Evaluation of a Method for Comparing Phosphorus Loads from Barnyards and Croplands in Otter Creek Watershed, Wisconsin

Introduction

Control of phosphorus from rural nonpoint sources is a major focus of current efforts to improve and protect water resources in Wisconsin and is recommended in almost every priority watershed plan prepared for the State's Nonpoint Source (NPS) Program. Barnyards and croplands usually are identified as the primary rural sources of phosphorus. Numerous questions have arisen about which of these two sources to control and about the method currently being used by the NPS program to compare phosphorus loads from barnyards and croplands. To evaluate the method, the U.S. Geological Survey (USGS), in cooperation with the Wisconsin Department of Natural Resources, used phosphorus-load and sediment-load data from streams and phosphorus concentrations in soils from the Otter Creek Watershed (located in the Sheboygan River Basin; fig. 1) in conjunction with two computer-based models. This fact sheet describes:

- how stream data were used to simulate phosphorus loads in barnyard and cropland runoff,
- how measured concentrations of soil phosphorus were used to modify estimates of the cropland phosphorus loads,
- how the results of the model simulations and the soil phosphorus analysis affect the relative amount of phosphorus estimated to come from barnyards and croplands, and
- how the relative proportion of phosphorus estimated to come from barnyards increases as the number of barnyards in a watershed increases.

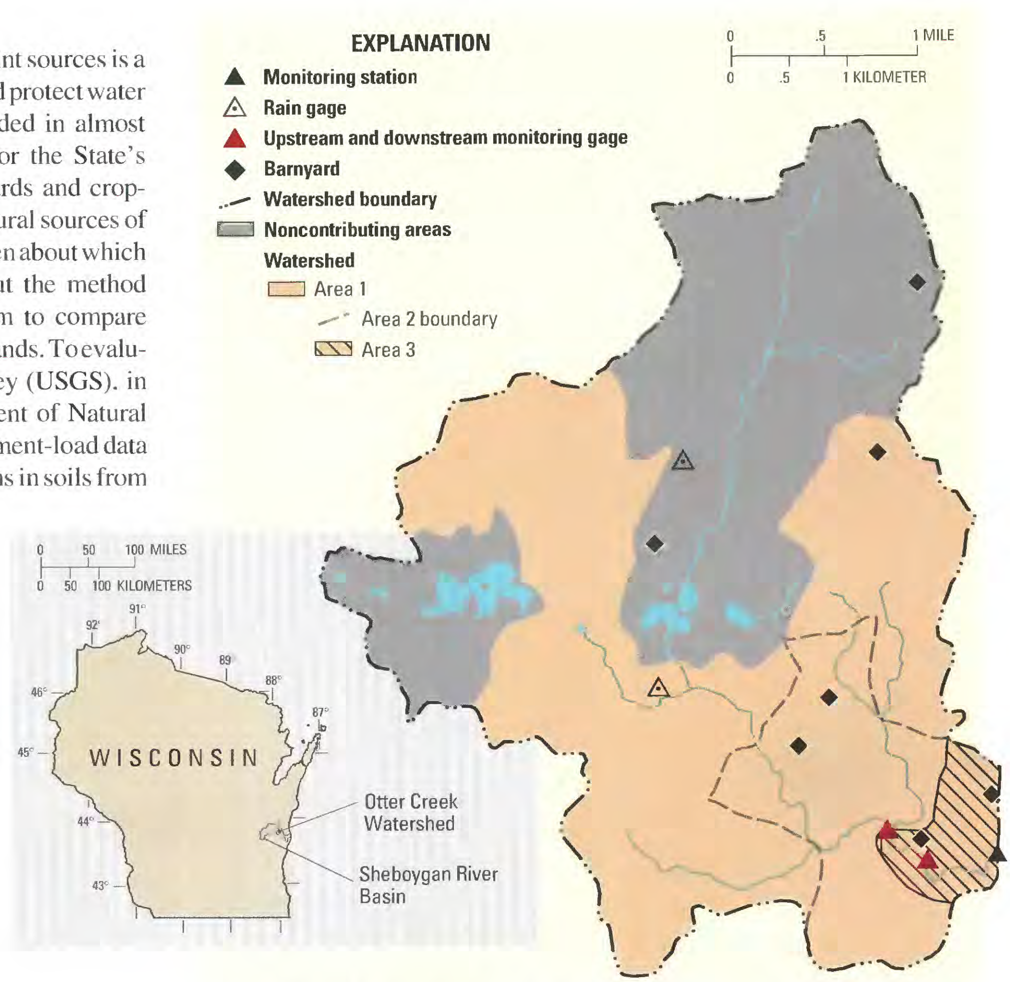

Figure 1. Otter Creek Watershed study areas.

