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Appendix E --- Watershed Model Calibration

E.1. Hydrologic Calibration

The Black Hawk Lake watershed SWAT model was calibrated and validated by comparing simulated hydrology to several sources of monitored and/or previously available data. The primary source of calibration/validation data is an in-lake water stage recorder maintained and operated by the USGS. USGS has utilized this gage, theoretical equations, and manually measured flow to construct a rating curve that predicts outflow from Black Hawk Lake based on the recorded stage (USGS, 2009).

In addition to the USGS stage recorder, Iowa State University (ISU) conducted flow and water quality monitoring as part of a lake diagnostic feasibility study (DFS). Data collection for the DFS commenced in July of 2008, was discontinued in November of 2008 due to ice formation, and was completed between March and July of 2009. ISU developed rating curves for two locations in the tributary stream, Carnarvon Creek, using continuous stage measurements and approximately a dozen manually measured flows throughout the study period. A series of manual flow measurements were made just downstream of the lake outlet structure as well. The monitoring period in the tributaries is too short for use in thorough calibration analysis, but it was helpful in evaluating hydrologic simulations on a daily basis, and for refining the calibration of lake outflow.

Black Hawk Lake Discharge

The discharge rating curve provided by USGS for Black Hawk Lake was developed as part of a study on the characterization of the hydrologic relationship between Black Hawk Lake and the Raccoon River (USGS, 2009). The USGS gage is located on the west end of the lake, over 1.5 miles from the outfall structure that discharges to the east. Because of this long fetch between the gage and outlet structure, it is possible that moderate winds could occasionally lead to a seiche effect, thereby causing the gage to record a water surface elevation that is slightly different from the elevation present at the outlet structure. Additionally, USGS only collected one manual flow to verify the accuracy of the proposed rating curve. Because of these potential sources of error, USGS does not recommend use of the rating curve to estimate the actual discharge on a specific date. Rather, the rating curve should be used to estimate flows over a longer period (e.g., monthly average flows) and to assess the lake’s response to precipitation (Dan Christiansen, USGS, April 14, 2010 personal communication). The USGS study that documents development of the rating curve acknowledges that “…discharges at 05482316 Black Hawk Lake at Outlet at Lake View, Iowa, that are determined from the rating table and lake levels measured at 05482315 Black Hawk Lake at Lake View, Iowa, must be rated poor.” (USGS, 2009). Figure E-1 shows the location of the USGS gage relative to the lake outlet structure.

Figure E-1: USGS lake gage (blue marker) and the outlet channel (red marker). Source: USGS, 2009

Because of the uncertainty associated with the USGS rating curve, calibration of lake outflow from the SWAT model used in this Water Quality Improvement Plan (WQIP) is based on the rating curve developed by the Iowa Department of Natural Resources (IDNR) using 12 measured discharges obtained by ISU during the DFS in 2008-09. Table E-1 reports the lake discharge values measured by ISU and the corresponding lake stage reported by the USGS water level recorder (USGS 05482316). Figure E-2 illustrates the correlation between flow and stage.

Table E-1. Observed discharge (ISU DFS) and lake stage (USGS 05482316).

Date	Stage (ft)	Discharge (cfs)
07/28/2008	8.05	108.0
08/26/2008	7.45	2.1
09/22/2008	7.43	2.0
10/30/2008	7.68	24.1
11/19/2008	7.63	22.0
12/08/2008	7.55	7.9
03/17/2009	7.61	21.0
04/06/2009	7.58	19.5
05/13/2009	7.60	15.0
06/11/2009	7.60	20.2
07/08/2009	7.80	53.2
09/10/2009	7.43	2.3

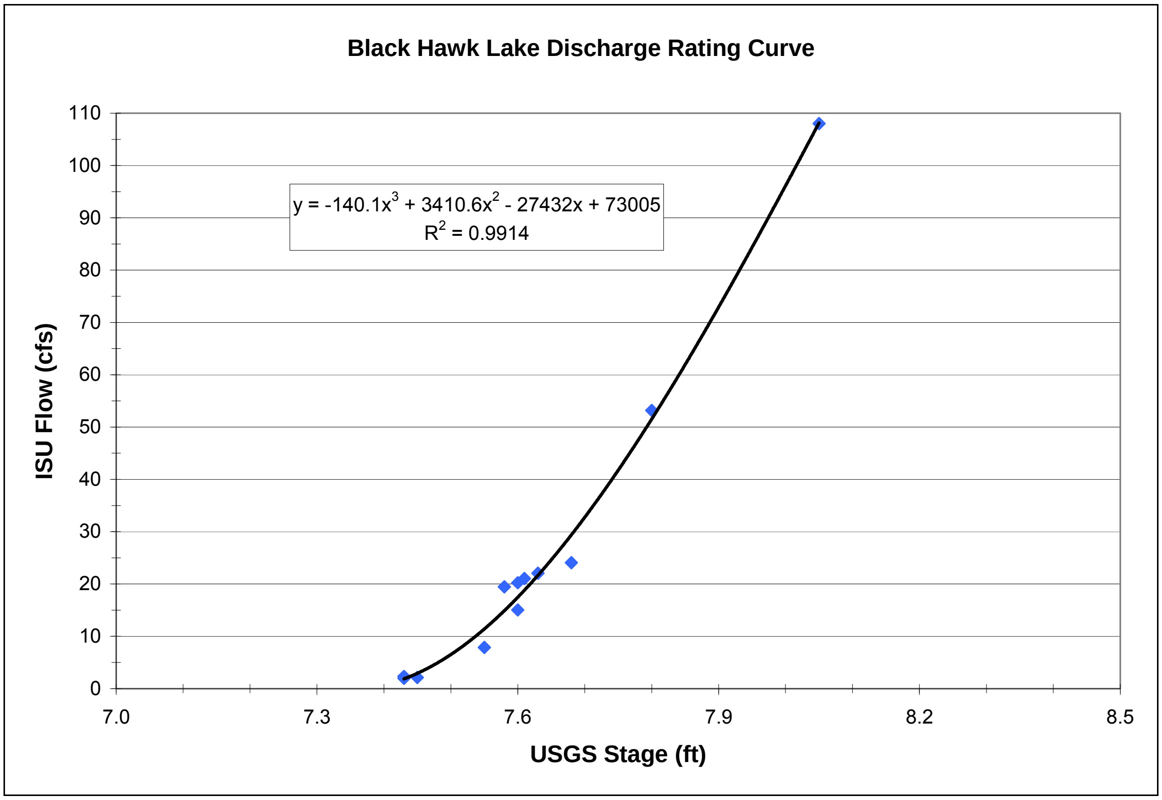

Figure E-2. Rating curve used for calibration of Black Hawk Lake discharge.

The polynomial regression has an R^2 value of 0.99. The equation can be rewritten as follows:

$$Q = -140.1h^3 + 3{,}410.6h^2 - 27{,}432h + 73{,}005$$

Where: Q = the average daily discharge (cfs) from the lake
h = the lake stage (ft) relative to the gage datum.

Calibration Parameters

Calibration of SWAT involved iterative adjustment of hydrologic parameters until graphical and/or statistical comparison of observed and simulated data revealed sufficient agreement. Initial values for all hydrologic parameters were obtained from previously existing SWAT models developed and calibrated in the Raccoon River Basin. These include a SWAT model application for TMDL development on the Raccoon River (IDNR, 2008) and a working paper produced by the Center for Agriculture and Rural Development CARD) and ISU (Jha et al, 2006). Final values for parameters that were adjusted during calibration of the Black Hawk Lake model are reported in Table E-2.

Table E-2. Summary of hydrologic calibration parameters in SWAT model.

Parameter	Input Description	Calibrated Value
Curve Number	Corn (COCT) – Soil Group B	67
	Soybeans (SOCT) – Soil Group B	68
	Pasture (PAST) – Soil Group B	64
	Grassland (BROS) – Soil Group B	59
	Forest (FRST) – Soil Group B	60
	Industrial (UIDU) – Soil Group B	66
	Residential (URMD) – Soil Group B	66
	Transportation (UTRN) – Soil Group B	66
NDTARGR	Number of days to reach target storage	5
IPET	Potential Evapotranspiration Method	Hargreaves
ESCO	Soil Evaporation Compensation	0.95 (default)
EPCO	Plant Uptake Compensation Factor	1.0 (default)
ICN	Daily curve number calculation method	Plant ET
CNCOEF	Plant ET curve number coefficient	0.7
SURLAG	Surface Runoff Lag	1 day
IRTE	Channel Routing Method	Variable Storage
NPERCO	Nitrogen percolation coefficient	0.2 (default)
PPERCO	Phosphorus percolation coefficient	10 (default)
GW_DELAY	Groundwater Delay	10 days
ALPH_BF	Alpha Base Flow Factor	0.9 days
GW_REVAP	Groundwater revap coefficient	0.02 (default)
REVAPMN	Threshold Revap Depth	30 mm
RCHRG_DP	Deep aquifer percolation fraction	0.05 (default)
GWQMN	Threshold depth required for return flow	0 mm (default)
DEP_IMP	Depth to impervious layer	2,400 mm

Average Annual Water Balance

The average annual water balance for the entire simulation period (1997-2009) was evaluated to ensure that the SWAT model was accounting for each of the hydrologic components. Water balance components reported in Table E-3 are all simulated values, except for precipitation, which is observed. Baseflow, as reported in Table E-3 is the summation of lateral flow, groundwater flow, and tile flow.

Table E-3. Average annual water balance components.

Component	(mm)	(in)
Precipitation	809.5	31.9
Surface runoff	70.32	2.8
Lateral flow	5.27	0.2
Groundwater flow	48.66	1.9
Tile flow	53.68	2.1
Evapotranspiration	649.9	25.6

Calibration Statistics

Evaluation of model performance followed guidelines developed by researchers at the United States Department of Agriculture-Agricultural Research Service (USDA-ARS), which actively supports and updates the SWAT model. The guidelines included a thorough literature review of SWAT model application and performance, and recommended use of two quantitative statistics during calibration/validation, in addition to graphical techniques (Moriasi et al., 2007). The statistics include the Nash-Sutcliffe efficiency (NSE) and percent bias (PBIAS). Graphical techniques included hydrograph analysis and percent exceedance probability curves (also called flow duration curves).

The NSE, like the slope and R^2 statistics, indicates how well the plot of simulated versus observed data fits the 1:1 line (Nash and Sutcliffe, 1970). The PBIAS statistic quantifies the tendency of the model to over or underestimate observed data. The optimal PBIAS value is zero, with low absolute values representing accurate model simulation. Positive values indicate underestimation bias, and negative values indicate overestimation bias. Table E-4 reports general performance ratings for the recommended statistics for use with monthly flow data. Statistical results are expected to be better for annual data and worse for daily data.

The most appropriate observed data set available for hydrologic model calibration and assessment was obtained from the rating curve developed by IDNR using observed lake stage (USGS) and measured lake discharges (ISU) previously described. Note that this flow data is not truly “observed”, but calculated from a rating curve based on observed stage. It is likely that the rating curve introduces some uncertainty and error to the data due to human error and natural variation in flow measurements used to construct the curve. The seiche affect, described previously, is another potential source of error in the observed data. Monthly flows calculated from the rating curve are more reliable, and hence more appropriate for model assessment, than daily estimates.

Table E-4. Performance ratings for recommended statistics.

[1]Performance Rating	NSE	PBIAS (%)
Very good	0.75 < NSE ≤ 1.00	PBIAS ≤ ±10
Good	0.65 < NSE ≤ 0.75	±10 < PBIAS ≤ ±15
Satisfactory	0.50 < NSE ≤ 0.65	±15 < PBIAS ≤ ±25
Unsatisfactory	NSE ≤ 0.50	PBIAS ≥ ±25

[1] Suggested SWAT statistics and ratings for monthly flow (Moriasi et al., 2007)

Average Annual Flow

The first step in model calibration involved comparing SWAT outputs to observed flows from the lake. Due to the limited years of available data, annual flows were not split into calibration and validation years. Figure E-3 illustrates simulated and observed annual flows for the entire simulation period (1997-2009).

Figure E-4 shows the regression analysis of annual discharge from the lake, which yielded an R^2 of 0.78. The NSE (0.73) and PBIAS (-9.54) are also reported on Figure E-4. The statistics indicate reasonable agreement between predicted and observed output. One would expect slightly better annual statistics compared with those based on monthly flow. However, statistics improve with larger data sets, and only 13 years of flow data are available for Black Hawk Lake. Subsequent analysis of monthly data suggests that the Black Hawk Lake SWAT model performs at least as well on a monthly basis.

Analysis of annual flow data reveals that the hydrology model is providing reasonable predictions of annual flow at the Black Hawk Lake outlet. The model overestimates annual flow in 1997 and between 1999 and 2006, and underestimates flow in all other years. Overall, results suggest a fair match between observed and simulated annual flows. For the 13-year simulation period, the simulated average annual discharge (8.3 inches) was reasonably close to the observed (rating curve) value (7.6 inches), a difference of 8.7 percent. There are years in which the simulated and observed outflows vary by a large amount. This is likely due to complexities related to modeling reservoirs, extended periods of non-discharge from the reservoir, and SWAT's limitations in simulating reservoir storage and outflow.

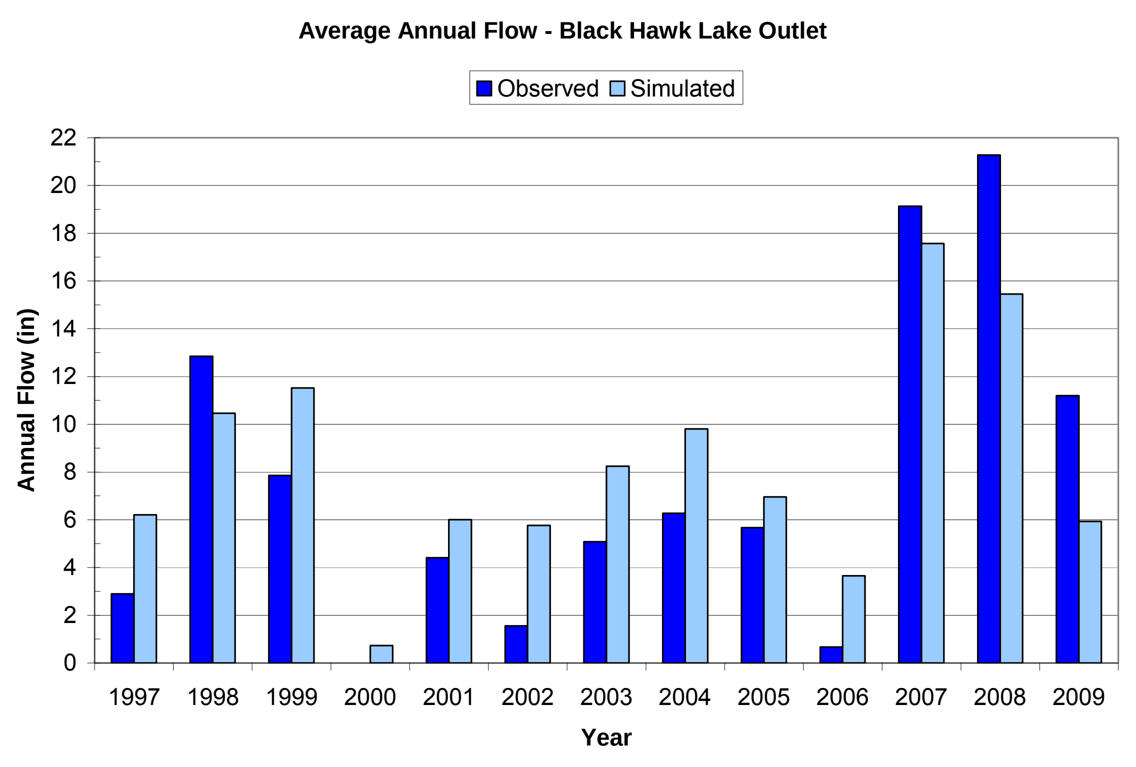

Figure E-3. Simulated and observed (rating curve) annual flow.

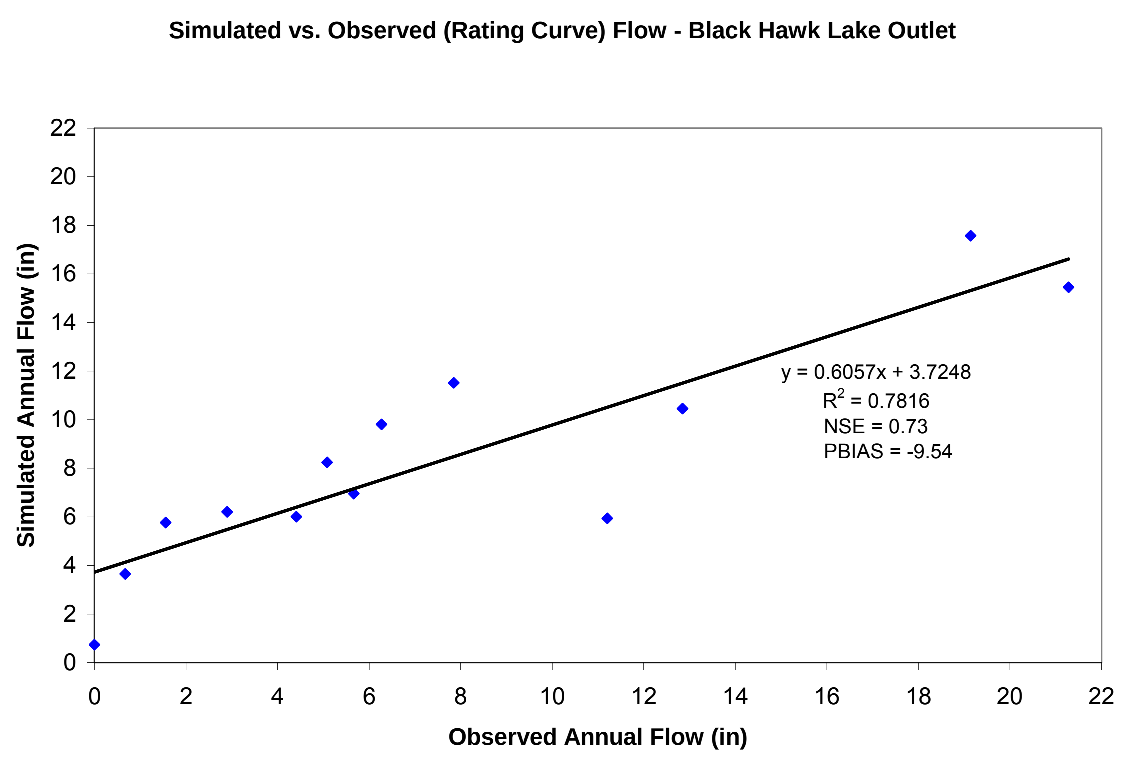

Figure E-4. Regression of simulated and observed (rating curve) annual flow.

Monthly Average Flow

A continuous time series of simulated and observed monthly average flow, in cubic feet per second (cfs), is plotted for the entire simulation period (1997-2009) in Figure E-5. This excludes the three-year spin-up period of 1994-1996. There are instances where high and low flows are not perfectly simulated, but overall agreement appears to be reasonably good. Excellent agreement is observed in years 2003, 2005, 2007, and 2008. The poorest agreement is observed 1997, 2001, and 2006, which were all relatively low-flow years.

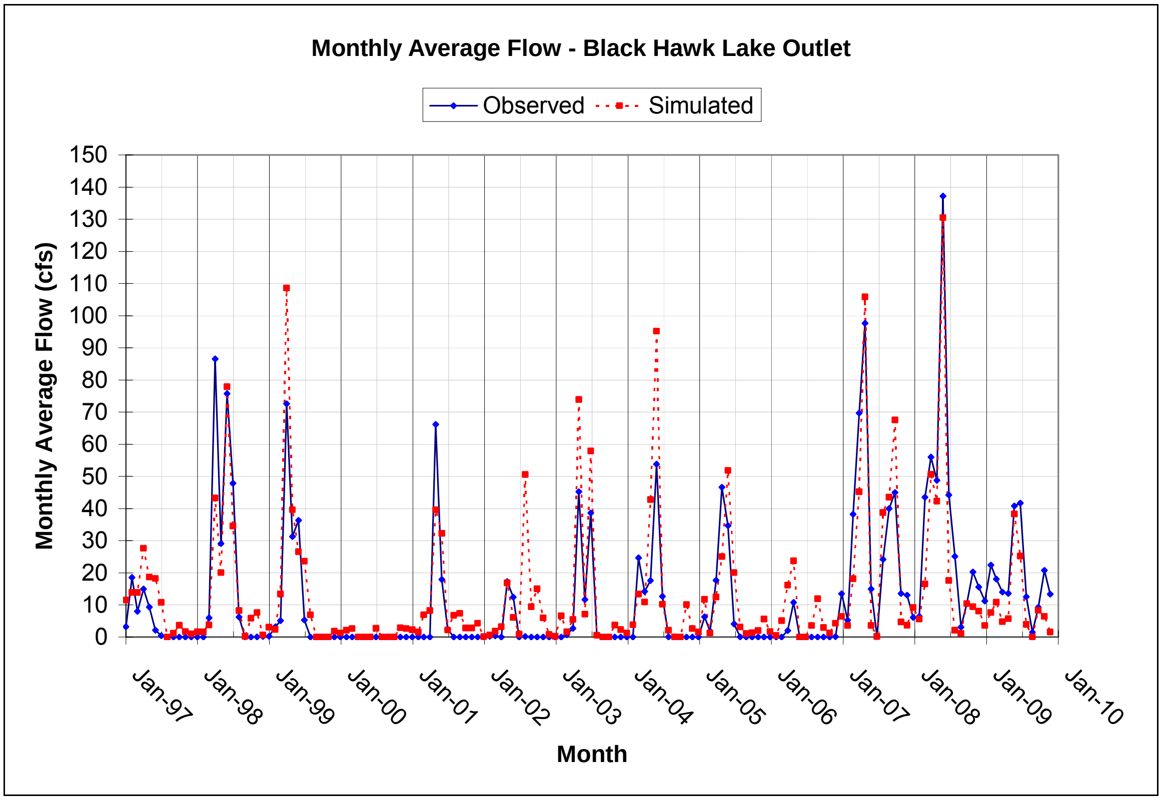

Figure E-5. Monthly average flows from Black Hawk Lake (1997-2009).

