogen, and phosphorus loads). As with any watershed model like GWLF, it is possible to focus on a single output measure (e.g., sediment or nitrogen) in order to improve the fit between observed and simulated loads. Isolating on one model output, however, can sometimes lead to less acceptable results for other measures. Consequently, it is sometimes difficult to achieve very high correlations (e.g., R^2 above 0.90) across all model outputs. Given this limitation, it was felt that very good results were obtained for the calibration sites. In model calibration, initial emphasis is usually placed on getting the hydrology correct. Therefore, adjustments to flow-related model parameters are usually finalized prior to making adjustments to parameters specific to sediment and nutrient production. This typically results in better statistical fits between stream flows than the other model outputs.

For the monthly comparisons, mean R^2 values of 0.80, 0.48, 0.74, and 0.60 were obtained for the calibration watersheds for flow, sediment, nitrogen and phosphorus, respectively. When considering the inherent difficulty in achieving optimal results across all measures as discussed above (along with the potential sources of error), these results are quite good. The sediment load predictions were less satisfactory than those for the other outputs, and this is not entirely unexpected given that this constituent is usually more difficult to simulate than nitrogen or phosphorus. An improvement in sediment prediction could have been achieved by isolating on this particular output during the calibration process; but this would have resulted in poorer performance in estimating the nutrient loads for some of the watersheds. Phosphorus predictions were less accurate than those for nitrogen. This is not unusual given that a significant portion of the phosphorus load for a watershed is highly related to sediment transport processes. Nitrogen, on the other hand, is often linearly correlated to flow, which typically results in accurate predictions of nitrogen loads if stream flows are being accurately simulated.

As expected, the monthly Nash-Sutcliffe coefficients were somewhat lower due to the nature of this particular statistic. As described earlier, this statistic is used to iteratively compare simulated values against the mean of the observed values, and values above zero indicate that the model predictions are better than just using the mean of the observed data. In other words, any value above zero would indicate that the model has some utility beyond using the mean of historical data in estimating the flows or loads for any particular time period. As with R^2 values, higher Nash-Sutcliffe values reflect higher degrees of correlation than lower ones.

Improvements in model accuracy for the calibration sites were typically obtained when comparisons were made on a seasonal basis. This was expected since short-term variations in model output can oftentimes be reduced by accumulating the results over longer time periods. In particular, month-to-month discrepancies due to precipitation events that occur at the end of a month are often resolved by aggregating output in this manner (the same is usually true when going from daily output to weekly or monthly output). Similarly, further improvements were noted when comparisons were made on a mean annual basis. What these particular results imply is that AVGWLF, when calibrated, can provide very good estimates of mean annual sediment and nutrient and loads.

Following the completion of the northeast AVGWLF model, there were a number of ideas on ways to improve model accuracy. One of the ideas relates to the basic assumption upon which the work undertaken in that project was based. This assumption is that a "regionalized" model can be developed that works equally well (without the need for resource-intensive calibration) across all watersheds within a large region in terms of producing reasonable estimates of sediment and nutrient loads for different time periods. Similar regional model calibrations were previously accomplished in earlier efforts undertaken in Pennsylvania (Evans et al., 2002) and later in southern Ontario (Watts et al., 2005). In both cases this task was fairly daunting given the size of the areas involved. In the northeast effort, this task was even more challenging given the fact that the geographic area covered by the northeast is about three times the size of Pennsylvania, and arguably is more diverse in terms of its physiographic and ecological composition.

As discussed, AVGWLF performed very well when calibrated for numerous watersheds throughout the region. The regionalized version of AVGWLF, however, performed less well for the verification watersheds for which additional adjustments were not made subsequent to the initial model runs. This decline in model performance may be as a result of the regionally-adapted model algorithms not being rigorous enough to simulate spatially-varying landscape processes across such a vast geographic region at a consistently high degree of accuracy. It is likely that un-calibrated model performance can be enhanced by adapting the algorithms to reflect processes in smaller geographic regions such as those depicted in the physiographic province map in Figure 11.

Fine-tuning & Re-Calibrating the Northeast AVGWLF for New York State

For the TMDL development work undertaken in New York, the original northeast AVGWLF model was further refined by The Cadmus Group, Inc. and Dr. Barry Evans to reflect the physiographic regions that exist in New York. Using data from some of the original northeast model calibration and verification sites, as well as data for additional calibration sites in New York, three new versions of AVGWLF were created for use in developing TMDLs in New York State. Information on the fourteen (14) sites is summarized in Table 8. Two models were developed based on the following two physiographic regions: Eastern Great Lakes/Hudson Lowlands area and the Northeastern Highlands area. The model was calibrated for each of these regions to better reflect local conditions, as well as ecological and hydrologic processes. In addition to developing the above mentioned physiographic-based model calibrations, a third model calibration was also developed. This model calibration represents a composite of the two physiographic regions and is suitable for use in other areas of upstate New York.

