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T. S. Soerens
University of Arkansas, Fayetteville

M. A. Nelson
University of Arkansas, Fayetteville

Arkansas Water Resources Center

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Final Report to:
Arkansas Soil and Water Conservation Commission

Principal Investigators

T.S. Soerens
Department of Civil Engineering
University of Arkansas
Fayetteville, Arkansas 72701

M.A. Nelson
Arkansas Water Resources Center
University of Arkansas
Fayetteville, Arkansas 72701

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Arkansas Water Resources Center
112 Ozark Hall
University of Arkansas
Fayetteville, Arkansas 72701

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T.S. Soerens
Department of Civil Engineering
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T.S. Soerens
Department of Civil Engineering
University of Arkansas
Fayetteville, Arkansas

M.A. Nelson
Arkansas Water Resources Center
University of Arkansas
Fayetteville, Arkansas

ABSTRACT

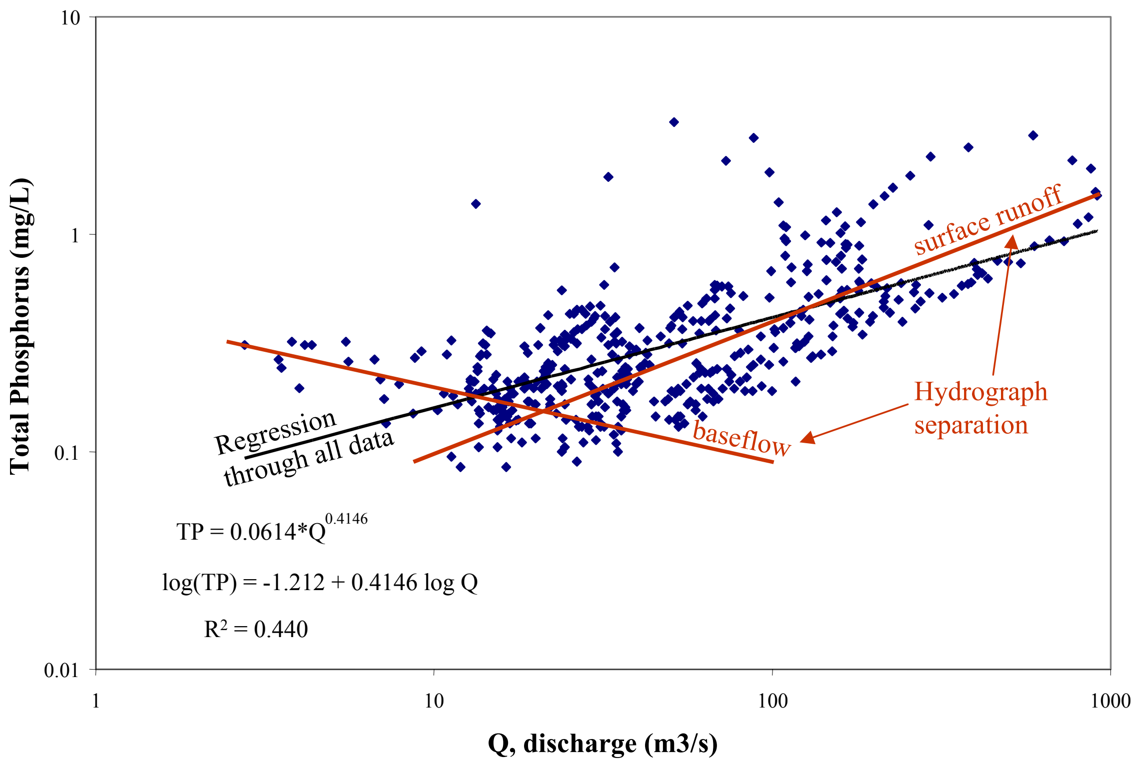
This study investigated the precision and accuracy of the two load calculation techniques. The study compared total phosphorus loads calculated by integration of Arkansas Water Resources Center (AWRC) intensive sampling data to loads calculated by a regression technique (rating curve) using fewer data. The 1998 AWRC dataset from the Illinois River at Arkansas Highway 59 was sub-sampled in a manner to simulate fixed period monitoring schemes supplemented with storm sampling. The ESTIMATOR software program was used to calculate loads. These loads were compared to the integrated load. The error of the integrated load when the variation in concentration between samples is not linear and the sensitivity of the integrated load to sampling interval were also investigated. The results show that the central tendency of the ESTIMATOR loads is accurate when storm data are included, but that the 95% confidence interval represents up to +/- 30-40% difference from the integrated load for individual estimates. More frequent sampling and more samples lead to more accurate loads. The results indicate that the central tendency of load estimates would be accurate for a method that uses a regression model with 32 or more samples including storm samples.