Figure E-6 shows the average flows summarized by month for the entire simulation period. The model tends to overestimate flows between June and October, but underestimates flow in March and April. However, agreement is good in April, May, July, November, December, January, and February.

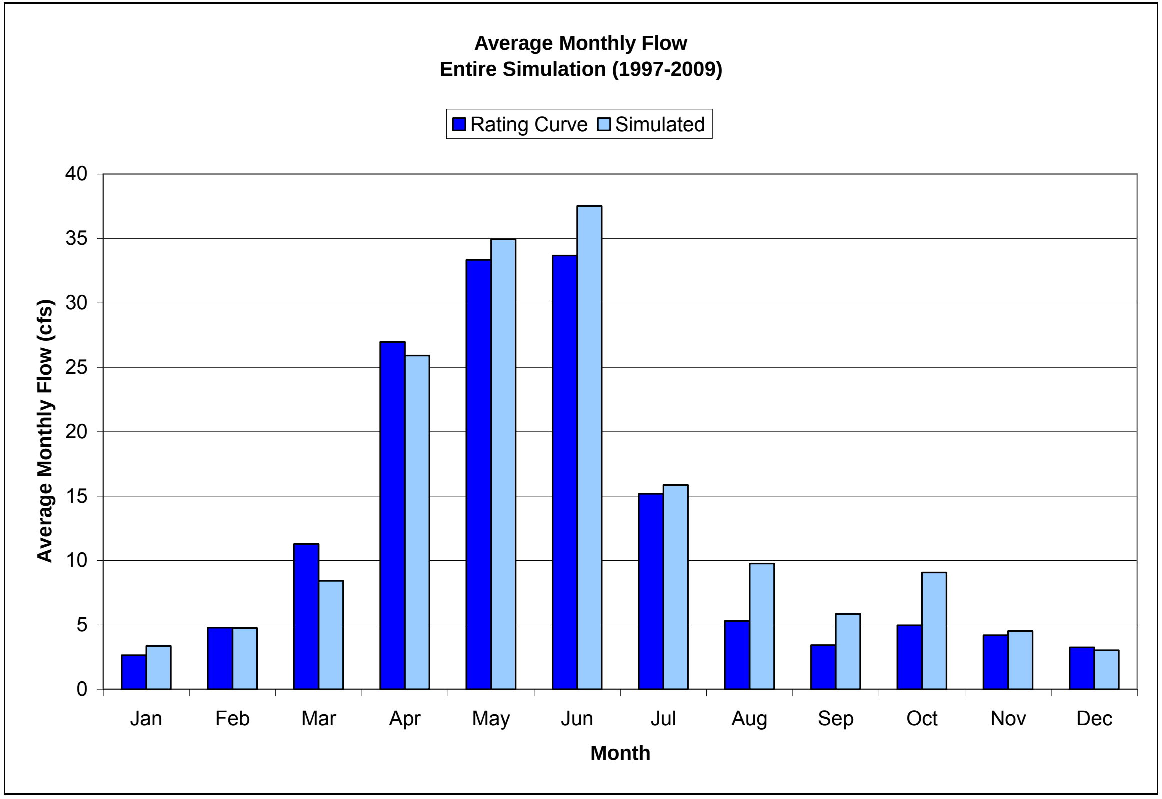

Figure E-6. Average monthly flows for each month (1997-2009).

It should be noted that both calibration and validation periods utilize the same spin-up period (1994-1996); however, output was retrieved for both periods from the same model run. In other words, the effective spin-up period for the calibration period includes the validation years. This is common practice in SWAT model application, and allows initialization of calibration and validation periods using previous real-world meteorological conditions.

Linear regression analysis was performed on the data for the calibration period (2002-2009) and validation period (1997-2001). In addition to linear regression, the NSE and PBIAS statistics were also calculated for comparison of simulated and observed monthly average flows. Figures E-7 and E-8 illustrate the linear regressions for calibration and validation, respectively. Table E-5 reports the model performance statistics for the calibration and validation of monthly discharge from the lake.

The calibration R^2 value is 0.74, which is acceptable according to recommendations made in modeling literature. The slope of the linear regression is 0.91. The calibration NSE of 0.71 is rated “good” and the PBIAS of -3.24 is considered “very good” according to guidance issued by developers of the SWAT model (Moriasi et al., 2007).

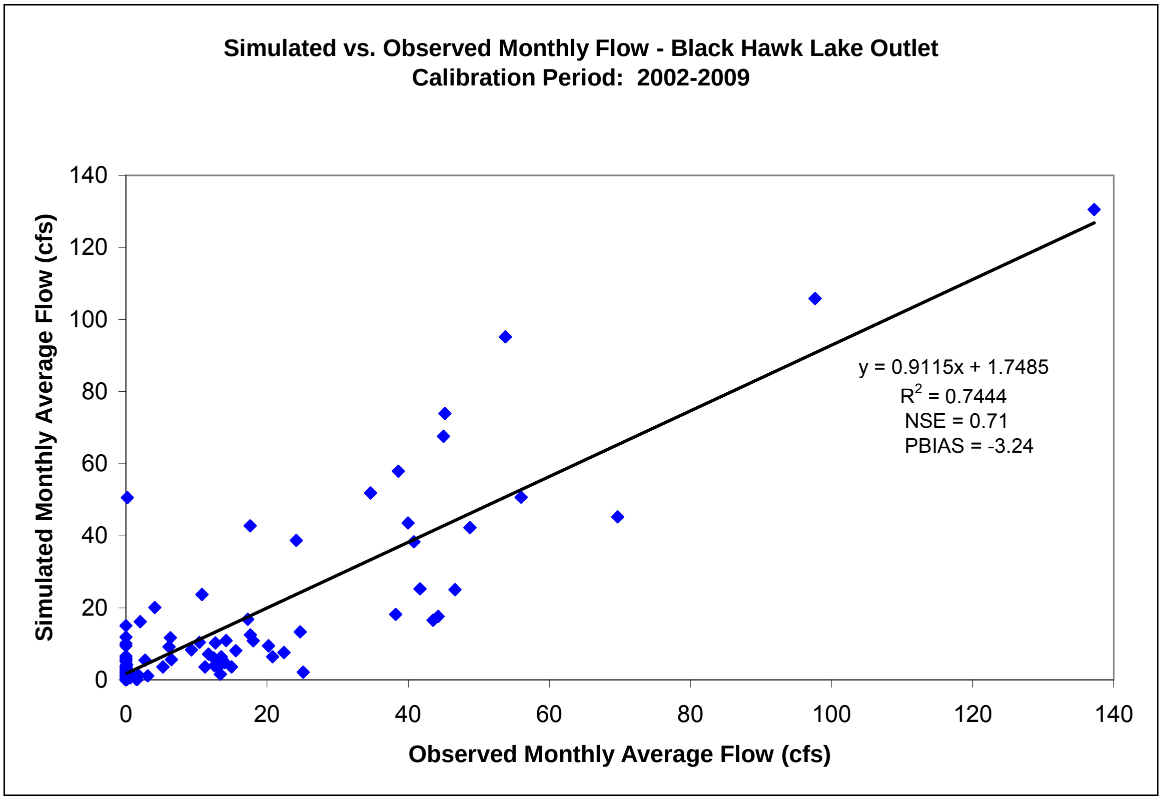

Figure E-7. Linear regression of monthly average flow (calibration).

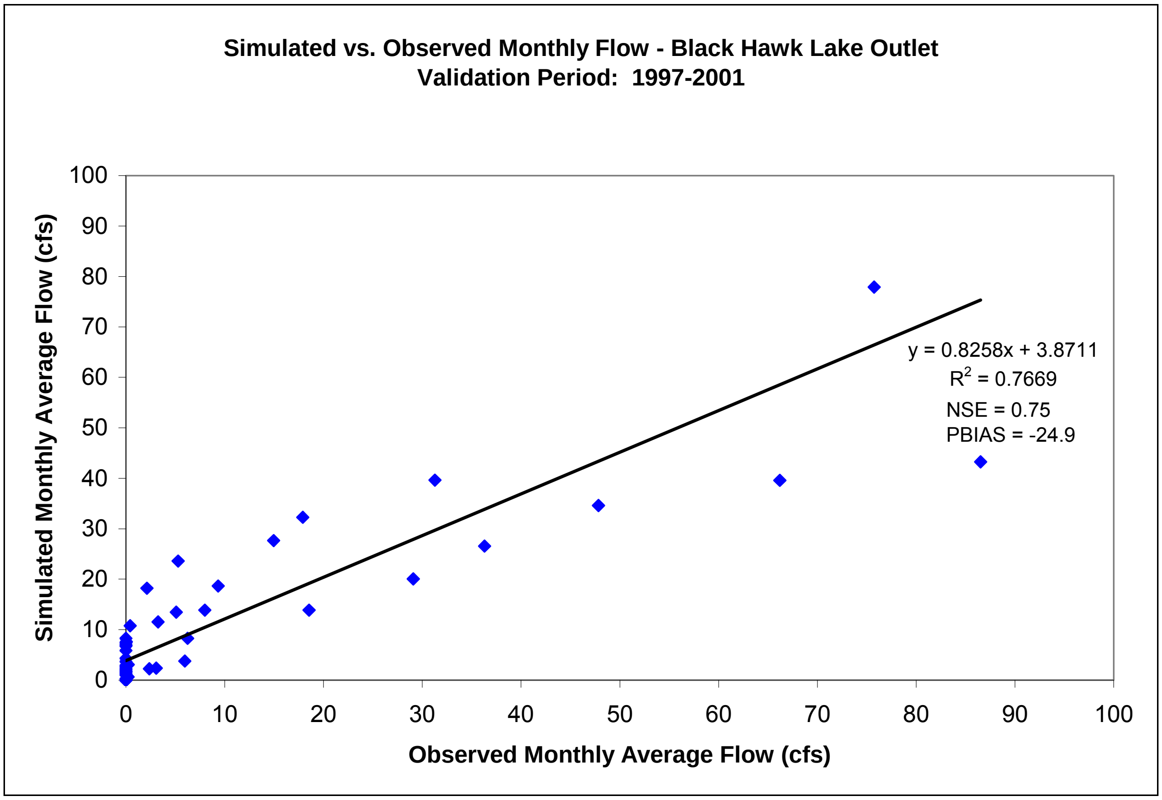

Figure E-8. Linear regression of monthly average flow (validation).

Table E-5. Monthly flow statistics (and suggested ratings[1]).

	Regression Slope	R^2	NSE	PBIAS
Calibration (2002-09)	0.91	0.74	0.71 (Good[1])	-3.24 (Very Good[1])
Validation (1997-2001)	0.83	0.77	0.75 (Very Good[1])	-24.9 (Satisfactory[1])

[1] Moriasi et al., 2007

Linear regression yielded a validation R^2 of 0.77 and a slope of 0.83. The validation NSE is 0.75 (very good) and PBIAS is -24.9 (satisfactory). The negative PBIAS value indicates that in general, the model tends to overestimate flows predicted by the rating curve. Examination of the regression equation provides greater temporal resolution and reveals that SWAT tends to overestimate smaller, more frequent flows and underestimate larger, infrequent flows. Overall, the statistics obtained during calibration and validation analysis suggest that the model provides reasonable estimates of monthly average flow from Black Hawk Lake.

Monthly Average Runoff and Baseflow

If data is available, SWAT model calibration should include analysis of runoff and base flow. Because no stream gage was available for the main tributary to Black Hawk Lake (Carnarvon Creek), no direct calibration of runoff and base flow was performed using SWAT model output. However, simulated base flow percentage was compared to the results of two previously calibrated SWAT models developed for the Raccoon River basin and for a stream with base flow estimates developed by USGS. Table E-6 lists the baseflow percentages from other sources, and describes the source of the data.

Table E-6. Percentage of total flow comprised of base flow.

Waterbody/ Location	USGS Gage	Drainage Area (mi^2)	Period of Record	Source	Baseflow (%)
Raccoon River @ Van Meter	05484500	3,441	1981-2003	Jha et al., 2006	58
North Raccoon River @ Sac City	05482300	700	1958-2005	IDNR, 2008	69.1
North Raccoon @ Jefferson	05482500	1,619	1940-2005	IDNR, 2008	68.2
Middle Raccoon @ Bayard	05483450	375	1979-2005	IDNR, 2008	69.7
Walnut Creek @ Des Moines	05484800	78	1971-2005	IDNR, 2008	57.3
Hazelbrush Creek near Maple River	05483343	9.2	1990-1994	USGS NHDPlus	57.3
Carnarvon Creek @ Black Hawk Lake	**--**	**22.2**	**1997-2009**	**SWAT Model (Current TMDL)**	**60.5**

The USGS gage on the North Raccoon at Sac City is the closest in proximity to Black Hawk Lake, and is only 4.5 miles northeast of the water elevation gage at the lake. However, it has a much larger drainage area than the Black Hawk Lake watershed, and a higher estimated base flow (69.1 percent). The gage on Hazelbrush Creek is the next closest, lying 12.5 miles directly south of the gage on Black Hawk Lake. This gage has a similar drainage area as Black Hawk Lake, and an estimated base flow portion of 57.3 percent. The SWAT-simulated base flow portion of the total flow to Black Hawk Lake (60.5 percent) lies well within the range of values from previous baseflow estimations listed in Table E-6 (57.3 to 69.1 percent). This indicates the model simulates base flow reasonably well.

Daily Tributary Flow

Some limited flow data was collected by ISU as part of the 2008-2009 Diagnostic Feasibility Study upstream of Black Hawk Lake. An ISCO automated sampler with bubbler attachment was deployed by the University of Iowa Hygienic Lab (UHL) on Carnarvon Creek at 350th Street, about a half mile upstream of Provost Slough. Two separate deployments were made (July 28 to November 18, 2008, and March 17 to June 30, 2009) because of ice during winter conditions. UHL discontinued deployment on June 30, 2009, due to the end of their contract with IDNR. ISU continued the 2009 deployment through September 10, 2009. Eleven manual flow measurements were made at this site (Site 03 in the ISU DFS) between July 2008 and September 2009. During the deployment periods, continuous stage was measured at 15-minute intervals, which were condensed to daily average stage. ISU developed a flow rating curve for Site 03 in 2008 based on observed flow and stage for data collected. UHL calculated flow using a similar method based on the 2009 data. UHL staff noted that correlations between stage and flow were weak in 2008, but correlation was better in 2009 (Travis Morarend, December 22, 2008, and Jim Luzier, August 6, 2009, personal communications).

The location of Site 03 (and other tributary sites monitored by ISU) is shown in Figure E-9. Monitoring at other sites consisted primarily of grab samples for water quality parameters. The data collection period of the ISU monitoring was too short to provide adequate data for detailed calibration statistics. Additionally, field observation indicated that backwater from the lake frequently affects water stage at Site 03. The backwater effect introduces some error and uncertainty to the accuracy of the rating curve by “clouding” the correlation of flow and stage. This issue appeared to be more problematic in 2008 than 2009. Nonetheless, analysis of daily flow at Site 03 was helpful in making general assessments of the hydrologic response of the SWAT model.

Figure E-10 illustrates the linear regression of simulated and rating curve daily flows for the 2008 and 2009 data collection periods. The R^2 value of 0.30 is much lower than for monthly data, as expected. The low slope of 0.43 suggests that overall, the SWAT model is under-predicting daily flow at 350th Street. Backwater’s negative influence on the accuracy of the rating curve is likely the primary reason for this under-prediction. Increases in stage may falsely suggest increases in flow under backwater conditions, which would cause the rating curve to over-estimate flow.

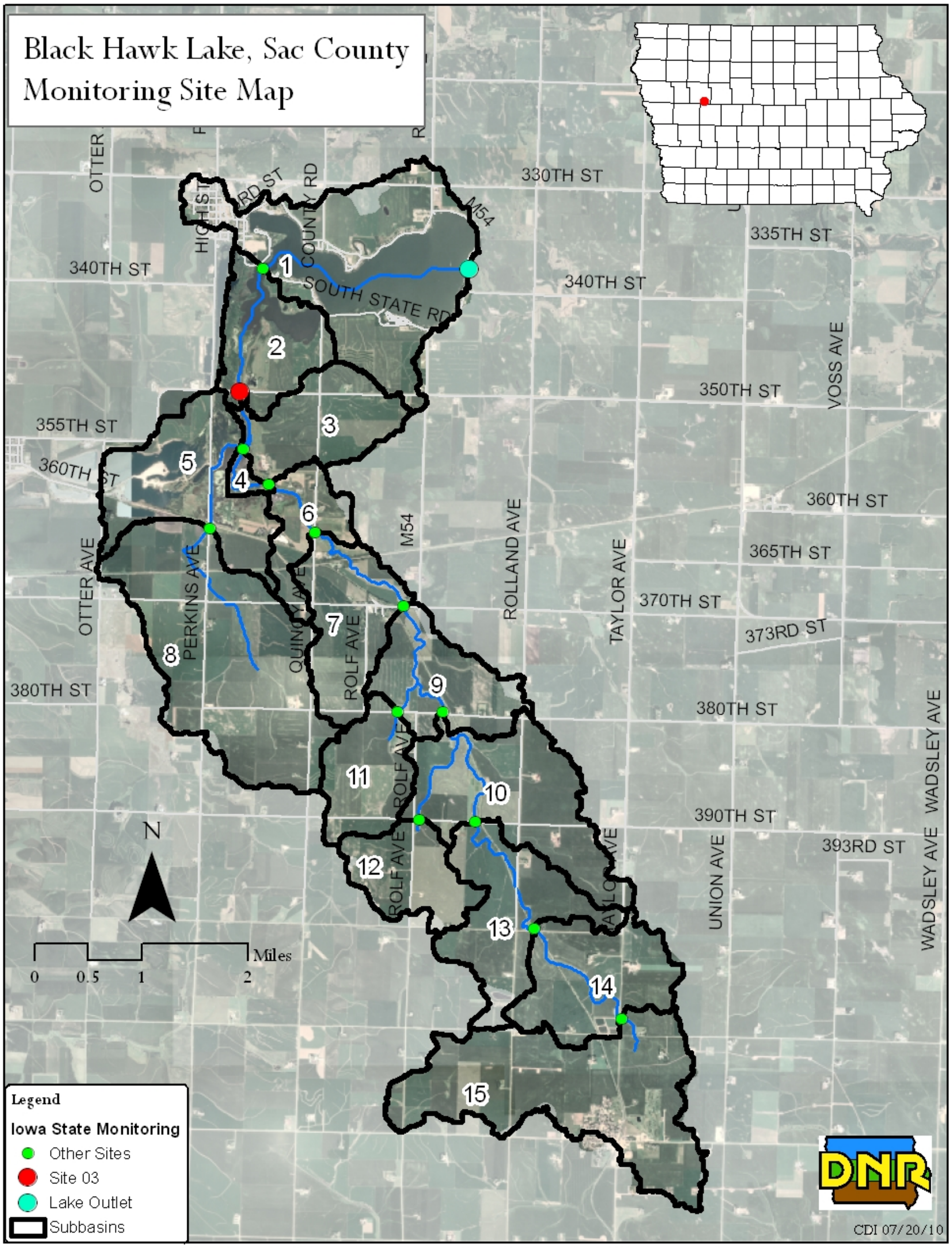

Figure E-9. Iowa State University monitoring sites.

The statistics are more favorable using only the 2009 data. This is best explained by the observation that the correlation of flow and stage was better in 2009 than 2008. Figure E-11 illustrates the regression of 2009 data and the improved R^2 (0.63) and slope (0.92).

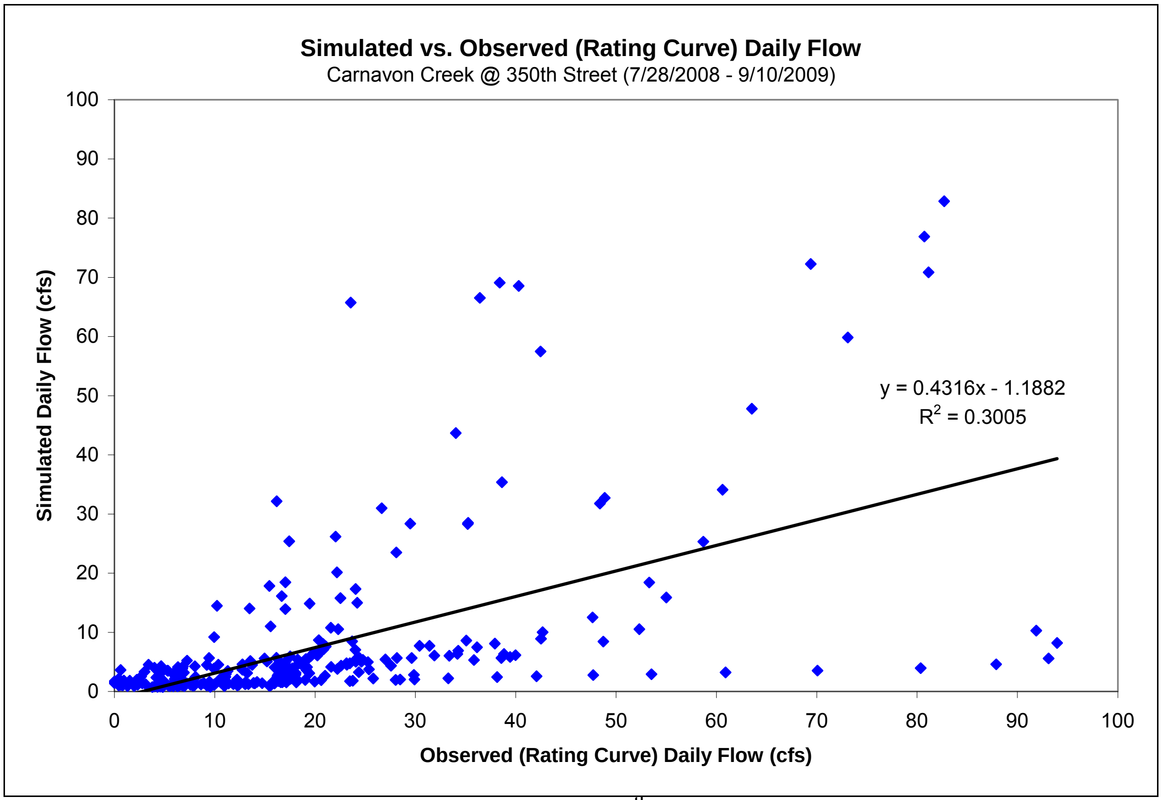

Figure E-10. Regression of daily flow at 350th Street (2008 and 2009).