Figure 11. Location of Physiographic Provinces in New York and New England

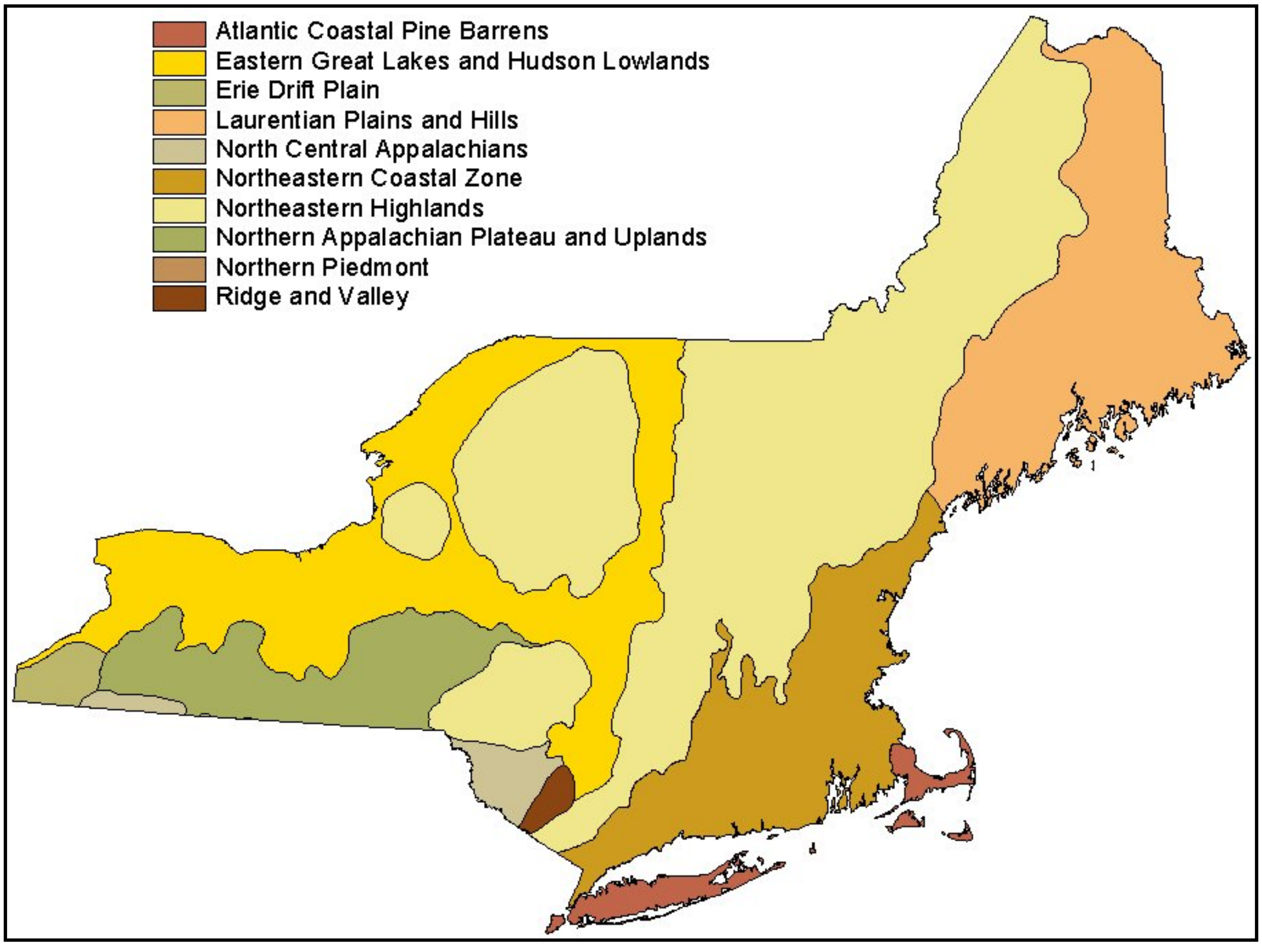


Table 8. AVGWLF Calibration Sites for use in the New York TMDL Assessments

Site	Location	Physiographic Region
Owasco Lake	NY	Eastern Great Lakes/Hudson Lowlands
West Branch	NY	Northeastern Highlands
Little Chazy River	NY	Eastern Great Lakes/Hudson Lowlands
Little Otter Creek	VT	Eastern Great Lakes/Hudson Lowlands
Poultney River	VT/NY	Eastern Great Lakes/Hudson Lowlands & Northeastern Highlands
Farmington River	CT	Northeastern Highlands
Saco River	ME/NH	Northeastern Highlands
Squannacook River	MA	Northeastern Highlands
Ashuelot River	NH	Northeastern Highlands
Laplatte River	VT	Eastern Great Lakes/Hudson Lowlands
Wild River	ME	Northeastern Highlands
Salmon River	CT	Northeastern Coastal Zone
Norwalk River	CT	Northeastern Coastal Zone
Lewis Creek	VT	Eastern Great Lakes/Hudson Lowlands

Set-up of the "New York State" AVGWLF Model

Using data for the time period 1990-2004, the calibrated AVGWLF model was used to estimate mean annual phosphorus loading to bay. Table 9 provides the sources of data used for the AVGWLF modeling analysis. The various data preparation steps taken prior to running the final calibrated AVGWLF Model for New York are discussed below the table.

Table 9. Information Sources for AVGWLF Model Parameterization

WEATHER.DAT file	
Data	**Source or Value**
	Historical weather data from Oswego, NY and Sodus Center, NY National Weather Services Stations
TRANSPORT.DAT file	
Data	**Source or Value**
Basin size	GIS/derived from basin boundaries
Land use/cover distribution	GIS/derived from land use/cover map
Curve numbers by source area	GIS/derived from land cover and soil maps
USLE (KLSCP) factors by source area	GIS/derived from soil, DEM, & land cover
ET cover coefficients	GIS/derived from land cover
Erosivity coefficients	GIS/ derived from physiographic map
Daylight hrs. by month	Computed automatically for state
Growing season months	Input by user
Initial saturated storage	Default value of 10 cm
Initial unsaturated storage	Default value of 0 cm
Recession coefficient	Default value of 0.1
Seepage coefficient	Default value of 0
Initial snow amount (cm water)	Default value of 0
Sediment delivery ratio	GIS/based on basin size
Soil water (available water capacity)	GIS/derived from soil map
NUTRIENT.DAT file	
Data	**Source or Value**
Dissolved N in runoff by land cover type	Default values/adjusted using GWLF Manual
Dissolved P in runoff by land cover type	Default values/adjusted using GWLF Manual
N/P concentrations in manure runoff	Default values/adjusted using AEU density
N/P buildup in urban areas	Default values (from GWLF Manual)
N and P point source loads	Derived from SPDES point coverage
Background N/P concentrations in GW	Derived from new background N map
Background P concentrations in soil	Derived from soil P loading map/adjusted using GWLF Manual
Background N concentrations in soil	Based on map in GWLF Manual
Months of manure spreading	Input by user
Population on septic systems	Derived from census tract maps for 2000 and house counts
Per capita septic system loads (N/P)	Default values/adjusted using AEU density

Land Use

The 2001 NLCD land use coverage was obtained, recoded, and formatted specifically for use in AVGWLF. The New York State High Resolution Digital Orthoimagery (for the time period 2000 – 2004) was used to perform updates and corrections to the 2001 NLCD land use coverage to more accurately reflect current conditions. The following were the most common types of corrections:

1) Areas of low intensity development that were coded in the 2001 NLCD as other land use types were the most commonly corrected land use data in this analysis. Discretion was used when applying corrections, as some overlap of land use pixels on the bay boundary are inevitable due to the inherent variability in the aerial position of the sensor creating the image. If significant new development was apparent (i.e., on the orthoimagery), but was not coded as such in the 2001 NLCD, than these areas were re-coded to low intensity development.
2) Areas of water that were coded as land (and vise-versa) were also corrected. Discretion was used for reservoirs where water level fluctuation could account for errors between orthoimagery and land use.
3) Forested areas that were coded as row crops/pasture areas (and vise-versa) were also corrected. For this correction, 100% error in the pixel must exist (e.g., the supposed forest must be completely pastured to make a change); otherwise, making changes would be too subjective. Conversions between forest types (e.g., conifer to deciduous) are too subjective and therefore not attempted; conversions between row crops and pasture are also too subjective due to the practice of crop rotation. Correction of row crops to hay and pasture based on orthoimagery were therefore not undertaken in this analysis.

Phosphorus retention in wetlands and open waters in the basin can be accounted for in AVGWLF. AVGWLF recommends the following coefficients for wetlands and pond retention in the northeast: nitrogen (0.12), phosphorus (0.25), and sediment (0.90). Percentage wetland land use area is required to run the nutrient retention routine in AVGWLF. To determine percentage wetland, the total basin land use area was derived using Arc View. The areas of emergent and woody wetlands were summed to yield total wetland area. If a basin displays large areas of surface water (ponds) aside from the water body being modeled, than this open water area is calculated by subtracting the water body area from the total surface water area. Total wetland area and total open water area are then summed and divided by the total land use area to obtain the percentage wetland/pond area required by the AVGWLF nutrient retention routine.

On-site Wastewater Treatment Systems ("septic tanks")

GWLF simulates nutrient loads from septic systems as a function of the percentage of the unsewered population served by normally functioning vs. three types of malfunctioning systems: ponded, short-circuited, and direct discharge (Haith et al., 1992).