INTRODUCTION

Different water quality monitoring strategies have been applied to estimate the total mass transport, or load, of specific constituents past a fixed point on a stream. The most accurate approach includes recording continuous streamflow and frequently collecting water-quality samples, particularly during storm events. Loads are estimated by multiplying the concentration values by the streamflow volumes for a given time period. Concentrations for time periods that were not sampled can be estimated by the integration method or by the rating curve (regression) method. Using the integration method, constituent concentrations are plotted through time, and missing concentrations are filled in by interpolating between measured concentrations. Integration is generally considered the most accurate method to estimate loading if "sufficient" data are collected to describe the changes in water quality. Sufficient data often means that many samples must be collected during storm events to reflect the variability in water quality. Loads calculated by the integration method are often used as a reference to evaluate results from other methods.

The regression method (Cohn, 1995) uses the relation between concentration (or load) and daily average flow to estimate daily concentrations (or loads) of the constituent. The daily loads can then be summed to calculate an annual load. The regression model can also include time and seasonal coefficients. Hydrograph separation techniques can be used to produce different regressions for base flow and surface runoff conditions (Green and Haggard, 2001). Recently, some investigators have used in-stream dissolved oxygen and turbidity meters to provide “real-time water-quality monitoring” data that can be included in the regression (Christensen et al., 2000). Figure 1 shows an example of a regression of total phosphorus concentration on discharge. The regression equation shown is the regression through all the data. Also shown are possible trend lines for baseflow and surface runoff if hydrograph separation were employed.

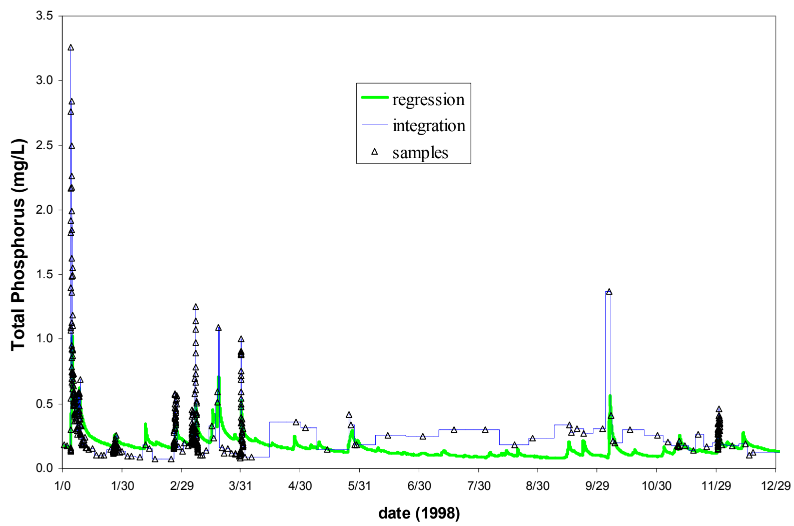
Figure 1. Regression of total phosphorus versus discharge for Illinois River at Hwy 59 1998 data.



The regression approach has come into widespread use because it requires less data than integration, it can be used to produce estimates for periods beyond when concentration data were collected, and it enables confidence limits to be placed on the estimates as a measure of the modeling error. The regression method is often used with very small datasets that have been assembled over several years.

Figure 2 shows an example of the concentrations used in a regression model compared to the concentrations used for integration. The regressions in Figures 1 and 2 are illustrative examples using the AWRC data from the study period, but do not represent the actual results from the ESTIMATOR software. The results using sub-sampling of the data and ESTIMATOR are presented in the Results section.

Figure 2. Integration and regression concentrations.