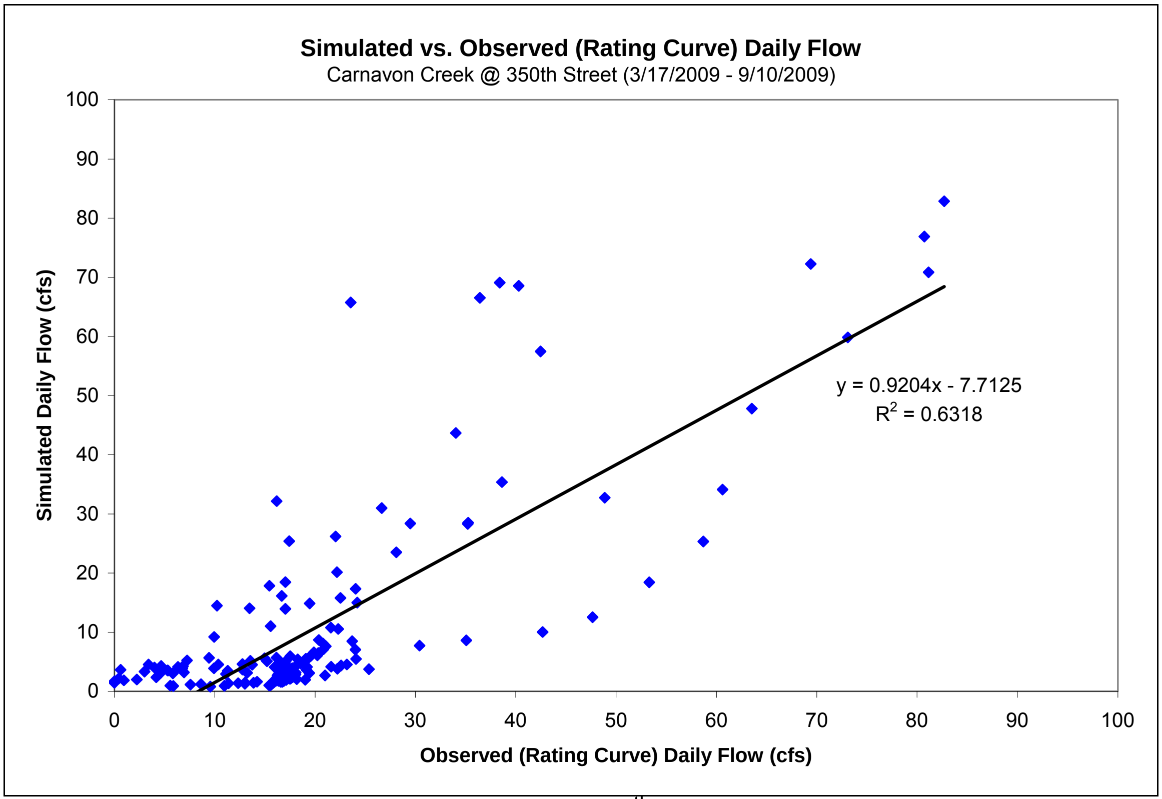

Figure E-11. Regression of daily flow at 350th Street (2009 data only).

Daily flow at 350th Street was used to improve model performance in the calibration process. Results may not indicate extremely reliable prediction of daily flow, but performance on a monthly scale is of more importance in development of the TMDLs for Black Hawk Lake because lake eutrophication is driven by cumulative nutrient loads rather than individual (i.e., daily) events. Daily calibration at Site 03 was used as a tool for model improvement, not final assessment of model performance.

Daily Lake Outflow

Observed daily flow from the reservoir, calculated using the rating curve, was also used to adjust calibration parameters and assess model performance. Average daily flows from the lake are plotted in Figures E-12 through E-19. Each plot includes one year of the calibration period (2002-2009).

SWAT greatly overestimates flow in the latter half of 2002 (Figure E-12), most likely due to heavy localized rainfall at the precipitation gages in Carroll and Sac City that did not occur in the Black Hawk Lake watershed. Simulated flows match observed flows well in 2003 (Figure E-13), although SWAT simulates continuous low flows from January to March and August to September, when the rating curve data suggests that the water level is below the lake outfall during these periods. Model and rating curve agreement is fair in 2004 and 2005 (Figures E-14 and E-15), but poor for 2006 (Figure E-16), wherein SWAT consistently overestimates discharge from the lake. Agreement is good in 2007 (Figure E-17) and 2008 (Figure E-18). The time series plot for 2009 (Figure E-19) shows that SWAT mimics the pattern of daily flows well, but consistently underestimates magnitude of flow.

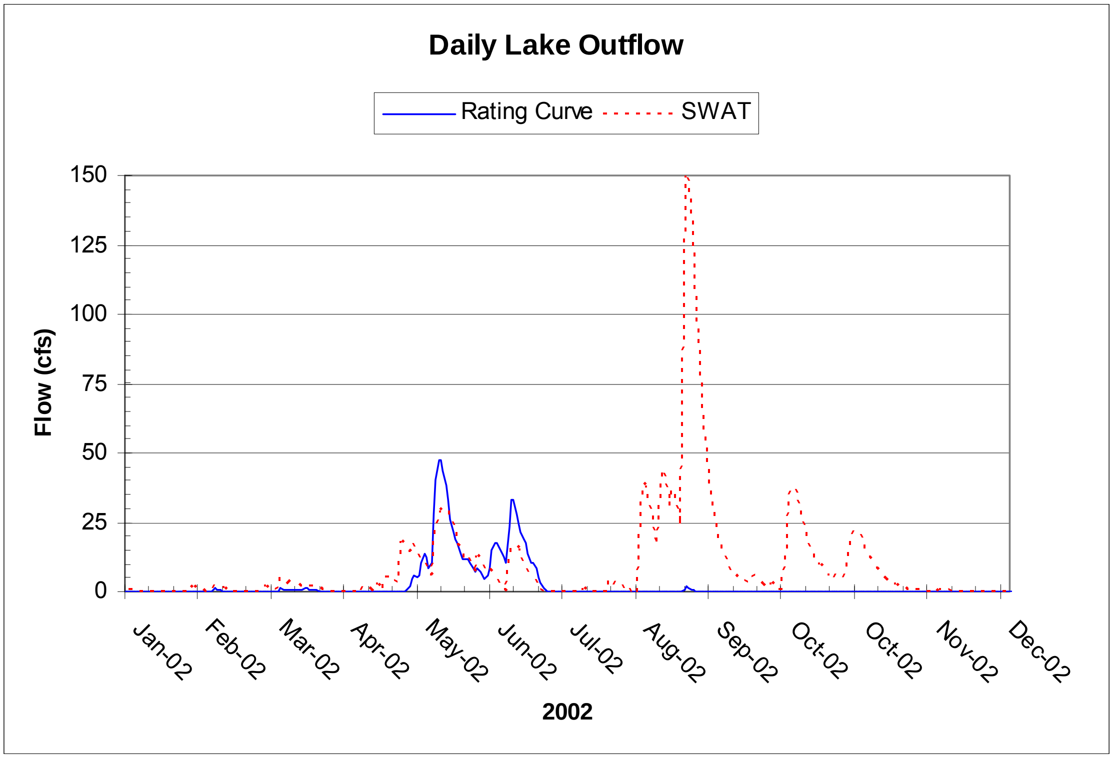

Figure E-12. Daily simulated and observed (rating curve) flow from lake (2002).

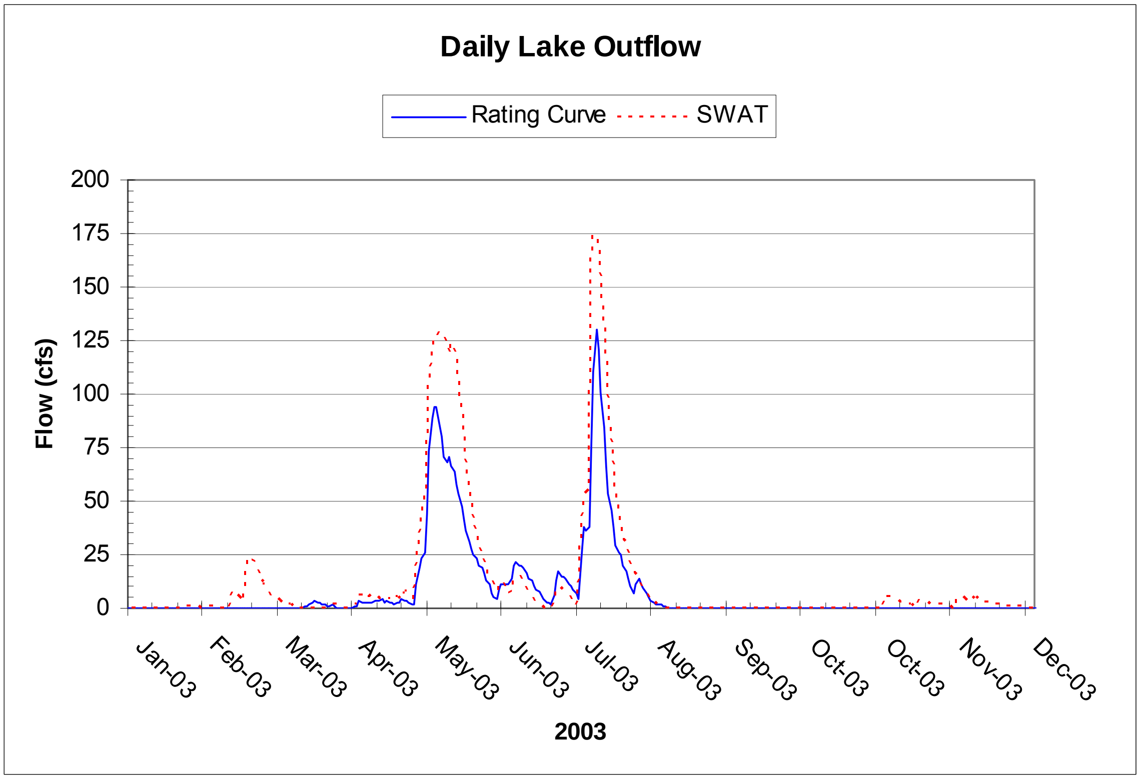

Figure E-13. Daily simulated and observed (rating curve) flow from lake (2003).

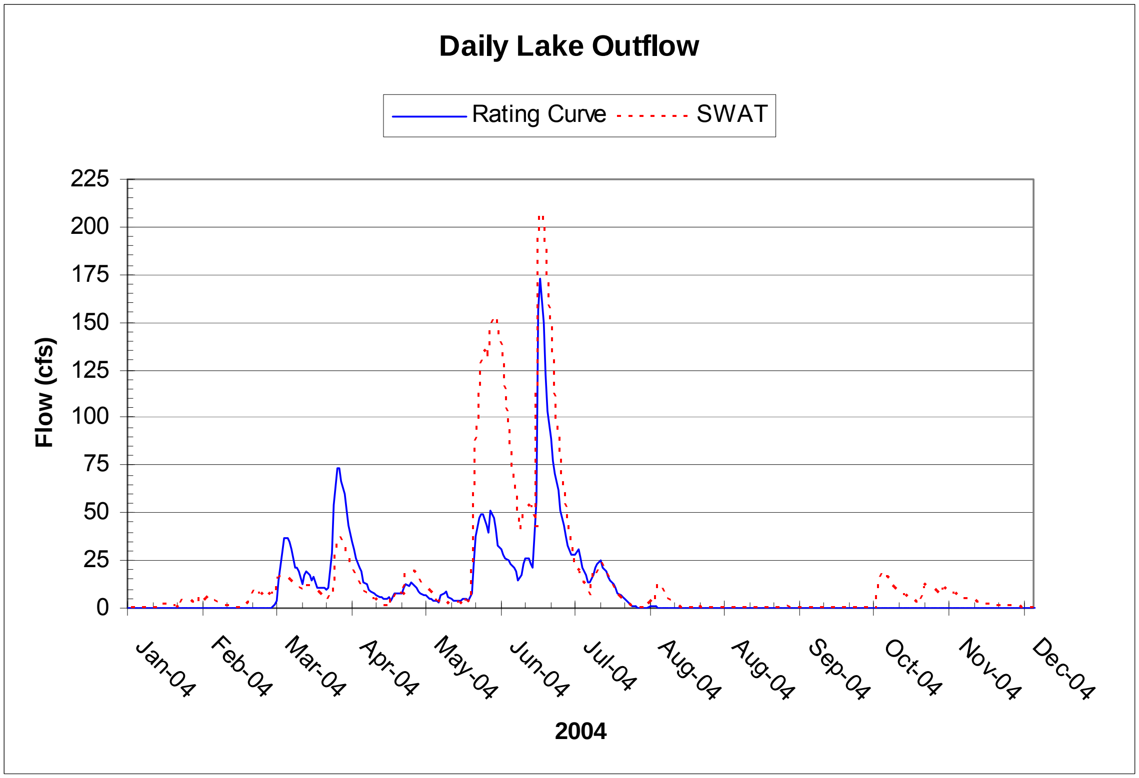

Figure E-14. Daily simulated and observed (rating curve) flow from lake (2004).

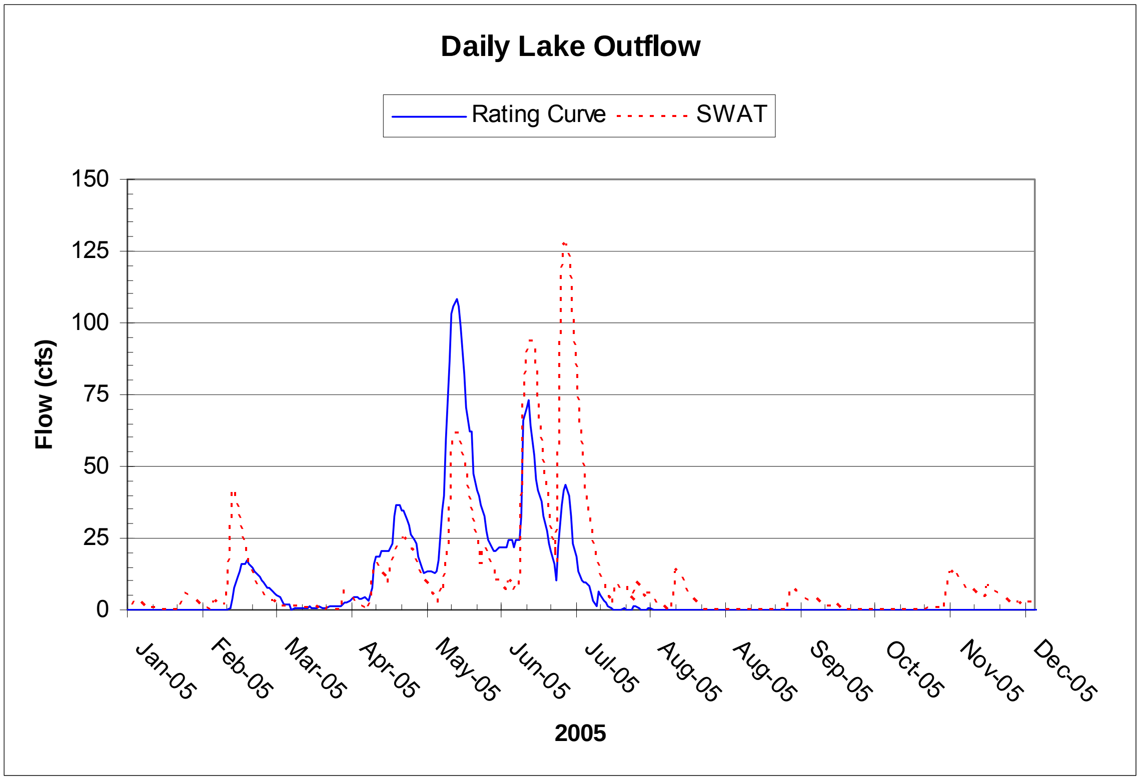

Figure E-15. Daily simulated and observed (rating curve) flow from lake (2005).

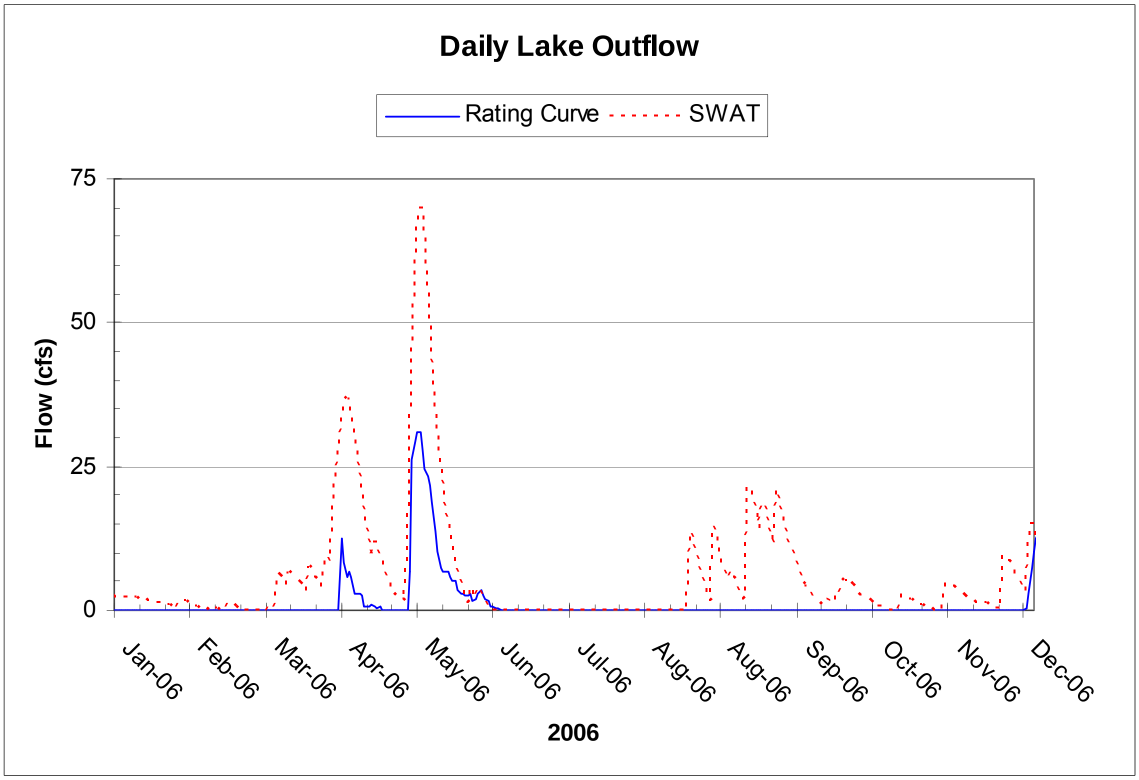

Figure E-16. Daily simulated and observed (rating curve) flow from lake (2006).

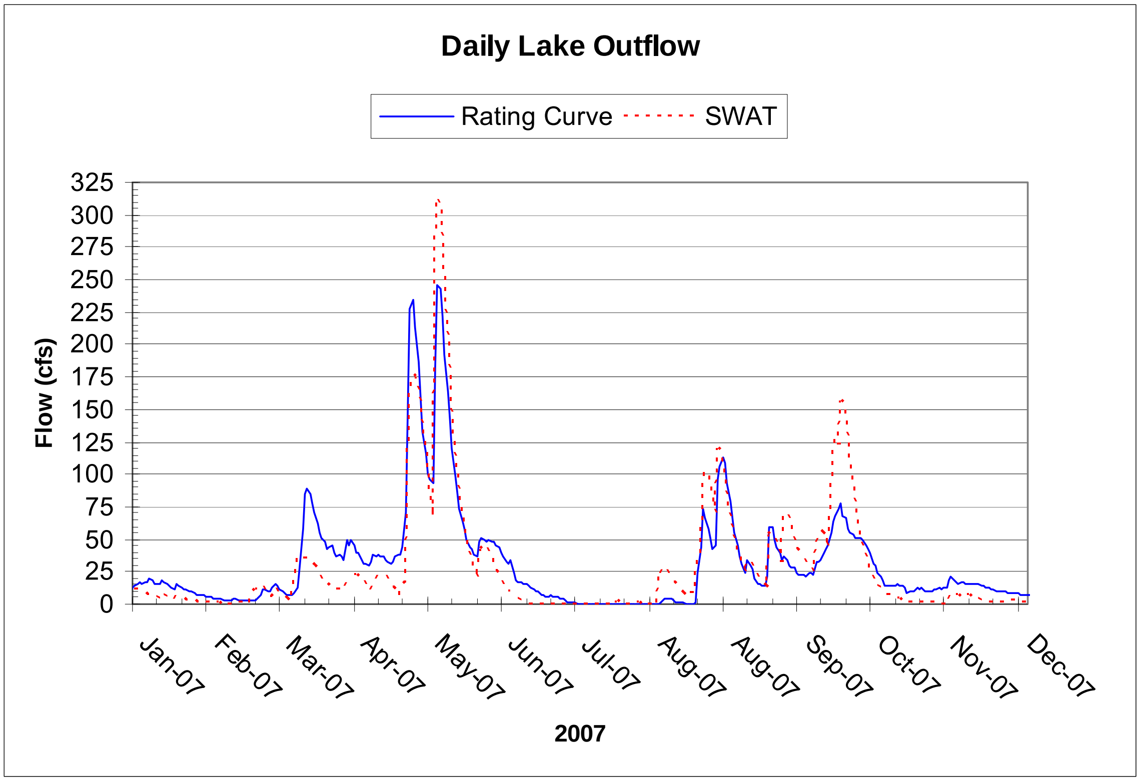

Figure E-17. Daily simulated and observed (rating curve) flow from lake (2007).