- **Normal Systems** are septic systems whose construction and operation conforms to recommended procedures, such as those suggested by the EPA design manual for on-site wastewater disposal systems. Effluent from normal systems infiltrates into the soil and enters the shallow saturated zone. Phosphates in the effluent are adsorbed and retained by the soil and hence normal systems provide no phosphorus loads to nearby waters.

- **Short-Circuited Systems** are located close enough to surface water (~15 meters) so that negligible adsorption of phosphorus takes place. The only nutrient removal mechanism is plant uptake. Therefore, these systems are always contributing to nearby waters.
- **Ponded Systems** exhibit hydraulic malfunctioning of the tank's absorption field and resulting surfacing of the effluent. Unless the surfaced effluent freezes, ponding systems deliver their nutrient loads to surface waters in the same month that they are generated through overland flow. If the temperature is below freezing, the surfacing is assumed to freeze in a thin layer at the ground surface. The accumulated frozen effluent melts when the snowpack disappears and the temperature is above freezing.
- **Direct Discharge Systems** illegally discharge septic tank effluent directing into surface waters.

GWLF requires an estimation of population served by septic systems to generate septic system phosphorus loadings. In reviewing the orthoimagery for the bay, it became apparent that septic system estimates from the 1990 census were not reflective of actual population in close proximity to the shore. Shoreline dwellings immediately surround the bay account for a substantial portion of the nutrient loading to the bay. Therefore, the estimated number of septic systems in the drainage basin was refined using a combination of 1990 and 2000 census data and GIS analysis of orthoimagery to account for the proximity of septic systems immediately surrounding the bay. Great attention was given to estimating septic systems within 250 feet of the bay (those most likely to have an impact on the bay). To convert the estimated number of septic systems to population served, an average household size of 2.61 people per dwelling was used based on the circa 2000 USCB census estimate for number of persons per household in New York State.

GWLF also requires an estimate of the number of normal and malfunctioning septic systems. This information was not readily available for the bay. Therefore, several assumptions were made to categorize the systems according to their performance. These assumptions are based on data from local and national studies (Day, 2001; USEPA, 2002) in combination with best professional judgment. All of the septic systems within 50 feet of the bay and 25% of systems between 50 and 250 feet of the bay were categorized as short-circuiting systems. Approximately 10% of septic systems beyond 250 feet (up to the drainage basin boundary) were categorized as ponding systems. All remaining systems in the basin were categorized as normal.

To account for seasonal variations in population, data from the 2000 census were used to estimate the percentage of seasonal homes for the town(s) surrounding the bay. The failure rate for septic systems closer to the bay (i.e., within 250 feet) were adjusted to account for increased loads due to greater occupancy during the summer months. For the purposes of this analysis, seasonal homes are considered those occupied only during the month of June, July, and August.

Groundwater Phosphorus

Phosphorus concentrations in groundwater discharge are derived by AVGWLF. Watersheds with a high percentage of forested land will have low groundwater phosphorus concentrations while watersheds with a high percentage of agricultural land will have high concentrations. The GWLF manual provides estimated groundwater phosphorus concentrations according to land use for the eastern United States. Completely forested watersheds have values of 0.006 mg/L. Primarily agricultural watersheds have values of 0.104 mg/L. Intermediate values are also reported. The

AVGWLF-generated groundwater phosphorus concentration was evaluated to ensure groundwater phosphorus values reasonably reflect the actual land use composition of the drainage basin. Modifications were deemed unnecessary. The groundwater phosphorus concentration used in the analysis was 0.017 mg/L.

Point Sources

If permitted point sources exist in the drainage basin, their location was verified and an estimated monthly total phosphorus load and flow was determined using either actual reported data (e.g., from discharge monitoring reports) or estimated based on expected discharge/flow for the facility type.

Confined Animal Feeding Operations (CAFOs)

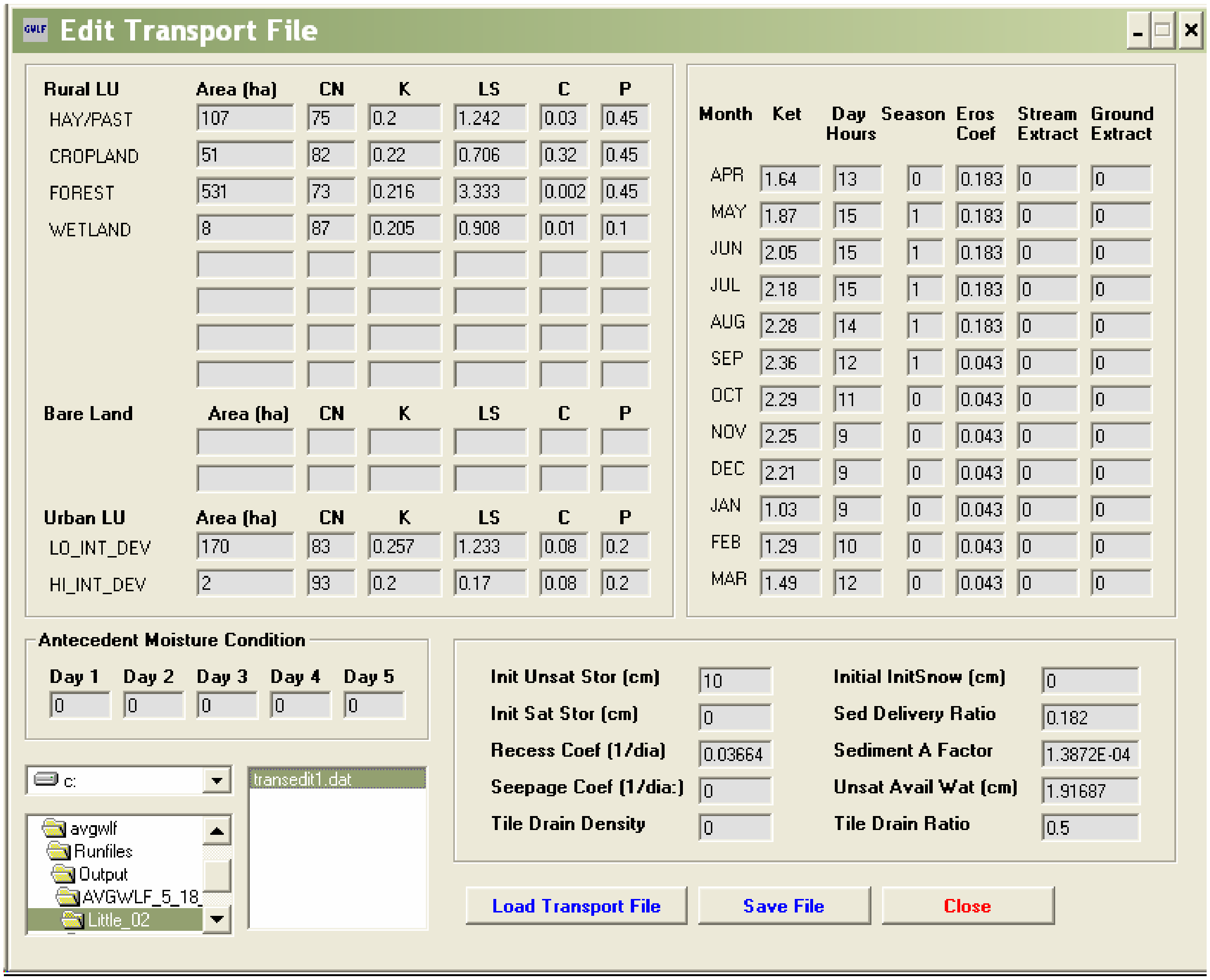
A state-wide Confined Animal Feeding Operation (CAFO) shapefile was provided by NYS DEC. CAFOs are categorized as either large or medium. The CAFO point can represent either the centriod of the farm or the entrance of the farm, therefore the CAFO point is more of a general gauge as to where further information should be obtained regarding permitted information for the CAFO. If a CAFO point is located in or around a basin, orthos and permit data were evaluated to determine the part of the farm with the highest potential contribution of nutrient load. In Arc View, the CAFO shape file was positioned over the basin and clipped with a 2.5 mile buffer to preserve those CAFOS that may have associated cropland in the basin. If a CAFO point is found to be located within the boundaries of the drainage basin, every effort was made to obtain permit information regarding nutrient management or other best management practices (BMPs) that may be in place within the property boundary of a given CAFO. These data can be used to update the nutrient file in AVGWLF and ultimately account for agricultural BMPs that may currently be in place in the drainage basin.

