



JOINT PROJECT REPORT
KBS PUBLICATION NO. 112

**CHENEY RESERVOIR WATER QUALITY
AND ITS WATERSHED ASSESSMENT**





JOINT PROJECT REPORT
KBS PUBLICATION NO. 112

**CHENEY RESERVOIR WATER QUALITY
AND ITS WATERSHED ASSESSMENT**

Steven Wang, Donald G. Huggins, Niang C. Lim, Debra S. Baker,
William W. Spotts and Clint A. Goodrich
Central Plains Center for BioAssessment
Kansas Biological Survey
University of Kansas

Frank deNoyelles, Jr. and Scott W. Campbell
Kansas Field Station and Ecological Reserves
Kansas Biological Survey
University of Kansas

Lyle Frees and Chad Volkman
Natural Resources Conservation Service, Salina, KS
U.S. Department of Agriculture

ACKNOWLEDGMENT

The study was completed under the guidance of Dr. Steven Wang of the Kansas Biological Survey with technical assistance and support from Dr. Ming-shu Tsou of the Kansas Biological Survey (former Kansas Geological Survey employee) and Dr. Xiaoyong Zhan of the Kansas Geological Survey. Special thanks are given to Mr. Gerald Blain of the City of Wichita, Dr. Larry Pope of the U.S. Geological Survey (Lawrence, KS), and Dr. Val Smith of the Department of Ecology and Evolutionary Biology, University of Kansas for permission of using watershed, stream, and lake data.

Appreciation is extended to Drs. Kyle Mankin and James Koelliker of the Kansas State University and Dr. Marios Sophocleous of the Kansas Geological Survey for sharing their experience in streamflow (baseflow/runoff) separation techniques. In addition, many thanks are given to Connie Tra and Andrew Hwang for their assistance in bioassay experiments. The assistance, advice, and comments of Drs. Ronald L. Bingner, Fred D. Theurer, and Yongping Yuan of the Agricultural Research Service, U.S. Department of Agriculture, have been of great value in preparing this report. This study was funded by the U.S. Environmental Protection Agency through award number X-99797001-0 to the Kansas Biological Survey.

TABLE OF CONTENTS

1. INTRODUCTION	1
2. METHOD OF DATA COLLECTION AND ANALYSIS	2
2.1. Description of Integrative Modeling.....	2
2.2. Cheney Reservoir and Its Watershed Characteristics.....	3
2.3. AnnAGNPS Input Preparation.....	5
2.4. Calibration of AnnAGNPS	7
2.4.1. <i>Sediment Calibration</i>	12
2.4.2. <i>Nutrient Calibration</i>	12
2.5. Validation of AnnAGNPS	13
2.5.1. <i>Sediment Validation</i>	17
2.5.2. <i>Nutrient Validation</i>	17
3. RESULTS AND DISCUSSION	19
3.1. Application of AnnAGNPS	19
3.2. Watershed Management Scenarios.....	20
3.3. Application of Eutrophication Response Model.....	24
3.3.1. <i>Hydrology</i>	24
3.3.2. <i>Light and Nutrient Limitation</i>	26
3.3.3. <i>Synopsis of Model Calibration and Simulation</i>	26
3.4. Coupling of Watershed and Lake Models	29
3.5. Taste and Odor.....	30
3.6. Sedimentation	31
4. CONCLUSION.....	33
REFERENCES.....	34

Cheney Reservoir Water Quality and Its Watershed Assessment

1. INTRODUCTION

Water quality is a major concern, especially in the agricultural states of the Midwest United States. Several common water quality problems have been noted in reservoirs of the Central Plains. There have been reports of elevated plant nutrient levels with concurrent elevations in plant biomass (Smith, 1998). Suspended solids and siltation have increased; increases in these factors reduce light penetration, aesthetics, lake depth and volume, leading to alteration of the aquatic habitats (deNoyelles et al., 1999). Water quality assessments have shown elevated levels of pesticides and other toxic chemicals (Scribner et al., 1996). Further, local and state regulatory agencies have fielded complaints regarding objectionable taste and odor conditions (e.g., KDHE, 1999).

All these problems contribute to or are symptomatic of water quality degradation. However, excess nutrients and siltation, both of which result from intensive agricultural production, are the water quality factors that contribute most to eutrophication (Carpenter et al., 1998). Eutrophication is itself a serious and widespread problem in the Midwest. According to the National Water Quality Report to Congress, 50% of assessed U.S. lakes and a higher percentage of reservoirs in the agriculturally dominated Midwest were considered eutrophic (USEPA, 2000). For example, 193 of the 240 publicly owned reservoirs evaluated in Kansas were eutrophic and frequently showed symptoms of eutrophication, including nuisance algal blooms, reduced water transparency, and depleted levels of hypolimnetic dissolved oxygen.

Cheney Reservoir, a federal multipurpose reservoir constructed between 1962 and 1965 by the Bureau of Reclamation, serves as the major source of drinking water for the City of Wichita (Jerry Blain, City of Wichita Water and Sewer Department, written communication, 2002). Because of increasing agricultural activities from its watershed, Cheney Reservoir has experienced degraded water quality problems (Christensen and Pope, 1997; Pope, 1998; Pope and Milligan, 2000; Milligan and Pope, 2001; Mau, 2001; Smith et al., 2001). Currently, Cheney Reservoir is listed in the state 2002's high priority 303(d) of the Clean Water Act as a result of eutrophication and siltation (KDHE, 2002).

The major goal of this study was to use an integrative modeling approach to estimate the quantitative relationships between watershed management strategies and nutrient enrichment in the reservoir. Additionally, the predevelopment and/or early land use development was evaluated to provide managers and regulators estimates of background nutrient loadings and historic reservoir conditions. The impact of sedimentation (or siltation) on the reservoir trophic conditions was also examined.

2. METHOD OF DATA COLLECTION AND ANALYSIS

2.1. Description of Integrative Modeling

A vital key to the development of a reservoir management strategy is to identify nutrient loading that describes associated eutrophic conditions in reservoirs. Annualized Agricultural Nonpoint Source (AnnAGNPS 2.2) is a batch-process, continuous-simulation, watershed-scale model designed for agriculturally dominated watersheds, which was developed jointly by U.S. Department of Agriculture's Agricultural Research Service and Natural Resources Conservation services (Bosch et al., 1998; Cronshey and Theurer, 1998; Geter and Theurer, 1998; Theurer and Cronshey, 1998; Johnson et al., 2000). The model does distributed-modeling that divides a watershed into homogenous cells or subwatersheds (up to 10,000 acres) to quantitatively estimate runoff and sediment and nutrient loading. The cells or drainage areas are irregular basins with uniform physical and hydrological characteristics; this approach allows analyses for any point within the watershed. Over recent years, AnnAGNPS has been used as a screening tool or in detailed applications such as the evaluation of best management practices (BMP) or changes in land use (Yuan et al., 2001). The earlier versions of this model (e.g., AGNPS), which are event-related models, have been broadly and successfully used in the central United States (e.g., Mankin and Kalita, 2000; Mankin and Koelliker, 2001).

AnnAGNPS requires more than 400 parameters in 34 data categories, including include land use, topography, hydrology, soils, feedlot operation, field management, and climate. AnnAGNPS uses updated technologies that expand the original modeling capabilities of AGNPS. For example, soil loss from each field is predicted based on the Revised Universal Soil Loss Equation (RUSLE) (Renard et al, 1997) and the sediment yield leaving each field is based on the Hydrogeomorphic Universal Soil Loss Equation (HUSLE) (Theurer and Clarke, 1991).

AnnAGNPS is an effective tool for watershed management. However, the complexity of modeling procedures and massive data preparation render its application tedious and time consuming. Automation of the preparation and processing of repetitive data would be helpful. In response to this, a user-friendly modeling interface has been developed to assist decision-makers in conducting easier, effective watershed assessments. The modeling procedures documented in this study were just based on the preliminary implementation of the interface (Tsou et al., 2001).

One of the most effective methods to aid in the development of management policies for lakes and reservoirs is modeling. In this study, physical, chemical, and biological data were incorporated into a reservoir eutrophication program, BATHTUB, to determine future changes in reservoir water quality as a function of hypothetical nutrient loading through implementing watershed management plans. BATHTUB, an empirical model designed to assess eutrophication for morphometrically complex reservoirs (Walker, 1996), is an effective tool for water quality assessment and management (Ernst et al., 1994). BATHTUB is composed of three major components that include water balance, nutrient sedimentation, and eutrophication response models (expressed in terms of total N, total P, chlorophyll *a*,

transparency, organic N, and organic P). One major advantage of BATHTUB over other models is its use of simple steady-state calculations to address eutrophication processes, which reduces data demands. In addition, the windy, relatively flat agricultural landscape of the Central Plains creates well mixed and turbid lentic waterbodies (O'Brien, 1975; Randtke and deNoyelles, 1985), thus rendering the comparatively simple BATHTUB model as more appropriate to use than the more complex two or three dimensional models such as CE-QUAL-W2 (Cole and Buchak, 1995).

2.2. Cheney Reservoir and Its Watershed Characteristics

Cheney Reservoir is located in the south-central portion of Kansas near the City of Wichita. Although the reservoir is fed by a number of streams, it is mainly an impoundment on the North Fork Ninescah River. The Silver Creek, Goose Creek, Red Rock Creek, and Wolf Creek are four major streams that join the Ninescah River to feed the reservoir. Cheney Reservoir (average depth 4.87 m) is a multiple-use reservoir (e.g. fishing, boating, swimming, and sightseeing) and has a normal surface area of 3,885 ha.

The Cheney Reservoir watershed encompasses nearly 933 square miles (597,000 acres) of land located in Sedgwick, Reno, Kingman, Pratt, Stafford, and Kiowa Counties. Most of the watershed is underlain by consolidated rocks of Permian age covered by unconsolidated fluvial and windblown deposits of Pleistocene age (Christensen and Pope, 1997). Generally, clay-loamy soils are on the uplands and sand or sandy loam on bottomlands with slopes less than 3% (Figure 1). Topographic relief is about 168 m, with maximum local relief (within 1.6 km) of about 15 m (Milligan and Pope, 2001).

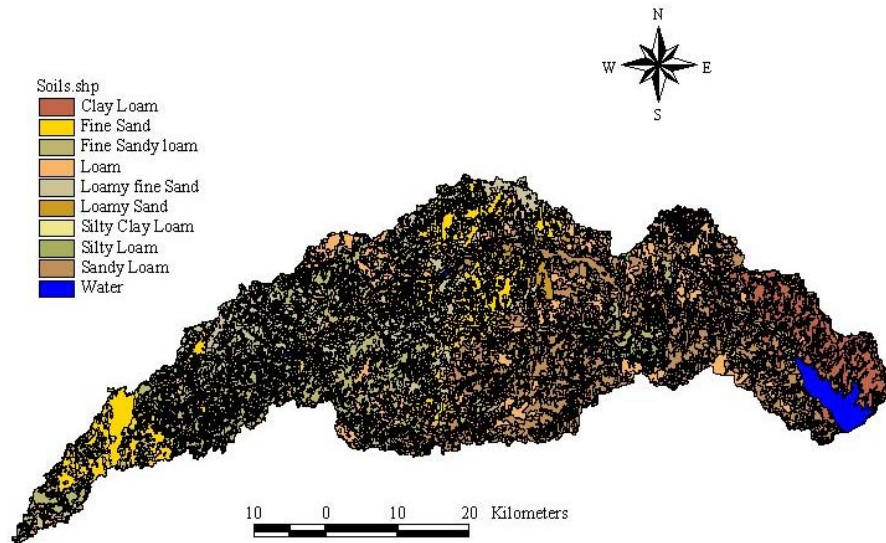


Figure 1. A plot of surface soil texture in Cheney Reservoir watershed.

The Cheney Reservoir watershed has an average soil permeability of 0.13 m per hour. Runoff usually occurs from storms of 2-3 hours in duration. However, 13% of the watershed would produce runoff under drier conditions or smaller storms (KDHE, 2002). Land use/land cover in the watershed is predominately agricultural, with 79.4% of the land in grassland (such as pasture and hay field) and cultivated cropland (Table 1 and Figure 2). Corn (*Zea mays* [L.]), sorghum (*Sorghum bicolor* [L.]) and soybean (*Glycine max* [L.]) are the major crops planted in the watershed. Woodland occupies approximately 2.4% of the total area of the watershed. About 2% of the watershed is in residential or commercial uses.

Table 1. Land use/land cover for the Cheney Reservoir watershed.

Land use (Land cover)	Area (%)
Cropland - Non-irrigated	48.6
Cropland - Irrigated	10.3
CRP	15.5
Rangeland	20.5
Woodland	2.4
Waterbody	0.3
Waterway	0.4
Buildup/Urban	2.0
Others	0.1
<i>Total</i>	100

Land cover does not include Cheney Reservoir or Kiowa County.

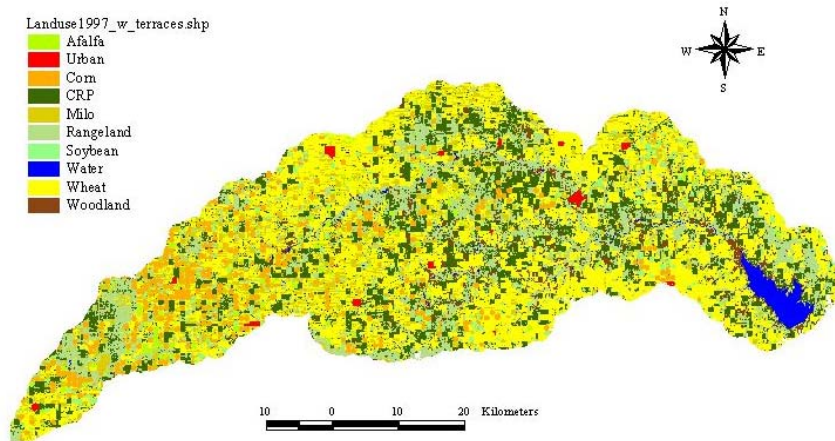


Figure 2. A plot of Land use/land cover in Cheney Reservoir watershed.

Fewer than 4,000 people in the watershed. The majority live on approximately 1,000 farms in the area. Four wastewater discharge point sources are located for the communities of Arlington, Staffors, Turon, and Preston, which they together produce annual N and P loads of 3.69 and 1.46 ton, respectively, to the receiving streams and eventually to Cheney Reservoir (Koelliker and Bhuyan, 2000). There are approximately 100 feedlots identified by the Cheney Reservoir Project Office (CRPO, South Hutchinson, Kansas), most of which are located in the Red Rock Creek watershed (22 feedlots) and the middle part of the West Ninnescah watershed (43 feedlots) (Figure 3).