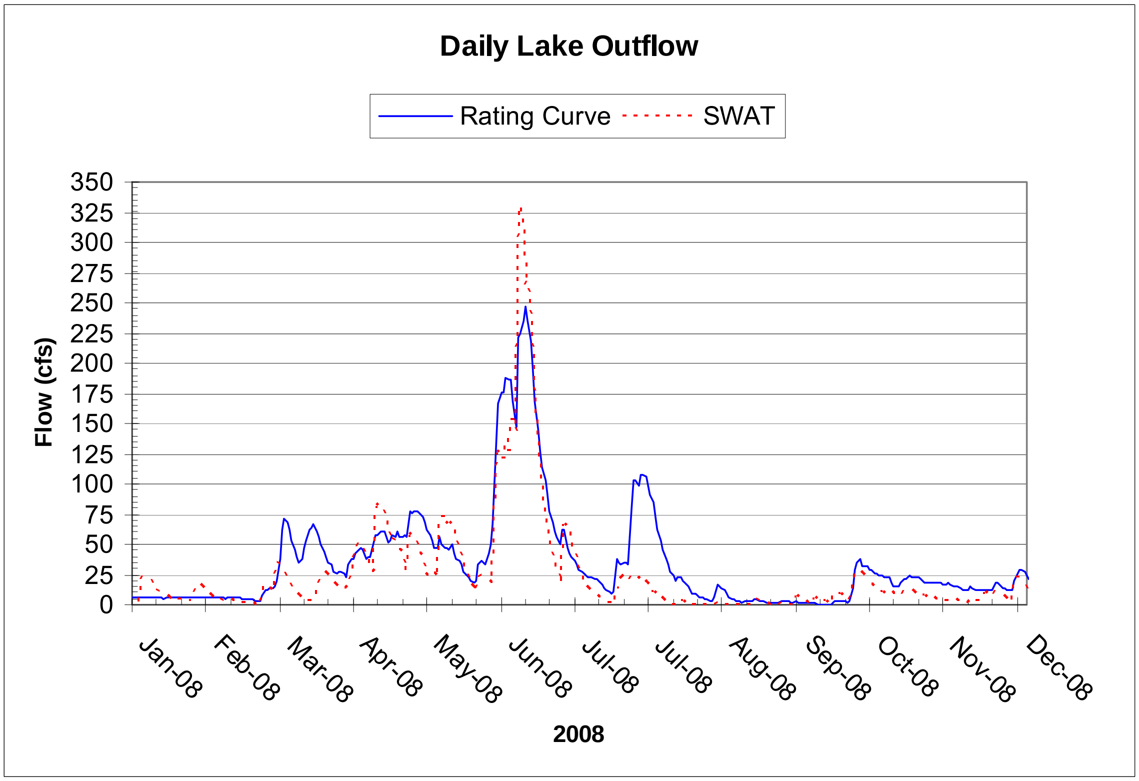

Figure E-18. Daily simulated and observed (rating curve) flow from lake (2008).

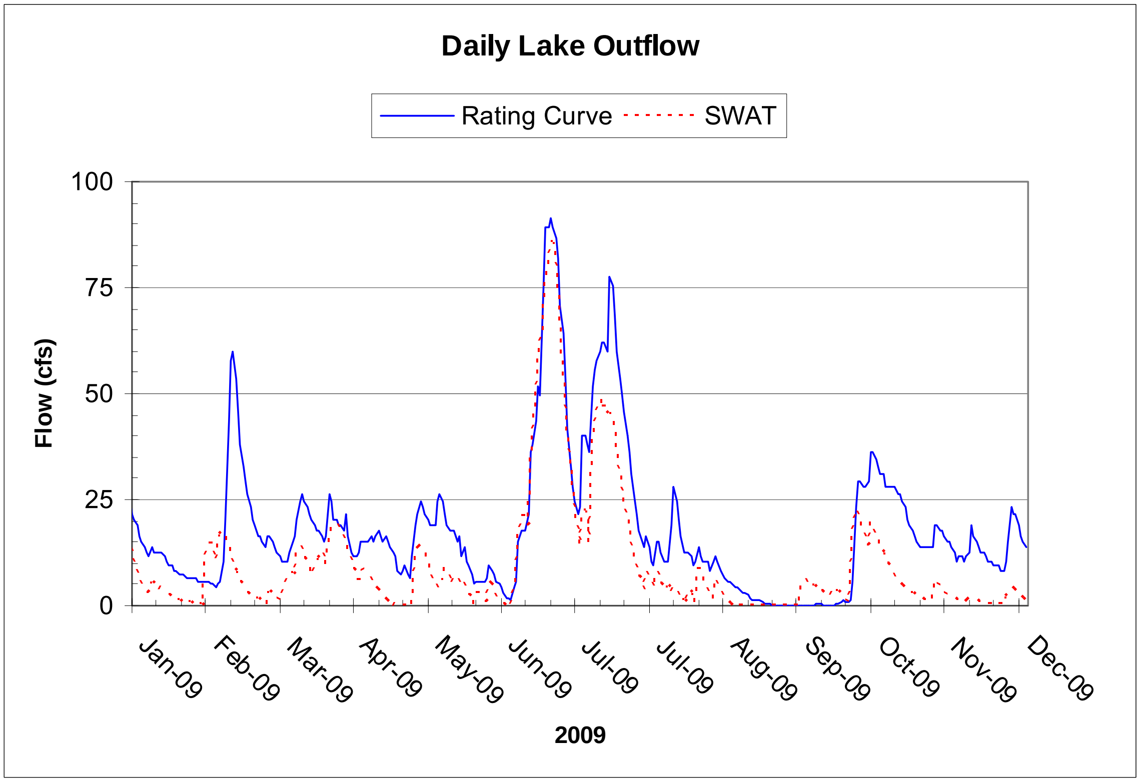

Figure E-19. Daily simulated and observed (rating curve) flow from lake (2009).

Figure E-20 illustrates the linear regression of simulated daily flow at the lake outlet. The R^2 of 0.70 indicates excellent agreement between the model and the rating curve daily flows. The slope of the regression is near 1.0 (0.94), indicating that the model is not significantly biased towards over or underestimate of observed flows in the calibration period. Further examination of the regression equation reveals that SWAT tends to overestimate flows under 19 cfs and underestimate flows greater than 19 cfs. The PBIAS value of -3.30 reveals that SWAT tends to slightly overestimate flow. The NSE of 0.61 is also quite good for a daily time-step. If all days for which the rating curve outflow equals zero (i.e., days when no water flows over the outfall structure) are removed from the data, the R^2, slope, NSE, and PBIAS become 0.69, 0.98, 0.56, and 6.99, respectively. All values remain well within a reasonable range per literature recommendations.

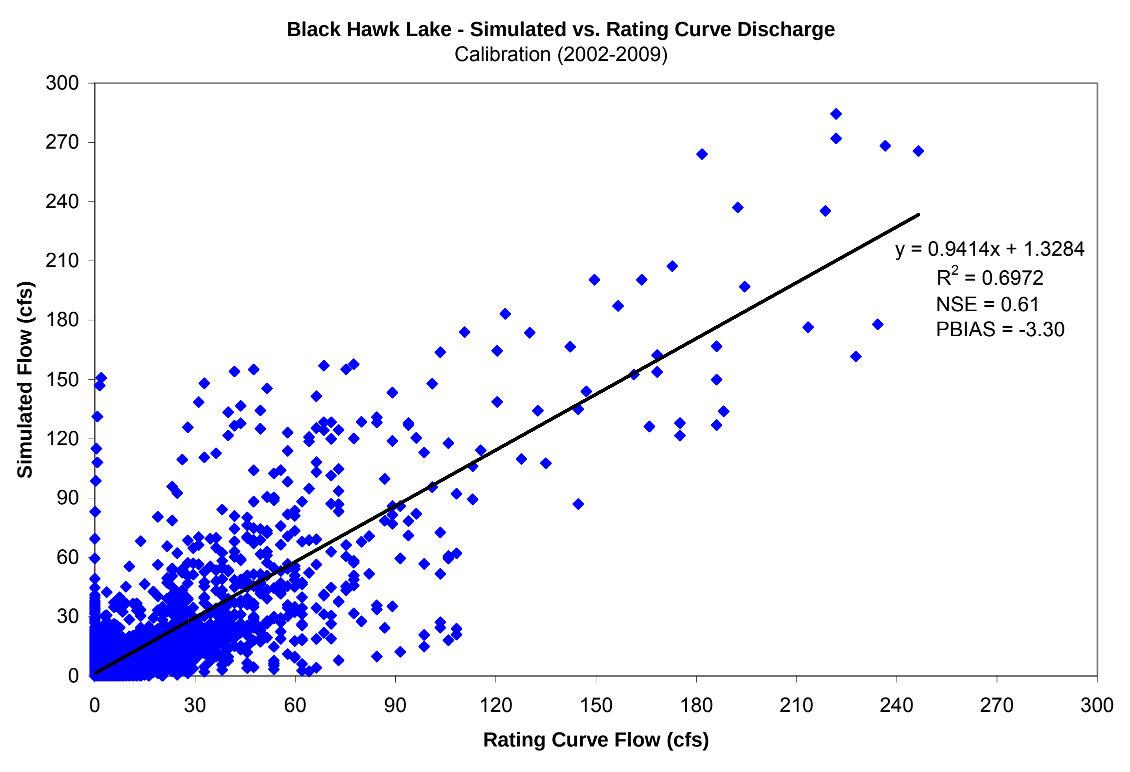

Figure E-20. Regression of daily flow from Black Hawk Lake (calibration period).

Time series daily flows for the validation period (1997-2001) are shown in Figures E-21 through E-25. Figure E-21 shows relatively poor agreement between simulated and rating curve-predicted flows in 1997, especially in July, where it appears that the precipitation gages received much more rainfall than the Black Hawk Lake watershed. Agreement appears to be fair to good in 1998 and 1999 (Figure E-22 and E-23). There was no flow out of Black Hawk Lake in 2000 according to rating curve calculations; however, SWAT predicted periods of low flow in January-February and November-December (Figure E-24). Agreement was poor in 2001, in which the model under-predicted flow in May, performed well in June, and predicted low flows throughout the rest of the year, while the rating curve predicted no flow out of the lake (Figure E-25).

Figure E-26 illustrates the linear regression of daily flows for the validation period. The R^2 of 0.62 suggests acceptable agreement between the model and the rating curve during the validation period. The slope of the regression is 0.70. The negative PBIAS of -25.5 indicates that the model tends to overestimate flows predicted by the rating curve. Further examination of the regression equation provides greater temporal resolution and reveals the model overestimates flows under 16 cfs and underestimates flows over 16 cfs. The NSE of 0.61 is good for a daily time interval, but the R^2 value is inflated due to zero-flow days when the water level is below the outfall structure. If all of the days with rating curve predictions of 0.0 cfs are removed from the data, the R^2, slope, NSE, and PBIAS become 0.55, 0.63, 0.53, and -7.42, respectively. All values are still well within a reasonable range per literature recommendations, and the PBIAS improves significantly.

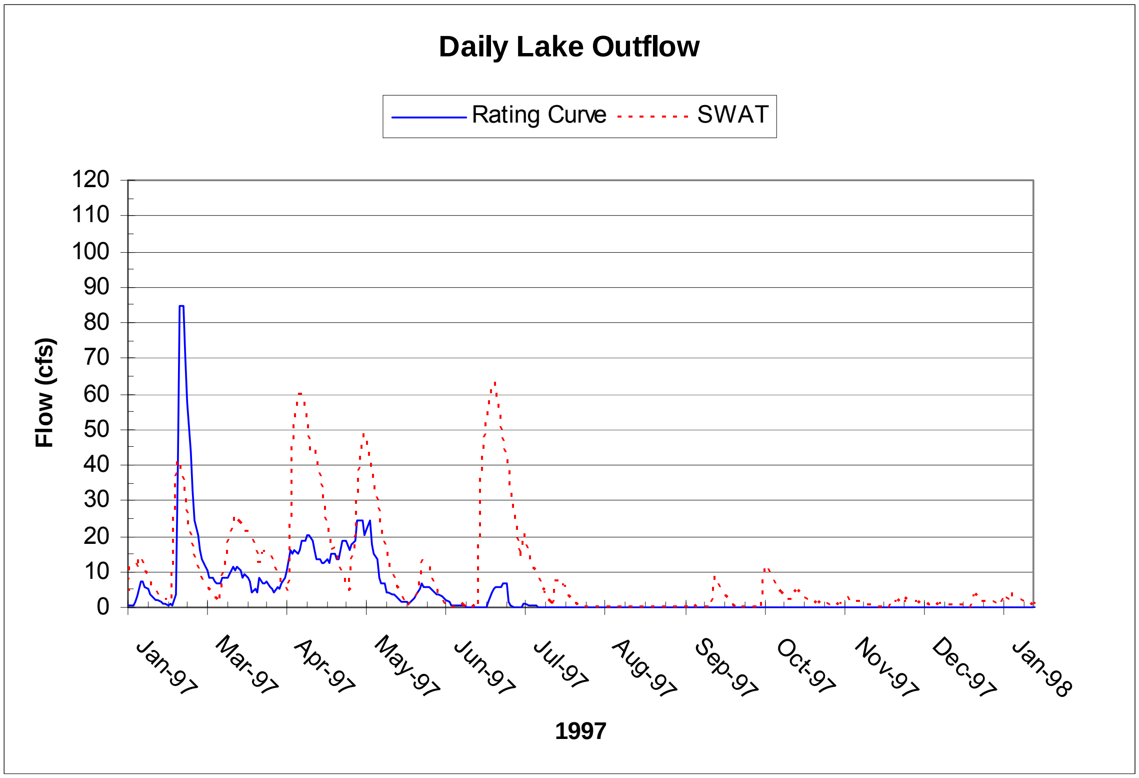

Figure E-21. Daily simulated and observed (rating curve) flow from lake (1997).

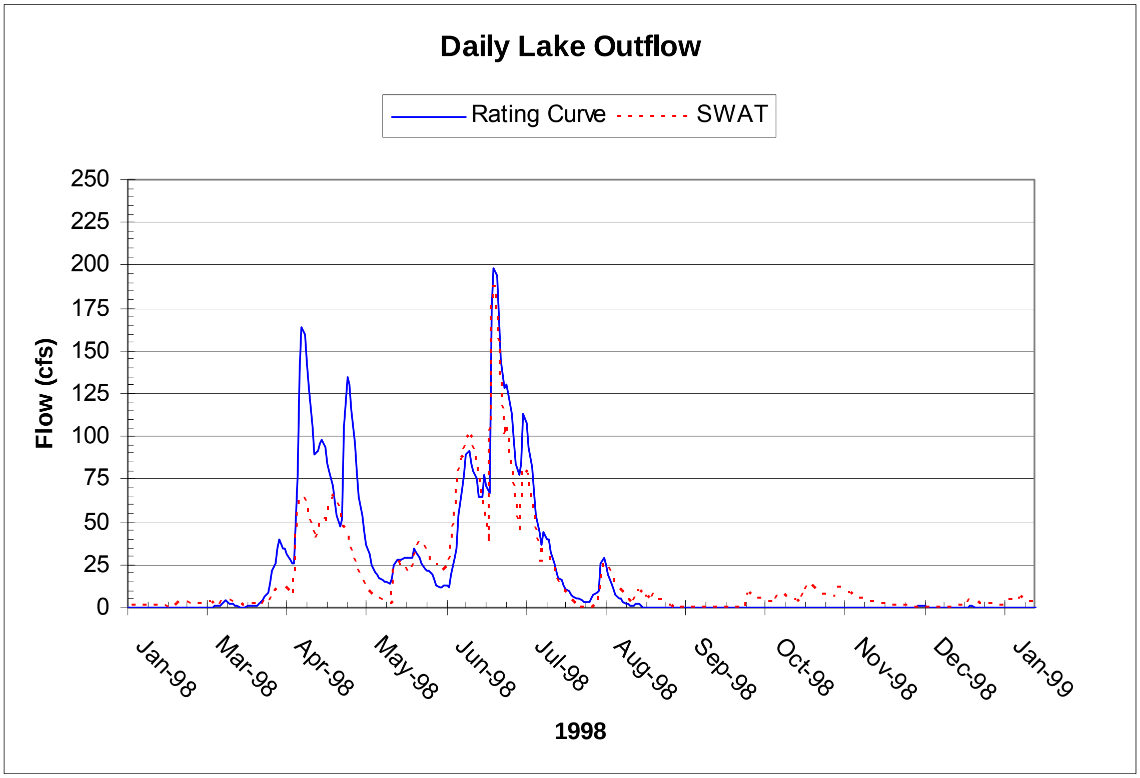

Figure E-22. Daily simulated and observed (rating curve) flow from lake (1998).

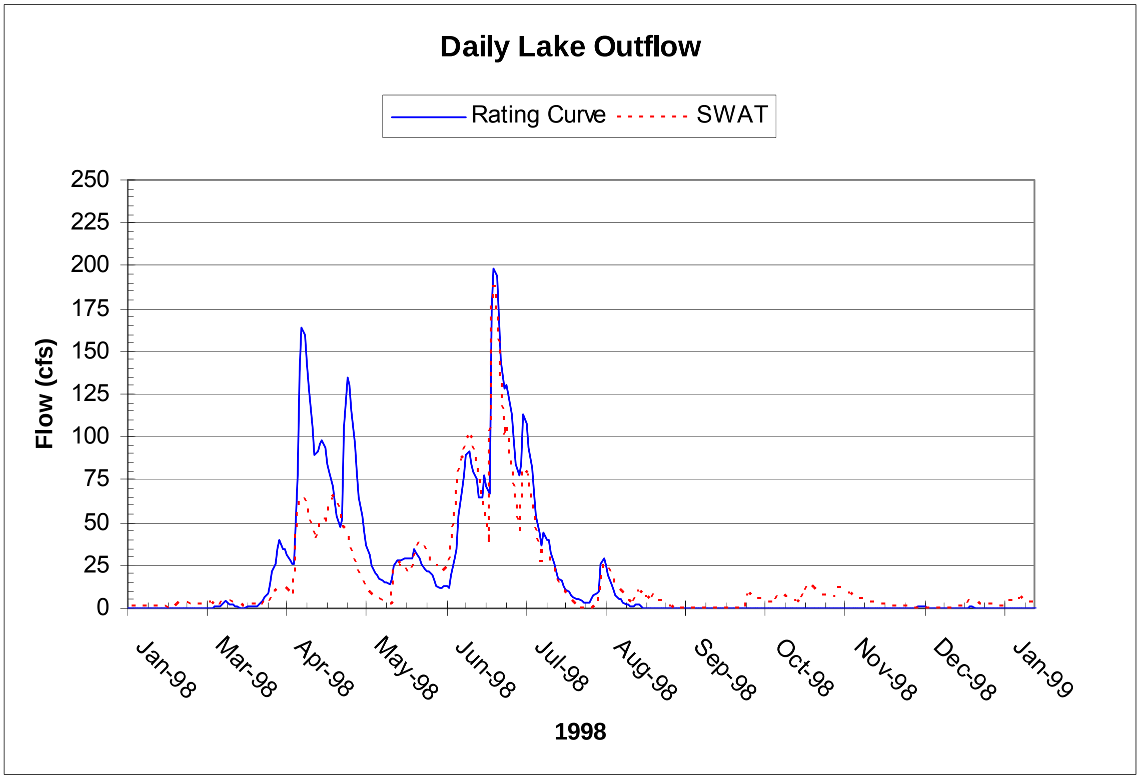

Figure E-23. Daily simulated and observed (rating curve) flow from lake (1999).

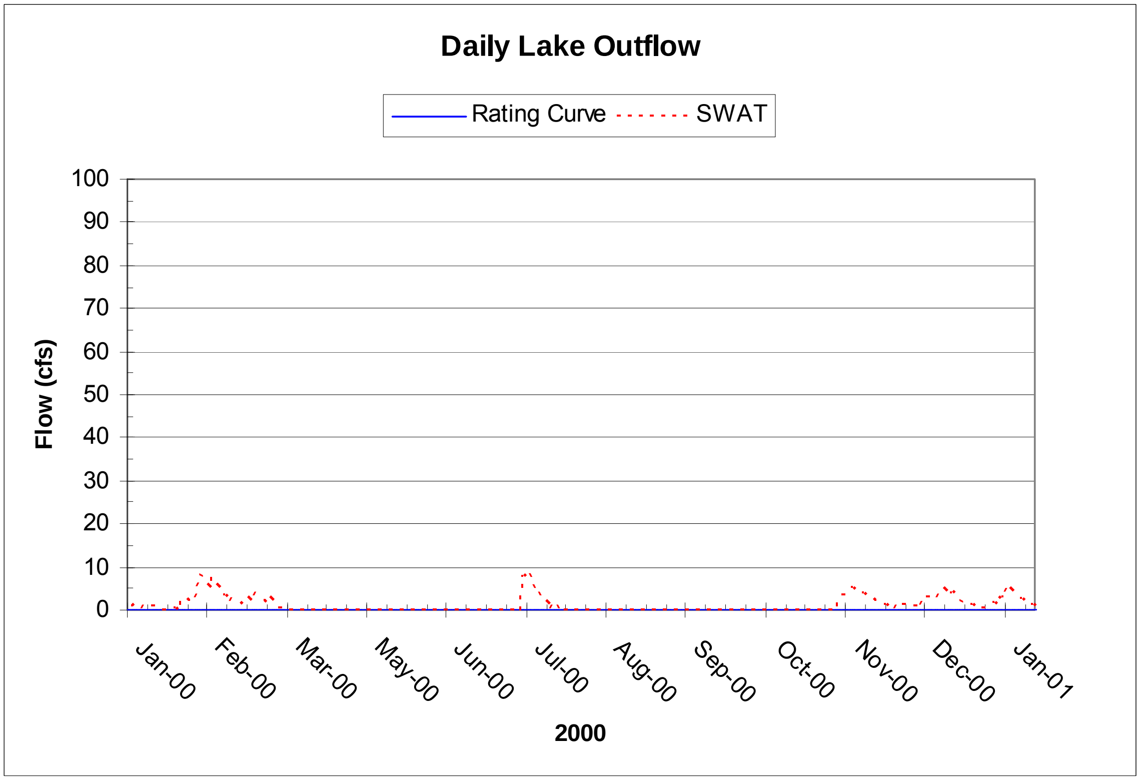

Figure E-24. Daily simulated and observed (rating curve) flow from lake (2000).