Municipal Separate Storm Sewer Systems (MS4s)

Stormwater runoff within Phase II permitted Municipal Separate Storm Sewer Systems (MS4s) is considered a point source of pollutants. Stormwater runoff outside of the MS4 is non-permitted stormwater runoff and, therefore, considered nonpoint sources of pollutants. Permitted stormwater runoff is accounted for in the wasteload allocation of a TMDL, while non-permitted runoff is accounted for in the load allocation of a TMDL. NYS DEC determined there are no MS4s in this basin.

AVGWLF Model Simulation Results

Input Transport File



Edit Transport File

Rural LU	Area (ha)	CN	K	LS	C	P
HAY/PAST	107	75	0.2	1.242	0.03	0.45
CROPLAND	51	82	0.22	0.706	0.32	0.45
FOREST	531	73	0.216	3.333	0.002	0.45
WETLAND	8	87	0.205	0.908	0.01	0.1

Bare Land	Area (ha)	CN	K	LS	C	P

Urban LU	Area (ha)	CN	K	LS	C	P
LO_INT_DEV	170	83	0.257	1.233	0.08	0.2
HI_INT_DEV	2	93	0.2	0.17	0.08	0.2

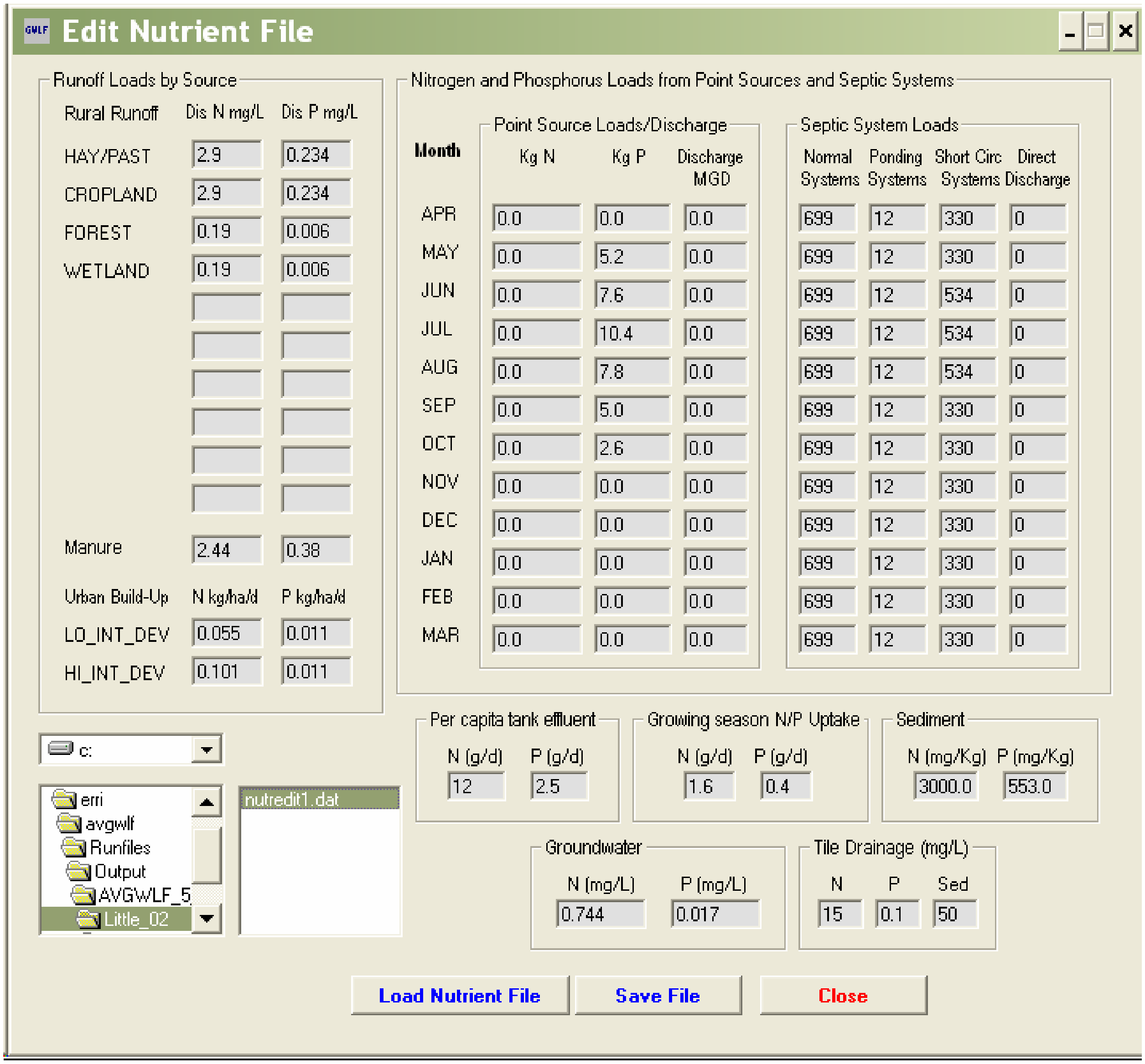
Month	Ket	Day Hours	Season	Eros Coef	Stream Extract	Ground Extract
APR	1.64	13	0	0.183	0	0
MAY	1.87	15	1	0.183	0	0
JUN	2.05	15	1	0.183	0	0
JUL	2.18	15	1	0.183	0	0
AUG	2.28	14	1	0.183	0	0
SEP	2.36	12	1	0.043	0	0
OCT	2.29	11	0	0.043	0	0
NOV	2.25	9	0	0.043	0	0
DEC	2.21	9	0	0.043	0	0
JAN	1.03	9	0	0.043	0	0
FEB	1.29	10	0	0.043	0	0
MAR	1.49	12	0	0.043	0	0