In 1998, AWRC collected and analyzed approximately 400 water samples from the Illinois River at the Arkansas Highway 59 bridge using an automatic sampler (Figure 3). Grab samples were taken at two-week intervals and discrete storm samples were taken at thirty minute or sixty-minute intervals during storm events (events where the river stage was above five feet for at least twelve hours). These samples were used to calculate an annual load for TSS, T-P, TKN and NO3 by mass accumulation. Concentrations were assigned for time periods when no samples were taken by applying concentrations from an actual sample to the time period from half way to the previous sample to half way to the next sample. Thus, the AWRC data set has discharge and concentration values every thirty minutes for the entire year. This method is the same as the “trapezoid method” of integration, which assumes a linear variation between points.

The U.S. Geological Survey (USGS) monitors stream flow at the same Illinois River site and has collected samples every other month and during selected high-flow events for the period November 1996 through August 1999. The USGS collects water-quality samples sites manually using depth- and width-integrating techniques periodically during baseflow and during six to nine targeted storm (surface runoff) events per year. The data are used to develop a regression between concentration and discharge. When sufficient data are available, the regression may also include time and seasonal coefficients. Figure 3 shows the daily discharge and the sampling times for 1998-1999.

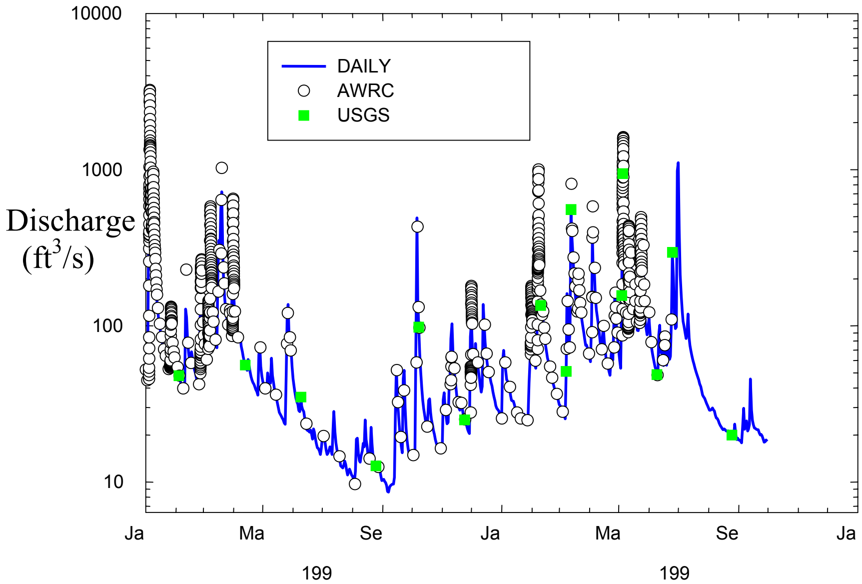


Figure 3. Daily discharge and sampling times at Illinois River at Hwy 59 during study period.

OBJECTIVES

The objective of this study was to investigate the precision and accuracy of the two load calculation techniques. The 1998 AWRC dataset from the Illinois River at Arkansas Highway 59 was sub-sampled in a manner to simulate fixed interval monitoring schemes supplemented with storm samples. The USGS ESTIMATOR regression model was used to calculate loads. These loads were compared to the integrated load to determine:

1. The precision and accuracy of the loads calculated with the regression model using a fixed interval monitoring scheme supplemented with storm samples.

2. The sampling frequency (or protocol) necessary to achieve a desired level of precision and accuracy.

The sensitivity of the integrated load to sampling interval was also investigated.

RESULTS

<u>Regression Method - Simulations</u>

The 1997, 1998, and 1999 Illinois River data were sampled to simulate fixed interval monitoring schemes supplemented with storm samples and annual loads were calculated with the ESTIMATOR software. The sampling intervals simulated were 15, 30, 45, and 60 days. Twenty simulations were performed in each case. The cases were:

- 9 random storm samples from upper 50% of flow. The 15 day sampling interval required 32 samples (N = 23 base flow samples + 9 storm samples = 32). Similarly, for 30 days (N = 28), 45 days (N = 23), and 60 days (N = 19).
- 9 samples from the upper 50% flow. Regression on Q only (1998 only), removing the seasonal or time component.
- 9 random storm samples.
- No storm samples - 15 and 30 day only

The results of the simulations are tabulated in Tables 1 through 6. Tables 1-3 report the median, maximum, and minimum of the 20 load simulations. Tables 3-6 report the percent relative difference between the simulations and the integrated load. The relative difference equals (simulated load – integrated load)/(integrated load).