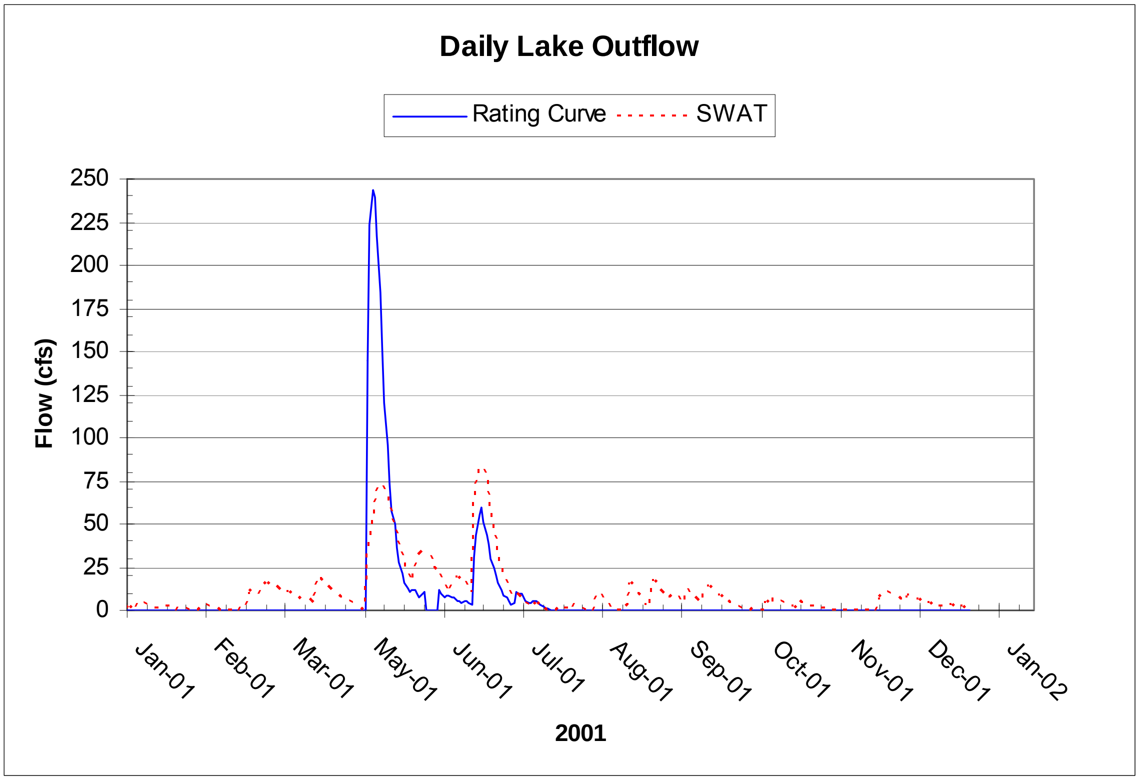

Figure E-25. Daily simulated and observed (rating curve) flow from lake (2001).

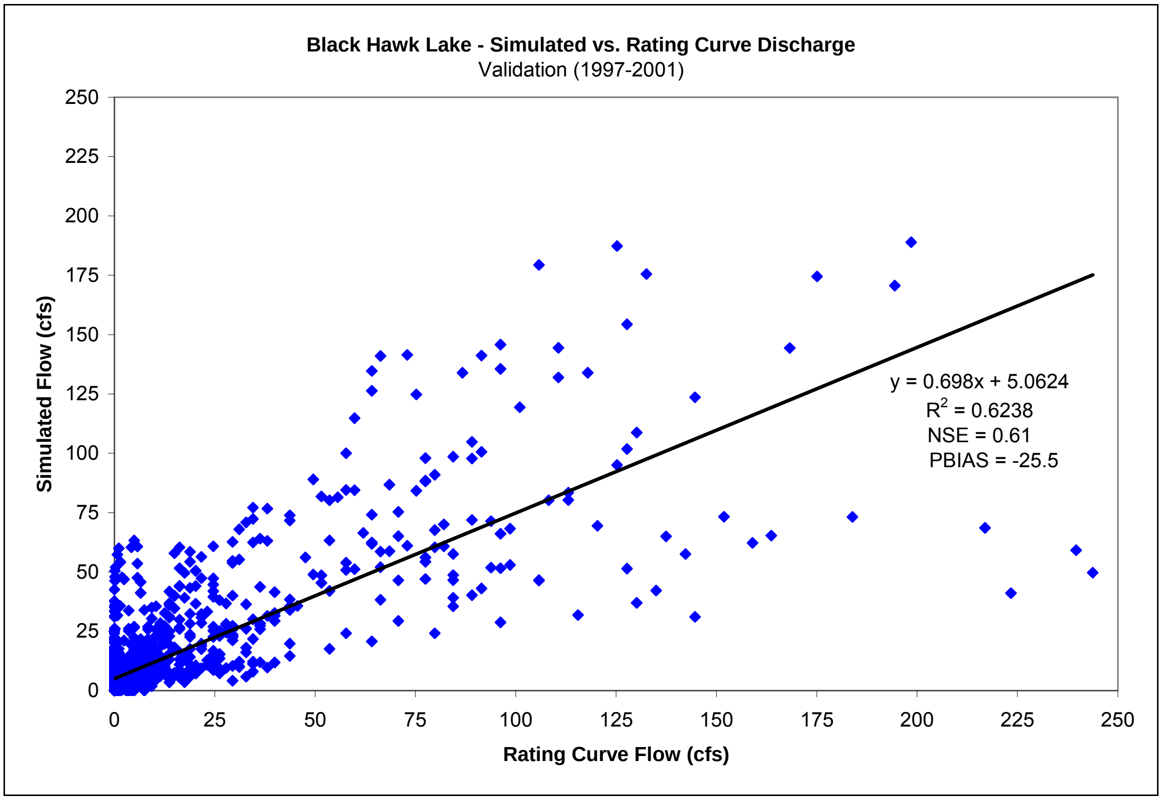

Figure E-26. Regression of daily flow from Black Hawk Lake (validation period).

Calibration and validation statistics for daily flow from Black Hawk Lake are summarized in Table E-7. All statistical results rate satisfactory to very good according to recommendations by Moriasi et al., (2007) for monthly flow. Lower ratings would be expected for daily statistics. These results indicate adequate model performance in terms of hydrologic simulation, especially in light of the fact that monthly flows (and resulting monthly pollutant loads) were used in the development of TMDLs for Black Hawk Lake.

Table E-7. Calibration/validation statistics for daily flow from lake.

	Regression Slope	**R^2**	**NSE**	**PBIAS**
Calibration (2002-09)	0.94	0.70	0.61	-3.30
Validation (1997-2001)	0.70	0.62	0.61	-25.5

Flow Duration Curves

Flow duration curves (FDCs) provide an illustration of how well the model simulates the frequency of observed daily flows throughout the calibration and validation periods (Van Liew et al., 2003). FDCs were not used to develop numeric targets for the Black Hawk Lake TMDLs; however, because they are a measure of model performance, they were used in the calibration process. Figure E-27 illustrates the simulated FDC compared with the FDC predicted by the lake stage and rating curve.

The model simulates the highest 30 percent of flows from Black Hawk with a high degree of accuracy. At the 5 percent duration interval (95th percentile), SWAT-predicted flow exceeds the rating curve flow by 1.9 percent. At the 25 percent duration (75th percentile), SWAT underestimates rating curve flow by only 3.1 percent. However, the rating curve predicts that outflow from the lake is zero approximately half the time, whereas SWAT predicts that low flows are present approximately 78 percent of the time. Adjustment of calibration parameters indicated that this discrepancy is likely related to the manner in which SWAT simulates storage in reservoirs and not problems with hydrologic simulation of inflows to the lake.

Errors resulting from the rating curve described previously may also contribute to the discrepancy at low flows. The two FDCs in Figure E-27 diverge at outflows lower than 9 cfs. The rating curve predicts that a stage of 0.18 feet (2.16 inches) results in a lake discharge of 9 cfs. Wave action, seiche effects, and other factors could result in discharges on days when the rating curve predicts no outflow. If only non-zero flows predicted by the rating curve are included in the FDC analysis, the agreement becomes substantially better. Figure E-28 shows the simulated and rating curve FDCs for all non-zero flow days (i.e., rating curve flows less than 0.0 cfs). The modified FDC reveals excellent agreement for beyond the 92 percent duration interval. Because the bulk of pollutant transport to the lake occurs during periods of runoff (i.e., high flow), the low flow discrepancies are not critical to TMDL development for Black Hawk Lake.

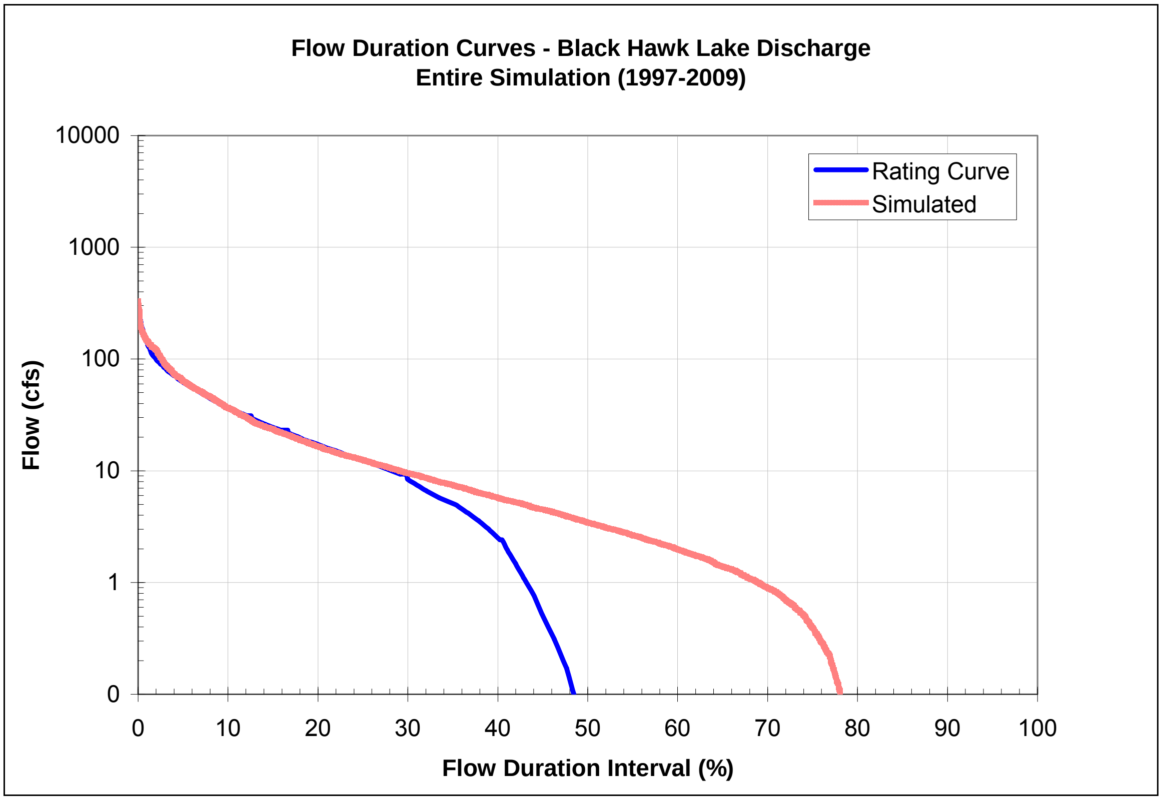

Figure E-27. FDCs of daily flow at lake outlet (1997-2009).

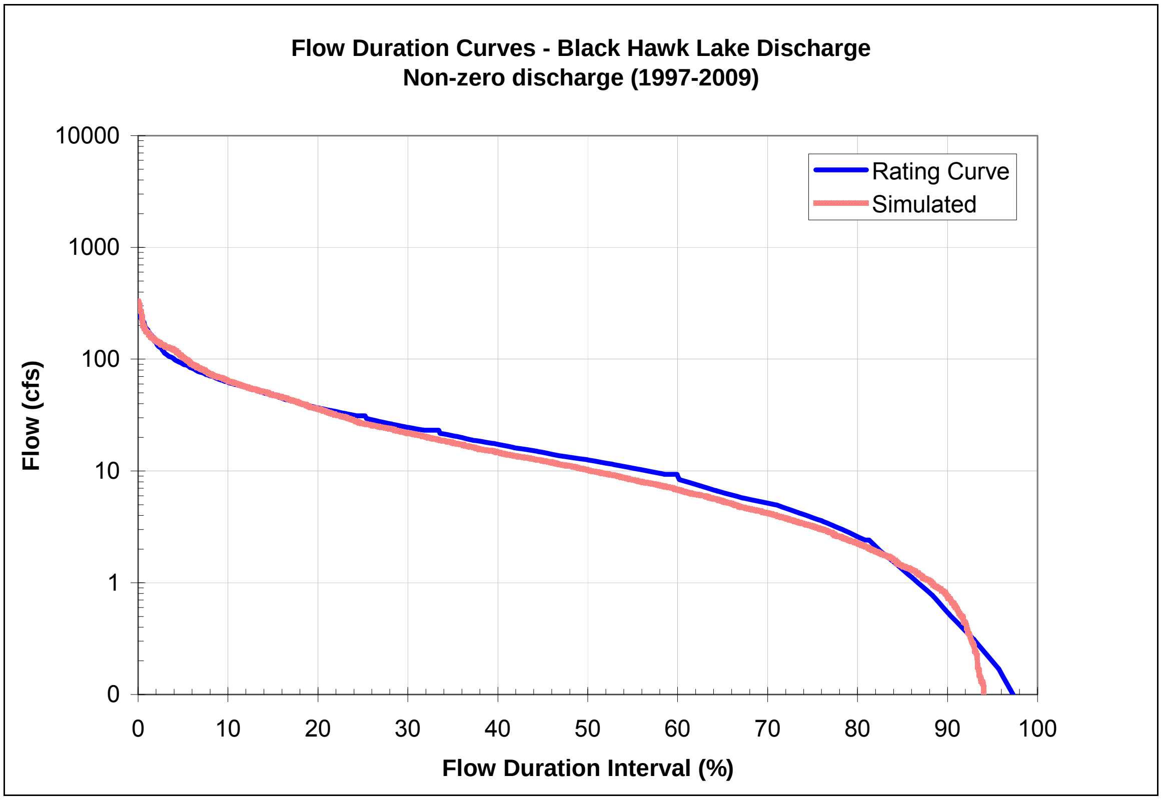

Figure E-28. FDCs of daily flow for all non-zero observed flow days (1997-2001).

E.2. Sediment

Evaluation and improvement of model performance with respect to sediment loading to Black Hawk Lake was based on several general comparisons. The frequency and amount of observed sediment data was inadequate for detailed and robust statistical calibration. However, several alternative estimates of sediment are available for comparison with model data, including the ISU Diagnostic Feasibility Study, NRCS methodology, and other state and local data. Parameters used in assessment of sediment output included:

- Simulated sheet and rill erosion vs. generally accepted ecoregion erosion rates
- Simulated streambank erosion vs. previous IDNR estimates using NRCS methodology
- Simulated sediment loads vs. sediment loads predicted by the ISU DFS
- Simulated sediment delivery ratio vs. generally accepted ecoregion-specific delivery ratio
- Simulated sediment concentration vs. observed total suspended solids (TSS) concentrations measured via monthly sampling in the ISU DFS.

Sheet and Rill Erosion

The Watershed Improvement Section of IDNR regularly assists locally led watershed groups in the development of stream and watershed assessments to facilitate soil and water quality conservation efforts. Watershed assessments include estimates of sheet and rill erosion using the Revised Universal Soil Loss Equation (RUSLE) method. Sheet and rill erosion is represented in the SWAT model as sediment yield, in metric tons per hectare per year (mtons/ha/yr). SWAT utilizes the Modified Universal Soil Loss Equation (MUSLE) method to predict sheet and rill erosion. The RUSLE method necessitates the development of a sediment delivery ratio to predict sediment transport, since RUSLE predicts erosion as a function of rainfall energy. MUSLE, and hence, the SWAT model, does not require the user to derive a sediment delivery ratio because sediment detachment and transport in MUSLE is a function of runoff, rather than rainfall.

The non-runoff parameters in the MUSLE equation are K, C, P, LS, and CFRG

Where:
K = USLE soil erodibility factor
C = USLE cover and management factor
P = USLE practice factor
LS = USLE topographic factor
CFRG = coarse fragment factor

K and CFRG are determined by the soil coverage (SSURGO) and are not adjusted in SWAT model development or calibration. LS is determined by topographic data during watershed delineation process using the ArcSWAT interface. Typically, only the C and P factors are adjusted by the user. For simulation of existing conditions, which are represented in the calibration/validation scenarios, all HRUs have a P-factor of 1.0. This factor may be adjusted for future scenarios to aid with selection and placement of potential BMPs. The C-factor is dependent on land use and varies regionally. C-factors used in the Black Hawk Lake SWAT are discussed in Section D-6 and listed in Table D-9.

Table E-8 compares sheet and rill erosion rates estimated by IDNR for several watersheds in northwest Iowa to sediment yield predicted by SWAT for the Black Hawk Lake watershed.

Table E-8. Comparison of watershed sheet and rill erosion rates.

Watershed	County	Ecoregion	Area (acres)	Distance (miles)	Erosion (tons/acre)
Storm Lake	Buena Vista	Northwest Iowa Plains	14,719	23	1.9
Littlefield Lake	Audubon	Southern Iowa Drift Plains	2,500	51	1.8
Briggs Woods Lake	Hamilton	Des Moines Lobe	7,210	62	1.6
Lost Island Lake	Palo Alto	Des Moines Lobe	6,270	60	2.2
Silver Lake	Dickinson	Des Moines Lobe	17,019	80	1.6
Brushy Creek Lake	Webster	Des Moines Lobe	56,930	52	0.8
Little Clear Lake	Pocahontas	Des Moines Lobe	365	29	1.7
Marrowbone Creek	Carroll	Des Moines Lobe	8,916	17	2.4
[1]Black Hawk Lake	**Sac**	**[3]Transition**	**--**	**--**	**1.1**
[2]Black Hawk Lake	**Sac**	**[3]Transition**	**--**	**--**	**2.8**

[1] Annual average of entire simulation period (1997-2009)

[2] Simulated sheet and rill erosion in heavy rainfall year (2008)

[3] The Black Hawk Lake watershed is primarily in the Des Moines Lobe ecoregion, but intersects the transition between the Des Moines Lobe, Iowa Southern Drift Plains, and Northwest Iowa Plains ecoregions.

The Black Hawk Lake SWAT model predicts sheet and rill erosion rates that are similar to rates predicted by IDNR for other lakes in the region. The 1997-2009 simulated annual average rate was 1.1 tons/acre, near the low end of the range observed in other watersheds (0.8 to 2.4 tons/acre). In 2008, SWAT predicted an erosion rate of 2.8 tons/acre, slightly above the range predicted for nearby watersheds. This is explained by the occurrence of multiple high intensity rainfall events in the spring of 2008, and is not unreasonable given the highly erosive weather patterns that year.

Streambank Erosion

SWAT simulates channel erosion in addition to upland sheet and rill erosion. It is beyond the scope of this document to describe the channel erosion methodology in detail, which is readily available in the SWAT2005 documentation. SWAT allows the user to choose whether the model simulates channel degradation throughout the simulation. This option was made active in the Black Hawk Lake SWAT model. Channel (i.e., streambank) erosion parameters that were adjusted in the Black Hawk Lake SWAT model are reported in Table E-9.

Table E-9. Streambank/channel erosion parameters.

Parameter	Input Description (Allowable Range)	Calibrated Value
SPCON	Linear coefficient in sediment transport equation (0.0001 ≤ 0.01)	0.002
SPEXP	Exponential coefficient in sediment transport equation (1.0 ≤ 2.0)	1.1
CH_COV	Channel cover factor (0.0 ≤ 1.0)	Varies by reach
CH_EROD	Channel erodibility factor (0.0 ≤ 1.0)	Varies by reach

Channel cover factor and channel erodibility vary by reach because field reconnaissance revealed channel vegetation and conditions are not uniform throughout the watershed. Table E-10 reports the reach specific values for CH_COV and CH_EROD. These inputs are based on the 2009 stream assessment data for Carnarvon Creek. These data are reported in Figures E-29 and E-30. Figure E-29 illustrates the varying degrees of vegetative cover, and Figure E-30 shows areas of existing streambank erosion.

Table E-10. Channel cover and erodibility factors.