Antecedent Moisture Condition

Day 1	Day 2	Day 3	Day 4	Day 5
0	0	0	0	0

Init Unsat Stor (cm)	10	Initial InitSnow (cm)	0
Init Sat Stor (cm)	0	Sed Delivery Ratio	0.182
Recess Coef (1/dia)	0.03664	Sediment A Factor	1.3872E-04
Seepage Coef (1/dia:)	0	Unsat Avail Wat (cm)	1.91687
Tile Drain Density	0	Tile Drain Ratio	0.5

Input Nutrient File



Edit Nutrient File

Runoff Loads by Source

Rural Runoff	Dis N mg/L	Dis P mg/L
HAY/PAST	2.9	0.234
CROPLAND	2.9	0.234
FOREST	0.19	0.006
WETLAND	0.19	0.006
Manure	2.44	0.38

Urban Build-Up	N kg/ha/d	P kg/ha/d
LO_INT_DEV	0.055	0.011
HI_INT_DEV	0.101	0.011

Nitrogen and Phosphorus Loads from Point Sources and Septic Systems

	Point Source Loads/Discharge			Septic System Loads			
Month	Kg N	Kg P	Discharge MGD	Normal Systems	Ponding Systems	Short Circ Systems	Direct Discharge
APR	0.0	0.0	0.0	699	12	330	0
MAY	0.0	5.2	0.0	699	12	330	0
JUN	0.0	7.6	0.0	699	12	534	0
JUL	0.0	10.4	0.0	699	12	534	0
AUG	0.0	7.8	0.0	699	12	534	0
SEP	0.0	5.0	0.0	699	12	330	0
OCT	0.0	2.6	0.0	699	12	330	0
NOV	0.0	0.0	0.0	699	12	330	0
DEC	0.0	0.0	0.0	699	12	330	0
JAN	0.0	0.0	0.0	699	12	330	0
FEB	0.0	0.0	0.0	699	12	330	0
MAR	0.0	0.0	0.0	699	12	330	0

Per capita tank effluent: N (g/d) 12, P (g/d) 2.5

Growing season N/P Uptake: N (g/d) 1.6, P (g/d) 0.4

Sediment: N (mg/Kg) 3000.0, P (mg/Kg) 553.0

Groundwater: N (mg/L) 0.744, P (mg/L) 0.017

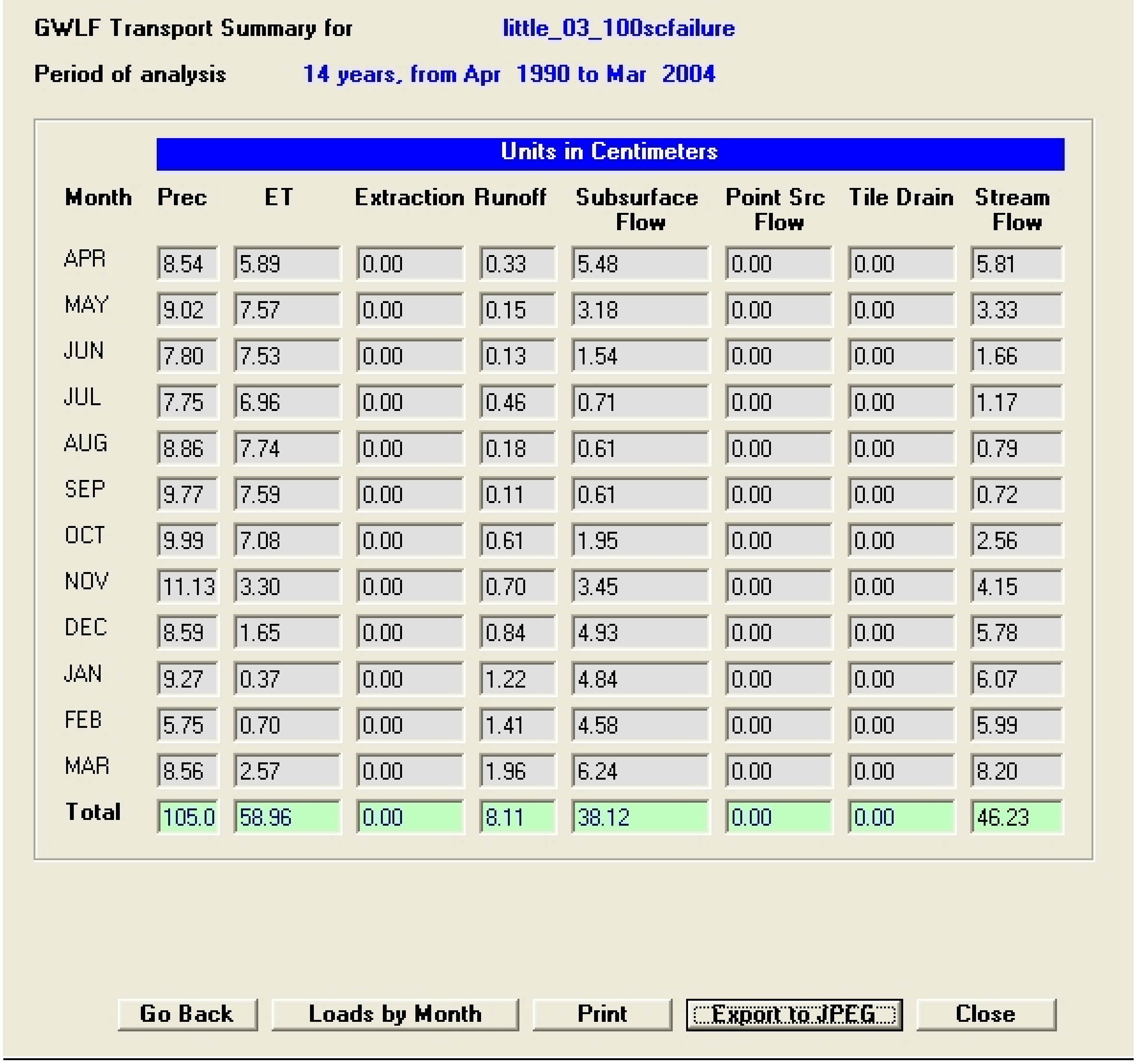
Tile Drainage (mg/L): N 15, P 0.1, Sed 50

c:

erri
avgwlf
Runfiles
Output
AVGWLF_5
Little_02

nutredit1.dat

Simulated Hydrology Transport Summary



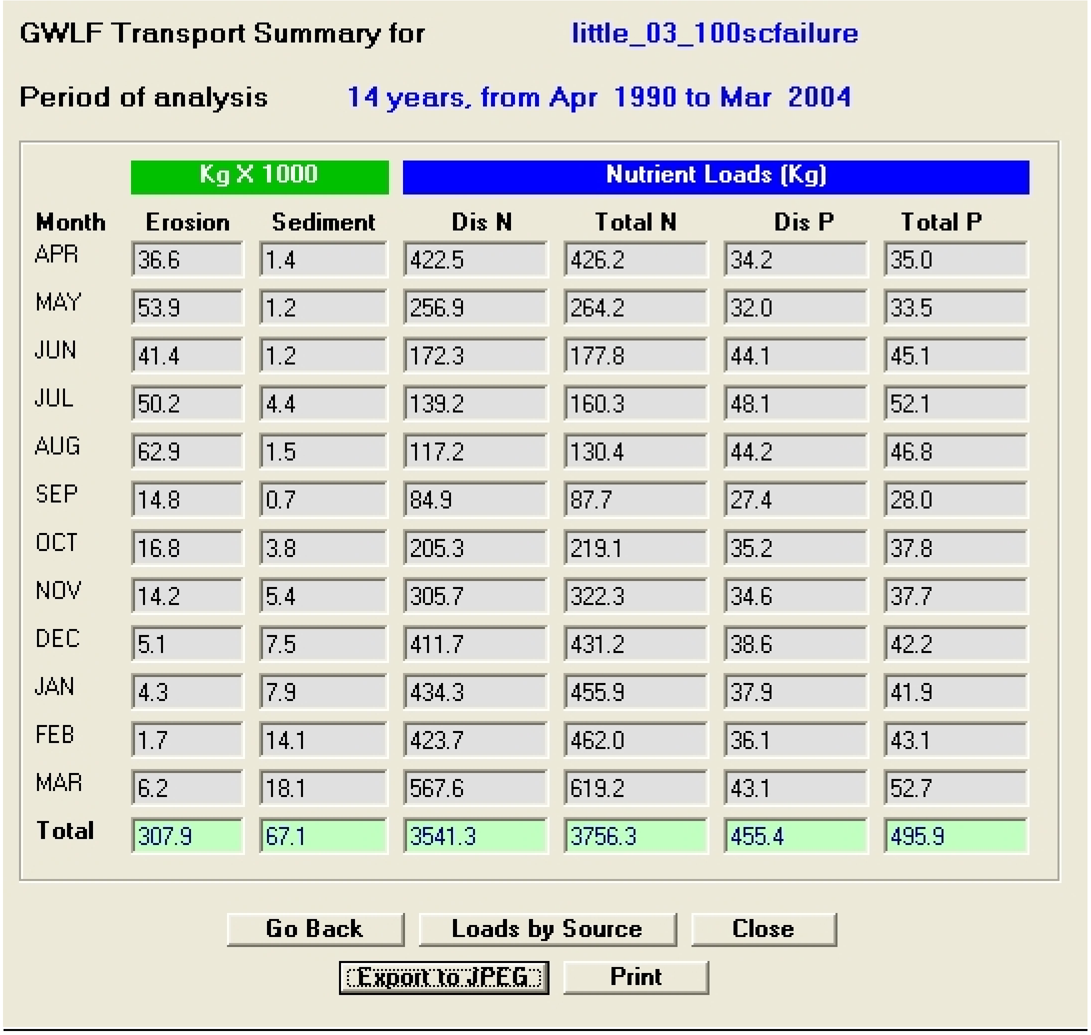
GWLF Transport Summary for little_03_100scfailure

Period of analysis 14 years, from Apr 1990 to Mar 2004

Units in Centimeters

Month	Prec	ET	Extraction	Runoff	Subsurface Flow	Point Src Flow	Tile Drain	Stream Flow
APR	8.54	5.89	0.00	0.33	5.48	0.00	0.00	5.81
MAY	9.02	7.57	0.00	0.15	3.18	0.00	0.00	3.33
JUN	7.80	7.53	0.00	0.13	1.54	0.00	0.00	1.66
JUL	7.75	6.96	0.00	0.46	0.71	0.00	0.00	1.17
AUG	8.86	7.74	0.00	0.18	0.61	0.00	0.00	0.79
SEP	9.77	7.59	0.00	0.11	0.61	0.00	0.00	0.72
OCT	9.99	7.08	0.00	0.61	1.95	0.00	0.00	2.56
NOV	11.13	3.30	0.00	0.70	3.45	0.00	0.00	4.15
DEC	8.59	1.65	0.00	0.84	4.93	0.00	0.00	5.78
JAN	9.27	0.37	0.00	1.22	4.84	0.00	0.00	6.07
FEB	5.75	0.70	0.00	1.41	4.58	0.00	0.00	5.99
MAR	8.56	2.57	0.00	1.96	6.24	0.00	0.00	8.20
Total	105.0	58.96	0.00	8.11	38.12	0.00	0.00	46.23