Table 1. 1997 Load Simulations

1997	AWRC Integrated load = 127,000 kg									
ESTIMATOR loads (kg):										
	15 day upper 50%	15 day 9 storm	15 day no storm	30 day upper 50%	30 day 9 storm	30 day no storm	45 day upper 50%	45 day 9 storm	60 day upper 50%	60 day 9 storm
median	144477	121404	108698	147710	130188	99878	172729	172729	156957	156957
max	198023	153660	166510	228397	229151	162550	244169	249732	310438	348282
min	107029	97403	82832	95104	74215	59033	95350	95350	89611	89611

Table 2. 1998 Load Simulations

1998	AWRC Integrated load = 232,000 kg													
ESTIMATOR loads (kg):														
	15 day upper 50%	15day Q only	15 day 9 storm	15 day no storm	30 day upper 50%	30 day Q only	30 day 9 storm	30 day no storm	45 day upper 50%	45 Q only	45 9 storm	60 day upper 50%	60 day Q only	60 day 9 storm
median	235043	216500	201222	208123	246014	237500	212139	226804	256594	236500	258488.82	272828.9	260000	268579.26
max	271250	251000	239136	258896	306517	289000	292916	298472	343827	324000	343827.37	423848.37	345000	481302.43
min	190297	178000	169378	157056	213754	196000	161523	175009	217921	195000	217921.39	207508.05	204000	207508.05

Table 3. 1999 Load Simulations.

1999	AWRC Integrated load = 270,000 kg									
ESTIMATOR loads (kg):										
	15 day upper 50%	15 day 9 storm	15 day no storm	30 day upper 50%	30 day 9 storm	30 day no storm	45 day upper 50%	45 day 9 storm	60 day upper 50%	60 day 9 storm
median	289487	262400	216567	246014	300822	180660	256594	294184	272829	338416
max	393090	352102	285450	306517	375310	490670	343827	411131	423848	475107
min	220782	191781	163412	213754	184042	105323	217921	203634	207508	211253

Table 4. 1997 Relative difference between load simulations and integrated load.

1997										
relative difference from integrated load = (load - integrated load)/(integrated load)										
	15 day upper 50%	15 day 9 storm	15 day no storm	30 day upper 50%	30 day 9 storm	30 day no storm	45 day upper 50%	45 day 9 storm	60 day upper 50%	60 day 9 storm
median	14%	-4%	-14%	16%	3%	-21%	36%	36%	24%	24%
max	56%	21%	31%	80%	80%	28%	92%	97%	144%	174%
min	-16%	-23%	-35%	-25%	-42%	-54%	-25%	-25%	-29%	-29%

Table 5. 1998 Relative difference between load simulations and integrated load.

1998														
relative difference from integrated load = (load - integrated load)/(integrated load)														
	15 day upper 50%	15day Q only	15 day 9 storm	15 day no storm	30 day upper 50%	30 day Q only	30 day 9 storm	30 day no storm	45 day upper 50%	45 Q only	45 9 storm	60 day upper 50%	60 day Q only	60 day 9 storm
median	1%	-7%	-13%	-10%	6%	2%	-9%	-2%	11%	2%	11%	18%	12%	16%
max	17%	8%	3%	12%	32%	25%	26%	29%	48%	40%	48%	83%	49%	107%
min	-18%	-23%	-27%	-32%	-8%	-16%	-30%	-25%	-6%	-16%	-6%	-11%	-12%	-11%

Table 6. 1998 Relative difference between load simulations and integrated load.