Subbasin/Reach	Channel Cover (CH_COV)	Channel Erodibility (CH_EROD)
1	0.5	0.3
2	0.6	0.4
3	0.6	0.4
4	0.5	0.3
5	0.5	0.3
6	0.5	0.3
7	0.9	0.6
8	0.5	0.3
9	1.0	0.6
10	0.7	0.3
11	0.5	0.3
12	0.5	0.3
13	1.0	0.6
14	1.0	0.6
15	0.5	0.3

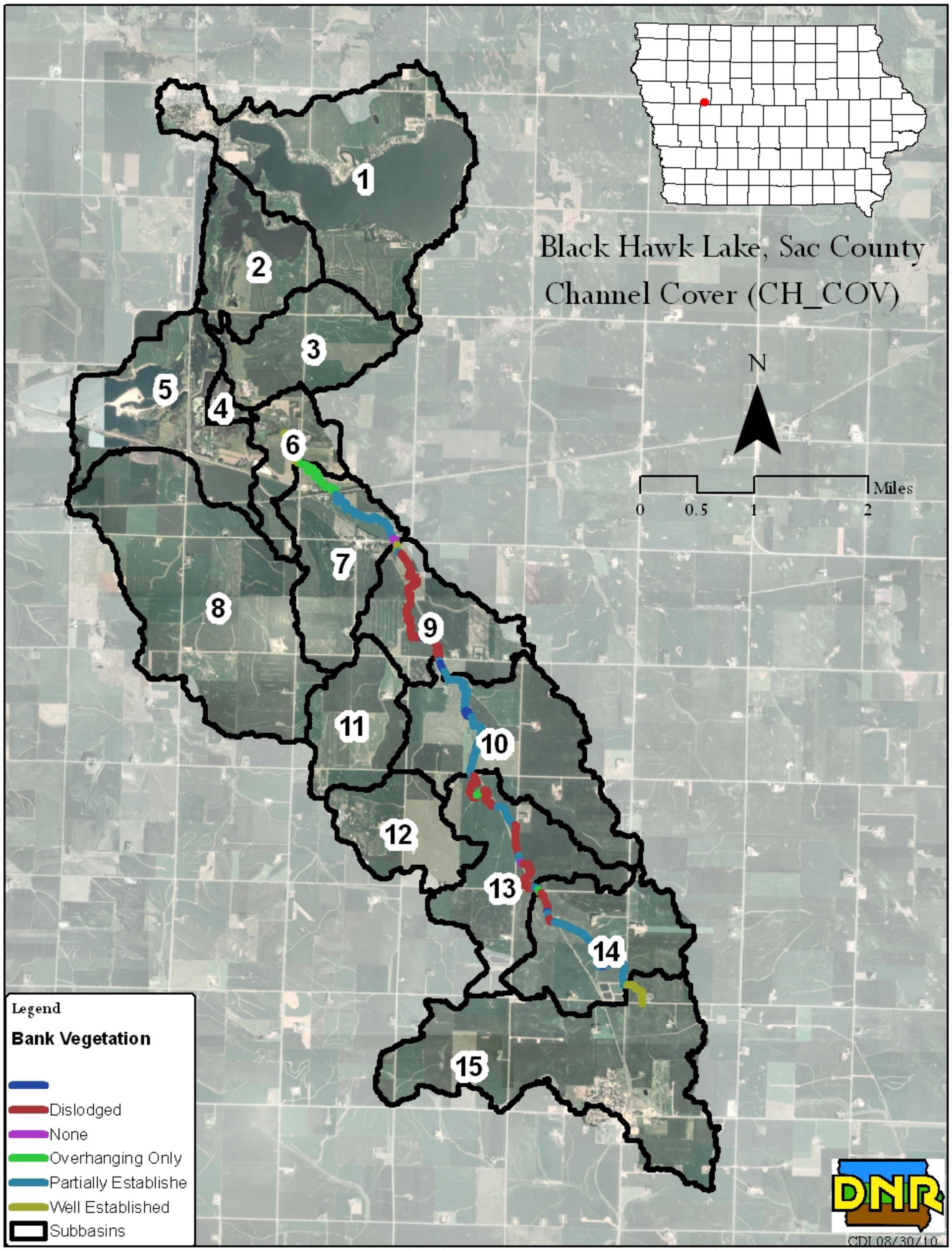

Figure E-29. Channel vegetation per 2009 stream assessment.

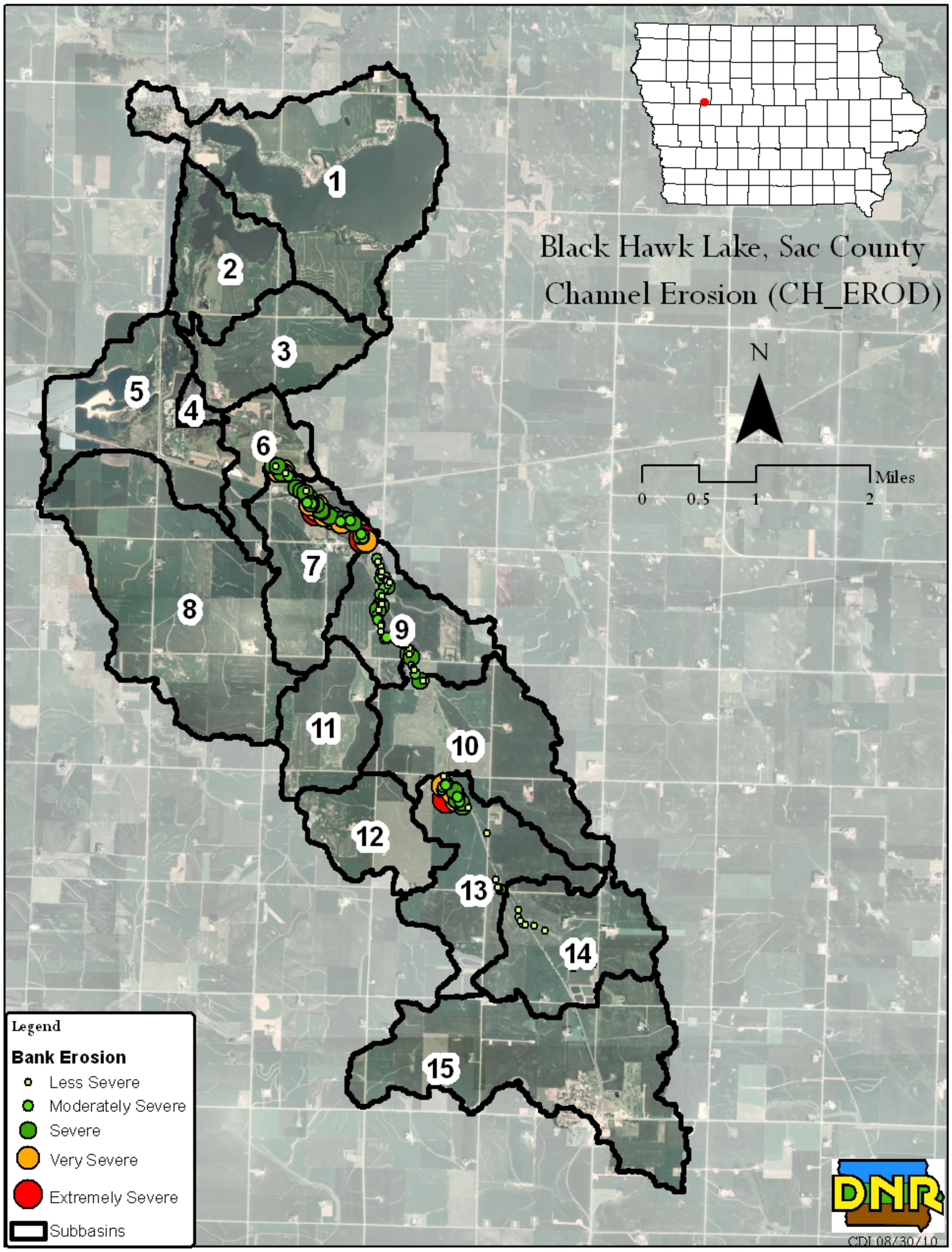

Figure E-30. Channel erosion per 2009 stream assessment.

Examination of SWAT output reveals that some reaches act as channel erosion sources, while other reaches act as sinks and accumulate sediment as it is transported through Carnarvon Creek. Existing channel erosion was estimated as part of the 2009 stream assessment using the “Erosion and Sediment Delivery” methodology developed by the state geologist for Iowa NRCS (Natural Resources conservation Field Office Technical

Guide, Section 1, Erosion Prediction; IA-198 "Erosion and Sediment Delivery", Schneider, March 27, 1998). Total streambank erosion predicted using this method, based on 2009 conditions was 945 tons per year (tons/yr). In some cases, channel erosion may accumulate in stream reaches rather than being directly transported to the watershed outlet. Even if transport is delayed and inefficient, bank erosion does contribute to the overall sediment load and should be considered. Note that channel erosion is highly variable both temporally and spatially, and erosion rates are expected to vary from year to year.

The SWAT model estimate for channel erosion in 2009 is 943 metric tons per year, or 1,039 English tons/yr. This exceeds the NRCS method estimate by 10 percent. The comparison of the stream assessment estimate and SWAT output is reported in Table E-11. This analysis indicates that the model appears to provide a reasonable simulation of channel erosion, although this process is highly variable and a large degree of uncertainty is inherent with any attempt to quantify channel erosion.

Table E-11. Streambank/channel erosion estimates (2009).

Estimation Method	Channel Erosion (mtons/yr)	Channel Erosion (tons/yr)
Black Hawk Lake SWAT model	943	1,039
NRCS Technical Guide	857	945

Total Sediment Load

SWAT aggregates upland sheet and rill erosion in individual HRUs to the subbasin level, simulates channel erosion as previously discussed, and routes sediment through the reach network to generate a total sediment load out of the watershed. This total sediment load is assumed to enter Black Hawk Lake, and is a key driver of in-lake water quality.

ISU estimated annual sediment load to the lake between July 2008 and 2009 (IDNR and ISU, 2010). Because the heavy rainfall and highly erosive storm events of 2008 occurred before ISU began their study, 2009 is the best period of comparison between study data and SWAT output. The SWAT model simulated a total sediment load of 630 metric tons (694 tons) to the lake in 2009, compared to 781 mtons/yr (861 tons/yr) estimated by ISU. The SWAT estimate is approximately 19 percent lower than the ISU prediction. Sediment transport, like sheet and rill erosion, is highly variable and difficult to quantify. Comparison of ISU predictions and SWAT indicate the Black Hawk Lake SWAT model's ability to provide reasonable estimates of sediment load, but detailed and robust calibration is not possible due to lack of observed sediment data. Predicted sediment loads are reported in Table E-12 for several simulation periods.

Table E-12. Total sediment load estimates.

Estimation Method	Period	Sediment Load (tons/yr)
Black Hawk Lake SWAT model	1997-2009	1,405
	2008	3,003
	2009	694
ISU Diagnostic Feasibility	[1]2009	861

[1] The ISU data is based on monthly flow and TSS measurements between July 2008 and July 2009.

Sediment Delivery Ratio

The total sediment load to the lake can be compared with upland and channel erosion to examine the effective sediment delivery ratio of sediment transport in the SWAT model. The effective sediment delivery ratio should be reasonably close to ratios estimated by the NRCS field guidance, which is used in conjunction with RUSLE methodology. Table E-13 reports the effective sediment delivery ratios for 2008, 2009, and 1997-2009 simulation periods. These ratios were calculated by summing total sheet and rill erosion plus channel erosion divided by the total sediment load out of the downstream reach. Table E-13 also reports expected sediment delivery ratios calculated using the NRCS technical guidance. The NRCS ratios are dependent on drainage area and the ecoregion in which the watershed resides. Estimates for the Des Moines Lobe and the Plains regions are included because the watershed is located in a transition area between these ecoregions.

Table E-13. Sediment delivery ratios.

Estimation Method	Period/Ecoregion	SDR (%)
Black Hawk Lake SWAT model	1997-2009	8.4
	2008	7.1
	2009	13.9
NRCS Technical Guidance	Des Moines Lobe	3.9
	S. Drift/NW IA Plains	24.4

Similar to previous sediment simulation performance metrics, analysis of sediment delivery ratios suggests that the model provides reasonable estimates of sediment loads to Black Hawk Lake. While a robust calibration is not possible, this quantitative analysis supports the use of the SWAT model to predict existing sediment loads and assess potential impacts of BMP implementation, as discussed in Section 4.

In-Stream Sediment Concentration

SWAT also simulates and reports suspended sediment concentrations in the stream reach, in addition to sediment yields and loads. As with other sediment-related parameters, lack of observed data prevents detailed and robust calibration. However, monthly grab samples were collected at several sites in Carnarvon Creek between July 2008 and 2009. Refer to Figure E-9 for a map of ISU monitoring locations. Monthly grab sample concentrations were averaged and compared with average concentrations in the SWAT output to test model performance. In addition to limited observed data, other factors add uncertainty and potential error in comparison of observed and simulated sediment data. SWAT simulates suspended sediment concentration, which is not numerically equivalent to total suspended solids (TSS), the parameter most commonly used to quantify sediment concentration in lab analysis. More research is necessary to fully address this problem. Nonetheless, comparison of SWAT sediment concentrations with observed TSS values provides insight to model performance.

Figure E-31 illustrates observed and simulated sediment concentrations in each SWAT reach/subbasin for the ISU study period and 2009 simulation period. Reach 1 is the downstream-most reach and Reach 15 is at the upstream end of the watershed. Note that there is no observed data in Reach 01, 04, 05, or 06. Also note that observed data is reported as TSS, whereas SWAT output is suspended sediment (both in mg/L).

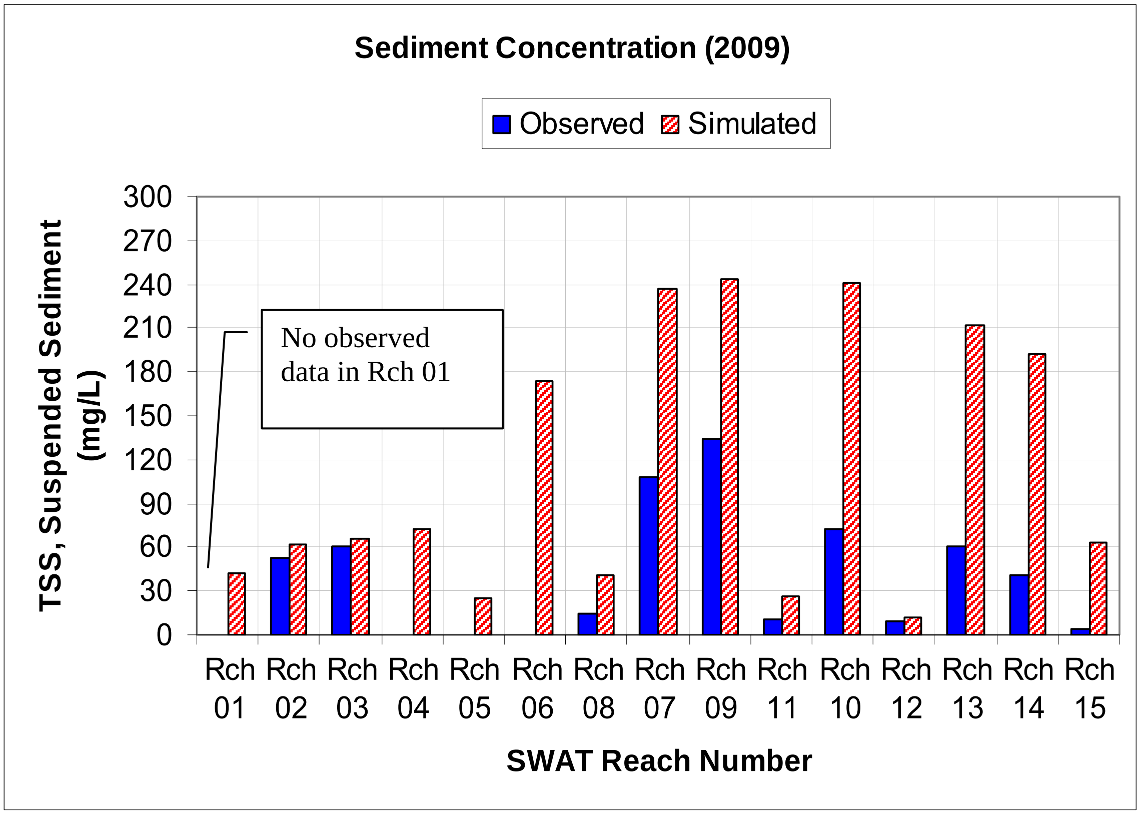

Figure E-31. Average in-stream sediment concentrations (2009).

Analysis of Figure E-31 reveals good agreement between observed and simulated concentration near the downstream end of the watershed (Reaches 02 and 03), which represents the water entering the Provost Slough and Black Hawk Lake. In the upper end, SWAT tends to overestimate in-stream sediment concentration (Reaches 10, 13, and 14), but trends are similar. The highest concentrations in the SWAT output are present in reaches that exhibit the highest observed concentrations. In-stream concentration is not critical in the development of the Black Hawk Lake TMDL because sediment and associated phosphorus loads to the lake are the key drivers of in-lake water quality.

However, evaluation of sediment concentration suggests that the model provides reasonable spatial representation of sediment levels in the Black Hawk Lake watershed.

E.3. Nutrients

Availability of observed data for the evaluation and improvement of model performance with respect to nutrient loading to Black Hawk Lake was even more limited than sediment related data. ISU estimated nitrogen and phosphorus loads to Black Hawk Lake as part of the 2009 DFS. Therefore, the following parameters were compared:

- Simulated total phosphorus (TP) loads vs. TP loads predicted by the ISU DFS
- Simulated total nitrogen (TN) loads vs. TN loads predicted by the ISU DFS
- Simulated TP export vs. estimated TP exports for other tile-drained watersheds in the Midwest

Table E-14 reports TP and TN loads to Black Hawk Lake predicted by the SWAT model used in this study and the results of the Diagnostic Feasibility Study developed by ISU (IDNR and ISU, 2010). Although nitrogen results were analyzed, the algal impairment in Black Hawk Lake is attributed to phosphorus. The difference in TP loads between the DFS and TMDL is not insignificant. However, given that the estimates are based on different methods of analysis (i.e., modeling vs. monitoring and flux calculations) with slight differences in time span (July 2008 to July 2009 for DFS vs. Calendar year 2009 for SWAT) the comparison is reasonable.

Table E-14. Nitrogen and phosphorus loading comparison.

Source	TP (kg/yr)	TN (kg/yr)
Black Hawk Lake SWAT model	[1]4,666	[1]67,315
ISU Diagnostic Feasibility	3,611	71,517
Difference	**29.2 %**	**5.9%**

[1]Loads simulated for 2009

Table E-15 compares the annual average and median TP export simulated by the Black Hawk Lake SWAT model with study results in other tile-drained watersheds in the Midwest. TP export in the Black Hawk Lake watershed is at the upper end of the range of literature values and closely matches TP export in the Skunk River. Because the SWAT model predicted nutrient loads of similar magnitude to estimates developed in the ISU study, and TP export is within the range of exports in similar watersheds, IDNR has determined the SWAT model to be adequate for estimation of phosphorus loads to Black Hawk Lake for development of TMDLs and implementation planning.

Table E-15. Comparison of TP exports in tile-drained watersheds.

Watershed/Location	Source	TP Export (lb/ac)
East Central Illinois	Royer et al., 2006	0.1-1.9
South Fork Iowa River	Tomer et al., 2008	0.4-0.6
Skunk River at Augusta, IA	USGS, 2001	2.5
Iowa River at Wapello, IA	USGS, 2001	0.88
Lake Geode, Henry Co.	IDNR (Previous TMDL)	1.38
Silver Lake, Dickinson Co.	IDNR (Previous TMDL)	0.7
Other Study Average	**4 studies above**	**[1]1.4**
Black Hawk Lake	**SWAT Model (Current TMDL)**	**[2]2.1**
Black Hawk Lake	**SWAT Model (Current TMDL)**	**[3]1.6**
Black Hawk Lake	**SWAT Model (Current TMDL)**	**[4]2.5**

[1] Average annual TP export (1997-2009)
[2] Median annual TP export (1997-2009)
[3] Average growing season TP export (2001-2008)
[4] Average annual TP export: Skunk River, Iowa River, Lake Geode, and Silver Lake

E.4. References

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Appendix F --- BATHTUB Model Methodology

A combination of modeling software packages were used to develop the Total Maximum Daily Load (TMDL) for Black Hawk Lake. Watershed hydrology and pollutant loading was simulated using the Soil & Water Assessment Tool (SWAT2005), version 2.3.4. SWAT model development was described in detail in Appendix D of this Water Quality Improvement Plan (WQIP). SWAT model performance/calibration was discussed in Appendix E.

In-lake water quality simulations were performed using BATHTUB 6.1, an empirical lake and reservoir eutrophication model. This appendix of the WQIP discusses development of the BATHTUB model. The integrated watershed and in-lake modeling approach allows the holistic analysis of hydrology and water quality in Black Hawk Lake and its watershed.

F.1. BATHTUB Model Description

BATHTUB is a steady-state water quality model developed by the U.S. Army Corps of Engineers that performs empirical eutrophication simulations in lakes and reservoirs (Walker, 1999). Eutrophication-related parameters are expressed in terms of total phosphorus (TP), total nitrogen (TN), chlorophyll a (chl-a), and transparency. The model can distinguish between organic and inorganic forms of phosphorus and nitrogen, and simulates hypolimnetic oxygen depletion rates, if applicable/desired. Water quality predictions are based on empirical models that have been calibrated and tested for lake and reservoir applications (Walker, 1985). Control pathways for nutrient levels and water quality response are illustrated in Figure F-1.

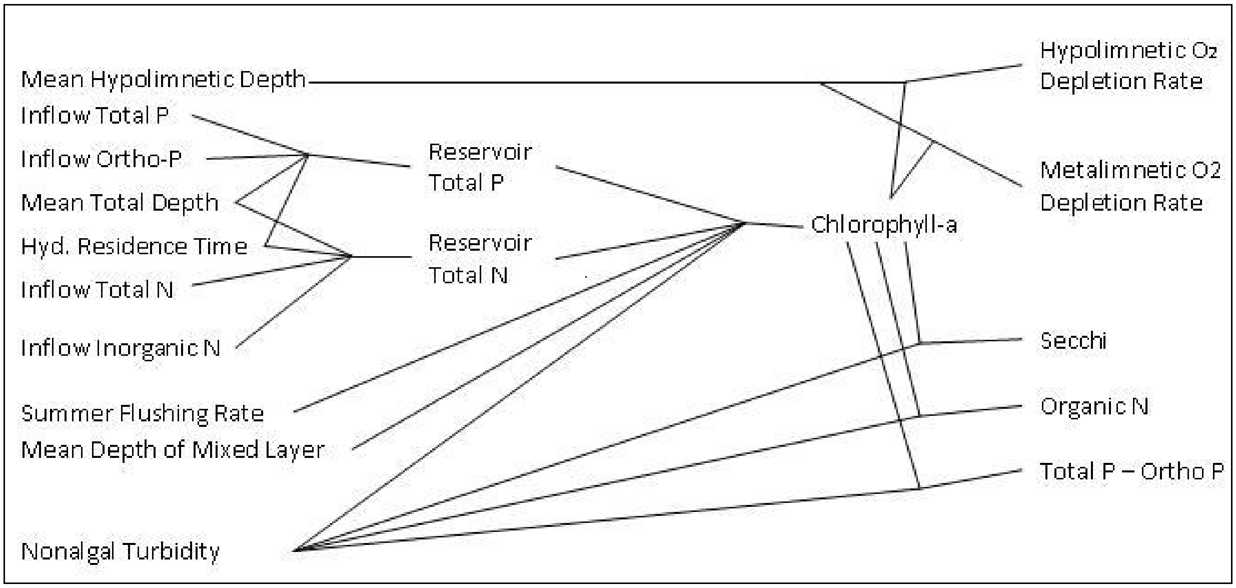


Figure F-1. Eutrophication control pathways in BATHTUB (Walker, 1999).