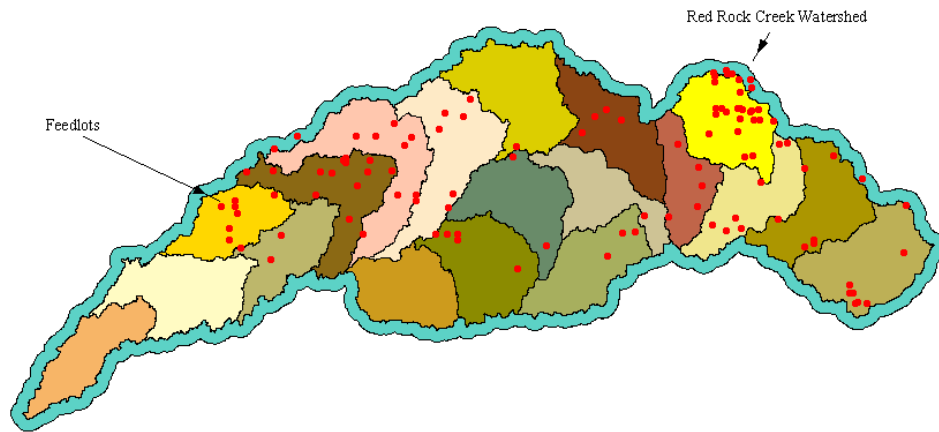


Figure 3. A plot of feedlot operations in the Cheney Reservoir watershed.

2.3. AnnAGNPS Input Preparation

Topographical, soil, land use/land cover and cropping data were all obtained and organized as an AnnAGNPS input file with the newly developed GIS-integrated interface (Frees et al., 2002). The detailed information on how to use the interface has been described by Tsou et al (2001). Figure 4 illustrates the structure and function of the interface. The topographical parameters such as slope, slope length, slope-shape factor, and aspect/flow direction were derived from a digital elevation model (DEM) at a scale of 1:250,000 from the U.S. Geological Survey. Soil parameters required by AnnAGNPS were derived from the Soil Survey Geographic Database (SSURGO). The SSURGO data are typically published at scales between 1:15,840 and 1:24,000, which is the most detailed level of soil database available. The 1997 LANDSAT image was used to generate the required land use coverage for the model. Crop operation and field-management data were obtained from the Kansas NRCS field offices.

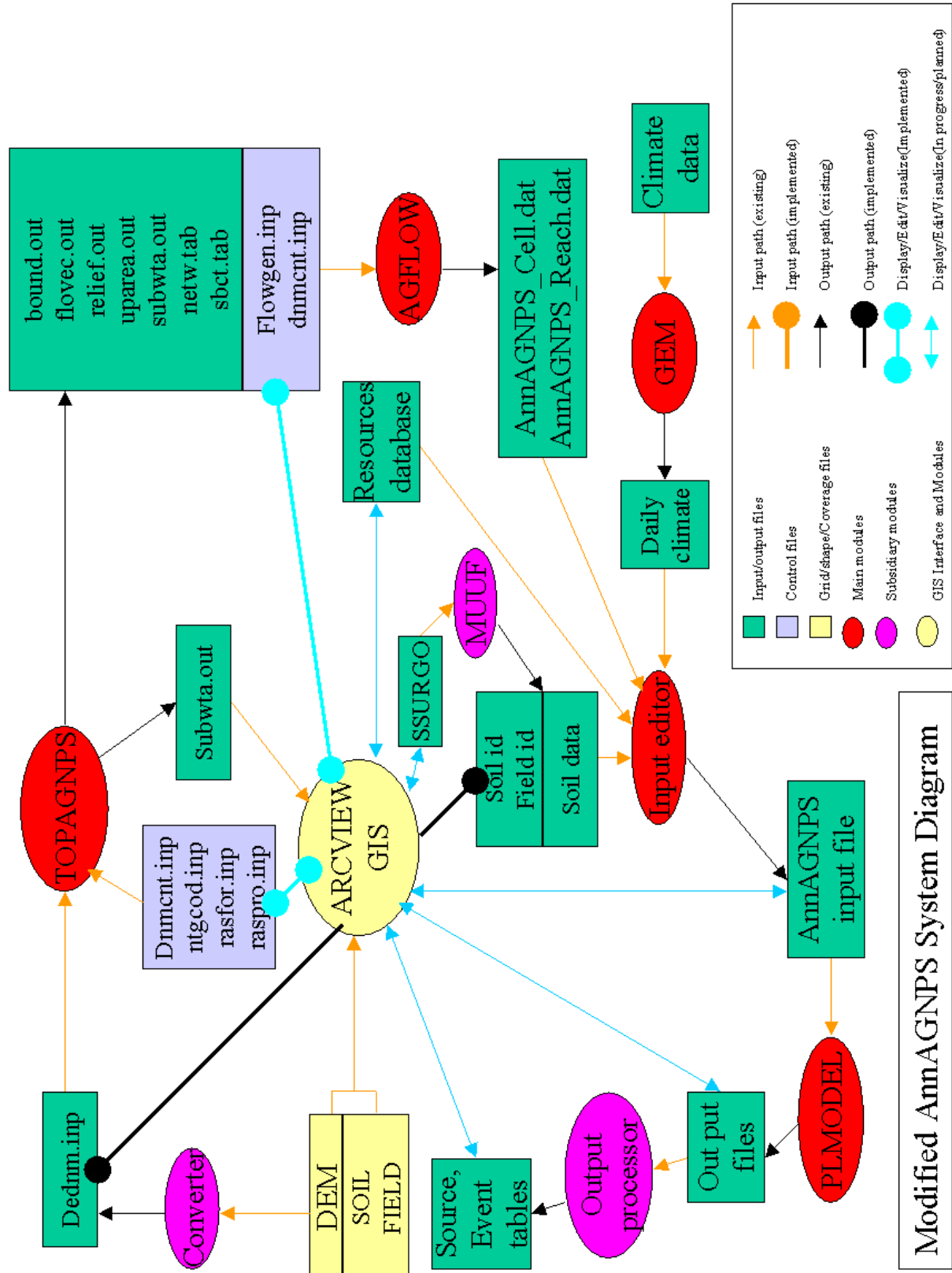


Figure 4. The structures and functions of the GIS-based interface.

2.4. Calibration of AnnAGNPS

Two years (January 1997 – December 1998) of streamflow and water quality data collected in the Red Rock Creek watershed were used to calibrate and validate AnnAGNPS for the Cheney Reservoir watershed. The daily volume of runoff from a storm was estimated using the USGS Hydrograph Separation Program HYSEP (Sloto and Crouse, 1996) that is based on the methods (i.e., fixed interval, sliding interval, and local minimum) of Pettyjohn and Henning (1979). HYSEP is intended to evaluate natural flows in watersheds and assumes minimal changes in watershed runoff from snowpack, urbanization or retention/detention facilities, or any other factors that violate the model (Linsley et al., 1983). It calculates the duration of surface runoff from the empirical relationship,

$$N = A^{0.2}$$

where N is the number of days after which surface runoff ceases and A is the watershed area. For this study, the local minimum method was employed because little is known about the physical conditions governing streamflow in the watershed. Figure 5 shows daily total stream flow and the baseflow hydrograph.

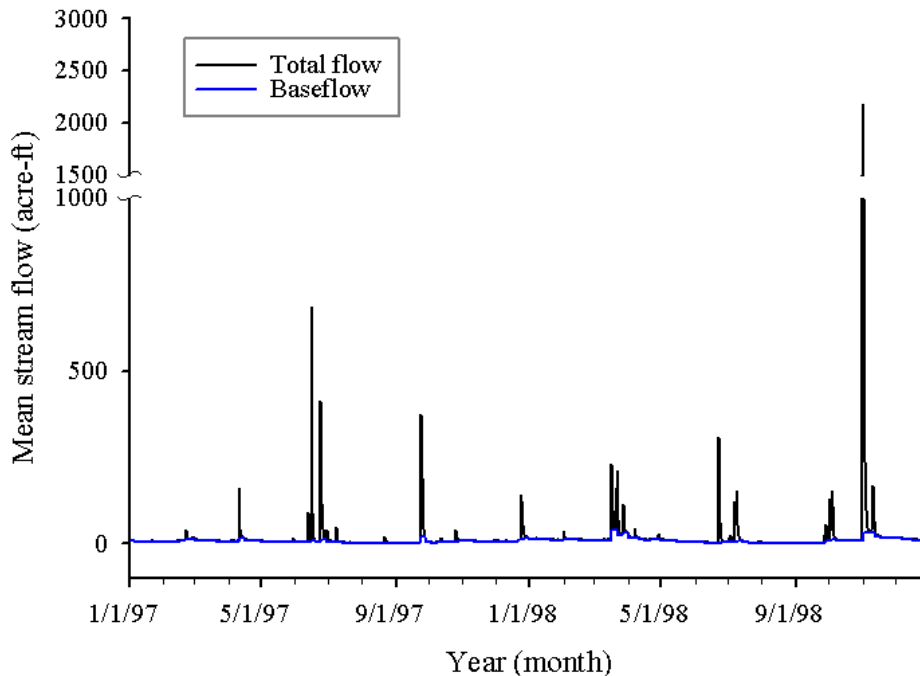


Figure 5. Hydrograph of total stream flow and baseflow at the Red Rock Creek USGS gaging station (07144730) for 1997-1998.

The results of HYSEP indicated that runoff volume accounted for 62% of the total annual stream flow in 1997 and 65% in 1998. During these two years, the total stream flow and separated runoff depths were 2.11 and 1.32 in for 1997 and 4.05 and 2.66 in for 1998, respectively.

To determine nutrient loading that represents typical runoff conditions, the separated runoff and average monthly total suspended solids (TSS) concentrations were plotted and evaluated (Figure 6). Based on the intensity and duration of runoff events in 1997 and 1998, the TSS concentration of 90 mg/L was selected as the upper limit for baseflow conditions and the lower limit for runoff conditions. In total, ten events in 1997 and 17 events in 1998 were used to characterize sediment and nutrient loading associated with runoff conditions. Statistics of these individual event data for 1997 and 1998 were summarized in Table 2.

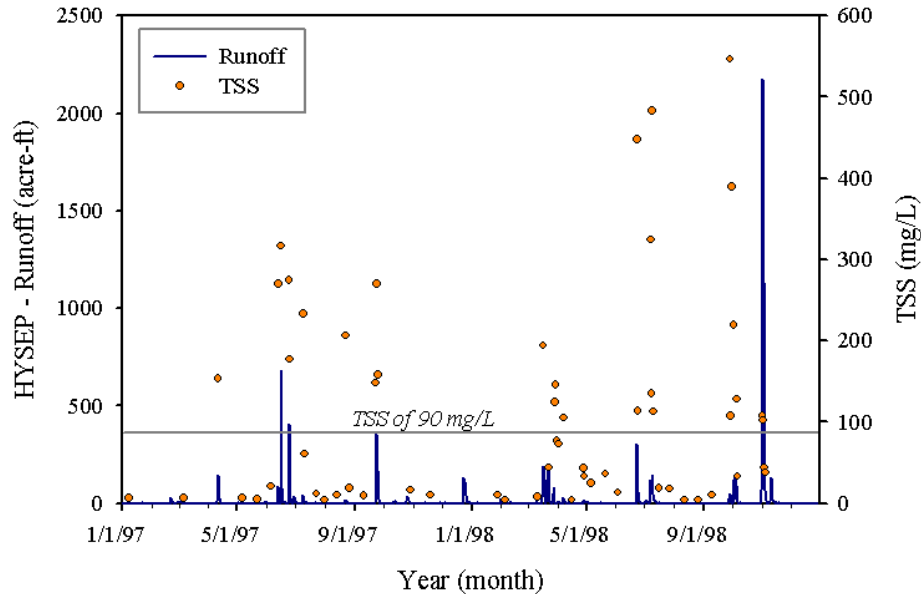


Figure 6. Separated runoff hydrograph and TSS for storm flow events for the Red Rock Creek in 1997-1998.

Table 2. Summary of statistics for the runoff samples (n = 25) of the selected 10 storm events in 1997 and the runoff samples (n = 33) of the 17 storm events in 1998 for the Red Rock Creek.

Parameter	TSS/Sediment -- mg/L --	Nitrogen			Phosphorus		
		Dissolved	Organic	Total	Dissolved P	Organic	Total
		----- mg/L -----			----- µg/L -----		
1997							
Mean	238	1.21	1.70	2.89	459	392	851
Median	218	1.06	1.68	2.80	470	395	805
Standard Deviation	109	0.61	0.37	0.77	144	216	252
Flow-weighted mean	258	1.17	1.56	2.73	535	390	925
1998							
Mean	283	1.29	1.81	3.10	379	294	678
Median	188	1.16	1.64	3.02	413	256	640
Standard Deviation	224	0.60	0.60	0.76	111	218	225
Flow-weighted mean	196	1.10	2.04	3.14	418	241	659
USGS ¹ (1997-200)	222	1.30	---	---	---	---	620

¹(Milligan and Pope, 2001, Occurrence of Phosphorus, Nitrate, and Suspended Solids in Streams of the Cheney Reservoir Watershed, south-central Kansas, 1997-2000. U.S. Geological Survey, Water-Resources Investigations Report 01-4199).

The initial procedure for the calibration of AnnAGNPS was to estimate the model runoff using individual and average precipitation data from two weather stations located in the watershed (Hutchinson and RN1086). However, due to the presence of localized storms (rainfall variability) at weather stations, these simulation results exhibited both monthly and annual values that were significantly different from the observed values (Table 3). Therefore, adjustments were made to the average rainfall values in an attempt to better-fit the volume estimates of individual runoff events. Additionally, slightly different curve numbers were assigned to AnnAGNPS. Figures 7 and 8 show the adjusted rainfall and its associated simulation results, respectively, and Table 4 shows the assigned curve numbers used in AnnAGNPS.

Table 3. Comparisons of water yields estimated by HYSEP and AnnAGNPS using individual and average rainfall data from the Hutchinson and RN1086 stations in 1997.

	HYSEP	Hutchinson	RN1086	Average rainfall
		----- acre-ft -----		
January	19.05	0	0	0
February	66.68	49.22	50.24	58.16
March	27.39	47.05	0	21.19
April	218.69	530.89	162.91	450.16
May	28.38	76.79	24.72	86.23
June	1495.89	1537.61	960.02	960.93
July	73.70	5.16	87.19	37.17
August	39.07	60.42	140.92	41.41
September	588.20	3202.35	2103.95	2550.08
October	100.81	24.58	29.59	19.75
November	13.49	0	0	0
December	330.61	227.85	89.98	119.12
<i>Total</i>	3001.96	5761.91	3649.52	4344.20

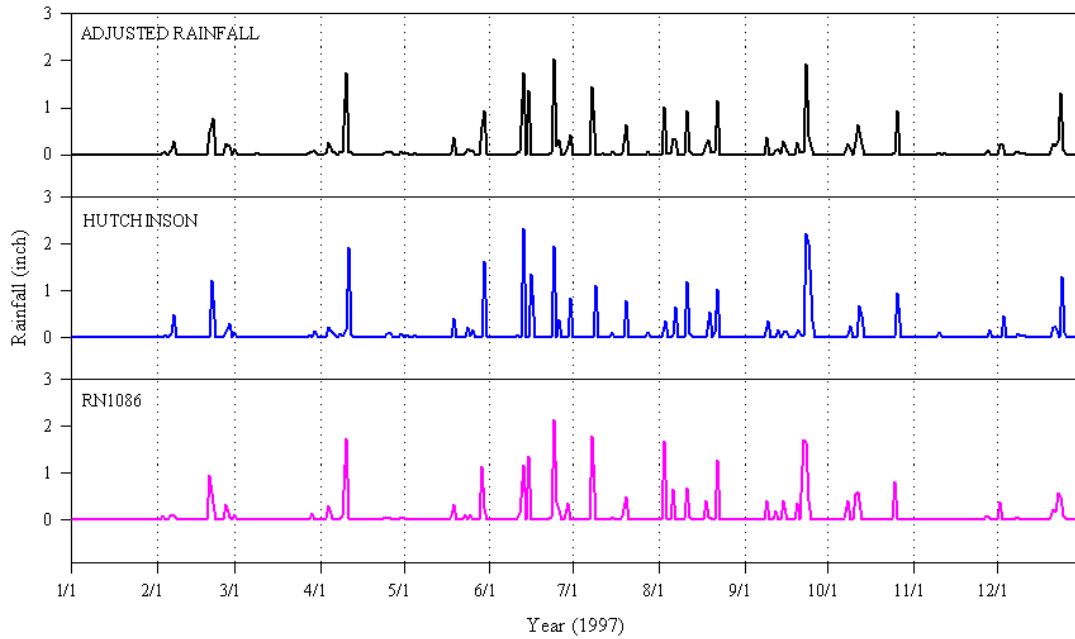


Figure 7. Hydrographs showing the adjusted and individual rainfall data used AnnAGNPS in 1997.