Method for Comparing Phosphorus Loads From Barnyards and Croplands

Two computer models are used by NPS to compare phosphorus loads from barnyards and croplands. The BARNY model (Wisconsin Department of Natural Resources, 1994a) is used to estimate loads of phosphorus and chemical oxygen demand in stormwater runoff from individual barnyards. The WINHUSLE model (Wisconsin Department of Natural Resources, 1994b) is used to estimate average annual loads of sediment (eroded soil) delivered to the nearest channel from individual farm fields. WINHUSLE does not, however, directly estimate the phosphorus loads from individual fields; sediment loads from individual farm fields estimated from WINHUSLE must be multiplied by a phosphorus enrichment factor (pounds of phosphorus per ton of sediment). The enrichment factor used by the NPS program is usually based on annual phosphorus and sediment loads measured at outlets of watersheds from several locations around Wisconsin. Median values for this watershed-outlet phosphorus enrichment factor have been about 4 and 8 lb/ton (pounds per ton) for streams in the southwestern and southeastern parts of Wisconsin, respectively (Corsi and others, 1998). Because monitoring data are not available for most watersheds, enrichment factors for unmonitored watersheds are based on data from monitored watersheds.

Testing the BARNY and WINHUSLE Models

An important part of evaluating the method used for comparing phosphorus loads from barnyards and croplands is to test the accuracy of the individual models used in the method. Although the accuracy of a model is improved if the model is first tested with site-specific data, it is not practical to collect phosphorus-load and stream-sediment data in every watershed. Water-quality data collected in the Otter Creek Watershed (fig. 1) were used to evaluate the models.

BARNY

Data on phosphorus loads from a barnyard in the Otter Creek Watershed were used to test the BARNY model. Otter Creek was monitored before pollution-control structures were installed at the barnyard (Stuntebeck, 1995). Water samples were collected and flow was measured just upstream and downstream from the barnyard for 11 runoff events (periods of runoff associated with storms) in 1995. Phosphorus load in runoff from the barnyard was determined by subtracting the upstream load from the downstream load. BARNY underestimated the phosphorus loads for most of the individual runoff events, and the total simulated load for the 11 storms was about one-half of the monitored load (fig. 2).

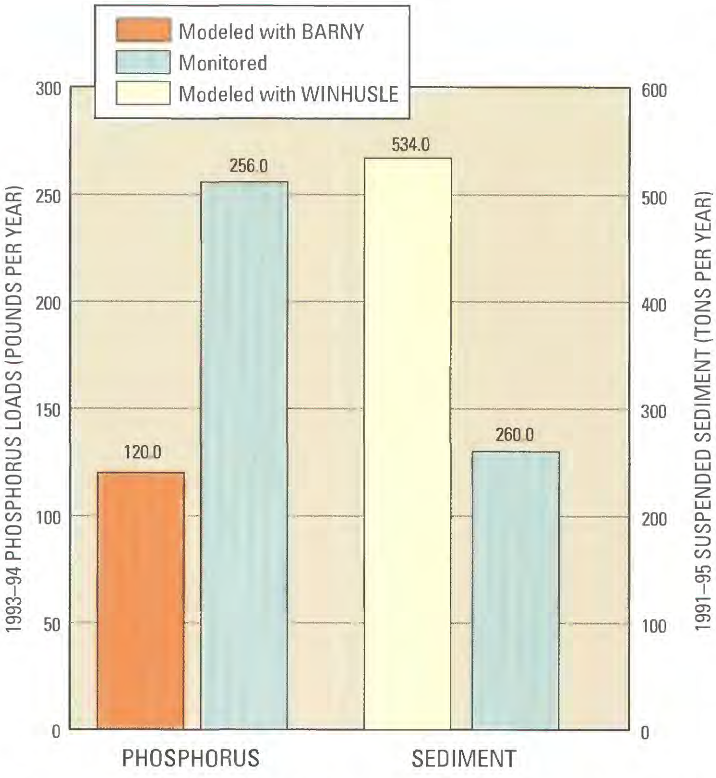

Figure 2. Monitored and modeled phosphorus and sediment loads from croplands and barnyards for selected storms in Otter Creek.