Simulated Nutrient Transport Summary

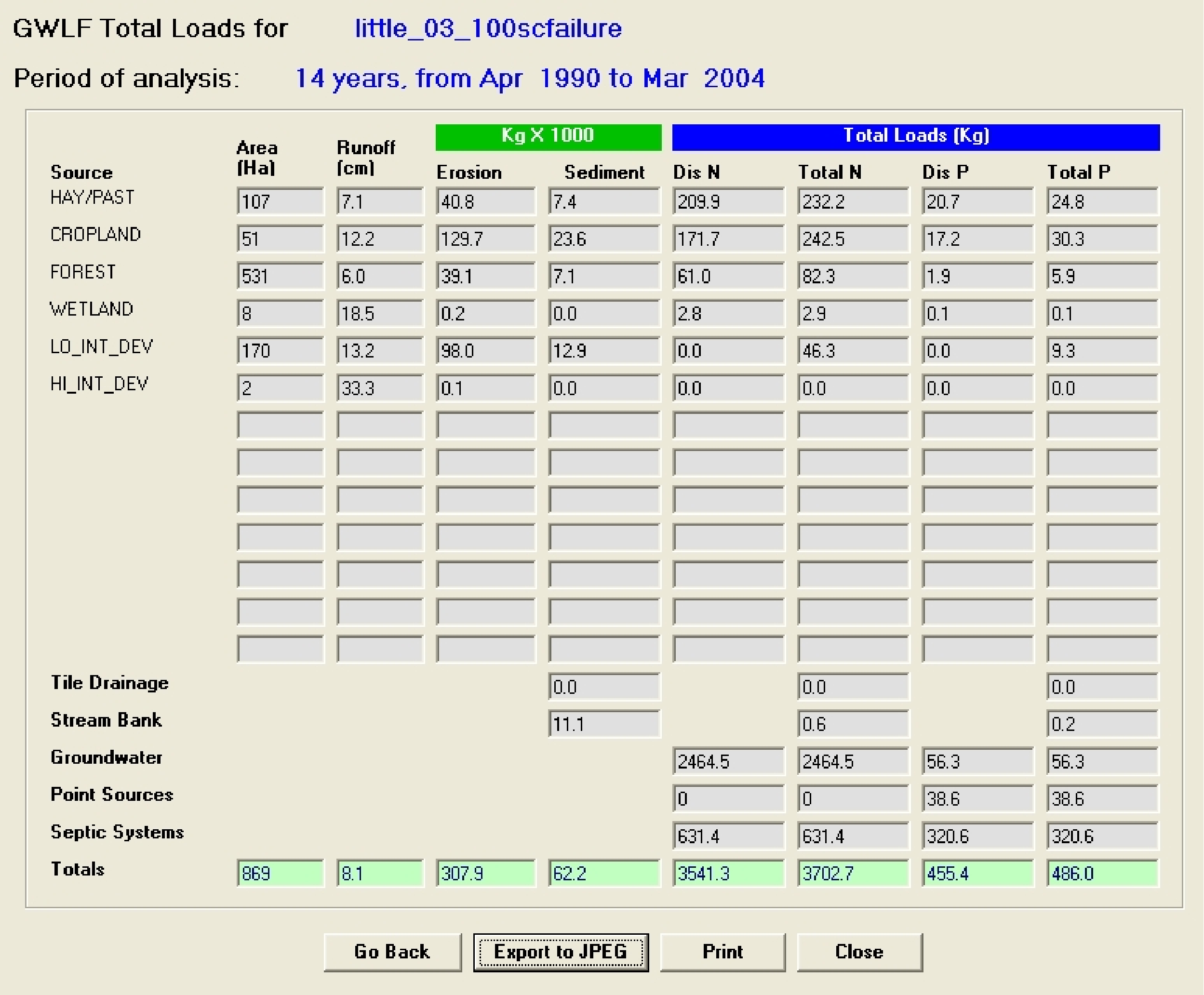


GWLF Transport Summary for little_03_100scfailure

Period of analysis 14 years, from Apr 1990 to Mar 2004

	Kg X 1000		Nutrient Loads (Kg)			
Month	**Erosion**	**Sediment**	**Dis N**	**Total N**	**Dis P**	**Total P**
APR	36.6	1.4	422.5	426.2	34.2	35.0
MAY	53.9	1.2	256.9	264.2	32.0	33.5
JUN	41.4	1.2	172.3	177.8	44.1	45.1
JUL	50.2	4.4	139.2	160.3	48.1	52.1
AUG	62.9	1.5	117.2	130.4	44.2	46.8
SEP	14.8	0.7	84.9	87.7	27.4	28.0
OCT	16.8	3.8	205.3	219.1	35.2	37.8
NOV	14.2	5.4	305.7	322.3	34.6	37.7
DEC	5.1	7.5	411.7	431.2	38.6	42.2
JAN	4.3	7.9	434.3	455.9	37.9	41.9
FEB	1.7	14.1	423.7	462.0	36.1	43.1
MAR	6.2	18.1	567.6	619.2	43.1	52.7
Total	307.9	67.1	3541.3	3756.3	455.4	495.9

Simulated Total Loads by Source



GWLF Total Loads for little_03_100scfailure

Period of analysis: 14 years, from Apr 1990 to Mar 2004

			Kg X 1000		Total Loads (Kg)			
Source	**Area (Ha)**	**Runoff (cm)**	**Erosion**	**Sediment**	**Dis N**	**Total N**	**Dis P**	**Total P**
HAY/PAST	107	7.1	40.8	7.4	209.9	232.2	20.7	24.8
CROPLAND	51	12.2	129.7	23.6	171.7	242.5	17.2	30.3
FOREST	531	6.0	39.1	7.1	61.0	82.3	1.9	5.9
WETLAND	8	18.5	0.2	0.0	2.8	2.9	0.1	0.1
LO_INT_DEV	170	13.2	98.0	12.9	0.0	46.3	0.0	9.3
HI_INT_DEV	2	33.3	0.1	0.0	0.0	0.0	0.0	0.0
Tile Drainage				0.0		0.0		0.0
Stream Bank				11.1		0.6		0.2
Groundwater					2464.5	2464.5	56.3	56.3
Point Sources					0	0	38.6	38.6
Septic Systems					631.4	631.4	320.6	320.6
Totals	869	8.1	307.9	62.2	3541.3	3702.7	455.4	486.0

APPENDIX B. BATHTUB MODELING ANALYSIS

Model Overview

BATHTUB is a steady-state (Windows-based) water quality model developed by the U. S. Army Corps of Engineers (USACOE) Waterways Experimental Station. BATHTUB performs steady-state water and nutrient balance calculations for spatially segmented hydraulic networks in order to simulate eutrophication-related water quality conditions in lakes and reservoirs. BATHTUB's nutrient balance procedure assumes that the net accumulation of nutrients in a lake is the difference between nutrient loadings into the lake (from various sources) and the nutrients carried out through outflow and the losses of nutrients through whatever decay process occurs inside the lake. The net accumulation (of phosphorus) in the lake is calculated using the following equation:

$$\text{Net accumulation} = \text{Inflow} - \text{Outflow} - \text{Decay}$$

The pollutant dynamics in the lake are assumed to be at a steady state, therefore, the net accumulation of phosphorus in the lake equals zero. BATHTUB accounts for advective and diffusive transport, as well as nutrient sedimentation. BATHTUB predicts eutrophication-related water quality conditions (total phosphorus, total nitrogen, chlorophyll-a, transparency, and hypolimnetic oxygen depletion) using empirical relationships derived from assessments of reservoir data. Applications of BATHTUB are limited to steady-state evaluations of relations between nutrient loading, transparency and hydrology, and eutrophication responses. Short-term responses and effects related to structural modifications or responses to variables other than nutrients cannot be explicitly evaluated.

Input data requirements for BATHTUB include: physical characteristics of the watershed lake morphology (e.g., surface area, mean depth, length, mixed layer depth), flow and nutrient loading from various pollutant sources, precipitation (from nearby weather station) and phosphorus concentrations in precipitation (measured or estimated), and measured lake water quality data (e.g., total phosphorus concentrations).

The empirical models implemented in BATHTUB are mathematical generalizations about lake behavior. When applied to data from a particular lake, actual observed lake water quality data may differ from BATHTUB predictions by a factor of two or more. Such differences reflect data limitations (measurement or estimation errors in the average inflow and outflow concentrations) or the unique features of a particular lake (no two lakes are the same). BATHTUB's "calibration factor" provides model users with a method to calibrate the magnitude of predicted lake response. The model calibrated to current conditions (against measured data from the lakes) can be applied to predict changes in lake conditions likely to result from specific management scenarios, under the condition that the calibration factor remains constant for all prediction scenarios.

Model Set-up

Using descriptive information about Little Sodus Bay and its surrounding drainage area, as well as output from AVGWLF, a BATHTUB model was set up for Little Sodus Bay. Mean annual phosphorus loading to the bay was simulated using AVGWLF for the period 1990-2004. After initial model development, NYS DEC sampling data were used to assess the model's predictive capabilities and, if necessary, "fine tune" various input parameters and sub-model selections within

BATHTUB during a calibration process. Once calibrated, BATHTUB was used to derive the total phosphorus load reduction needed in order to achieve the TMDL target.

Sources of input data for BATHTUB include:

- Physical characteristics of the watershed lake morphology (e.g., surface area, mean depth, length, mixed layer depth) - Obtained from CSLAP and bathymetric maps provided by NYS DEC or created by the Cadmus Group, Inc.
- Flow and nutrient loading from various pollutant sources - Obtained from AVGWLF output.
- Precipitation – Obtained from nearby National Weather Services Stations.
- Phosphorus concentrations in precipitation (measured or estimated), and measured lake water quality data (e.g., total phosphorus concentrations) – Obtained from NYS DEC and CSLAP.