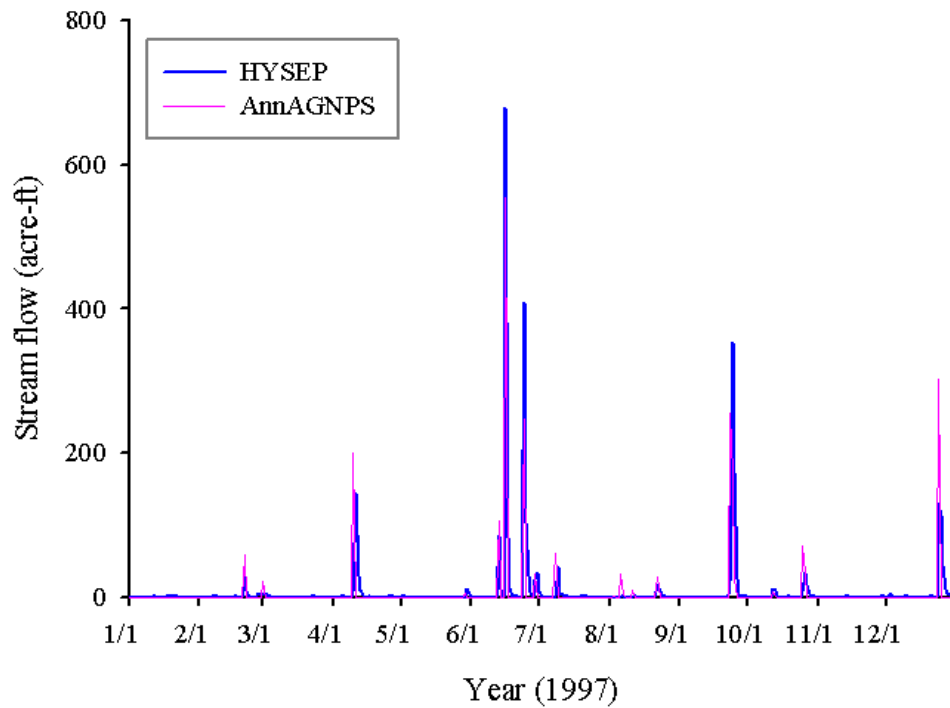


Figure 8. Hydrographs showing measured (HYSEP) and predicted (AnnAGNPS) runoff in 1997.

Table 4. Runoff curve number assigned in the AnnAGNPS simulations.

Land cover class	Hydrologic soil group			
	A	B	C	D
Pasture or range poor	73	79	86	89
Pasture or range fair	60	69	79	84
Pasture or range good	58	61	74	80
Row crops contoured & grassed terraces	68	75	78	81
Row crops straight row	72	80	85	88
Small grain contoured & grassed terraces	59	70	78	81
Small grain straight row	63	74	82	85
Woods fair	50	60	70	79
Misc.	72	82	87	89

The AnnAGNPS model predicted annual runoff was 2657.03 acre-ft (1.07 in) against the measured value of 3001.96 acre-ft (1.21 in) in 1997. The overall accuracy of model prediction was 89%. Monthly comparisons of the predicted and measured runoff were shown in Figure 9.

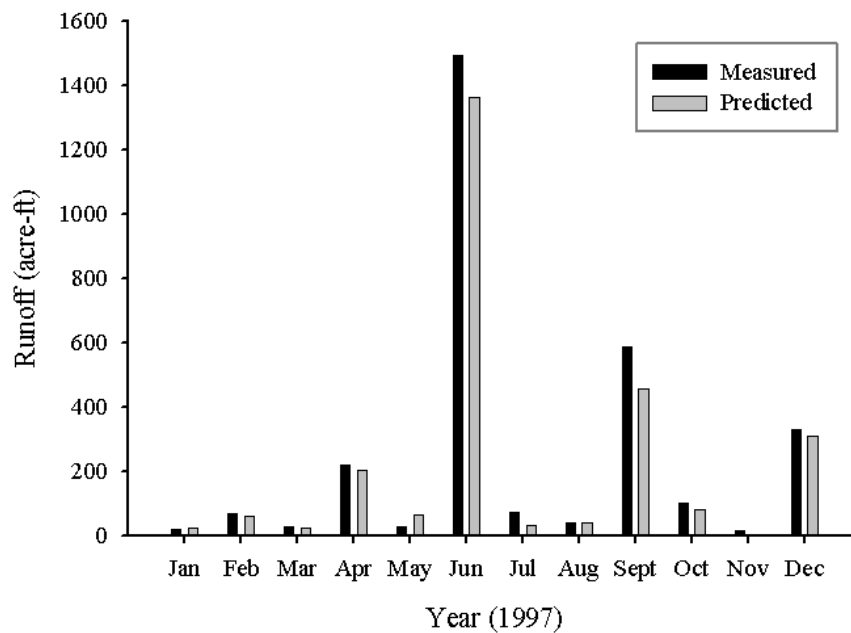


Figure 9. Monthly comparisons of measured and predicted runoff in 1997.

2.4.1. Sediment Calibration

Monthly sediment loads estimated by the summation of clay and silt values predicted by AnnAGNPS were compared to the measured TSS concentrations (Figure 10). In general, the predicted sediment loads corresponded reasonably well to the measured values. Large discrepancies were noticed in April when the first flush occurred in the field and in June when the amount and intensity of rainfall were highest. For 1997, the total sediment yield estimated by AnnAGNPS was 2657.45 ton (0.089 ton/acre) whereas the measured sediment yield (USGS runoff flow x annual TSS mean value) was 969.52 ton (0.033 ton/ac).

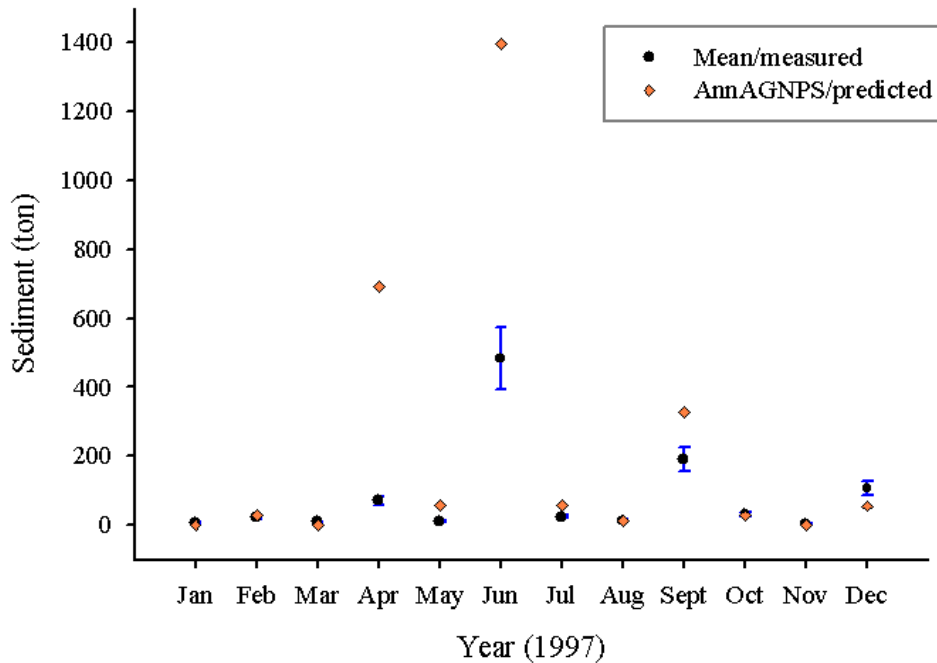


Figure 10. Error bar plots (mean \pm 95% confidence interval) showing the measured and predicted sediment yield.

2.4.2. Nutrient Calibration

To calibrate the nutrient components of the model to the Cheney Reservoir watershed, the required parameters such as soil organic N, inorganic N, organic P, inorganic P, surface residue decomposition, surface residue cover, fertilizer application, and feedlot operation were obtained from the CRPO as starting values. Table 5 summarizes the initial results using the previous calibrated model. The initial AnnAGNPS results showed that there was a close agreement between the predicted and measured data for annual sediment-attached N (or organic N). However, weaker agreements were found for dissolved N (inorganic N), sediment-attached P (organic P), and dissolved P (inorganic P). Thus, the adjustment of model parameters was made on these three nutrients until satisfactory results were found. For this study, sediment P and dissolved P were calibrated by adjusting model parameters. However, very few changes were noted for dissolved N using the same

approach. Because the difference between the predicted and measured values varied consistently, a factor was then applied to adjust each monthly value.

Table 5. Comparison between predicted and measured values of nutrient loads in 1997.

	Sediment N	Dissolved N	Sediment P	Dissolved P
	----- ton/yr -----		-----	
Predicted	6.53	4.93	6.09	8.76
Observed	8.15	38.97	1.27	2.04

Figure 11 shows the predicted nutrient loads after AnnAGNPS was calibrated. Most of the monthly-predicted sediment-attached N and P values, and dissolved N and P values matched the measured data. In April 1997, the calibrated AnnAGNPS predicted higher nutrient loads, which were in part due to the spring flush phenomenon whereby excess nutrients accumulated in the watershed over the winter were washed into the stream channels. However, the field sampling equipment did not provide sufficient data to characterize the spring flush effect on water quality. For 1997, the calibrated model overpredicted the total sediment-attached N (25%), sediment-attached P (25%), dissolved N (3%), and dissolved P (5%) with annual loads of 8.15 ton (0.55 lb/ac), 1.59 ton (0.11 lb/ac), 4.72 ton (0.32 lb/ac), and 2.13 ton (0.14 lb/ac), respectively.

2.5. Validation of AnnAGNPS

After calibrating AnnAGNPS to the Cheney Reservoir watershed conditions using 1997 data, the model was used to simulate 1998 runoff (water year), sediment and nutrient loads. Predicted values were then compared to 1998 field data to validate the model predictive abilities. Prior to the simulation, rainfall and stream flow data were discreetly examined together so that localized storms or rainfall variability was reduced to the minimum. As indicated earlier, neither HYSEP nor AnnAGNPS can extract stream flow from melted snow. In March 1998, 6 in of snow occurred on the 8th and 20th, and 4.5 in occurred on the 19th (Figure 12). To ratify the effect of these snow events, the appropriate amount of precipitation was therefore added to their associated rainfall. The rainfall data used in the calibrated AnnAGNPS is shown in Figure 13 and the predicted runoff events are exhibited in Figure 14.

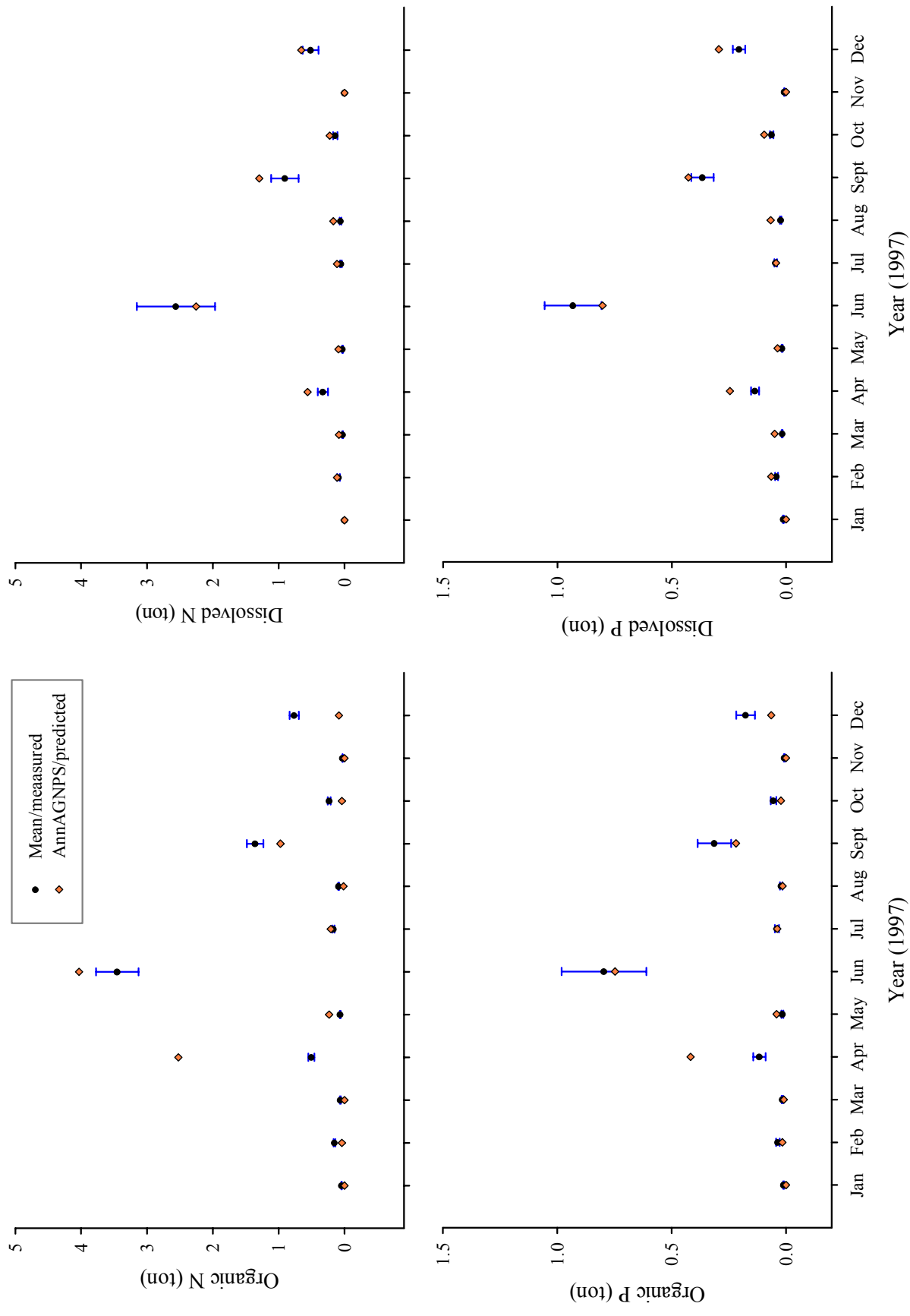


Figure 11. Error bar plots (mean \pm 95% confidence interval) showing measured and predicted sediment-attached (organic) N and P, and dissolved (inorganic) N and P in 1997.