Average annual phosphorus loads estimated by BARNY for individual barnyards were particularly sensitive to the dimensions of the yard, the size of the area draining to the barnyard, and the distance of the barnyard to the stream. For example, the total simulated load was six times lower than the monitored load before the size of the yard was increased to include a cow path area between the yard and the stream.

Phosphorus loads estimated with BARNY were about one-half the monitored value.

Barnyard at Otter Creek before pollution-control structures were installed.

WINHUSLE

Sediment loads for runoff events measured for 5 years (1991 to 1995) at the mouth of Otter Creek were used to evaluate the WINHUSLE model (Owens and others, 1996). Water samples were collected during most of the significant runoff events during this period along with routine bimonthly base-flow monitoring. Monitoring was done before most upland pollution practices were implemented. However, WINHUSLE was only applied to the farm fields in one of Otter Creek's subwatersheds, because two of the three subwatersheds in Otter Creek are non-contributing. These non-contributing subwatersheds drain into lakes that are considered effective sinks for sediment loads (fig. 1). All the Otter Creek rainfall values that were greater than 0.1 inch were used to run the model. The data inputs into the WINHUSLE model were stored in and derived from a detailed geographic information system land-use data base. This data base was used to determine the acreage of the fields and soil types, the overall watershed acreage, and the length and elevation of the channels. Also, a large number of the farm fields were inventoried to verify the values used in the model to calculate soil loss. Croplands were approximately 60 percent of the total land use/land cover, soils were predominantly Kewaunee silt-loams, and average field slopes were 5 to 6 percent (Rappold and others, 1997).

Average annual sediment loads estimated by WINHUSLE were compared with those measured at the mouth of Otter Creek between 1991 and 1995. WINHUSLE was found to overpredict sediment loads by a factor of about 2.

Sediment loads estimated with WINHUSLE were about double the monitored value.

Farm field before implementation of pollution-control practices in Otter Creek Watershed.

Cropland Phosphorus Loads

As mentioned previously, the method for estimating cropland phosphorus loads depends on using a phosphorus enrichment factor. A watershed-outlet phosphorus enrichment factor might not represent the phosphorus concentration in the soils delivered to the edge of a channel. Selective transport of different-size soil particles could result in a phosphorus concentration in the vicinity of farmed fields that is different from that at the mouth of a stream. In addition, phosphorus loads at the mouth of Otter Creek could reflect the effects of other phosphorus sources, such as barnyards.

Site-specific soils data from Otter Creek were used to determine a soils-concentration enrichment factor. Soil samples were collected from five fields that could contribute runoff to the stream. The samples were divided into sand, silt, and clay particle-size fractions. Each fraction was then analyzed for phosphorus content following the method of Dong and others (1979). The average soil concentrations for phosphorus for the sand-, silt-, and clay-size fractions were 142, 835, and 1,850 μg/g (micrograms of phosphorus per gram of soil), respectively. The total concentration of phosphorus in the soil was 737 μg/g, which is equivalent to 1.5 pounds of phosphorus per ton of soil. The total soil phosphorus concentration was then adjusted for the deposition of the sand-sized particles before they reached the edge of the channels. Particle-size analysis of the soil in the water samples collected from Otter Creek showed the sand content of the soil was reduced from 42 to 8 percent by the time the soil reached the channel. By decreasing the sand-size fraction to 8 percent, the particle size distributions were shifted to higher proportions of clay and silt in the soil. The soils phosphorus concentration representing this new particle-size distribution was 1,074 μg/g, or 2.1 lb/ton.

Application of the Model Tests Results and Soil Phosphorus Concentrations to Three Otter Creek Study Areas

Results from testing the models and the determination of phosphorus enrichment factors in Otter Creek indicates that the application of these results would significantly change previous estimates of how much phosphorus is coming from barnyards and croplands. To adjust the modeled load estimates for Otter Creek, the phosphorus load from BARNY should be doubled and the sediment load from WINHUSLE should be reduced by one-half. Assuming that the soil-concentration phosphorus enrichment factor produces a more accurate estimate of cropland phosphorus load than the watershed-outlet enrichment factor, the sediment loading value for Otter Creek would have to be multiplied by 2.1 lb/ton instead of 9.5 lb/ton. The magnitude of these adjustments will probably vary between watersheds, depending on the soil phosphorus concentrations and on the particle-size distributions of the farm-field sediment.

