Minnesota Phosphorus Source Assessment Tool

Based on the CWP Watershed Treatment Model

User Guide

and

Documentation

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What is the Phosphorus Source Assessment Tool?

The Minnesota Phosphorus Source Assessment Tool (PSAT) is an Excel-based tool used at the watershed scale to identify the relative contribution of sources of P to a lake or stream. It is a modification of the Watershed Treatment Model. (See www.cwp.org for more information about the WTM).

The PSAT has two main applications: education and initial watershed assessments or screenings.

Education. PSAT identifies and illustrates the relative contribution of most P sources. This helps watershed planners explain the sources of phosphorus and how the sources are affected by changes in land use and land management. Teachers can use PSAT to increase awareness of watershed issues and discuss the application of models to environmental planning.

Initial assessment. PSAT does not require specialized software or training, so it is suitable for an initial screening to identify phosphorus sources in a watershed. Results from PSAT will help clarify which additional models or data collection are needed to adequately understand a watershed to support decision making and planning.

How PSAT relates to other tools. Estimating sources of phosphorus is an inexact science. The PSAT is meant to be one of several pieces of evidence used to understand phosphorus movement in a watershed.

Benefits and limitations. The advantages of PSAT are that it addresses a comprehensive list of P sources and does not require specialized software or training. The major disadvantages are that it only provides relative P amounts, not actual P loads, and the simplified calculations may provide misleading results if not interpreted correctly. The main barrier to use is the need for land use data, but such data will be needed for any analysis of phosphorus sources.

Where can PSAT be used?

PSAT is suitable for assessing lakesheds or river watersheds.

Watershed size. PSAT is intended for small to medium-sized watersheds. Loading factors for rural areas are based on data from watersheds less than 200 sq miles, so the PSAT should not be applied to larger watersheds. In urban watersheds (more than 30% urban development), the maximum watershed size should be limited to 20 square miles. This is because the urban runoff estimate is based on the Simple Method, which was originally designed for development lots less than 1 mile square.

TMDL studies. The PSAT may be more useful during for the implementation stage than for setting TMDLs. Despite the conservative assumptions in the PSAT, it may be necessary to assign an explicit margin of safety when a specific target needs to be met. The PSAT is not a calibrated model, so relative change in P loading should be used rather than the absolute loading values. The PSAT generates annual loads, so it cannot account for critical conditions that occur during the year.

How to use PSAT

1. Gather inputs. Gather the inputs needed to run the model. Information about each input is available below, and a list of all necessary inputs is in the data collection sheet available on the web site (http://www.mnpi.umn.edu/psat.htm). Sources of input data are described starting on page 12. The quality of results depends on the quality of inputs. Document all the assumptions and uncertainties related to the inputs.

2. Enter data for multiple scenarios. After you gather your input data, enter it into the Excel spreadsheet. Your inputs will include some uncertainties and the assumptions made by the tool have some uncertainty. Show the impact of uncertainty by running the tool a few times using different input assumptions.

3. Use PSAT to generate questions. Compare results from scenarios that represent the high and low possible input values. This will help you identify other models or data needed to improve understanding of the watershed. For example, results from multiple scenarios might show that you need to gather information about the condition of septic tanks or run a more detailed model of the effect of agricultural practices.

4. Use PSAT to educate. Graphs from the model can be used to explain P sources to stakeholders.

A Tour of the Excel File

Color of cells

Green cells need to be completed by the user
Blue cells have default or calculated values but may be substituted
Grey cells should not be changed
Purple Cells Reflect "Bottom Line" Loads or Load Reductions

Worksheets

The Excel file consists of several worksheets. You can switch among the worksheets by clicking on the tabs at the bottom of the window. You sill mainly focus on the green tabs: Primary Sources, Secondary Sources, and Results. Here is a description of each of the worksheets:

	Worksheet name	Purpose
The main load calculation sheets	Primary Sources	Enter land use data.
	Secondary Sources	Enter data about other P sources, such as septic systems, permitted discharges, and feedlots.
	Results	View results of load calculations.
Calculate load reductions from current management practices	Existing Management Practices	Enter data about practices that can reduce loading, such as catch basins or septic system education.
	Discounts – Existing	
	Existing Loads	
Estimate P load changes with changes in land use and management practices.	Future Management Practices	
	Discounts – Future	
	Future Land Use	
	New Development	For data about developments, such as the number of households with septic systems.
	Loads with Future Practices	
	Loads Including Growth	
Information	Data sources	Suggestions for data inputs
	Summary Sheet	
	WTM user guide	User guide that came with the original model on which the PSAT is based.

Entering Data

Input data goes into the green cells. Not all green cells need to be completed – only those that relate to P sources found in your watershed.

The blue cells are default or calculated values that can be left as is, or can be changed to better match local conditions. The default values are typical for central Minnesota, but actual values may vary substantially. The quality of results can be improved by using values that fit local conditions. For example, you may want to change the P loading rates in cells H36-H41 if farming practices in the watershed are higher or lower risk than in average watersheds. For instructions, see “Adjusting agricultural loading factors” on page 14.

Primary Sources Worksheet

Watershed data

Enter average **annual rainfall** for the watershed. (See “Data Sources” worksheet for a rainfall map.)

Watershed area will be summed automatically.

Stream length of all streams within the watershed is only used in the estimate of channel erosion.

Planning horizon is only used in the Future Management Practices worksheet, so most users can leave this blank.

Land use acres

Enter number of acres of each land use within the watershed. If desired, add labels in Column C. If the land use distribution is uncertain, determine a range of possibilities. Then, run the tool for two or more possible land use distributions to learn the range of potential P sources. See page 12 for suggestions for acquiring land use data.

Residential

LDR, MDR, and HDR stands for low-, medium- and high-density residential. The only difference among these is the percentage impervious cover (Column E). You can change these default impervious cover values if you have local data.

If residential lots are larger than 2 acres or less than 10% impervious cover, list them as “rural development” in Row 35.

Impervious cover includes any hard surfaces where rain water cannot infiltrate, i.e., roofs, any paved surfaces, and gravel roadways.

Commercial and Industrial

When deciding whether land should be categorized as commercial or industrial, the main distinction is the percent impervious cover (column E). A distinction between the two categories is not defined in the original WTM documentation (See References on page 21).

Urban Roadways

“Urban roadways” includes the right-of-way.

Rural roads should not be included in “urban roadways” because they are accounted for in the loading factors for agricultural and forest lands.

If your data source separates rural road acres from other rural land cover, you can create a separate rural road category on one of the blank lines. Use a P loading factor of 0.1 to 0.2 (column H), depending how well road runoff is connected to surface water. For example, if a road ditch has water in it for much of the year, then most of the P that reaches the ditch will eventually be carried to surface water, and the loading factor should be 0.2. If little of the runoff is likely to reach surface water, use a loading factor of 0.1. (The two sources of P from roads are atmospheric deposition at 0.2 lbs/ac and road sanding, which is handled under secondary sources.)

Forest, brush, or grassland

Include any land where the soil is generally undisturbed and uncompacted. Infiltration is much higher on these lands than any others.

Gravel pits and other large open mines can be ignored because of their small area. If they constitute a significant proportion of the watershed, the acres should not be included in the total acres in the watershed on the assumption that no runoff is generated from them. If the mines generate runoff, consider including the acreage in “Active construction”.

Rural development

"Rural development" refers to housing on lots that are 2 acres or larger, or less than 10% impervious cover. Farm home sites can be included in this category or as part of agricultural acreage.

Agriculture

If possible, divide agricultural land acreage into row crops with manure applications, row crops without manure applications, and pasture/perennials. If that level of detail is not available, put all agricultural land into the category of "mixed agriculture", or into "dairy" if dairy is the primary ag system in the watershed. "Mixed agriculture" is an average of the factors used for "Row crop ag" and "Pasture, perennial ag". "Dairy" is based on a rotation of 2 years corn with manure applications followed by 3 years alfalfa.