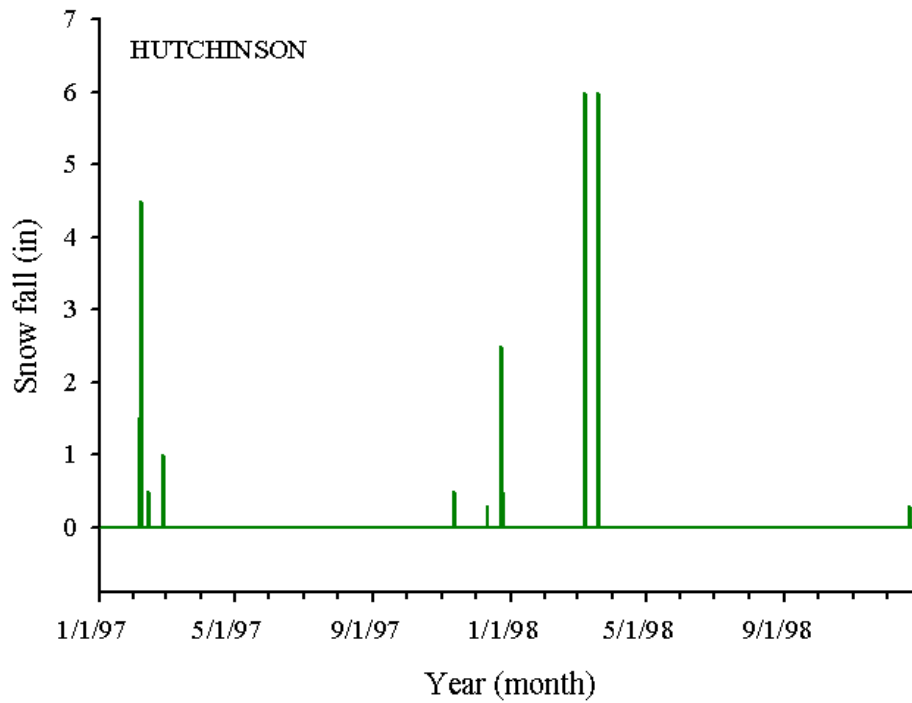


Figure 12. Snow events occurred at the Hutchinson weather station in 1997-1998.

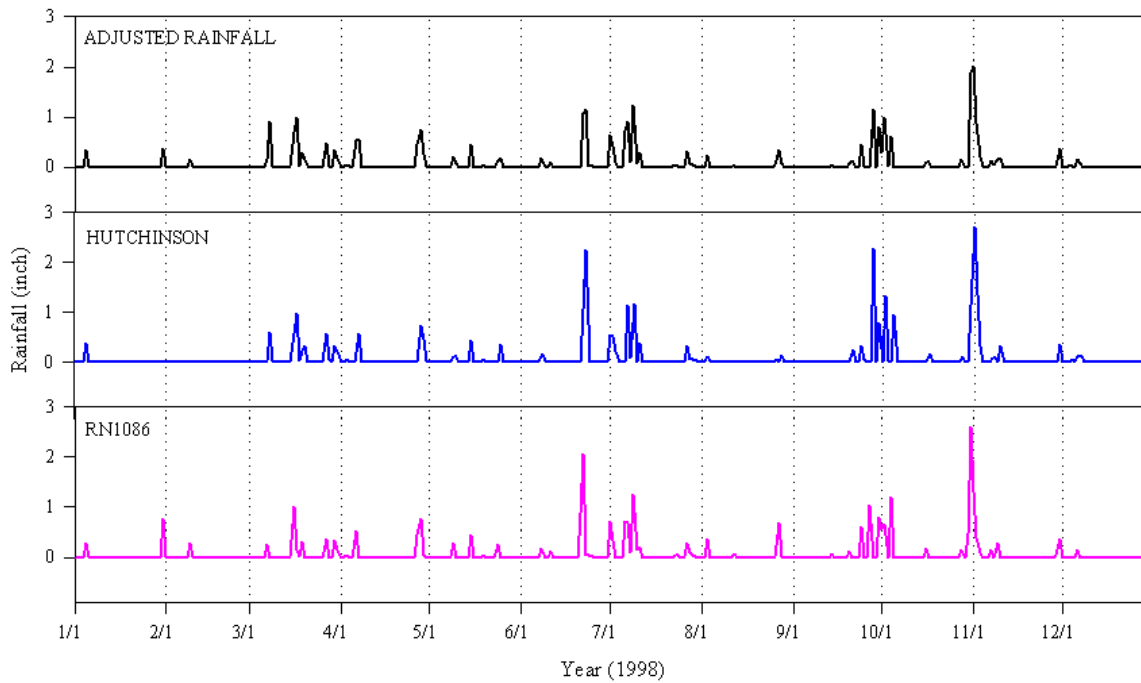


Figure 13. Hydrographs showing the adjusted and individual 1998 rainfall data used in AnnAGNPS.

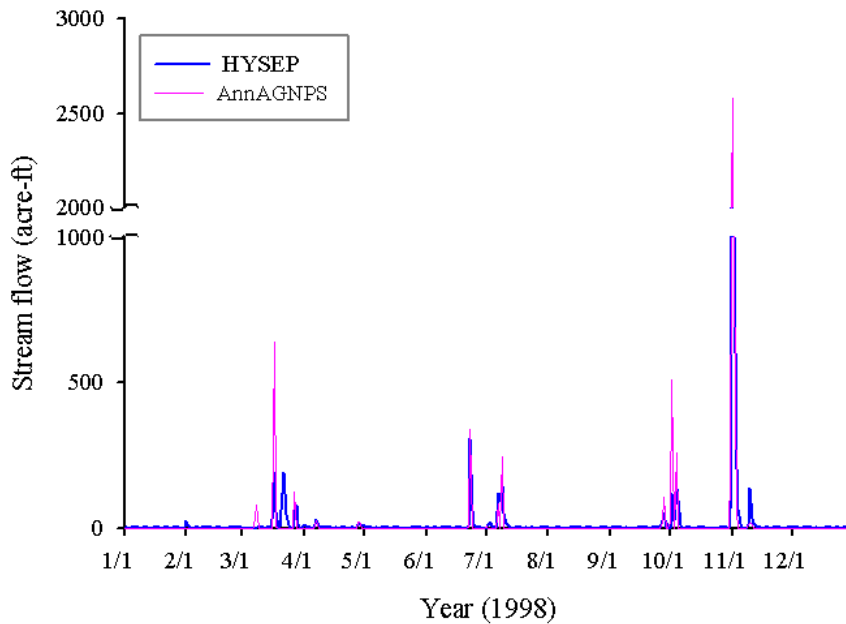


Figure 14. Hydrographs showing measured (HYSEP) and predicted (AnnAGNPS) runoff in 1998.

The calibrated AnnAGNPS model prediction of annual runoff was 6254.72 acre-ft (2.52 in.) against the measured value of 6302.23 acre-ft (2.54 in.) in 1998. The overall accuracy of model prediction was 99%. Monthly comparisons of the predicted and measured runoff are shown in Figure 15.

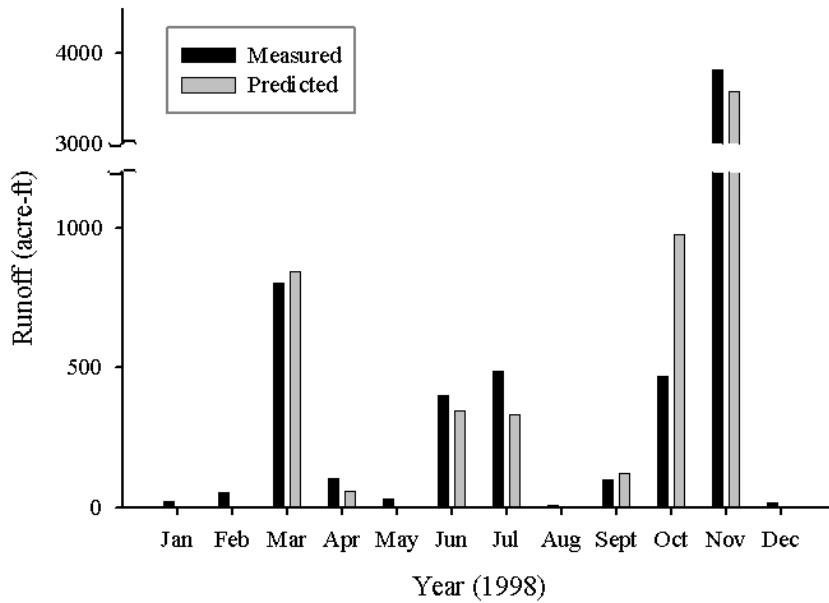


Figure 15. Monthly comparisons of measured and predicted runoff in 1998.

2.5.1. Sediment Validation

Figure 16 shows the monthly-predicted sediment loads estimated by AnnAGNPS and the measured sediment loads calculated using the TSS concentrations. The predicted sediment loads typically corresponded well to the measured values. For 1998, the total sediment yield was estimated 2,026.45 ton (0.068 ton/ac) as opposed to the measured sediment yield of 2,415.94 ton (0.081 ton/ac) using the annual mean value. The sediment prediction of the calibrated model was 84% of the measured values. In November 1998, the model underestimated sediment yield, showing that there was another important sediment source that significantly contributed to the loading. One such likely source is sediment eroded from the stream network system (i.e., stream bank erosion).

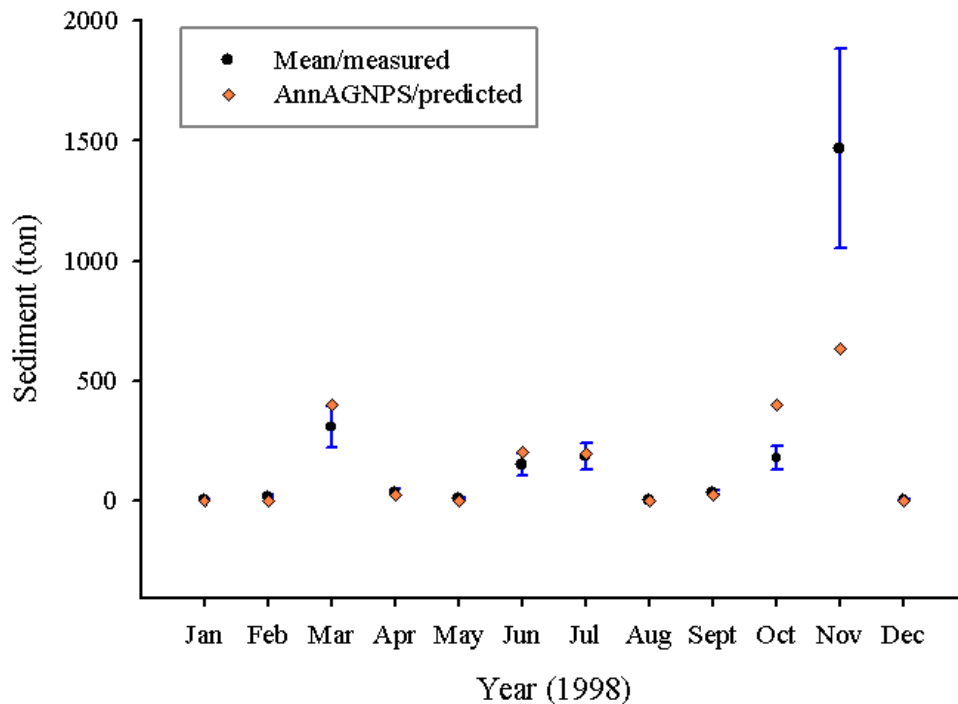


Figure 16. Error bar plots (mean \pm 95% confidence interval) showing the measured and predicted sediment yield.

2.5.2. Nutrient Validation

Figure 17 shows the nutrient loads predicted using the calibrated AnnAGNPS model. Typically, monthly-predicted sediment N and P, and dissolved N and P corresponded well with the measured data. The calibrated AnnAGNPS consistently underestimated these four nutrient loads in November 1998. This is likely because AnnAGNPS was not intended to model the nutrients that were washed along with the eroded sediment from the stream system during excess high flow events. For 1998, the calibrated model underestimated the total sediment N (74%), sediment P (57%), and dissolved N (34%), and dissolved P (19%)

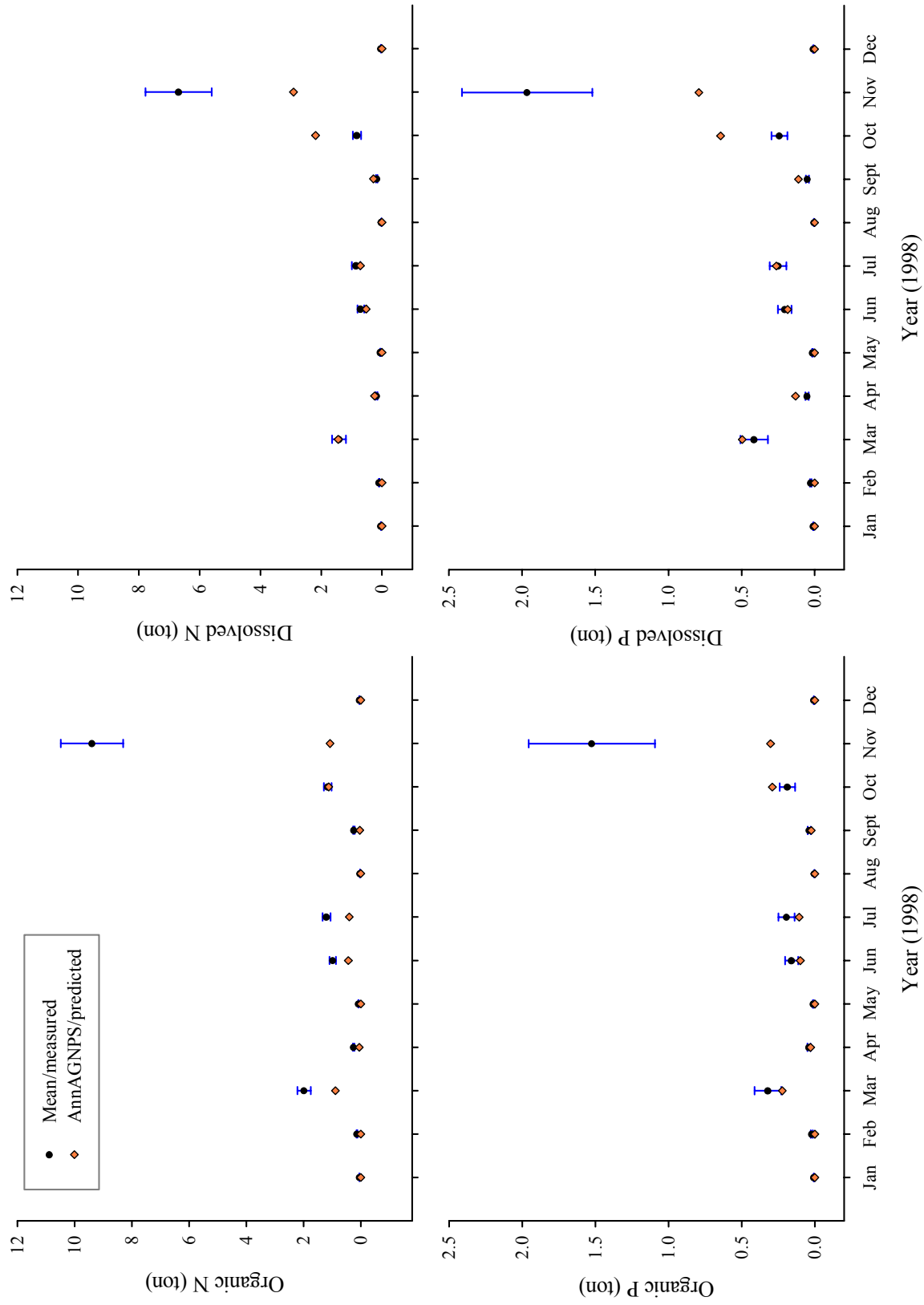


Figure 17. Error bar plots (mean \pm 95% confidence interval) showing measured and predicted sediment-attached (organic) N and P, and dissolved (inorganic) N and P in 1998.

with annual loads of 3.97 ton (0.27 lb/ac), 1.07 ton (0.07 lb/ac), 7.25 ton (0.49 lb/ac), and 2.62 ton (0.18 lb/ac), respectively. In other words, the model only predicted 26% and 43% of the measurements for sediment N and P but provided a fairly good estimation for both dissolved N and P, with an accuracy of 66% and 81%, respectively.