> This soil-concentration enrichment factor is about one-fifth of the watershed-outlet enrichment factor of 9.5 lb/ton for Otter Creek.

Corrections applied to the model outputs and the phosphorus enrichment factor increased the relative importance of the barnyards as phosphorus sources in three study areas (fig. 3). Study area 1 is the Otter Creek watershed used to evaluate the model (fig. 1). The other two study areas are nested within study area 1, and have a lower farm-field to barnyard ratio (that is, a higher density of barnyards) (table 1). Ratios of the number of farm fields to barnyards range from 32:1 to 10:1. This ratio includes only the fields and barnyards classified as high priority for management (Category I and II management sources eligible for funding or technical assistance; Wierl and others, 1996). Percentages of each land-use/land-cover category and soil types and slopes are similar for all the study areas. The correction increased the relative importance of the barnyards as phosphorus sources in the three study areas (fig. 3). In study area 1, for example, the barnyard loads increased from 2 percent of the total load to 24 percent of the total load when the barnyard and cropland corrections were applied. In terms of relative proportion of the total phosphorus load, barnyards go from being a negligible or small source of phosphorus (before the application of the corrections) to a significant source in all three study areas.

Table 1. Ratio of fields to barnyards and percentage of loads from barnyards for three study areas in Otter Creek Watershed

Study area	Number of Category I and II fields (acres)	Number of barnyards	Ratio of fields to barnyards	Percentage of phosphorus from barnyard before corrections	Percentage of phosphorus from barnyard after corrections
1	161 (1,395)	5	32:1	2	24
2	83 (794)	4	21:1	4	41
3	20 (149)	2	10:1	15	76

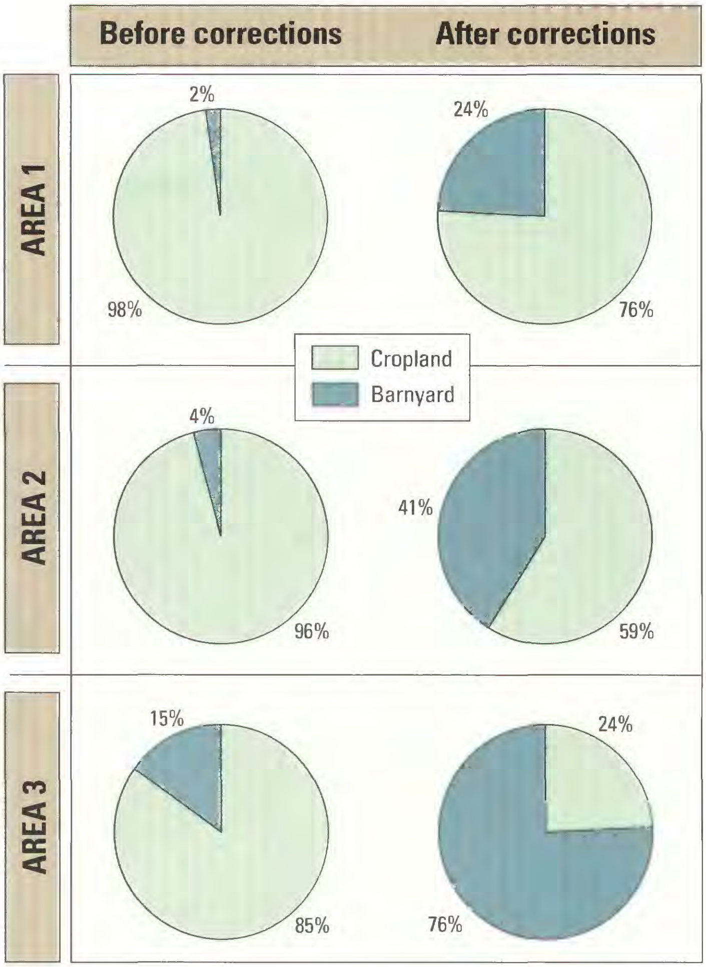

Figure 3. Changes in proportion of cropland and barnyard contributions to watershed phosphorus loads using uncorrected and corrected phosphorus loads for three areas in the Otter Creek Watershed.