The agricultural loading factors in column H can be adjusted to better reflect practices in the watershed by using the Minnesota Phosphorus Index to assess P loss risk. See "Adjusting agricultural loading factors" on page 14 for instructions.

Open water

Enter the surface area of the lake whose watershed is being studied in the category of "Lake or river of interest". Other lakes and open water wetlands should be included as "Upstream open water". Wetlands without open water can be included in "Forest, brush, or grassland.

The P loading factor for the lake of interest represents atmospheric deposition of P. Of the atmospheric P that lands on upstream water bodies, not all will be transported to the end of the watershed.

Active construction

Estimate the average number of acres at any point in time that is under construction or otherwise exposed to severe sediment losses.

Highly erosive unpaved drives may be included as "Active construction".

Vacant lots

This category is meant for mostly unvegetated urban lots.

Secondary Sources Worksheet

Dwellings or population

The number of dwelling units and the total population are used in calculations of loading from septic and sewer systems. Enter either the number of dwellings or population and the program will calculate the other value based on the number of individuals per dwelling (Cell E3).

If some people are seasonal residents, reduce the number of dwellings or population proportionately.

To account for waste from commercial properties use the following conversions: For motels or other lodging, add 1 dwelling unit for every 4 guests (average daily occupancy). For restaurants, add 1 dwelling unit for every 8 seats. For other types of commercial operations, see the Metropolitan Council Environmental Services (2003).

Soil phosphorus

The surface soil total P is only used in the calculation of P load from active construction. The subsoil total P is only used in the calculation of P load from channel erosion. Use the equation and map on page 12 to estimate the percent total P in surface and subsurface soil.

Septic systems

Enter the proportion of dwellings on septic systems.

Check the default values in E17, G17, and I17 which indicate the proportion of systems that are compliant, failing, or an imminent threat to public health and safety (ITPHS). The defaults are average values for central Minnesota, but your county or watershed could be quite different. ITPHS systems include direct discharge to surface water or to the ground surface. Failing systems are those with obvious leaks or with less than the required vertical separation above the seasonal water table.

SSOs and Illicit Connections

These two sections relate to sewer systems. Use local data as much as possible. Avoid using the default values.

Channel erosion

Choose one of two methods to estimate channel erosion, or enter an estimate from an alternative model into the cell labeled "Bank Erosion Rate (tons/mi/yr):

Method 1 requires that you enter a measurement of the total sediment load going into the lake, or the load leaving the watershed. PSAT will subtract all runoff sediment sources and assume the remainder is from channel erosion.

Method 2 is only appropriate for use in primarily urban watersheds (>10% impervious cover). It assumes that changes in impervious cover cause a predictable enlargement in the stream's cross-sectional area and estimates the amount of annual channel erosion that would be required to reach that enlarged area.

Livestock on open lots

Estimate the number of animals in confined areas exposed to rainfall runoff. Do not include animals kept in covered barns or on pasture. (Pasture should be included as agricultural land in the Primary Sources worksheet.) For "% Exposed to Runoff", estimate the percent of time that the animals are in the confined area exposed to rainfall runoff.

Geese

If large numbers of geese defecate near your lake, you may want to include an estimate of their P contribution. On the other hand, geese generally defecate near what they eat, so goose feces may only represent a change in the form of P and not a net P input to the lake.

Marine toilets and recreation

Use this section to account for human waste dumped directly into the lake, such as from marine toilets that are not properly pumped out or from waste associated with fishing derbies or ice fishing.

The tool provides two methods for estimating this P source. You can use either or both, depending on the activities in your watershed.

For method A, enter the number of people that are on a boat for a full 8-hour day multiplied by the number of days. The calculation assumes all waste for the 8-hour day on the lake ends up in the lake. Proper dumping of waste can be accounted for in the “Existing Management Practices” worksheet in the Marina Pumpouts or Portable Toilets section. Alternatively, the flow rate (Cell E60) can be reduced proportionately.