F.2. Model Parameterization

BATHTUB includes several data input menus/modules to describe lake characteristics and set up water quality simulations. Data menus utilized to develop the BATHTUB model for Black Hawk Lake include: model selections, global variables, segment data, and tributary data. The model selections menu allows the user to specify which modeling equations (i.e., empirical relationships) are to be used in the simulation of in-lake nitrogen, phosphorus, chlorophyll-a, transparency, and other parameters. The global variables menu describes parameters consistent throughout the lake such as precipitation, evaporation, and atmospheric deposition. The segment data menu is used to describe lake morphometry, observed water quality, calibration factors, and internal loads in each segment of the lake/reservoir. The tributary data menu specifies nutrient loads to each segment using mean flow and concentration in the averaging period. The following sub-sections describe the development of the Black Hawk Lake BATHTUB model and report input parameters for each menu.

Model Selections
BATHTUB includes several models/empirical relationships for simulating in-lake nutrients and eutrophication response. For TP, TN, chl-a, and transparency, Models 1 and 2 are the most general formulations, based upon model testing results (Walker, 1999). Alternative models are provided in BATHTUB to allow the user to evaluate other common eutrophication models, evaluate sensitivity of each model, and allow water quality simulation in light of potential data constraints.

Table F-1 reports the models selected for each parameter used to simulate eutrophication response in Black Hawk Lake. Preference was given to Models 1 and 2 during evaluation of model performance and calibration of the Black Hawk Lake model. Final selection of model type was based on applicability to lake characteristics, availability of data, and agreement between predicted and observed data. Although calibration by the BATHTUB user is possible, the underlying data used to derive empirical relationships included some calibration during creation of the BATHTUB model (Walker, 1999). For Black Hawk Lake, the calibration method is irrelevant, since all calibration factors were left as 1.0 because of good agreement between observed and simulated data. Model performance is discussed in more detail in Appendix F.3.

Table F-1. Model selections for Black Hawk Lake.

Parameter	Model No.	Model Description
Total Phosphorus	02	2nd order, decay
Total Nitrogen	00	Not computed *
Chlorophyll-a	02	P, Light, T *
Transparency	01	vs. Chl-a & Turbidity *
Longitudinal Dispersion	01	Fischer-Numeric *
Phosphorus Calibration	01	Decay rates *
Nitrogen Calibration	01	Decay rates *
Availability Factors	00	Ignore *

* Asterisks indicate BATHTUB defaults

Global Variables

Global variables are independent of watershed hydrology or lake morphometry, but affect the water balance and nutrient cycling of the lake. The first global input is the averaging period. The BATHTUB user documentation provides guidance for determining averaging period based on nutrient residence times. According to the user manual, seasonal averaging periods are appropriate for reservoirs with phosphorus residence times less than 0.2 years (Walker, 1999). This holds true for Black Hawk Lake in nearly every scenario (i.e., simulation year) that was evaluated. In fact, phosphorus residence times predicted by BATHTUB, considering input hydrology and TP loads from SWAT, are well below this threshold in most years. Additionally, model output provided better agreement with in-lake water quality when an averaging period of 6 months was utilized, when compared with a full year. Therefore a seasonal averaging period of 0.5 years (April to September) was utilized to quantify existing loads and in-lake water quality, and to develop TMDL targets.

Precipitation, evapotranspiration, and change in storage vary with each simulation period. Monthly (April through September) precipitation and evapotranspiration data were obtained from the SWAT model for each simulation period. These data were summarized and converted to BATHTUB units (meters) and entered in the global data menu. The change in storage was calculated from the simulated reservoir volume in SWAT at the beginning and end of each growing season. Note that change in storage over a growing season is often negative due to high evapotranspiration and low flow in the summer months.

Atmospheric deposition rates were obtained from a regional study (Anderson and Downing, 2006). Nutrient deposition is assumed to be in inorganic form and deposition rates are assumed constant from year to year.

Global input data for Black Hawk Lake is reported in Table F-2. The precipitation and evaporation totals shown are growing season averages for 2005-2008. Individual growing seasons between 2001 and 2008 were also simulated with distinct precipitation and evaporation inputs for each season.

Table F-2. Global variables data for the Black Hawk Lake BATHTUB model.

Parameter	Measured or Simulated Data	BATHTUB Input
Averaging Period	April – September	0.5 years
[1]Precipitation	660 mm	0.660 m
[1]Evaporation	555 mm	0.550 m
[2]Increase in Storage	-402,500 m^3	-0.131 m
[3]Atmospheric Loads:		
TP	0.3 kg/ha-yr	30 mg/m^2-yr
TN	7.7 kg/ha-yr	770.3 mg/m^2-yr

[1] Growing season averages for 2005-2008. Taken from monthly SWAT output.

[2] Change in lake volume from beginning to end of simulation period.

[3] From Anderson and Downing, 2006. Assumed all deposition is inorganic form.

Segment Data

Lake morphometry, observed water quality, calibration factors, and internal loads are all included in the segment data menu of the BATHTUB model. Separate inputs can be made for each segment of the lake or reservoir system that the user wishes to simulate. In lakes with simple morphometry and one primary tributary, simulation of the entire lake as one segment is often acceptable. This configuration is described as a "single reservoir, spatially averaged" in the BATHTUB user guidance. Assessment and calibration of model performance for Black Hawk Lake is based primarily on the single reservoir, spatially averaged configuration. Morphometric data for the spatially averaged configuration are listed in Table F-3.

Table F-3. Segment morphometry for the spatially averaged configuration.

Parameter	Measured or Monitored Data	BATHTUB Input
Lake Surface Area	760 acres	3.08 km^2
Mean Depth	5.97 feet	1.82 m
[1]Reservoir Length	3,532 meters	3.53 km
Mixed Layer Depth	5.97 feet	1.82 m
[2]Hypolimnetic Depth	14 feet	4.27 m

[1] Estimated using GIS

[2] Not applicable – lake stratifies only rarely and for short durations

The single reservoir, spatially averaged configuration was used to confirm nutrient loading and develop TMDL targets for Black Hawk Lake. However, the lake was divided into three segments to examine intra-lake variability, which provides insight for lake management. This configuration is described as "single reservoir, segmented" in the BATHTUB user guidance. The segments are illustrated in Figure F-2, as are monitoring locations for each segment. Morphometric data for the segmented configuration is reported in Table F-4. Division of the lake into segments was based on the locations of observed water quality data. The Middle Segment includes the ambient lake monitoring location (STORET ID 22810002). Hypolimnetic depth is included in Table F-4, but is not relevant to model output because the lake stratifies only in rare occurrences, and for short durations.

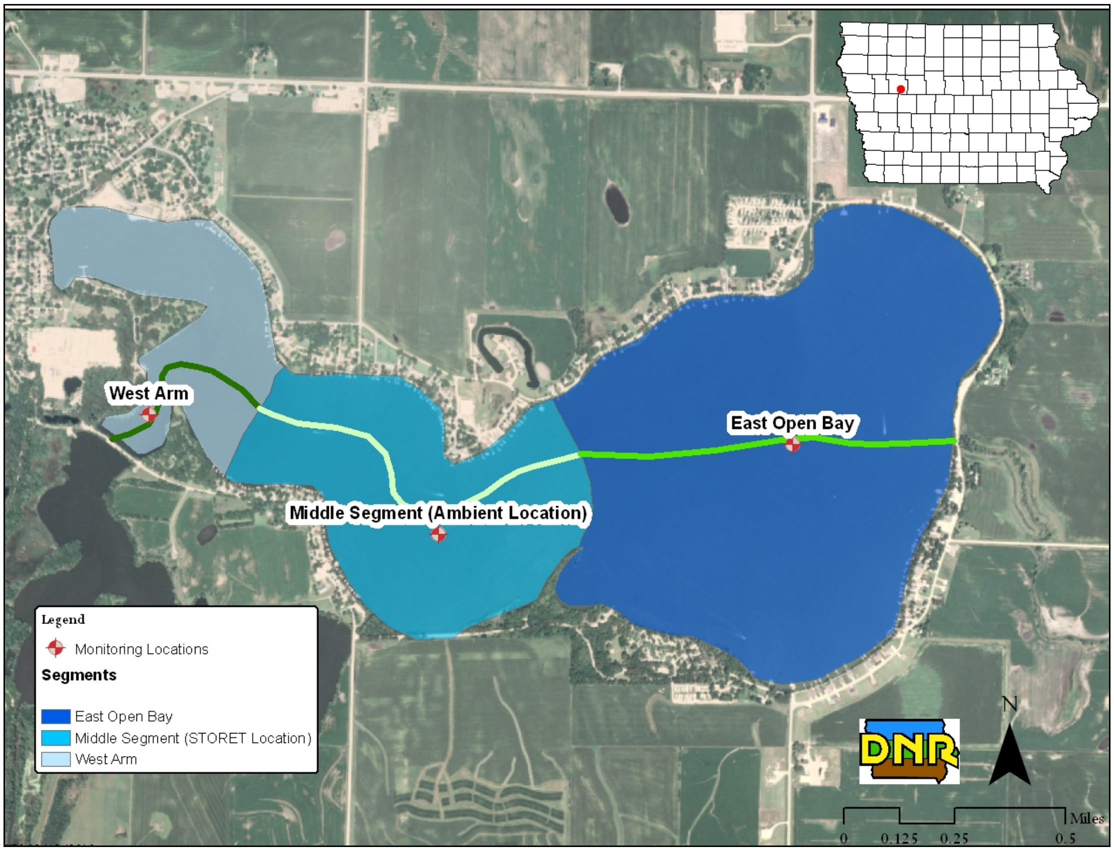


Figure F-2. Segmented configuration of Black Hawk Lake BATHTUB Model.

Table F-4. Segment morphometry for the segmented configuration.

Parameter	Measured or Monitored Data	BATHTUB Input
West Arm		
Lake Surface Area	102.0 acres	0.41 km^2
Mean Depth	6.0 feet	1.84 m
[1]Reservoir Length	761 meters	0.76 km
Mixed Layer Depth	6.0 feet	1.84 m
Hypolimnetic Depth	6.0 feet	1.84 m
Middle Segment (Ambient)		
Lake Surface Area	201.0 acres	0.81 km^2
Mean Depth	5.9 feet	1.79 m
[1]Reservoir Length	1,406 meters	1.41 km
Mixed Layer Depth	5.9 feet	1.79 m
Hypolimnetic Depth	5.9 feet	1.79 m
East Open Bay		
Lake Surface Area	457.7 acres	1.85 km^2
Mean Depth	5.2 feet	1.59 m
[1]Reservoir Length	1,366 meters	1.37 km
Mixed Layer Depth	5.2 feet	1.59 m
Hypolimnetic Depth	5.2 feet	1.59 m

[1] Estimated using GIS

Multiple scenarios were simulated using BATHTUB, with each scenario representing a distinct growing season or average conditions over several growing seasons between 2001 and 2008. Observed water quality data for each growing season is included in Appendix C – Water Quality Data. Mean water quality parameters observed for the 2005-2008 growing seasons are reported in Table F-5.

Table F-5. Observed water quality (2005-2008 growing season means).

Parameter	Measured or Monitored Data	[1]BATHTUB Input
Total Phosphorus	163.2 ug/L	163.2 ppb
Total Nitrogen	3.205 mg/L	3,205 ppb
Chlorophyll-a	68.5 ug/L	68.5ppb
Secchi Depth	0.38 m	0.38 m
Ammonia	242.8 ug/L	[2]N/A
Nitrate/Nitrite	1.12 mg/L	[2]N/A
Organic Nitrogen	1.84 mg/L	1,842 ppb
Ortho P	25.0 ug/L	[2]N/A
TP – Ortho P	138.2 ug/L	138 ppb

[1] Measured or monitored data converted to units required by BATHTUB
ppb = parts per billion = micrograms per liter (ug/L)
[2] Used to calculate organic form of nutrient, not an input parameter

Inclusion of observed water quality data in the BATHTUB model allows built in assessment of model performance and convenient calibration. However, calibration factors in the Black Hawk Lake models were not adjusted because BATHTUB provided reasonable agreement with observed water quality for each scenario without calibration.

Because the 2nd order decay TP model was empirically calibrated during development of BATHTUB, effects of internal loading (phosphorus recycling from bottom sediments) are generally reflected in the model without manually inputting an internal load (Walker, 1999). However, there is potential for higher internal phosphorus recycling in lakes with low summer overflow rates (Walker, 1999). The growing season flows to Black Hawk Lake were extremely low in several years. Extreme low-flow designations were made for years in which BATHTUB overflow rates were less than 5 m/yr. Using that definition, low-flow years included 2001, 2002, 2006, and 2009. The BATHTUB model under-predicted nutrient concentrations and chlorophyll-a levels and over-predicted transparency in those years. Therefore, internal TP loads were added to the segment data until predicted concentrations were reasonably similar to observed data in low-flow years. No measured data regarding internal loads are available for Black Hawk Lake. Internal loads are discussed in more detail in Appendix F.3 – BATHTUB Model Performance.

Tributary Data

The empirical eutrophication relationships in the BATHTUB model are influenced by the global and segment parameters previously described, but are heavily driven by flow and nutrient loads from the contributing drainage area (watershed). Flow and nutrient loads can be input to the BATHTUB model in a number of ways. The FLUX component of BATHTUB allows the user to estimate flow and nutrient loads based on a tributary monitoring network. This technique is similar to the methodology Iowa State University (ISU) utilized in the Diagnostic Feasibility Study. However, tributary data was available for less than one calendar year, which limits reliability and increases the uncertainty associated with water quality predictions.

Flow and nutrient loads used in the development of the Black Hawk Lake BATHTUB models utilize watershed hydrology and nutrient loads predicted using the SWAT model described in Appendix D. Output from SWAT is available for calendar years 1997-2009; however, in-lake water quality data necessary to assess model performance is only available from 2001-2009. SWAT flow and nutrient load output requires conversion into forms compatible with BATHTUB. This includes units conversion and converting nutrient loads into mean concentrations. Tributary input varies for each scenario (simulation period). Model runs for individual growing seasons and averages over several growing seasons were evaluated. Table F-6 shows tributary inputs averaged over the 2005-2008 growing seasons.

Table F-6. Tributary data (2005-2008 growing season means).

Parameter	Measured or Simulated Data	[1]BATHTUB Input
Flow Rate	23.5E+06 m^3/yr	[2]23.5 hm^3/yr
Total P	22,985 kg	980 ppb
Ortho P	4,988 kg	213 ppb
Total N	160,950 kg	6,862 ppb
Inorganic N	65,116 kg	2,776 ppb

[1] Measured data or SWAT output converted to units required by BATHTUB
[2] hm^3/yr = cubic hectometers per year

F.3. BATHTUB Model Performance

Performance of the BATHTUB model was assessed by comparing predicted water quality with observed data for several scenarios. Scenarios included averaging periods for each year between 2001 and 2008, averaging periods for growing seasons between 2001 and 2008, and averages over several growing seasons. The best agreement between observed and simulated TP occurred when growing season data (April-September) was considered, rather than annual loadings. There are two likely explanations for this. First, all in-lake data was collected during the growing season, therefore eutrophication-related parameters reflect growing season conditions, not annual averages. Second, the relatively low nutrient residence times (calculated within BATHTUB) in Black Hawk Lake suggest that seasonal averaging periods are most appropriate.

Simulation of TP concentration was given highest priority, followed by chlorophyll-a and transparency. Nitrogen constituents are less important because Black Hawk Lake is not nitrogen limited, except in a few rare occurrences. In-lake TP data collected and analyzed by the Limnology Laboratory at ISU was utilized for years 2001-2004. Data from the University of Iowa Hygienic Laboratory (UHL) was used for years 2005-2008. TP data collected by ISU in 2000 was disregarded due to known problems with the data. TP data collected by ISU in 2009 was also excluded from the analysis due to inconsistencies in the data for Black Hawk Lake. All chlorophyll-a data collected by ISU was excluded from evaluation of model performance due to similar problems with data quality. These issues have been documented by Watershed Improvement Section and Watershed Monitoring and Assessment Section staff at IDNR, and were discussed in more detail in Section 3.1.

Calibration/Validation

Table F-7 reports observed and simulated TP and chlorophyll-a for the calibration period (2005 growing season) and the validation period (2007 and 2008 growing seasons). The predicted TP matched observed TP in the calibration growing season (2005) with no adjustment of the calibration coefficient in the BATHTUB model. Simulated chlorophyll-a concentration was 14 percent lower than observed chlorophyll-a in the calibration period. The average simulated TP concentration for the 2007-2008 growing seasons was 218 ug/L, 11.9 percent higher than the simulated TP of 196 ug/L over both growing seasons. Simulated average chlorophyll-a concentration (71 ug/L) was 21 percent lower than observed chlorophyll-a (90 ug/L) in the validation period.

Table F-7. BATHTUB model calibration and validation results.

Growing Season	TP (ug/L)		Chl-a (ug/L)	
	Observed	Simulated	Observed	Simulated
2005 (calibration)	143	143	43	37
2007 (validation)	184	232	108	77
2008 (validation)	208	203	72	64
2007-08 average	196	218	90	71

2001-2008 Total Phosphorus Simulation

Observed and simulated TP concentrations (growing season means) for 2001-2008 are reported in Table F-8. The third column, “No internal loads added,” reflects simulated concentrations for each growing season using the global variables, model selections, segment data, and tributary data described in Section F.2. Tributary data was obtained from the monthly output files of the Black Hawk Lake SWAT model for each growing season.

Extreme low flow in years 2001, 2002, and 2006 resulted in a poor correlation between observed and simulated TP levels, with a linear regression slope of 0.86 but an extremely week R^2 value of -0.003. Overflow rates calculated in BATHTUB using SWAT hydrology reveal that flow is significantly lower in those years than in other years in the evaluation period. In most cases, the effects of internal loads are inherently reflected in the empirical relationships utilized by the BATHTUB model. However, low overflow rates reduce the dilution of internal loads and enhance the effects of internal recycling on in-lake water quality.

For this reason, model performance was evaluated with the low-flow years excluded from the analysis (see fourth column of Table F-8). Linear regression of the data excluding low-flow years indicates excellent correlation between observed and simulated TP, with a regression slope of 1.11 and R^2 of 0.68.

To address potential internal loads in the quantification of existing loads and TMDL targets, internal TP loads were added in the segment data of the 2001, 2002, and 2006 BATHTUB models. Internal loads were adjusted so that reasonable agreement between simulated and observed in-lake concentrations was obtained. Internal load amounts were 24,997 lbs (10.1 mg/m^2/day) in 2001, 20,542 pounds (8.3 mg/m^2/day) in 2002, and 4,752 pounds (1.9 mg/m^2/day) in 2006. Resulting BATHTUB output is reported in the fifth column of Table F-8. Linear regression reveals very good agreement with observed data, indicated by a regression slope of 1.06 and R^2 of 0.71. The linear regression with the inclusion of internal loads in low flow years is illustrated in Figure F-3.

Table F-8. Observed and simulated TP (growing season means).

Growing Season	[1]Observed TP concentration (ug/L)	Simulated TP concentration (ug/L)		
		[2]No internal loads added	[3]Low-flow years excluded	[4]Internal loads added in low-flow years
2001	202	84	low flow year	202
2002	193	131	low flow year	193
2003	113	141	141	141
2004	117	144	144	144
2005	143	143	143	143
2006	128	61	low flow year	129
2007	184	232	232	232
2008	208	203	203	203
Mean	161	142	173	173
Linear Regression	Slope R^2	0.86 -0.003	1.11 0.68	1.06 0.71

[1] Collected/analyzed by ISU (2001-2004) and UHL (2005-2008)
[2] BATHTUB output without addition of internal TP loads
[3] BATHTUB output excluding low flow years of 2001, 2002, and 2006
[4] BATHTUB output after addition of internal TP loads in low flow years

2005-2008 Chlorophyll-a Simulation

BATHTUB performs reasonably well in the simulation of chlorophyll-a levels in Black Hawk Lake. Model performance is illustrated in Figure F-4, which plots simulated versus observed chl-a concentrations (growing season means) for 2005-2008. Observed data in this analysis is limited to UHL data due to the documented problems with ISU data previously discussed. Simulated concentrations were obtained from model runs that incorporate the internal TP added for 2006. The regression reveals good agreement between simulated and observed chl-a levels, indicated by a regression slope of 0.77 and R^2 of 0.86. Agreement is especially good considering the increased complexity and variability inherent with eutrophication response parameters such as chlorophyll-a.

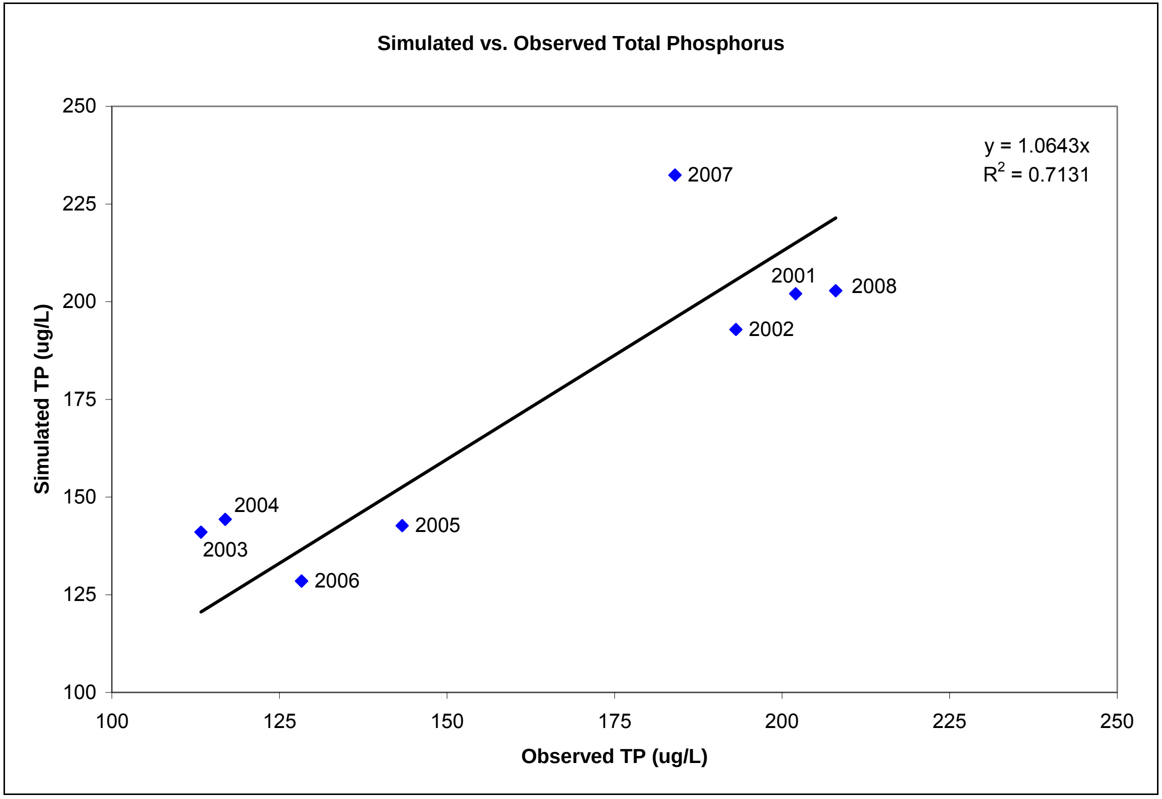


Figure F-3. Simulated vs. observed TP concentration in Black Hawk Lake.