3. RESULTS AND DISCUSSION

Four components were recognized as essential to manage the ecological health of Cheney Reservoir, 1) determine sediment and nutrient transports from the associated watershed, 2) evaluate the effectiveness of alternative farming operations used to reduce pollutants entering the reservoir system, 3) understand the linkage between reservoir health and watershed management, and 4) establish achievable water quality goals. The effects of hypothetical change in land management in the Cheney Reservoir watershed on the sediment and nutrient loads received by the reservoir were simulated using the calibrated AnnAGNPS.

3.1. Application of AnnAGNPS

Though there was daily rainfall data available from 11 weather stations surrounding the Cheney Reservoir watershed, the complexity of spatial rainfall patterns within the watershed had made it difficult to use this data directly in AnnAGNPS (as seen in the model calibration and validation). The Thiessen polygon method (Thiessen, 1911) could have been used to derive possible rainfall data that match the actual data. However, the GEM (Generation of weather Elements for Multiple applications) weather generator model was used in this study because of consideration of representative historic and future weather patterns used on scenario analysis (Johnson et al., 2000). The GEM is a stochastic model developed by the ARS and NRCS, which generates a time series of daily weather elements (e.g., precipitation, maximum and minimum temperature, and dewpoint) for a given location based on weather stations positioned in the region. This provides easy access to daily weather simulations within the contiguous United States. The time series-produced data is statistically representative of the weather that can be expected at that location over a period of time. The GEM data used in this study was generated by the NRCS through a thorough evaluation of the historical weather records of the 11 weather stations (per. comm. Lyle Frees).

Because of earlier mentioned limitations of HYSEP, the separated runoff flow at the USGS gauging station located on the North Fork Ninescah River above Cheney Reservoir (07144780) was determined by multiplying the gauged flow volume by the two-year mean percentage (54%) which was calculated by averaging the separated runoff percentages of its sub-watersheds (Red Rock Creek watershed 64% ; Goose Creek watershed 45%). Water quality data from 1997 to 1998 was used to calculate runoff-associated sediment and nutrient loads using the method described in the model calibration.

A series of GEM simulations was performed to obtain a typical and normalized weather data set that could characterize the watershed's water and sediment yields, and nutrient loads. The simulation results are illustrated in Figures 18a and 18b with comparisons to the measured loading. Table 6 summarizes the data used for loading calculation. As shown in Figures 18a and 18b, a 30-year simulation provided satisfactory results against the actual values, except for the dissolved P. The AnnAGNPS predicted annual runoff yield (45,582 acre-ft or 1.06 in) was 91% of the observed runoff (50,252 acre-ft or 1.17 in) and 103% of the observed sediment yield (26,093 ton or 101.00 lb/ac vs. 25,231 or 97.67 lb/ac). The predicted sediment P load was 88% over the 1997–1998 period (21.74 ton or 0.08 lb/ac vs. the observed, 24.69 ton or 0.10 lb/ac). Similarly, the AnnAGNPS provided a good estimation for annual sediment N (63%, 78.28 ton or 0.30 lb/ac) as compared to the observed (124.11 ton or 0.48 lb/ac). A good agreement was also noticed for dissolved N. The model predicted 92% of the actual dissolved N load (46.48 ton or 0.18 lb/ac vs. 50.73 ton or 0.20 lb/ac). However, the AnnAGNPS overestimated annual dissolved P, indicating the limitation of this model application for a large watershed. This is likely due to the fact that dissolved P washed from the surrounding field is readily bound to clay particles and organic sediment or other materials during its route to Cheney Reservoir.

Table 6. Summary of water quality statistics for runoff samples (n = 58) collected at a USGS gaging station (07144780) located at North Fork Minnescah River above Cheney Lake during 1997-1998.

Parameter	TSS/Sediment	Nitrogen			Phosphorus		
		Dissolved	Organic	Total	Dissolved P	Organic	Total
	-- mg/L --	----- mg/L -----			----- µg/L -----		
<i>Mean</i>	370	0.74	1.82	2.57	136	362	497
Median	243	0.66	1.73	2.46	130	360	382
Standard Deviation	356	0.35	0.73	0.79	68	298	325
Minimum	96	0.04	0.41	0.60	30	80	121
Maximum	1710	1.71	4.30	5.12	360	1,580	1,750

3.2. Watershed Management Scenarios

Three watershed management scenarios were tested to assess their hypothetical impacts on water quality of Cheney Reservoir. Scenario 1 converted the entire watershed to native-grass prairie to approximate predevelopment and/or early land use development. All land use was changed to grassland, no fertilizer was added, and feedlots and point sources were removed to estimate background nutrient loadings and historic reservoir conditions. Scenario 2 simulated the effect of changing continuous and conventional (mulch-till) wheat and/or milo (grain sorghum) cultivation to no-till wheat and milo rotation. Scenario 3 simulated the effect of converting the Conservation Reserve Program (CRP) filter strip corridors along stream banks back to conventional tillage. The Cheney Watershed Program encourages CRP contract holders to leave a 200 ft grass filter strip along blue line streams, as designated by the USGS (Conservation Technology Information Center, 2002).

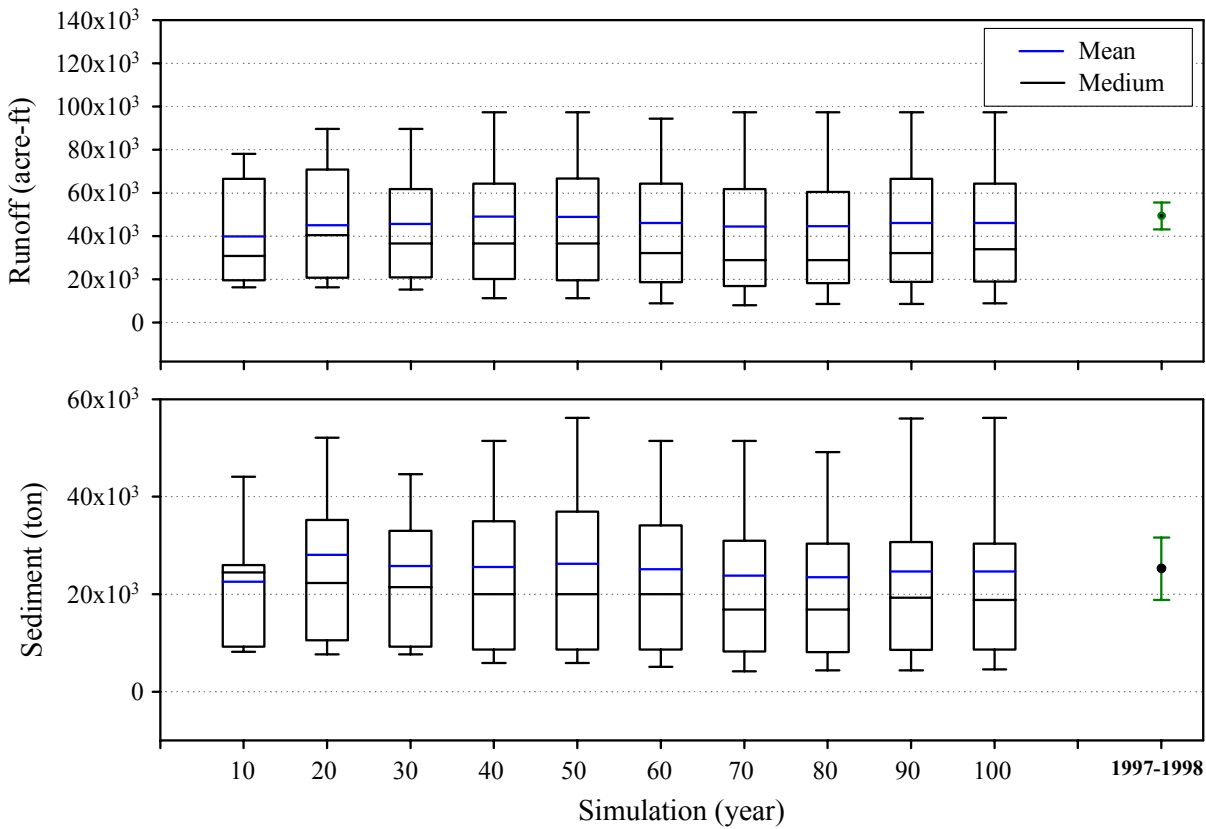
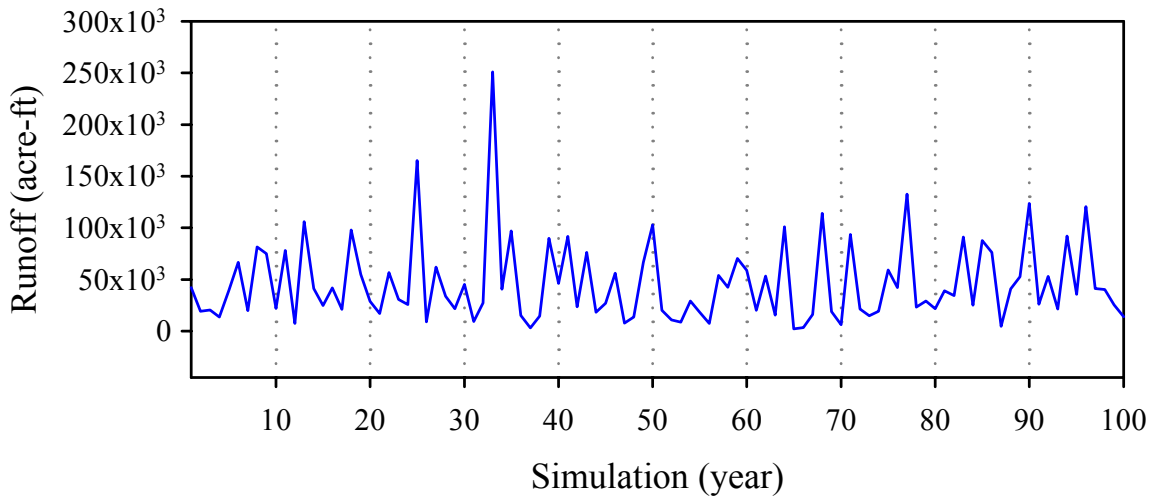


Figure 18a. Runoff simulation over a 100-year period using GEM weather data. Box plots showing the simulation results at 10-year intervals, with comparisons to the measured data (mean \pm 95% confidence interval) over the period of 1997-1998.

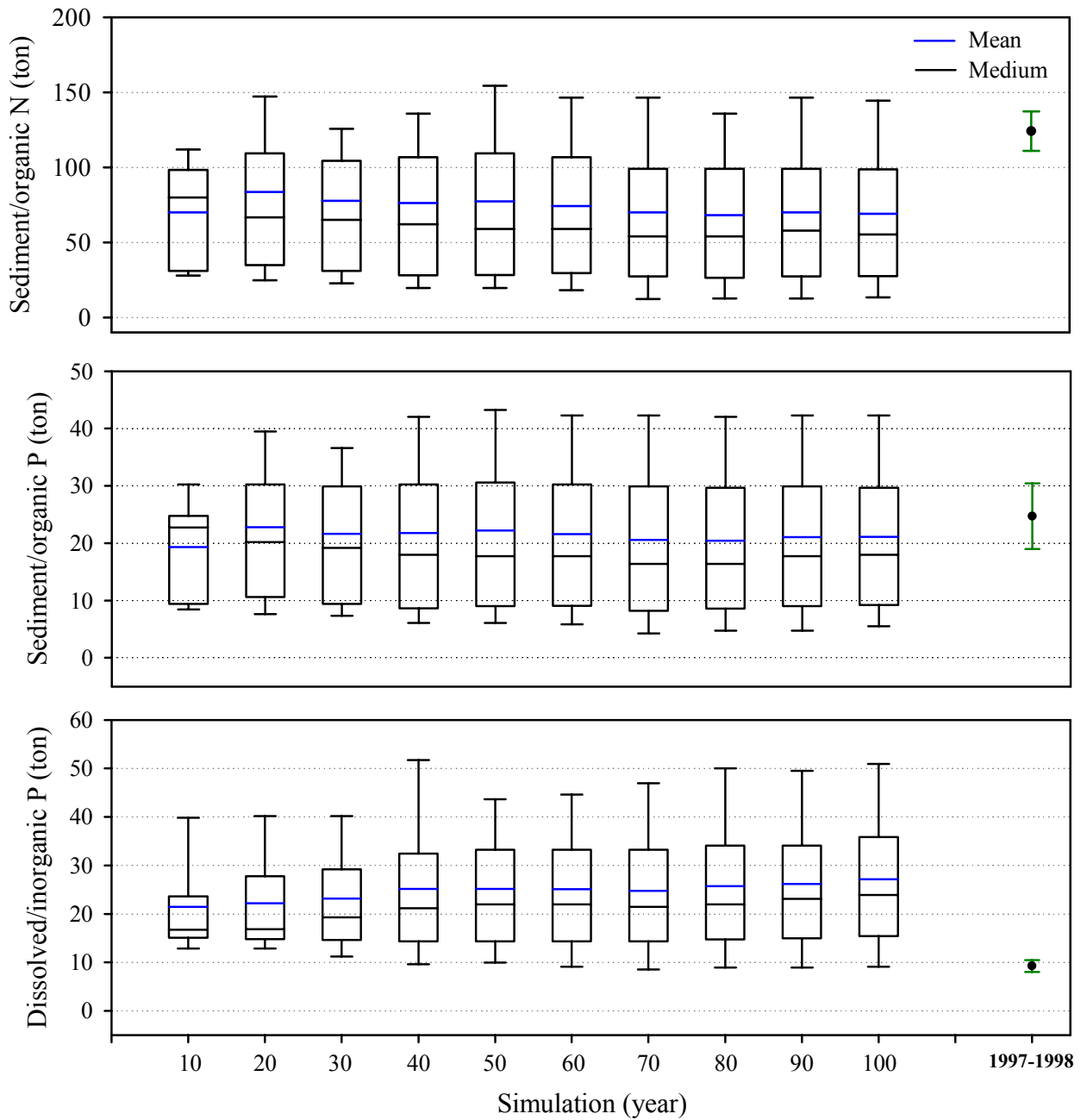


Figure 18b. Box plots showing the nutrient simulation results at 10-year intervals, with comparisons to the observed data (mean \pm 95% confidence interval) over the period of 1997-1998.