To estimate the number of people-days for boats with marine toilets, multiply the number of boats by two people/boat by the number of days in the boating season by 50%. This is based on the WTM estimates that boats are occupied up to 50% of the boating season and two people per boat.

Use method B for ice fishing. Enter the number of ice houses or other clusters of fishing holes on the lake multiplied by the number of weeks in the ice fishing season. This calculation is based on a single study at Granite Lake which counted an average of 3.8 urine spots per week around each fishing site. The calculation assumes 0.25 mg (0.00055 lb) P per urine spot.

Road sanding

The road sanding section only needs to be completed if the sand contains phosphorus. A “closed section road” is one with a curb.

Permitted dischargers

Fill in data from NPDES permits for wastewater treatment plants or other permitted dischargers.

If you have measured P loads in the outflow from a water body within the watershed, this can be entered as a point source in this section. In this case, the subwatershed drained by the measured outflow must be removed from the primary land use categories. This could complicate estimates of future loads based on land use changes and management practices. It may be necessary to estimate changes in the subwatershed separately from the remainder of the area.

Existing and Future Management Practices

The “Existing Management Practices” worksheet allows you to estimate P load reductions below the general loads assumed in the “Primary” and “Secondary Sources” worksheets. Most of the practices on this worksheet relate to urbanized or impervious areas.

The “Discounts-Existing” and “Discounts-Future” worksheets show the proportion of P load reductions expected from each practice. “T” in column C indicates the treatability, i.e., the proportion of acres that are treated with a practice or the proportion of a population that can be reached. “D” in columns D to F indicate discount factors or effectiveness factors. These account for the fact that practices do not perform at 100% of their potential. For example, not all people reached by an education program will change their behavior, and not all the P or sediment will be removed by a sediment basin or buffer.

See the documentation for the Watershed Treatment Model (www.cwp.org) for more information about these worksheets.

Viewing Results

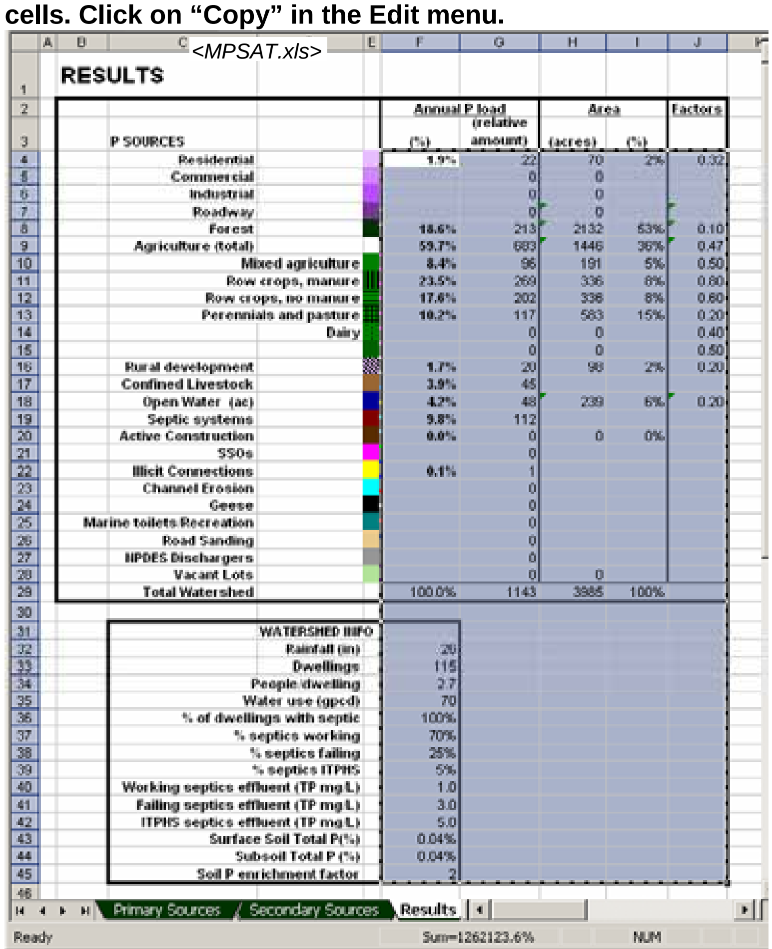
As soon as you fill in data on the Primary and Secondary Sources worksheets, loading calculations will appear on the Results worksheet. Two pie charts will be displayed – one showing the distribution of land use and the other showing the contribution of various sources of P to the end of the watershed. The table of annual P loads deliberately does not indicate the units. The PSAT should only be used to assess relative contributions, not actual P loads.