Changes in Phosphorus Loads With Increases in the Number of Barnyards in a Watershed

If phosphorus loads are computed with corrections to both the model loading values and phosphorus enrichment factors, the percentage of the phosphorus coming from barnyards increases by a factor of 3 from study area 1 to study area 3 (table 1). Controlling phosphorus in barnyard runoff appears to be as important as reducing phosphorus in cropland runoff where the ratio of farm fields to barnyards is about 20:1 or less. The ratios of fields to barnyards in watersheds around the State commonly fall in the range of the ratios of study areas 2 and 3. For example, the ratio for Eagle Creek in Buffalo County is about 10:1, and for Bower Creek in Brown County is about 15:1 (Wierl and others, 1996). Reducing barnyard phosphorus loads in watersheds with field-to-barnyard ratios of about 30:1 or higher, such as Otter Creek, does not appear to be as important as reducing cropland phosphorus loads.

Implications of Access to Site-Specific Data

Site-specific water-quality monitoring and soil phosphorus concentration data could improve the accuracy of estimating barnyard and cropland runoff. The computed relative loads of phosphorus from barnyards increased significantly when site-specific data were used for Otter Creek. This effect would be magnified in watersheds with small ratios of fields to barnyards. The differences in determining phosphorus loads with and without site-specific data were large enough to change the conclusion about which of the phosphorus sources was more important. Methods for estimating barnyard and cropland phosphorus loads could be improved by:

- verifying the accuracy of BARNY inputs, such as size of the barnyard, size of the areas draining to the barnyard, and the distance between the barnyard and the stream,
- calibrating WINHUSLE on existing monitored data or collecting new data in regional areas where gaps are apparent, and
- creating State regional site-specific soil-concentration phosphorus enrichment factors by occasionally processing (using the method of Dong and others, 1979) farm-field soil samples for the NPS priority watershed program.

References Cited

Corsi, S.R., Graczyk, D.J., Owens, D.W., and Bannerman, R.T., 1998, Unit-area loads of suspended sediment, suspended solids and total phosphorus from small watersheds in Wisconsin: U.S. Geological Survey Fact Sheet FS-195-97, 4 p.

Dong, Allen, Chesters, Gordon, and Simsiman, G.V., 1979, Dispersibility of soils and elemental composition of soils, sediments, and dust and dirt from the Menomonee River Watershed: U.S. Environmental Protection Agency Report EPA-905/4-79-029-F, 56 p.

Owens, D.W., Corsi, S.R., and Rappold, K.F., 1996, Evaluation of nonpoint contamination, Wisconsin; selected topics for water year 1995: U.S. Geological Survey Open-File Report 96-661A, 41 p.

Rappold, K.F., Wierl, J.A., and Amerson, F.U., 1997, Watershed characteristics and land management in the nonpoint-source evaluation monitoring watersheds in Wisconsin: U.S. Geological Survey Open-File Report 97-119, 39 p.

Stuntebeck, T.D., 1995, Evaluating barnyard best management practices in Wisconsin using upstream-downstream monitoring: U.S. Geological Survey Fact Sheet FS-221-95, 4 p.

Wierl, J.A., Rappold, K.F., and Amerson, F.U., 1996, Summary of the land-use inventory for the nonpoint-source evaluation monitoring watershed in Wisconsin: U.S. Geological Survey Open-File Report 96-123, 23 p.

Wisconsin Department of Natural Resources, 1994a, BARNY 2.2—The Wisconsin barnyard runoff model, inventory instructions and user's manual: Report WR-285-91, 35 p.

Wisconsin Department of Natural Resources, 1994b, WINHUSLE—Model documentation and user's manual, version 1.4.4: Report WR-294-91 [variously paged].

Information

For more information, please contact:
District Chief
U.S. Geological Survey
8505 Research Way
Middleton, WI 53562
(608) 828-9901
www: http://wi.water.usgs.gov/

Authors: Judy A. Wierl, and Elise M.P. Giddings, U.S. Geological Survey, Water Resources Division;
and Roger T. Bannerman, Wisconsin Department of Natural Resources

Layout and illustrations: Michelle Greenwood
Banner graphic: Karen Lonsdorf