As indicated in Table 7, it is not surprising to note that the presumed native conditions (Scenario 1) increased the ability of the watershed to retain water, as reflected in a 31% reduction in annual runoff. The native conditions also reduced watershed sediment load 97% to 832 ton per year (3.22 lb/ac/yr), sediment N load 99% to 1.13 ton per year (0.004 lb/ac/yr), dissolved N load 78% to 9.04 ton per year (0.04 lb/ac/yr), sediment P load 90% to 2.10 ton per year (0.01 lb/ac/yr), and dissolved P load 54% to 10.64 ton per year (0.04 lb/ac/yr).

Table 7. Summary of AnnAGNPS results for watershed management scenarios.

Management scenario:	1	2	3	
Description:	Current	Native	Wheat-milo rotation	CRP to cropland
Land use conversion, %	--	76.40	--	15.50
Average surface inflow, in/yr	1.06	0.73	1.02	1.00
Sediment in surface inflow, lb/ac/yr	101.00	3.22	75.18	125.51
Sediment N in surface inflow, lb/ac/yr	0.30	0.00*	0.22	0.38
Dissolved N in surface inflow, lb/ac/yr	0.16	0.04	0.15	0.15
Sediment P in surface inflow, lb/ac/yr	0.08	0.01	0.06	0.10
Dissolved P in surface inflow, lb/ac/yr	0.09	0.04	0.07	0.10

(* indicates 0.004)

With no-till wheat-milo rotation (Scenario 2), there was a 3% decrease in runoff accompanied by a 25% reduction in sediment load to 19,423 ton per year (75.18 lb/ac/yr), 28% reduction in sediment N load to 56.24 ton per year (0.22 lb/ac/yr), 2% reduction in dissolved N load to 39.68 ton per year (0.15 lb/ac/yr), 27% reduction in sediment P load to 15.77 ton per year (0.06 lb/ac/yr), and a 23% decrease in dissolved P load to 17.77 ton per year (0.07 lb/ac/yr). This indicates that crop rotation can be a good nutrient management practice that could provide Cheney Reservoir with substantial sediment or nutrient yield reductions. It is likely that crop rotations improve soil structure by incorporating crop residue into soil after harvest, which can increase soil fertility and water infiltration rate (Iowa State University, 2002).

Converting all CRP filter strips to cropland (Scenario 3) resulted in a 5% reduction in runoff along with 25% increase in sediment, 25% in sediment N, and 24% in sediment P loads to 32425 ton per year (125.51 lb/ac/yr), 98.21 ton per year (0.38 lb/ac/yr), and 26.28 ton per year (0.10 lb/ac/yr), respectively. Though there was a 2% reduction in dissolved N

load (40.53 ton per year or 0.15 lb/ac/yr), this returned cultivation could significantly increase dissolved P load by 9% (23.07 ton per year or 0.10 lb/ac/yr). This simulation demonstrates the important effect of CRP has had on sediment and nutrient load reductions and indicates that the present CRP management should be properly maintained to continue this important function.

3.3. Application of Eutrophication Response Model

For modeling purposes, Cheney Reservoir was segmented into four portions according to its water quality and basin characteristics; riverine, transition, Mud Creek Cove, and main basin (Figure 19). The following described synopsized model parameterization. The mean depth for each segment was determined using a map with lake-bottom topography from the Kansas Geological Survey and verified with the Smith's study (2001). The segment areas were calculated using a GIS technique (i.e., ArcView). Profile water quality data (i.e., non-algal turbidity, TN, TP, chlorophyll *a*, secchi depth, organic N, and organic P) of sampling sites located within each of the lake segments were averaged for the growing season from May through September 2000. Lake precipitation, evaporation, elevation, and total inflow data were attained from the Tulsa District of the Army Corps of Engineers. Atmospheric N and P inputs were compiled from National Atmospheric Deposition Program/National Trend Network, a 1994 USGS report (Puckett, 1994), and a recent ARS study (Burkart and James, 2002).

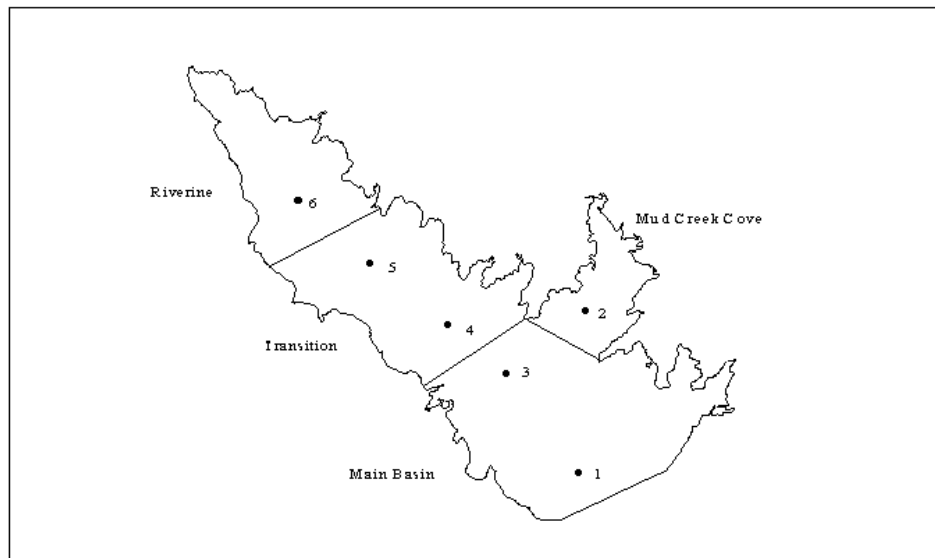


Figure 19. Map of Cheney Reservoir showing water sampling sites (Smith et al., 2001) and segments used in BATHTUB modeling.

3.3.1. Hydrology

Though many streams feed Cheney Reservoir, the North Fork Ninescah River is the major tributary. The total flow at the two USGS gaging stations above Cheney Reservoir for the water year 2000 (October 1999 to September 2000) was 84659.99 acre-ft (75903.49

acre-ft for Station 07144780 and 8756.50 acre-ft for Station 07144730). Combined drainage area of these stations accounted for 86% of the total Cheney Reservoir watershed area, the total inflow contributing to the reservoir was 98441.85 acre-ft, of which 14% was attributable to the near-lake area.

As shown in Figure 20, a discrepancy between precipitation-corrected lake inflow calculated by the Army Corps of Engineers and area-corrected USGS lake inflow was observed. This discrepancy corresponded well to the increased volumes of rainfall in the reservoir. This was likely to be the uncertainty associated with computation (per. communication with the Kansas City District of the Army Corps of Engineers). In addition, the water balance calculated by BATHTUB showed that there was only a 2% error between the lake inflow and outflow in relation to variations in lake elevation. Thus, it is not unreasonable to suspect that groundwater does not significantly and directly contribute flow to Cheney Reservoir despite the fact that the High Plains Aquifer underlies some portion of its watershed.

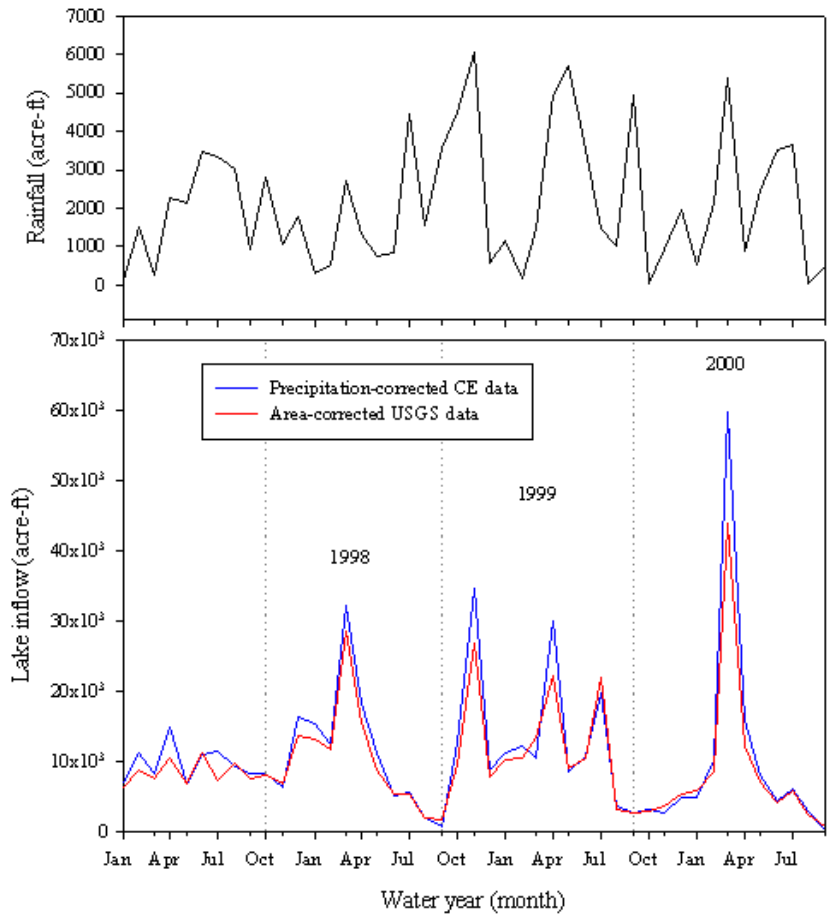


Figure 20. Rainfall data measured at Cheney Reservoir by the Army Corps of Engineers (upper figure) and Lake inflow calculated using precipitation-corrected inflow data from the Army Corps of Engineers and area-corrected inflow data from the USGS (bottom figure).

3.3.2. *Light and Nutrient Limitation*

To ensure that BATHTUB was applicable to the current reservoir condition, it was important to understand what limiting factors affect the phytoplankton community in the reservoir. The elemental ratios of TN to TP (TN:TP) have been used to infer nutrient limitation in term of which of these nutrients is most likely limiting plant growth in the water. This is based on the relative requirement for each nutrient by different types of plants. The TN:TP ratios for algae tend to be 10N:1P by weight. Higher ratios, particularly above 17:1, infer phosphorus limitation for algae and lower ratios, particularly below 5:1 infer nitrogen limitation and favor the nitrogen-fixing cyanobacteria (Smith, 1992 and 1998; Smith and Bennett. 1999).

The average ratio of TN and TP for Cheney Reservoir was 6:1, indicating a strong potential for N-limitation of algal growth (Smith et al., 2001). For modeling purposes, laboratory bioassays were conducted at the Kansas Biological Survey in July 2002 to corroborate the above conclusion. Raw surface water with naturally occurring algae was collected from the main basin of Cheney Reservoir and placed in bottles spiked with various combinations of nitrate (NO_3^-) and phosphate (PO_4^{3-}). Additional sample water was placed in bottles without nutrient spikes and exposed to different levels of light to determine light limitation. Conditions causing increased growth in the bottle provided some support for identifying the conditions regulating algal growth in the reservoir. As indicated in Figure 21, NO_3^- was required to support growth, suggesting that the availability of N was necessary for any acceleration of surface algal growth in the main basin. The TN:TP ratio in the collected surface water of the main basin was 7:1.

3.3.3. *Synopsis of Model Calibration and Simulation*

BATHTUB was constructed to characterize the current watershed and lake conditions according to the data gathered from the previous studies. Model coefficients were calibrated basin-wide, and residual TN and/or TP values were used to examine internal nutrient cycling; predicted nutrient values less than measured nutrient values reflect the potential internal nutrient cycling effect. Cheney Reservoir is a well-mixed reservoir because of its size, orientation, and an open landscape (O'Brien, 1975; Randtke and deNoyelles, 1985). Anoxic conditions that could result in a substantial nutrient release from the lake sediment seldom occur at the lake bottom (Smith et al., 2001). However, the results of calibrated BATHTUB indicated that a discrepancy existed between the predicted and measured data for the Mud Creek Cove. This was assumed to be the internal load. This is likely due to the fact that a large amount of water flowed into the Mud Creek Cove from the main basin of the reservoir, causing hydrologic turbulence to resuspend the bottom sediment, which resulted in a release of nutrients.

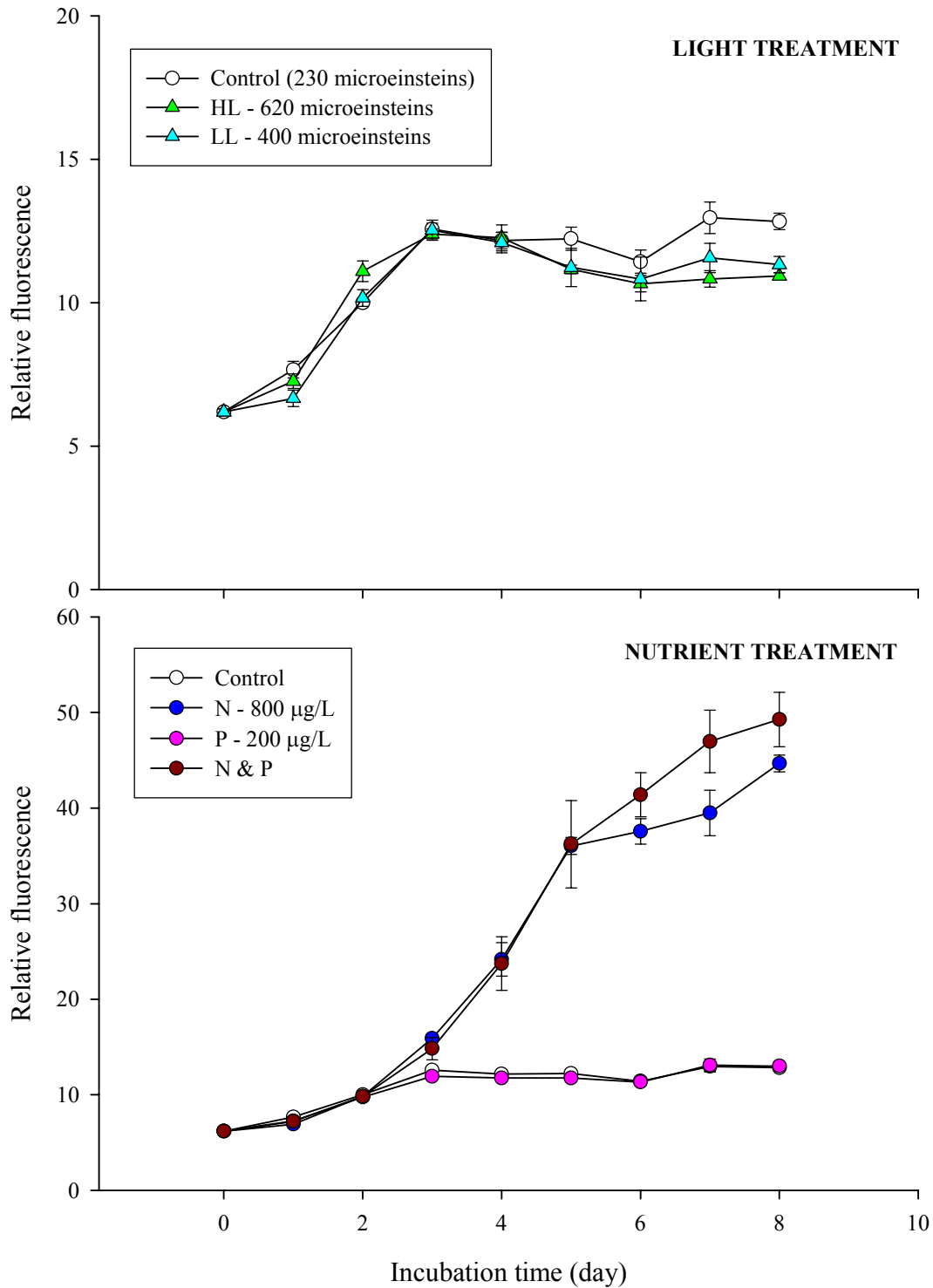


Figure 21. Mean fluorescence values for light and nutrient addition treatments for lake water collected from main basin of Cheney Reservoir on July 2, 2002. Fluorescence was measured daily during an eight-day period. An error bar represents one standard deviation.