1999										
relative difference from integrated load = (load - integrated load)/(integrated load)										
	15 day upper 50%	15 day 9 storm	15 day no storm	30 day upper 50%	30 day 9 storm	30 day no storm	45 day upper 50%	45 day 9 storm	60 day upper 50%	60 day 9 storm
median	7%	-3%	-20%	-9%	11%	-33%	-5%	9%	1%	25%
max	46%	30%	6%	14%	39%	82%	27%	52%	57%	76%
min	-18%	-29%	-39%	-21%	-32%	-61%	-19%	-25%	-23%	-22%

Figures 4 through 6 show box plots of the simulated loads. The box represents the 25^{th} to 75^{th} percentiles with the median being the line in the middle and whiskers extending to the 10^{th} and 90^{th} percentiles. Also shown on the plots are the USGS estimated load for that year along with the upper and lower 95% confidence limits for that estimation as well as the integrated load calculated by AWRC.

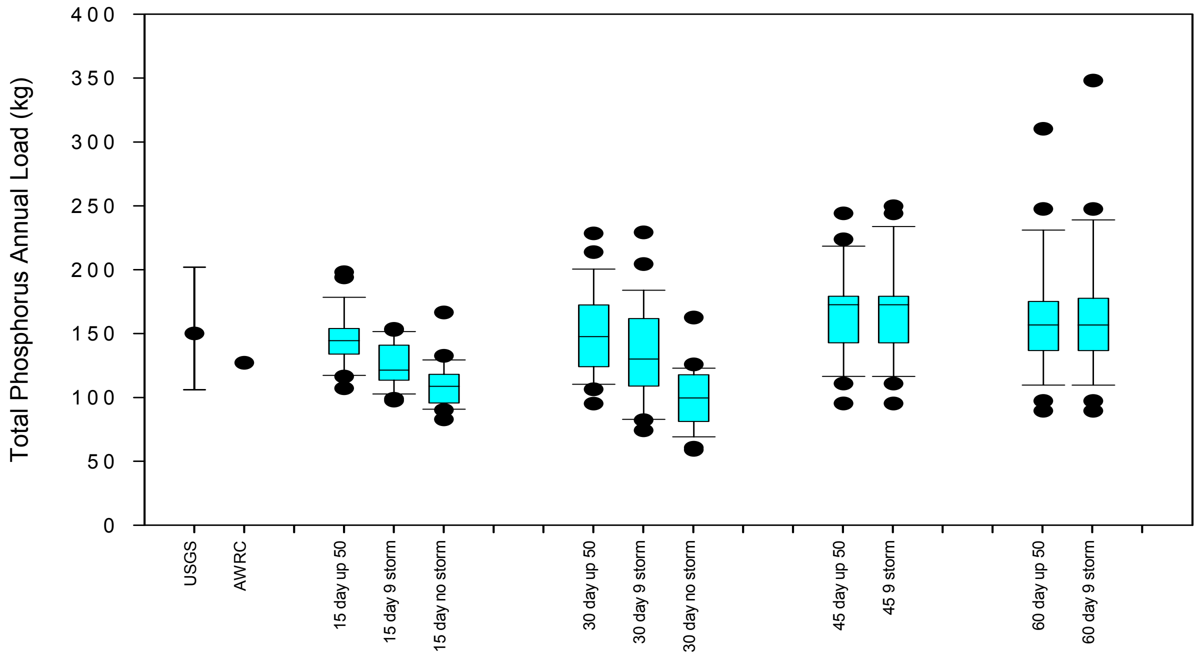


Figure 4. 1997 Load simulation results

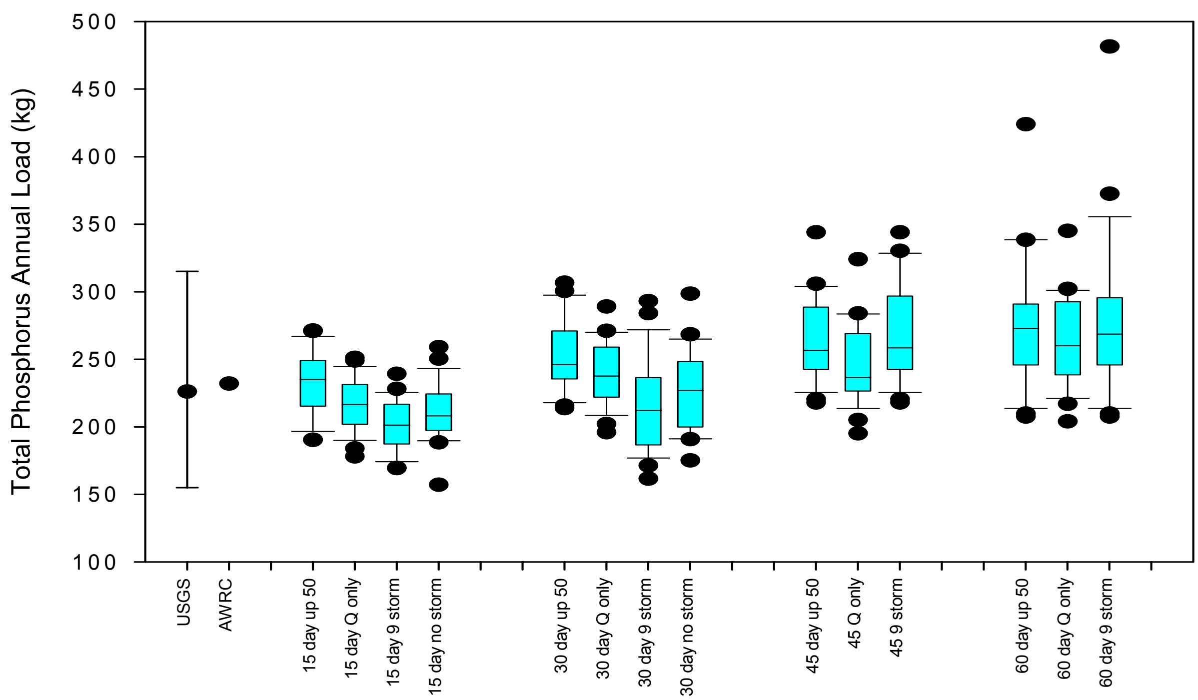


Figure 5. 1998 Load simulation results

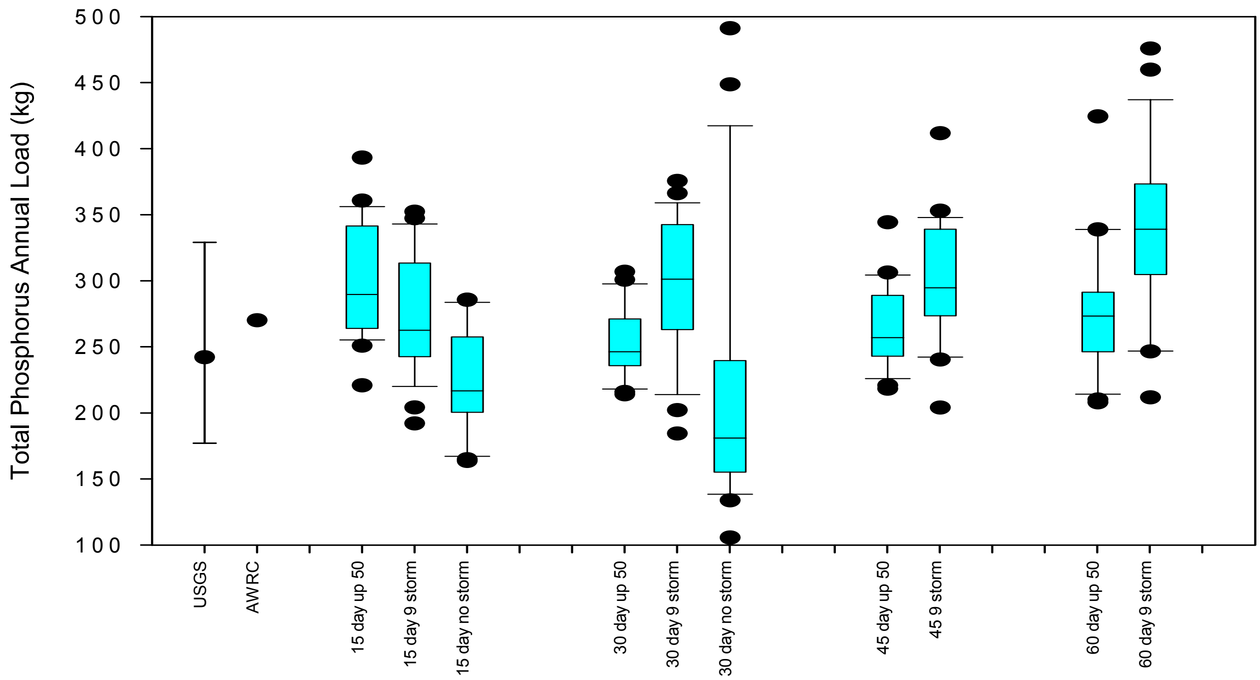


Figure 6. 1999 Load simulation results.