Because of uncertainty about inputs and default parameters in PSAT, the results pie chart should never stand alone. Ideally it should be displayed with one or more other graphs that illustrate the range of possible values for the watershed.

The MPSAT comparison graph file. To create bar graphs comparing alternative scenarios, use the Excel file <MPSATcomparisongraph.xls> available on the PSAT web site (www.mnpi.umn.edu/psat). To use the file,

1. Open <MPSATcomparisongraph.xls>
2. Go back to the PSAT "Results" worksheet. Copy the data within the dotted lines (Figure 1).
3. Switch to <MPSATcomparisongraph.xls>. Use "Paste special" from the edit menu to paste only the values starting in cell F8 (Figure 2).
4. Repeat steps 2 and 3 for another scenario for the watershed. This time, paste values starting in cell K8. There is room to paste six sets of data.
5. Add chart labels to row 5.
6. View "Comparison Chart" worksheet. (Figure 3)

Figure 1. To graph the results, first select the highlighted cells. Click on "Copy" in the Edit menu.



	P SOURCES	Annual P load (%)	Annual P load (relative amount)	Area (acres)	Area (%)	Factors
4	Residential	1.9%	22	70	2%	0.32
5	Commercial		0	0		
6	Industrial		0	0		
7	Roadway		0	0		
8	Forest	18.6%	213	2132	53%	0.10
9	Agriculture (total)	59.7%	683	1446	36%	0.47
10	Mixed agriculture	8.4%	96	191	5%	0.50
11	Row crops, manure	23.5%	269	336	8%	0.80
12	Row crops, no manure	17.6%	202	336	8%	0.60
13	Perennials and pasture	10.2%	117	583	15%	0.20
14	Dairy		0	0		0.40
15			0	0		0.50
16	Rural development	1.7%	20	98	2%	0.20
17	Confined Livestock	3.9%	45			
18	Open Water (ac)	4.2%	48	239	6%	0.20
19	Septic systems	9.8%	112			
20	Active Construction	0.0%	0	0	0%	
21	SSOs		0			
22	Illicit Connections	0.1%	1			
23	Channel Erosion		0			
24	Geese		0			
25	Marine toilets Recreation		0			
26	Road Sanding		0			
27	NPDES Dischargers		0			
28	Vacant Lots		0	0		
29	Total Watershed	100.0%	1143	3985	100%	

	WATERSHED INFO	
32	Rainfall (in)	20
33	Dwellings	115
34	People/dwelling	2.7
35	Water use (gpcd)	70
36	% of dwellings with septic	100%
37	% septics working	70%
38	% septics failing	25%
39	% septics ITPHS	5%
40	Working septics effluent (TP mg/L)	1.0
41	Failing septics effluent (TP mg/L)	3.0
42	ITPHS septics effluent (TP mg/L)	5.0
43	Surface Soil Total P(%)	0.04%
44	Subsoil Total P (%)	0.04%
45	Soil P enrichment factor	2

Figure 2. Use the “Paste Special” command (Edit menu) to paste just the values into Cell F8 or K8 or P8, etc.