Figure 22 shows the calibration results of BATHTUB for total and organic P, total and organic nitrogen, chlorophyll *a*, and secchi depth. The model prediction corresponded well with the measured values for each segmented region of Cheney Reservoir. No significant differences were noticed at the 95 % confident level between the predicted and observed values.

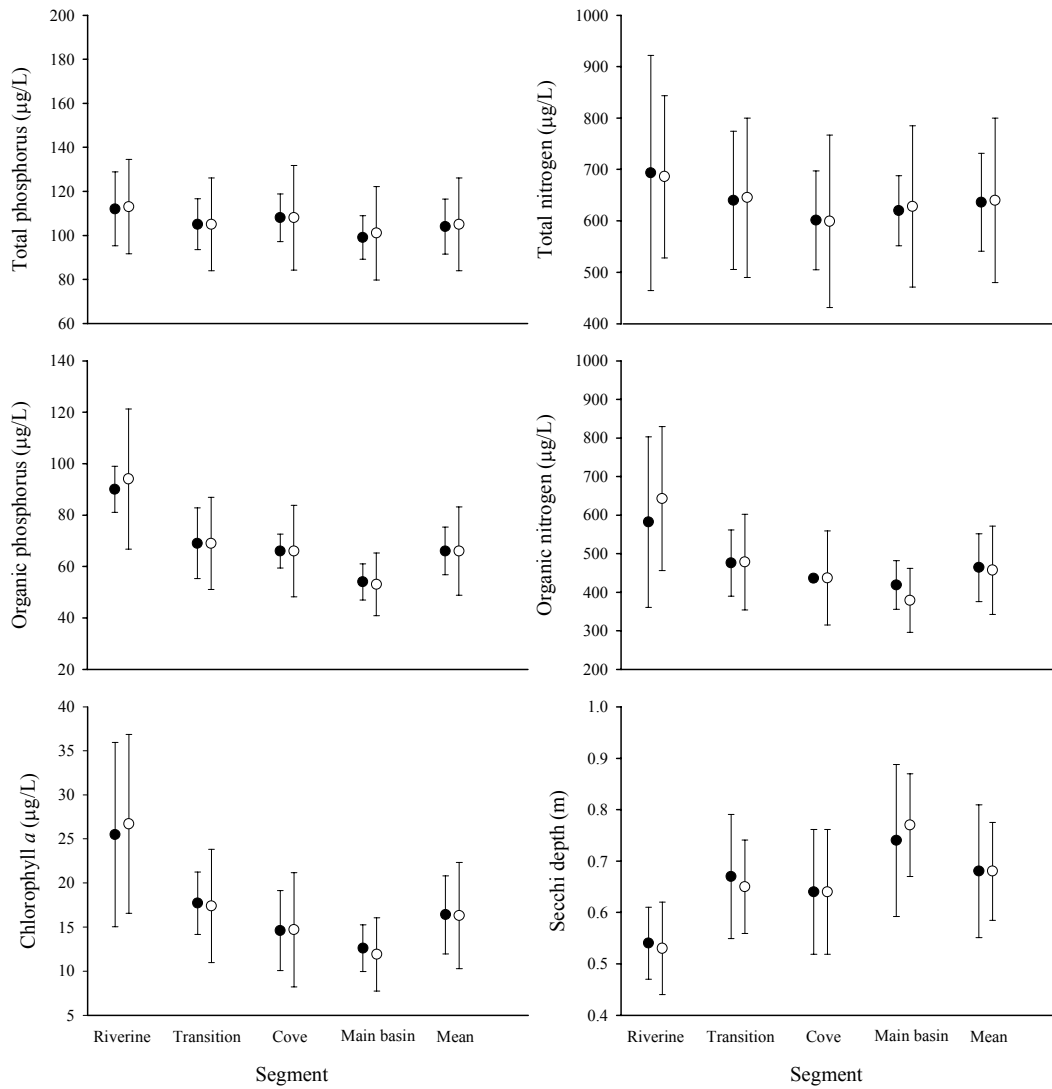


Figure 22. Error plots showing BATHTUB calibration. Data used in the model was from Smith et al (2001). Limnological parameters: observed values (●) and predicted values (○) for Cheney Reservoir. Error bars indicate standard error.

BATHTUB estimated the average depth and hydraulic residence time were 4.90 m and 2.56 yr, respectively, with an overflow rate of 1.93 m/yr. Based on these estimates, there were 344,155 kg of TN and 63,789 kg of TP entering, and 68,768 kg of TN and 11,092

kg of TP existing the reservoir annually, assuming nutrient values exported to be the same as the main basin nutrient concentrations. Approximately, 80% of TN (288,604 kg/yr) and 83% of TP (54,829 kg/yr) were retained during the water year 2000 (Table 8). The predicted area-weighted average concentrations of TN, TP, chlorophyll *a*, secchi, organic N, and organic P were 0.64 mg/L, 105 µg/L, 16 µg/L, 0.68 m, 0.46 mg/L, and 66 µg/L, respectively. Using an algal (chlorophyll *a*) nuisance threshold of 10 µg/L, Cheney Reservoir's water quality was impacted by nuisance levels of algae for 69% of days in the growing season.

Table 8. Estimated nutrient loads for Cheney Reservoir during the water year 2000.

Source	TN		TP	
	kg/yr	%	kg/yr	%
<u>Input</u>				
Atmospheric deposition	34021.3	10	1749.2	3
Internal load	7122.4	2	3276.3	5
Runoff at Station 07144780	120293.0	35	34993.4	55
Baseflow at Station 07144780	99763.5	29	4961.9	7
Red Rock Creek	24074.6	7	5458.3	8
Ungaged (near-lake) area	58880.1	17	13349.5	21
<i>Total</i>	344154.9	100	63788.6	100
<u>Output</u>				
Release from Dam	37559.2	55	6058.0	55
Water Withdrawal from Wichita	31208.3	45	5033.7	45
<i>Total</i>	68767.5	100	11091.7	100

3.4. Coupling of Watershed and Lake Models

The watershed management scenarios were evaluated using BATHTUB and compared with the current conditions. As seen in Table 9, without considering internal nutrient loading in the Mud Creek Cove, converting the entire watershed to native-grass prairies (Scenario 1, Table 7) resulted in substantial reductions in chlorophyll *a* (70%), total N (52%), and total P (48%), and a great improvement in secchi depth (22%).

Table 9. Summary of BATHTUB results for watershed management scenarios.

Management scenario:		1	2	3
Description:	Current	Native	Wheat-milo rotation	CRP to cropland
TN, mg/L	0.64	0.31	0.61	0.67
TP, $\mu\text{g/L}$	105	54	91	114
Chlorophyll <i>a</i> , $\mu\text{g/L}$	16	5	15	17
Secchi depth, m	0.68	0.83	0.69	0.67
Organic N, mg/L	0.46	0.26	0.44	0.47
Organic P, $\mu\text{g/L}$	66	39	63	68
Frequency of algal nuisance, %	69	7	64	71

The area-weighted trophic conditions for the watershed with the native-grass prairies were 0.31 mg/L, 54 $\mu\text{g/L}$, 5 $\mu\text{g/L}$, and 0.83 m for TN, TP, chlorophyll *a*, and secchi depth, respectively. With this watershed management, the frequency of algal nuisance occurrence showed a reduction from 69% to 7% of the growing season.

With wheat-milo rotation (Scenario 2, Table 7) there was a 7% decrease in chlorophyll *a* accompanied by a 5% reduction in TN concentrations, and a 13% reduction in TP concentrations. In addition, area-weighted secchi disc reading increased from 0.68 m to 0.69 m and the frequency of algal nuisance occurrence decreased from 69% to 64%.

Converting the 91,778 acres of all good pasture and CRP to cropland (Scenario 3, Table 7) resulted in a 6% increase in chlorophyll *a* concentration from 16 to 17 $\mu\text{g/L}$ along with a 4% increase in TN concentrations from 0.64 to 0.67 mg/L, 9% increase in TP concentrations from 105 to 114 $\mu\text{g/L}$, and a 1% decrease in secchi disc reading from 0.68 to 0.67 m. This demonstrates the positive impacts that CRP has had on nutrient load reductions in the receiving waters and lends support to the furthering of this program.

3.5. Taste and Odor

Cheney Reservoir is a eutrophic and N-limited lake. Frequently a massive build up of cyanobacterial biomass (often referred to as blue-green algae) has occurred, resulting in offensive tastes and odors of drinking water. To control taste and odor problems, Smith et al (2001) suggested that total P and chlorophyll *a* need to be maintained at concentrations below 110 $\mu\text{g/L}$ and 11 $\mu\text{g/L}$, respectively, in all parts of the reservoir. Though the wheat-milo rotation could improve water quality (Table 9), this management alone may not be sufficient to reduce taste and odor problems resulting from the presence of elevated chlorophyll *a* concentrations. Concentrations of chlorophyll *a* in Scenario 2 ranged from 24 $\mu\text{g/L}$ in the riverine to 11 $\mu\text{g/L}$ in the main basin.

The results of BATHTUB suggest that to reduce chlorophyll *a* concentrations below the target level for all parts of Cheney Reservoir, watershed TN and TP loads need be reduced by approximately 70% from the current loading (Figure 23). However, this practice may not be the best possible approach because it maintains the low nutrient condition (TN:TP = 6.3) favorable for cyanobacterial growth. Reducing the TP load alone shows only a slight reduction in chlorophyll *a* concentrations. However, this P management strategy may create the lake conditions that would not be conducive for cyanobacteria. For example, if P load is reduced by 70%, TN:TP ratio increases to 10.7 (from) 6.1 at the current condition, which is not as conducive to cyanobacterial growth and the associated taste and odor problems.

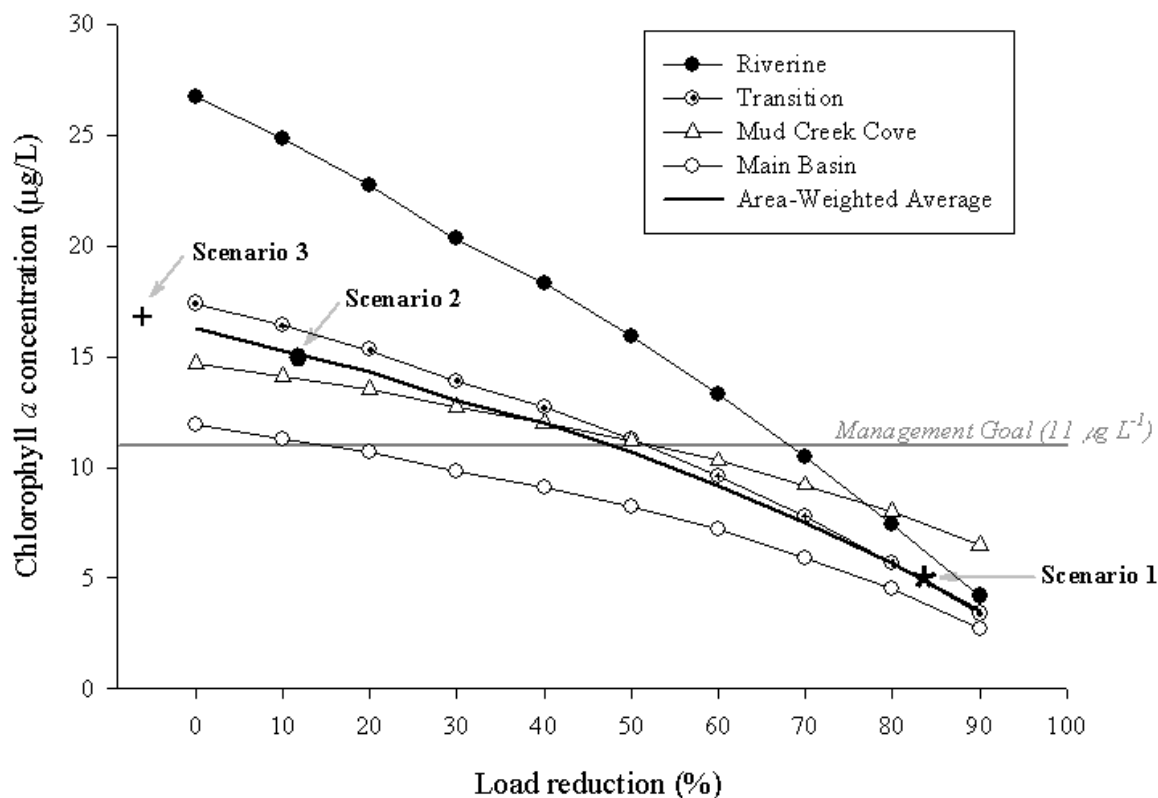


Figure 23. Effects of scaled reduction in inflow nutrient loading on chlorophyll *a* concentrations in Cheney Reservoir for current, scenario, and targeted conditions.

3.6. Sedimentation

Sediment deposition or siltation in reservoirs is a major concern for aquatic resource managers because it not only reduces the availability of water storage space over time (Thornton, 1990), but it also contributes to decreased water quality as a result of increased nutrients and turbidity, decreased lake depth, and other morphological changes that accelerate lake aging and eutrophication (e.g., deNoyelles et al., 1999). Cheney Reservoir, which was constructed between 1962 and 1965 by the Bureau of Reclamation, has a

designed 100-year sediment storage capacity of 15,300 acre-ft. The recent sediment study conducted by the U.S. Geological Survey indicated that the sediment had filled 27% of the capacity, which is less than the originally designed rate (Mau, 2001). At the current rate, the 100-year sediment storage capacity would be filled by 2090.