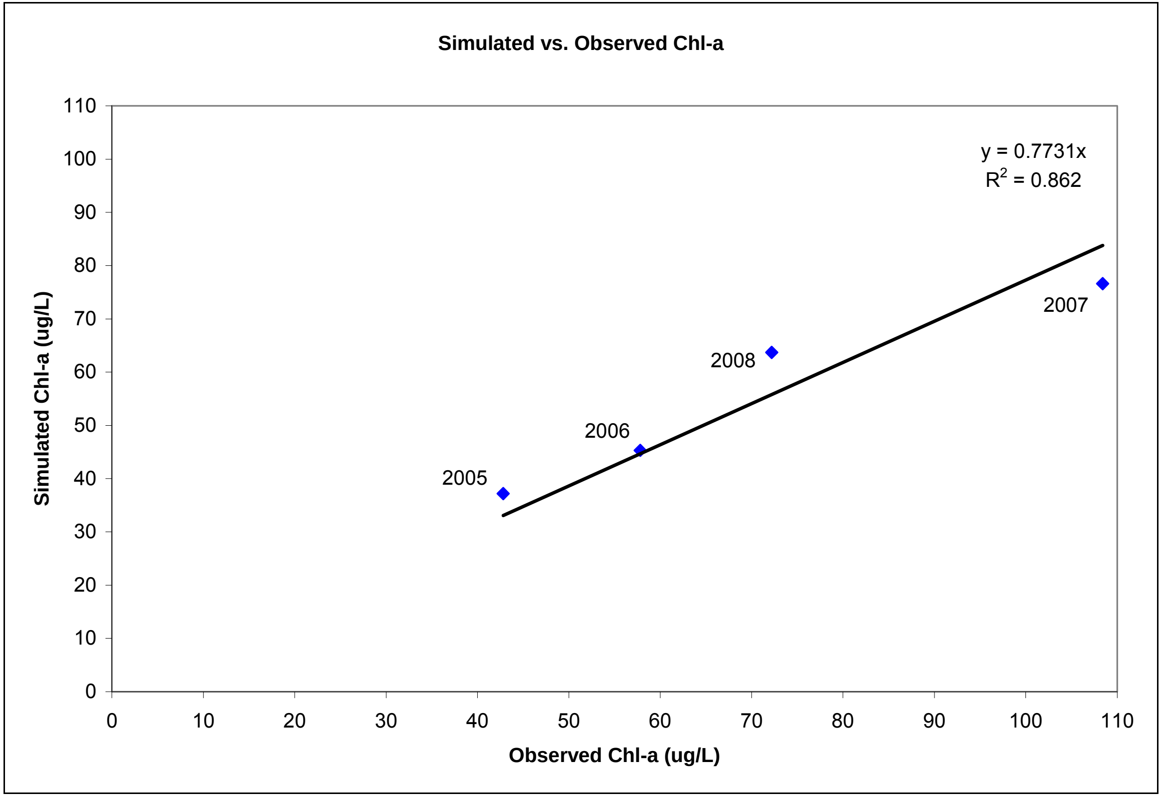


Figure F-4. Simulated vs. observed chlorophyll-a in Black Hawk Lake.

No calibration parameters were adjusted for any parameter in BATHTUB to obtain the level of agreement described above. This further suggests that BATHTUB, and the flow and nutrient loads from SWAT that drive the empirical relationships within BATHTUB, provide a reasonable representation of eutrophication in Black Hawk Lake. Therefore, IDNR determined model performance to be acceptable for the estimation of existing nutrient loads and development of TMDL targets. Estimation of existing loads and TMDL targets (discussed in Section 3) are based on average conditions simulated during the 2001-2008 growing seasons.

F.4. References

Anderson, K., and J. Downing. 2006. Dry and wet atmospheric deposition of nitrogen, phosphorus, and silicon in an agricultural region. Water, Air, and Soil Pollution, 176:351-374.

Walker, W. 1985. Empirical methods for predicting eutrophication in impoundments; Reprot 4, Phase III: Applications manual, “Technical Report E-81-9, U.S. Army Engineer Waterways Experiment Station, Vicksburg, Mississippi.

Walker, W. 1996 (Updated 1999). Simplified Procedures for Eutrophication Assessment and Prediction: User Manual. US Army Corps of Engineers Waterways Experiment Station. Instruction Report W-96-2.

Appendix G --- Expressing Average Loads as Daily Maximums

In November of 2006, The U.S. Environmental Protection Agency (EPA) issued a memorandum entitled *Establishing TMDL "Daily" Loads in Light of the Decision by the U.S. Court of Appeals for the D.C. circuit in Friends of the Earth, Inc. v. EPA, et al., No. 05-5015, (April 25, 2006) and Implications for NPDES Permits.* In the context of the memorandum, EPA

> *"…recommends that all TMDLs and associated load allocations and wasteload allocations include a daily time increments. In addition, TMDL submissions may include alternative, non-daily pollutant load expressions in order to facilitate implementation of the applicable water quality standards…"*

Per the EPA recommendations, the loading capacity of Black Hawk Lake for TP is expressed as both a maximum growing season (April-September) average and a daily maximum load. The growing season average load is more applicable to the assessment of in-lake water quality and water quality improvement actions, whereas the daily maximum load expression satisfies the legal uncertainty addressed in the EPA memorandum. The allowable growing season average was derived using the BATHTUB model described in this Appendix F, and is 9,366 lbs/season.

The maximum daily load was estimated from the allowable growing season average using a statistical approach. The methodology for this approach is taken directly from the follow-up guidance document titled *Options for Expressing Daily Loads in TMDLs* (EPA, 2007), which was issued shortly after the November 2006 memorandum cited previously. This methodology can also be found in EPA's 1991 *Technical Support Document for Water Quality Based Toxics Control*.

The *Options for Expressing Daily Loads in TMDLs* document presents a similar case study in which a statistical approach is considered the best option for identifying a maximum daily load (MDL) that corresponds to the allowable average load. The method calculates the daily maximum based on a long-term average and considers variation. This method is represented by the equation:

$$MDL = LTA \times e^{[z\sigma - .05\sigma^2]}$$

Where:
MDL = maximum daily limit
LTA = long term average
z = z statistic of the probability of occurrence
$\sigma^2 = \ln(CV^2 + 1)$
CV = coefficient of variation

The allowable growing season average of 9,366 lbs/season is equivalent to a long-term average (LTA) daily of 51.5 lbs/day. The LTA is the allowable growing season load divided by the 182-day averaging period (i.e., the length of the growing season). The average growing season allowable load must be converted to a MDL. The 182-day averaging period equates to a recurrence interval of 99.4 percent and corresponding z statistic of 2.541, as reported in Table G-1. The coefficient of variation (CV) is the ratio of the standard deviation to the mean of the simulated SWAT TP loads for the 2001-2008 period, and is 0.73. The resulting σ^2 value is 0.43. This yields a TMDL of 219 lbs/day. The TMDL calculation is summarized in Table G-2.

Because the WLA is for a controlled discharge lagoon, the allowable maximum daily load from the lagoon is calculated by multiplying the maximum allowable discharge, as specified in the current NPDES permit, by the allowable effluent TP concentration of 3.6 mg/L. This results in a daily maximum WLA of 37 lbs/day. The daily MOS is an explicit 10 percent of the TMDL, 22 lbs/day. The LA is the TMDL minus the WLA minus the MOS, or 160 lbs/day. The resulting TMDL, expressed as a daily maximum, is:

TMDL = LC = Σ WLA (37 lbs-TP/day) + Σ LA (160 lbs-TP/day)
+ MOS (22 lbs-TP/day) = **219 lbs-TP/day**

Table G-1. Multipliers used to convert a LTA to an MDL.

Averaging Period (days)	Recurrence Interval	Z-score	Coefficient of Variation								
			0.2	0.4	0.6	0.8	1.0	1.2	1.4	1.6	1.8
30	96.8%	1.849	1.41	1.89	2.39	2.87	3.30	3.67	3.99	4.26	4.48
60	98.4%	2.135	1.50	2.11	2.80	3.50	4.18	4.81	5.37	5.87	6.32
90	98.9%	2.291	1.54	2.24	3.05	3.91	4.76	5.57	6.32	7.00	7.62
120	99.2%	2.397	1.58	2.34	3.24	4.21	5.20	6.16	7.05	7.89	8.66
180	99.4%	2.541	1.62	2.47	3.51	4.66	5.87	7.06	8.20	9.29	10.3
210	99.5%	2.594	1.64	2.52	3.61	4.84	6.13	7.42	8.67	9.86	11.0
365	99.7%	2.778	1.70	2.71	4.00	5.51	7.15	8.83	10.5	12.1	13.7

Table G-2. Summary of LTA to MDL calculation for the TMDL.

Parameter	Value	Description
LTA	51.5 lbs/day	Growing season MOS (9,366 lbs/ 182 days)
Z Statistic	2.541	Based on 180-day averaging period
CV	0.73	Used CV from annual GWLF TP loads
σ^2	0.43	ln (CV^2 + 1)
MDL	**219 lbs/day**	**TMDL expressed as daily load**

Appendix H --- 2008 305(b) Water Quality Assessment

Black Hawk Lake
2008 Water Quality Assessment: Assessment results from 2004 through 2006
Release Status: Final

Segment Summary
Waterbody ID Code: IA 04-RAC-00475-L_0
Location: Sac County, S35,T87N,R36W, at Lake View.
Waterbody Type: Lake
Segment Size: 925 Acres
This is a Significant Publically Owned Lake
Segment Classes: Class A1Class B(LW)Class HH

Assessment Comments
Assessment is based on: (1) results of the IDNR-UHL beach monitoring program in the summers of 2004, 2005, and 2006 (2) results of the statewide survey of Iowa lakes conducted from 2002 through 2006 by Iowa State University (ISU), (3) results of the statewide ambient lake monitoring program conducted from 2005 through 2006 by University Hygienic Laboratory (UHL), (4) information from the IDNR Fisheries Bureau, and (5) results of EPA/DNR fish contaminant (RAFT) monitoring in 2003.

Assessment Summary and Beneficial Use Support
Overall Use Support - Not supporting
Aquatic Life Support - Fully
Fish Consumption - Fully
Primary Contact Recreation - Not supporting
Assessment Type: Monitored
Integrated Report Category: 5a – Water is impaired or a declining water quality trend is evident, and a TMDL is needed.
Trend: Stable
Trophic Level: Hypereutrophic

Basis for Assessment and Comments
SUMMARY: The Class A1 (primary contact recreation) uses are assessed (monitored) as “not supported” due to violations of the state water quality criteria for indicator bacteria and due to poor water clarity caused by algal and non-algal turbidity. The Class B(LW) (aquatic life) uses are assessed (monitored) as “fully supported.” Fish consumption uses are assessed (monitored) as “fully supported.” Sources of data for this assessment include (1) results of the IDNR-UHL beach monitoring program in the summers of 2004, 2005, and 2006 (2) results of the statewide survey of Iowa lakes conducted from 2002 through 2006 by Iowa State University (ISU), (3) results of the statewide ambient lake monitoring program conducted from 2005 through 2006 by University Hygienic Laboratory (UHL), (4) information from the IDNR Fisheries Bureau, and (5) results of EPA/DNR fish contaminant (RAFT) monitoring in 2003.

EXPLANATION: Results of IDNR beach monitoring from 2004 through 2006 suggest that the Class A1 uses are "not supported." Levels of indicator bacteria at Blackhawk Lake beach were monitored once per week during the primary contact recreation seasons (May through September) of 2004 (16 samples), 2005 (23 samples), and 2006 (28 samples) as part of the IDNR beach monitoring program. According to IDNR's assessment methodology, two conditions need to be met for results of beach monitoring to indicate "full support" of the Class A1 (primary contact recreation) uses: (1) all thirty-day geometric means for the three-year assessment period are less than the state's geometric mean criterion of 126 E. coli orgs/100 ml and (2) not more than 10 % of the samples during any one recreation season exceeds the state's single-sample maximum value of 235 E. coli orgs/100 ml. If a 5-sample, 30-day geometric mean exceeds the state criterion of 126 orgs/100 ml during the three-year assessment period, the Class A1 uses should be assessed as "not supported." Also, if significantly more than 10% of the samples in any one of the three recreation seasons exceed Iowa's single-sample maximum value of 235 E. coli orgs/100 ml, the Class A1 uses should be assessed as "partially supported." This assessment approach is based on U.S. EPA guidelines (see pgs 3-33 to 3-35 of U.S. EPA 1997b).

At Blackhawk Lake beach, the geometric means of 2 thirty-day periods during the summer recreation season of 2005 exceeded the Iowa water quality standard of 126 E. coli orgs/100 ml. No geometric means violated this criterion in 2004 or 2006. The percentage of samples exceeding Iowa's single-sample maximum criterion (235 E. coli orgs/100 ml) was not significantly greater than 10% in any of the years (2004: 0%, 2005: 13%, 2006: 11%). According to IDNR's assessment methodology and U.S. EPA guidelines, these results suggest impairment (nonsupport) of the Class A1 (primary contact recreation) uses.

Blackhawk Lake was sampled as part of IDNR's Safe Lakes Program, which aims to identify sources of bacteria to selected beaches where bacteria levels have consistently violated the state water quality criteria. The Safe Lakes Program found human contamination in a tile about 200 meters east of the beach. This tile had very high concentrations of detergents present and blood worms where the tile was discharging. The tile line was reported to the IDNR Field Office who could not find it when they went to investigate in the summer of 2006. During follow-up sampling in 2007 the IDNR Safe Lakes Program also could not find the tile. This tile was gone, capped off, or underwater as the lake water level was higher in 2007. This tile was a likely source of contamination to Blackhawk Lake beach. Continued follow-up monitoring including investigation for this tile will occur in 2008.

Results of the ISU lake survey and UHL ambient lake monitoring program also suggest that the Class A1 uses are "not supported" at Blackhawk Lake due to poor water transparency due to algal and non-algal turbidity. Using the median values from these surveys from 2002 through 2006 (approximately 27 samples), Carlson's (1977) trophic state indices for Secchi depth, chlorophyll a, and total phosphorus were 75, 70, and 74 respectively for Blackhawk Lake. According to Carlson (1977) the index values for Secchi depth, chlorophyll a, and total phosphorus all place Blackhawk Lake in the hypereutrophic category. These values suggest high levels of chlorophyll a and suspended algae in the water, very poor water transparency, and very high levels of phosphorus in the water column.

The median concentration of inorganic suspended solids is very high and contributes to the impairment at Blackhawk Lake. Results from the ISU and UHL lake surveys show that the median level of inorganic suspended solids in Blackhawk Lake from 2002-2006 was 18.0 mg/L, which was the 10th highest concentration of the 132 lakes monitored by these programs.

Data from the 2002-2006 ISU and UHL surveys suggest a moderate population of cyanobacteria exists at Blackhawk Lake, which does not contribute to impairment at this lake. These data show that cyanobacteria comprised only 48% of the phytoplankton wet mass at this lake. The median cyanobacteria wet mass (12.3 mg/L) was also the 44th lowest of the 132 lakes sampled.

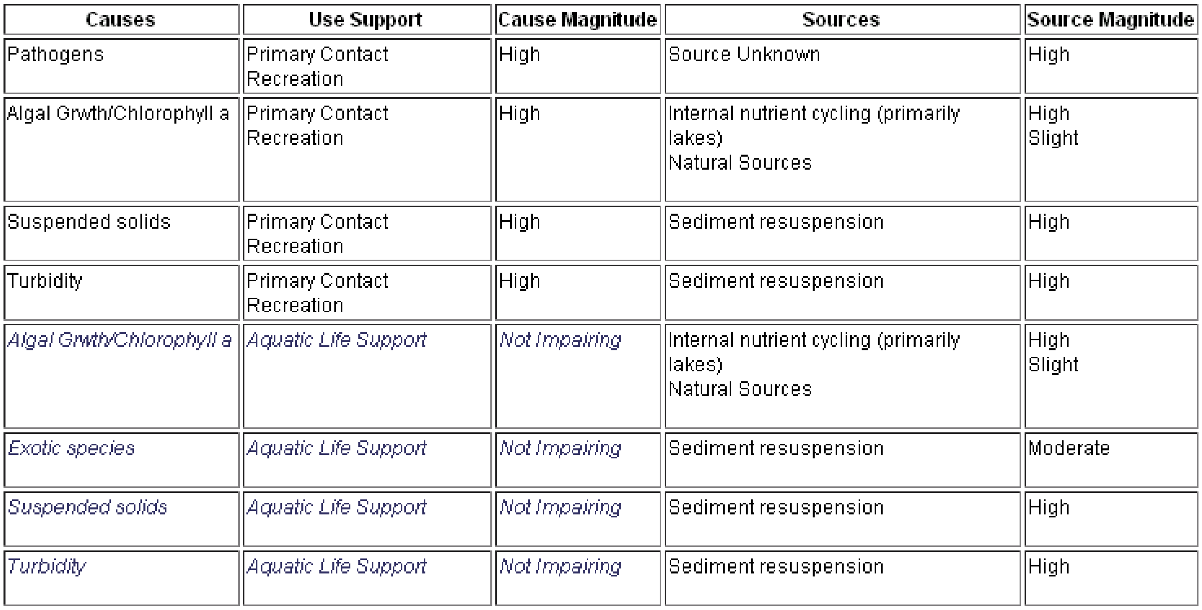
The Class B(LW) (aquatic life) uses are assessed as “fully supported” based on information from the IDNR Fisheries Bureau, results from the ISU and UHL lake surveys, and results of physical and chemical monitoring associated with IDNR’s beach monitoring program. The following factors, however, remain concerns at this lake: nuisance blooms of algae, re-suspension of sediment; the increasing population of common carp, and their tendency to increase levels of turbidity through re-suspension of sediment and algal nutrients. The ISU and UHL lake survey results show good chemical water quality at Blackhawk Lake. During 2002-2006 there were no violations of the Class B(LW) criterion for dissolved oxygen (27 samples) or pH (27 samples). There was one violation in 21 samples of the Class B(LW) criterion for ammonia. Based on IDNR’s assessment methodology, the one violation of the ammonia criterion does not constitute an impairment of water quality at Blackhawk Lake. The physical/chemical data associated with the beach monitoring data from 2004 through 2006 show 1 violation of the Class B(LW) criteria for dissolved oxygen in 64 samples (1%) and 1 violation of the Class B(LW) criterion for pH in 64 samples (1%). According to IDNR’s assessment methodology these results suggest full support of the Class B(LW) uses at Blackhawk Lake.

Fish consumption uses were assessed (monitored) as “fully supported” based on results of U.S. EPA/IDNR fish contaminant (RAFT) monitoring at Black Hawk Lake in 2003. The composite samples of fillets from common carp and black crappie had low levels of contaminants. Levels of primary contaminants in the composite sample of common carp fillets were as follows: mercury: <0.0181 ppm; total PCBs: 0.09 ppm; and technical chlordane: <0.03 ppm. Levels of primary contaminants in the composite sample of black crappie fillets were as follows: mercury: <0.0181 ppm; total PCBs: 0.09 ppm; and technical chlordane: <0.03 ppm. The existence of, or potential for, a fish consumption advisory is the basis for Section 305(b) assessments of the degree to which Iowa’s lakes and rivers support their fish consumption uses. The fish contaminant data generated from the 2003 RAFT sampling conducted at this lake show that the levels of contaminants do not exceed any of the advisory trigger levels, thus indicating no justification for issuance of a consumption advisory for this waterbody.

Monitoring and Methods
Assessment Key Dates
5/20/2002 Fixed Monitoring Start Date
9/11/2003 Fish Tissue Monitoring
10/3/2006 Fixed Monitoring End Date

Methods
Primary producer surveys (phytoplankton/periphyton/macrophyton)
Surveys of fish and game biologists/other professionals
Non-fixed-station monitoring (conventional during key seasons and flows)
Fish tissue analysis
Water column surveys (e.g. fecal coliform)

Causes and Sources of Impairment



Causes	Use Support	Cause Magnitude	Sources	Source Magnitude
Pathogens	Primary Contact Recreation	High	Source Unknown	High
Algal Grwth/Chlorophyll a	Primary Contact Recreation	High	Internal nutrient cycling (primarily lakes) Natural Sources	High Slight
Suspended solids	Primary Contact Recreation	High	Sediment resuspension	High
Turbidity	Primary Contact Recreation	High	Sediment resuspension	High
Algal Grwth/Chlorophyll a	*Aquatic Life Support*	*Not Impairing*	Internal nutrient cycling (primarily lakes) Natural Sources	High Slight
Exotic species	*Aquatic Life Support*	*Not Impairing*	Sediment resuspension	Moderate
Suspended solids	*Aquatic Life Support*	*Not Impairing*	Sediment resuspension	High
Turbidity	*Aquatic Life Support*	*Not Impairing*	Sediment resuspension	High

Appendix I --- Public Comments

The Iowa Department of Natural Resources (IDNR) received no public comments regarding the Black Hawk Lake TMDL.