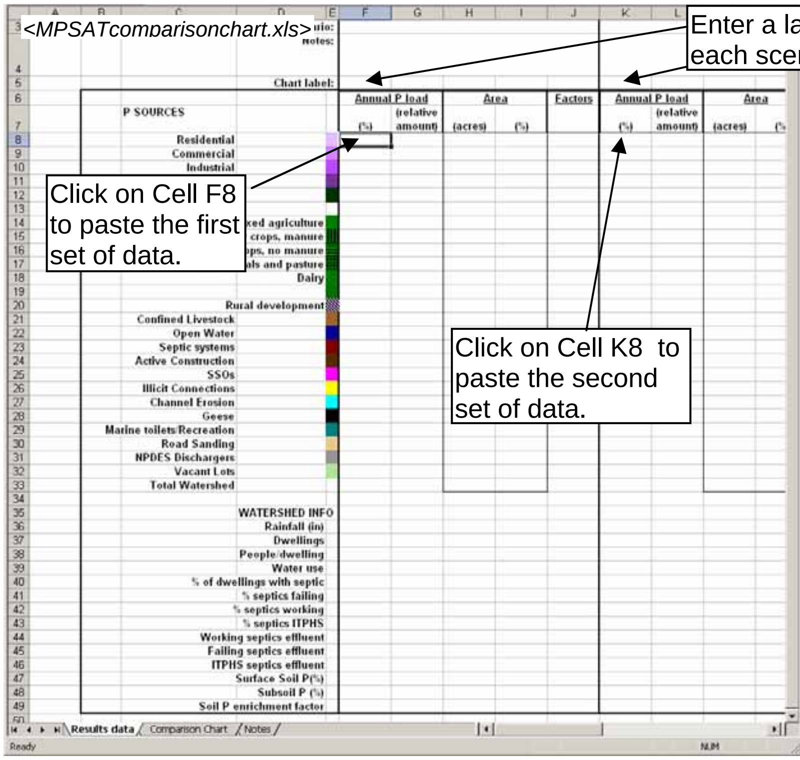
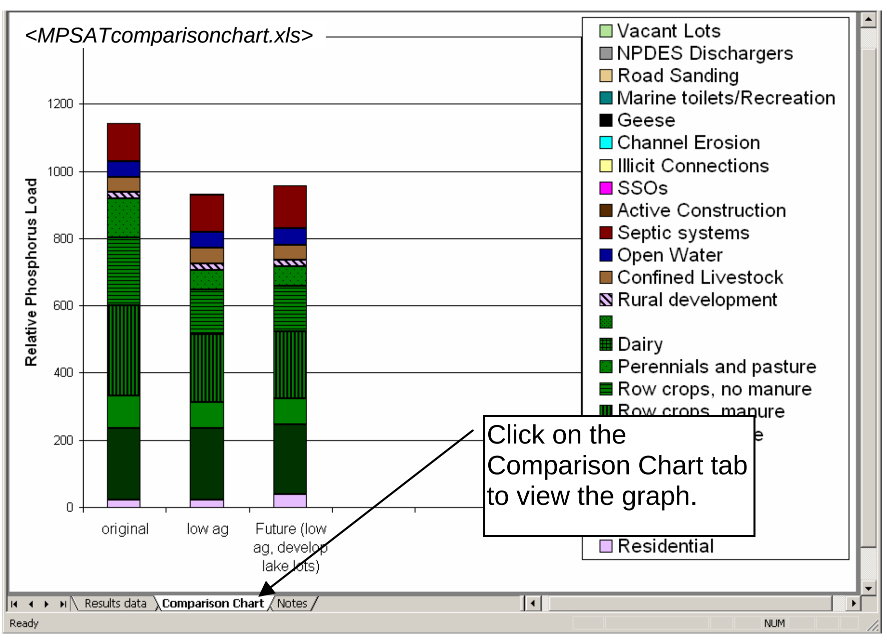
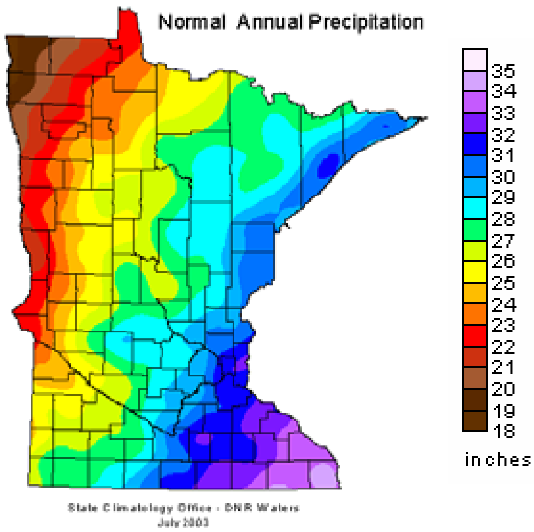