Sensitivity of Integration Method

The sensitivity of integrated load to sampling interval was investigated by comparing loads calculated using every other sample, every third, every fourth, etc… to the load calculated using all the data. Figure 7 shows that more sparse data lead to less precision and an underestimate of the load. We have shown this effect before (Soerens et al., 2000).

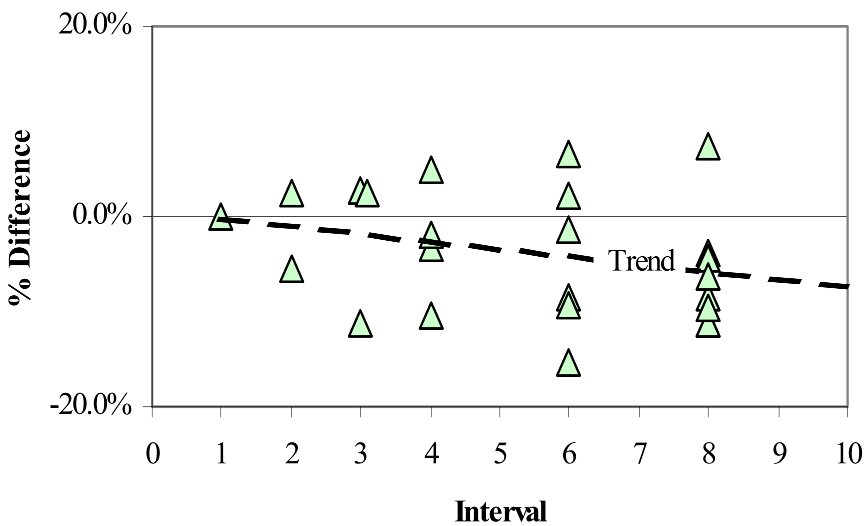


Figure 7. Sensitivity of integrated load to sampling interval.

DISCUSSION AND CONCLUSIONS

A total of 34 cases of 20 load calculation simulations each were summarized in this report. The results show that in 24 of the 28 cases incorporating targeted storm sampling, the median difference between the simulated loads and the load integrated from all the data was less than 20%. In 8 of the 28 storm sampling cases, the median difference was within 5% of the integrated load. 12 of the 28 storm sampling cases had at least one load that differed from the integrated load by 50% or more, and three cases had loads over 100% different from the integrated load. In general, more samples led to increased precision. The loads calculated for 1998, the year with the most samples in the whole data set, were the most precise.

This study elucidated some of the variations in load calculation techniques. The two load calculation methods examined have different strengths and weaknesses. The optimum method would make the most efficient use of resources to gather and utilize the most information in order to make the most accurate load estimate possible.

REFERENCES

Christensen, V.G., Jian, X., and Ziegler, A.C., 2000, Regression Analysis and Real-Time Water –Quality Monitoring to Estimate Constituent Concentrations, Loads, and Yields in the Little Arkansas River, South-Central Kansas, 1995-1999, U.S. Geological Survey, Water-Resources Investigations Report 00-4126.

Cohn, T., L.L. DeLong, E.J. Gilroy, R.M. Hirsch, and D.K. Wells, 1989, "Estimating Constituent Loads," *Water Resources Research*, 25(5), pp. 937-942.

Green, W.R., and Haggard, B.E., Phosphorus and Nitrogen Concentrations and Loads at Illinois River South of Siloam Springs, Arkansas, 1997-1999. U.S. Geological Water-Resources Investigations Report 01-4217, 12 pp, 2001.

Soerens, T.S., Nelson, M.A., and Spooner, J., 2000, Investigation of Optimum Sample Number and Timing for Determining Pollution Loads, Project Report, Arkansas Water Resources Center.