The effect of sedimentation on water quality of Cheney Reservoir was modeled by reducing reservoir depth. As can be seen in Figure 24, the area-weighted average chlorophyll *a* concentration increased as the reservoir became shallower. A 19% increase in the chlorophyll *a* concentration from the current condition was noted as the sediment capacity was filled up in year 2090. As expected, other accompanying conditions were elevated TN (6%), TP (6%), organic N (12%) and P (11%), and algal nuisance (13%) as well as reduced secchi disc reading (4%).

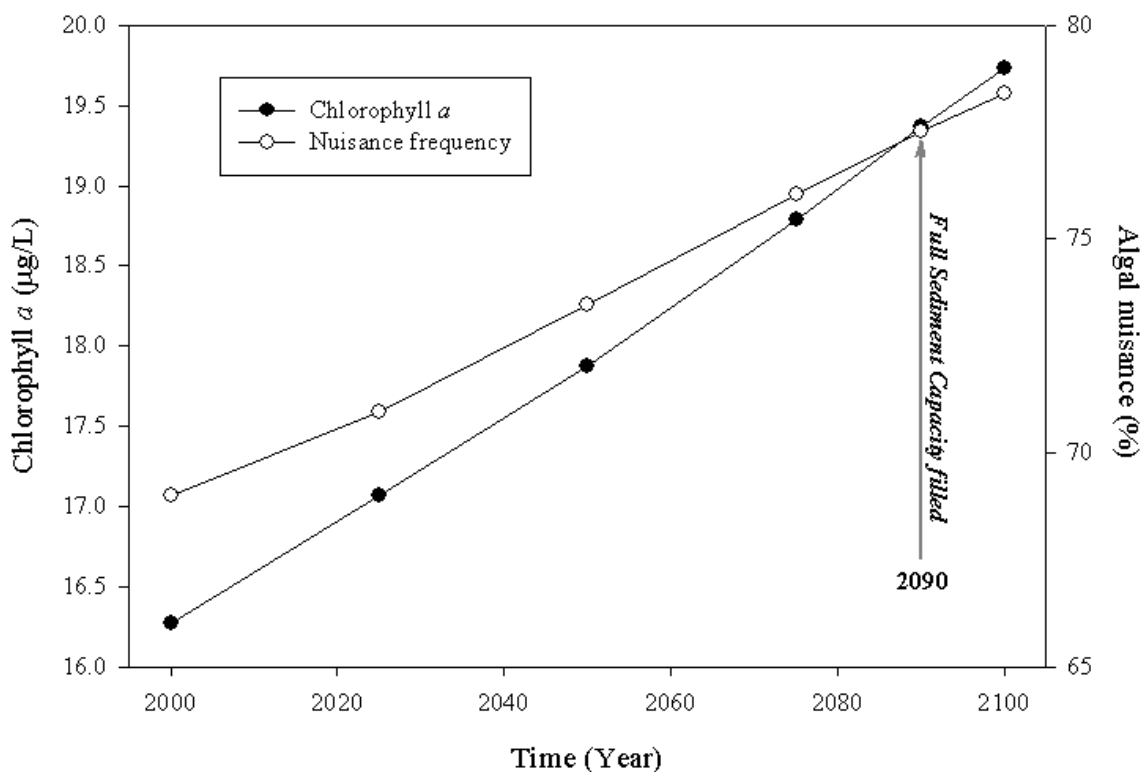


Figure 24. Effect of sedimentation on chlorophyll *a* and algal nuisance frequency for current conditions.

Though lake dredging may increase water storage and enhance water quality conditions, currently it is not warranted because of a slow sedimentation rate. In addition, dredging activities and storage of dredged material could potentially be very disruptive to the aquatic ecosystem and the surrounding terrestrial environment.

4. CONCLUSION

Cheney Reservoir currently experiences eutrophication and siltation problems and is named on the state's 303(d) list. Previous studies have shown that nonpoint sources closely associated with increasing agricultural activities in the watershed are the major contributor to the degraded water quality. The calibrated AnnAGNPS shows that at the presettlement or historic watershed condition Cheney Reservoir would have better water quality conditions, with chlorophyll *a*, secchi disc reading, and algal nuisance being 5 µg/L, 0.83 m, and 7%, respectively. Total N and TP concentrations would be approximately 50% lower than those at the current conditions.

The eutrophication model (BATHTUB) suggests that chlorophyll *a* levels would decrease in the future as nutrient loads, particularly N, decrease. To slow the eutrophication processes, nutrient loads need to be controlled. The model indicates that at the present deposition rate sedimentation will adversely affect water quality. There is a need for the project partners, watershed stakeholders, and resource management agencies to work together to develop a creative, proactive, and voluntary water quality management strategy that meshes with modeling tools to address watershed, riparian, and stream management.

Cheney Reservoir is likely a N-limited lake in nature (TN:TP = 5.7 at the presettlement condition) in which cyanobacterial growth and could lead to taste and odor problems. However, these problems can be managed through an ecological approach as suggested by Smith et al (2001): To shift the phytoplankton community from cyanobacteria to other desirable species (e.g., green algae) that are edible to *Daphnia* and/or other aquatic organisms, P concentrations need to be reduced more than N concentrations to create a lake condition that is not suitable for cyanobacteria. To monitor this biomanagement method, an ecological model needs to be introduced to carefully evaluate natural interactions between nutrients and phytoplankton, zooplankton, and fish communities if supplemental funding is available.

REFERENCES

- Bosch, D.D., R.L. Bingner, F.G. Theurer, G. Felton, and I. Chaubey, 1998. Evaluation of the AnnAGNPS water quality model. ASAE Paper No. 98-2195, St Joseph, Michigan, 12 pp.
- Burkart, M.R. and D.E. James, 2002. Geographic distribution of excess agricultural nitrogen in the Gulf of Mexico. USDA-ARS, National Soil Tilth Laboratory. Ames, Iowa. Internet accessed – August 20, 2002 at URL <http://www.nstl.gov/pubs/burkart/nia/hypoxia3.htm>
- Carpenter, S.R., N.F. Caraco, D.L. Correll, R.W. Howarth, A.N. Sharpley, and V.H. Smith, 1998. Non-point pollution of surface waters with phosphorus and nitrogen. *Ecological Applications* 8: 559-568.
- Christensen, V.G. and L.M. Pope, 2001. Occurrence of dissolved solids, nutrients, atrazine, and fecal coliform bacteria during low flow in the Cheney Reservoir Watershed, south-central Kansas, 1996. U.S. Geological Survey, Water-Resources Investigations Report 97-4153. Lawrence, KS. 13 pp.
- Conservation Technology Information Center, 2002. Community Award Winner: Cheney Watershed. Internet accessed – August 20, 2002 at URL <http://www.ctic.purdue.edu/KYW/newsreleases/wswinnercheney.html>
- Cole, R.W. and E.M. Buchak. 1995. CE-QUAL-W2: A two dimensional, laterally averaged, hydrodynamic and water quality model. Version 2.0. Instruction Report EL-95-1. U.S. Army Engineer Waterways Experiment Station. Vicksburg, MS.
- Cronshey, R.G. and F.G. Theurer, 1998. AnnAGNPS-Non Point Pollutant Loading Model. *In*: Proceedings of the First Federal Interagency Hydrologic Modeling Conference. 19-23 April 1998, Las Vegas, NV.
- deNoyelles, F., S.H. Wang, J.O. Meyer, D.G. Huggins, J.T. Lennon, W.S. Kolln, and S.J. Randtke, 1999. Water quality issues in reservoirs: some considerations from a study of a large reservoir in Kansas. 49th Annual Conference of Environmental Engineering. Department of Civil and Environmental Engineering and Division of Continuing Education, The University of Kansas. Lawrence, KS.
- Ernst, M.R., W. Frossard, and J.L. Mancini. 1994. Two eutrophication models make the grade. *Water Environment and Technology*, November, p. 15-16.
- Frees, L., C. Volkman, X.Y. Zhan, G. Misgna, M.S. Tsou, S. Wang, and D.G. Huggins, 2002. Integrative watershed management assessment based on an AnnAGNPS, GIS and database management system linkage. 19th Annual Water and the Future of Kansas Conference. 5 March 2002. Holiday Inn, Lawrence, Kansas.

- Geter, F. and F. G. Theurer, 1998. AnnAGNPS-RUSLE sheet and rill erosion. *In*: Proceedings of the First Federal Interagency Hydrologic Modeling Conference. 19-23 April 1998, Las Vegas, NV.
- Iowa State University, 2002. Nutrient management: crop rotation. Continuing education and communication services, Iowa State University. Water Resources and Water Quality Publications: NMEP5. 4 pp.
- Johnson, G.L., C.Daly, G.H. Taylor and C.L. Hanson, 2000. Spatial variability and interpolation of stochastic weather simulation model parameters. *J. Appl. Meteor.*, 39, 778-796.
- Kansas Department of Health and Environment (KDHE), 1999. Lake and reservoir monitoring program report. Division of Environment, Bureau of Environmental Field Services, KDHE. Topeka, KS. 60 pp.
- Kansas Department of Health and Environment, 2002. Lower Arkansas River total maximum load: Cheney Lake. Bureau of Water, KDHE. Topeka, KS. 7 pp.
- Koelliker, J.K. and S.J. Bhuyan, 2000. Evaluation of AGNPS modeling in Cheney Lake NPS management. Department of Biological and Agricultural Engineering, Kansas State University. Manhattan, KS. 99 pp.
- Linsley, R.K., M.A. Kohler and J.H. Paulhus, 1983. Hydrology for engineers. 3rd Edition. McGraw-Hill, Inc., New York, NY.
- Mankin, K.R. and P.K. Kalita, 2000. Horseshoe Creek watershed water quality assessment – Final report. KDHE Contract No. NPS 97–149. Bureau of Water, KDHE. Topeka, KS.
- Mankin, K.R. and J.K. Koelliker, 2001. Clinton Lake water quality assessment project – Final report. KDHE Contract No. NPS 98–059. Bureau of Water, KDHE. Topeka, KS.
- Mau, D.P., 2001. Sediment deposition and trends and transport of phosphorus and other chemical constituents, Cheney Reservoir watershed, south-central Kansas. U.S. Geological Survey, Water-Resources Investigations Report 01–4085. Lawrence, KS. 40 pp.
- Milligan, C.R. and L.M. Pope, 2001. Occurrence of phosphorus, nitrate, and suspended solids in streams of the Cheney Reservoir Watershed, south-central Kansas, 1997–2000. U.S. Geological Survey, Water-Resources Investigations Report 01–4199. Lawrence, KS. 18 pp.

- O'Brien, W.J., 1975. Factor limiting primary productivity in turbid Kansas reservoir. Project Completion Report No. 156. Kansas Water Resources Research Institute, University of Kansas. Lawrence, KS.
- Pettyjohn, W.A. and R.J. Henning, 1979. Preliminary estimate of regional effective groundwater recharge rates in Ohio. Water Resources Center, Ohio State University. Project Completion Report 52. 323 pp.
- Pope, L.M., 1998. Watershed trend analysis and water-quality assessment using bottom-sediment cores from Cheney Reservoir, south-central Kansas, 1997–1998. U.S. Geological Survey, Water-Resources Investigations Report 98–4227. Lawrence, KS. 24 pp.
- Pope, L.M. and C.R. Milligan, 2000. Preliminary assessment of phosphorus transport in the Cheney Reservoir Watershed, south-central Kansas, 1997–1998. U.S. Geological Survey, Water-Resources Investigations Report 00–4023. Lawrence, KS. 29 pp.
- Puckett, L.J., 1994. Nonpoint and point sources of nitrogen in major watersheds of the United States. U.S. Geological Survey, Water-Resources Investigations Report 94–4001. 9 pp.
- Randtke, S.J. and F. deNoyelles, 1985. A critical assessment of the management practices on water quality, water treatment, and sport fishing in multipurpose reservoir in Kansas. Project Completion Report 252. Kansas Water Resources Research Institute, University of Kansas. Lawrence KS. 171 pp.
- Renard, K.G., G.R. Foster, G.A. Weesies, D.K. McCool, and D.C. Yoder, 1997. Predicting soil erosion by water: A Guide to conservation planning with the Revised Universal Soil Loss Equation (RUSLE). U.S. Department of Agriculture. Agriculture Handbook No 703.
- Scribner, E.A., D.A. Goolsby, E.E. Thurman, M.T. Meyer and W.A. Battaglin. 1996. Concentrations of selected herbicides, herbicide metabolites and nutrients in outflow from selected midwestern reservoirs, April 1992 through September 1993. U.S. Geological Survey Open-File Report 96–393. Lawrence, KS. 128 pp.
- Smith, V.H., 1982. The nitrogen and phosphorus dependence of algal biomass in lakes: An empirical and theoretical analysis. *Limnology and Oceanography* 27:1101-1112.
- Smith, V.H., 1998. Cultural eutrophication of inland, estuarine, and coastal waters. *In*: M.L. Pace and P.M. Groffman (eds.) *Limitation and frontiers in ecosystem science*. Springer-Verlag, New York, NY. p. 7-49.
- Smith, V.H. and S. J. Bennett, 1999. Nitrogen:phosphorus supply ratios and phytoplankton community structure in lakes. *Archiv fur Hydrobiologie* 146:37-53

- Smith, V.H., F. deNoyelles, D.W. Graham, and S.J. Randtke, 2001. A comparative water quality study of Cheney Reservoir, Kansas. Department of Ecology and Evolutionary Biology, University of Kansas. Lawrence, KS.
- Sloto, R.A. and M.Y. Crouse, 1996. HYSEP – a computer program for streamflow hydrograph separation and analysis: U.S. Geological Survey Water-Resources Investigations Report 96–4040. 46 pp.
- Theurer, F. G. and C.D. Clarke, 1991. Wash load component for sediment yield modeling. *In*: Proceedings of the Fifth Federal Interagency Sedimentation Conference. 18-21 March 1991, Las Vegas, Nevada. p 7-1 to 7-8.
- Theurer, F. G. and R. G. Cronshey, 1998. AnnAGNPS-reach routing processes. *In*: Proceedings of the First Federal Interagency Hydrologic Modeling Conference. 19-23 April 1998, Las Vegas, NV.
- Thiessen, A.H., 1911. Precipitation for large areas. Monthly weather review 39:1082-1084. July 1911.
- Tsou, M.S., X.Y. Zhan, G. Misgna, S.H. Wang, D.G. Huggins, S. Liu, and C. Volkman, 2001. Modeling procedures for using AnnAGNPS ArcView extension. Kansas Geological Survey Open-File Report 01–57. Lawrence, KS. 27 pp.
- U.S. Environmental Protection Agency, 2000. National Water Quality Inventory: 1998 Report to Congress. EPA–841–R–00–001. Office of Water. Washington, D.C.
- Walker, W.W.Jr., 1985. Empirical methods for predicting eutrophication in impoundments; Report 3, Phase II: Model refinements, Technical Report E–81–9, U.S. Army Engineer Waterways Experiment Station, Vicksburg, MS.
- Walker, W.W.Jr., 1996. Simplified procedures for eutrophication assessment and prediction: user manual. Instructional Report W–96–2 (updated April 1999), U.S. Army Engineer Waterways Experiment Station, Vicksburg, MS.
- Yuan, Y., R. L. Bingner and R. A. Rebich, 2001. Evaluation of AnnAGNPS on Mississippi Delta MSEA Watersheds. Transaction of ASAE (in press).