Tables 10 – 13 summarize the primary model inputs for Little Sodus Bay. Default model choices are utilized unless otherwise noted. Spatial variations (i.e., longitudinal dispersion) in phosphorus concentrations are not a factor in the development of the TMDL for Little Sodus Bay. Therefore, division of the bay into multiple segments was not necessary for this modeling effort. Modeling the entire bay with one segment provides predictions of area-weighted mean concentrations, which are adequate to support management decisions. Water inflow and nutrient loads from the bay's drainage basin were treated as though they originated from one "tributary" (i.e., source) in BATHTUB and derived from AVGWLF.

BATHTUB is a steady state model, whose predictions represent concentrations averaged over a period of time. A key decision in the application of BATHTUB is the selection of the length of time over which water and mass balance calculations are modeled (the "averaging period"). The length of the appropriate averaging period for BATHTUB application depends upon what is called the nutrient residence time, which is the average length of time that phosphorus spends in the water column before settling or flushing out of the lake. Guidance for BATHTUB recommends that the averaging period used for the analysis be at least twice as large as nutrient residence time for the lake. The appropriate averaging period for water and mass balance calculations would be 1 year for lakes with relatively long nutrient residence times or seasonal (6 months) for lakes with relatively short nutrient residence times (e.g., on the order of 1 to 3 months). The turnover ratio can be used as a guide for selecting the appropriate averaging period. A seasonal averaging period (April/May through September) is usually appropriate if it results in a turnover ratio exceeding 2.0. An annual averaging period may be used otherwise. Other considerations (such as comparisons of observed and predicted nutrient levels) can also be used as a basis for selecting an appropriate averaging period, particularly if the turnover ratio is near 2.0. Limited reliable information on phosphorus residence time was available for Little Sodus Bay. Therefore, the averaging period was set to 1.

Precipitation inputs were taken from the observed long term mean daily total precipitation values from the Oswego, NY and Sodus Center, NY National Weather Services Stations for the 1990-2004 period. Evaporation was derived from AVGWLF using daily weather data (1990-2004) and a cover factor dependent upon land use/cover type. The values selected for precipitation and change in lake storage have very little influence on model predictions. Atmospheric phosphorus loads were specified using data collected by NYS DEC from the Moss Lake Atmospheric Deposition Station located within the watershed of Moss Lake, in Herkimer County. Atmospheric deposition is not a major source of phosphorus loading to Little Sodus Bay and has little impact on simulations.

Lake surface area, mean depth, and length were derived using GIS analysis of bathymetric data. Depth of the mixed layer was estimated using a multivariate regression equation developed by Walker (1996). Existing water quality conditions in Little Sodus Bay were represented using an average of the observed summer mean phosphorus concentrations for years 1990-1994. These data were collected through NYS DEC's CSLAP. The concentration of phosphorus loading to the bay was calculated using the average annual flow and phosphorus loads simulated by AVGWLF. To obtain flow in units of volume per time, the depth of flow was multiplied by the drainage area and divided by one year. To obtain phosphorus concentrations, the nutrient mass was divided by the volume of flow.

Table 10. BATHTUB Model Input Variables: Model Selections

Water Quality Indicator	Option	Description
Total Phosphorus	01	2nd Order Available Phosphorus*
Phosphorus Calibration	01	Decay Rate*
Error Analysis	01	Model and Data*
Availability Factors	01	Ignore*
Mass Balance Tables	01	Use Estimated Concentrations*

* Default model choice

Table 11. BATHTUB Model Input: Global Variables

Model Input	Mean	CV
Averaging Period (years)	1	NA
Precipitation (meters)	1.0503	0.2*
Evaporation (meters)	0.5895	0.3*
Atmospheric Load (mg/m^2-yr)- Total P	4.8748	0.5*
Atmospheric Load (mg/m^2-yr)- Ortho P	2.6051	0.5*

* Default model choice

Table 12. BATHTUB Model Input: Lake Variables

Morphometry	Mean	CV
Surface Area (km^2)	2.95	NA
Mean Depth (m)	6.7932	NA
Length (km)	3.6525	NA
Estimated Mixed Depth (m)	5.6	0.12
Observed Water Quality	**Mean**	**CV**
Total Phosphorus (ppb)	30.874	0.5

* Default model choice

Table 13. BATHTUB Model Input: Watershed "Tributary" Loading

Monitored Inputs	Mean	CV
Total Watershed Area (km^2)	8.69	NA
Flow Rate (hm^3/yr)	4.0174	0.1
Total P (ppb)	120.9760	0.2
Organic P (ppb)	113.3566	0.2

Model Calibration

BATHTUB model calibration consists of:

1. Applying the model with all inputs specified as above
2. Comparing model results to observed phosphorus data
3. Adjusting model coefficients to provide the best comparison between model predictions and observed phosphorus data (only if absolutely required and with extreme caution.

Several t-statistics calculated by BATHTUB provide statistical comparison of observed and predicted concentrations and can be used to guide calibration of BATHTUB. Two statistics supplied by the model, T2 and T3, aid in testing model applicability. T2 is based on error typical of model development data set. T3 is based on observed and predicted error, taking into consideration model inputs and inherent model error. These statistics indicate whether the means differ significantly at the 95% confidence level. If their absolute values exceed 2, the model may not be appropriately calibrated. The T1 statistic can be used to determine whether additional calibration is desirable. The t-statistics for the BATHUB simulations for Little Sodus Bay are as follows:

Year	Observed	Simulated	% Error	T1	T2	T3
1990	29	26	0.22	0.42	0.20	29
1991	27	30	-0.19	-0.35	-0.17	27
1992	32	27	0.32	0.59	0.29	32
1993	29	28	0.02	0.03	0.01	29
1994	37	34	0.18	0.33	0.16	37
Average	31	29	0.13	0.24	0.12	31

In cases where predicted and observed values differ significantly, calibration coefficients can be adjusted to account for the site-specific application of the model. Calibration to account for model error is often appropriate. However, Walker (1996) recommends a conservative approach to calibration since differences can result from factors such as measurement error and random data input errors. Error statistics calculated by BATHTUB indicate that the match between simulated and observed mean annual water quality conditions in Little Sodus Bay is quite good. Therefore, BATHTUB is sufficiently calibrated for use in estimating load reductions required to achieve the phosphorus TMDL target in the bay.

APPENDIX C. TOTAL EQUIVALENT DAILY PHOSPHORUS LOAD ALLOCATIONS

Source	Total Phosphorus Load (lbs/d)			% Reduction
	Current	Allocated	Reduction	
Agriculture*	0.332	0.332	0	0%
Developed Land*	0.277	0.277	0	0%
Septic Systems	1.937	0	1.9	100%
Forest, Wetland, Stream Bank, and Natural Background	0.159	0.159	0	0%
LOAD ALLOCATION (subtotal)	**2.704**	**0.767**	**1.937**	**72%**
Point Sources	0.233	0	0.233	100%
WASTELOAD ALLOCATION (subtotal)	**0.233**	0	0.233	100%
LA + WLA	**2.937**	**0.767**	**2.17**	**74%**
Margin of Safety	---	0.786	---	---
TOTAL	**2.937**	**1.553**	**n/a**	**n/a**

* Includes phosphorus transported through surface runoff and subsurface (groundwater)