Figure 3. Data will be graphed in the Comparison Chart worksheet.



Sources of Input Data

Rainfall



Land use

Determining acreages involves defining the boundaries of your lake shed, determining land uses, and summing up the acres of each land use. Land cover and land use information may be available from a local planning agency such as:

- City zoning department,
- County Planning and Zoning, Environmental Services, or Information Services,
- Watershed District,
- Soil and Water Conservation District.

The Land Management Information Center (LMIC) has a table comparing several sources of land cover data at http://www.lmic.state.mn.us/chouse/land_use_comparison.html.

Land use data is available from the Land Management Information Center www.lmic.state.mn.us/chouse/land_use.html,
the DNR http://deli.dnr.state.mn.us/data_catalog.html,
and MetroGIS www.datafinder.org/index.asp.

Soil phosphorus

Surface soil P. Convert agronomic soil tests to percent soil phosphorus using the following equations:

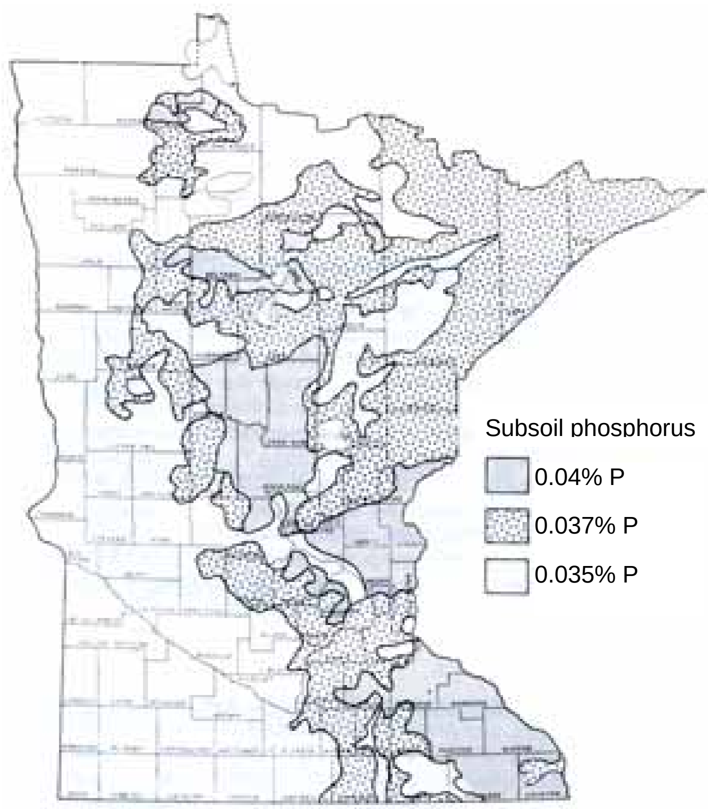
% P in soil = [321.9 + (2.785 X Olsen) + (29.11 X %OM)] / 10,000

Olsen-P ppm = 0.65 X Mehlich-P ppm

Olsen-P ppm = 0.71 X Bray-P ppm

These calculations will be done automatically in a table on the “Data Sources” worksheet in PSAT.

Subsoil P. Use the map below to estimate subsoil P.



Septic systems

Many counties estimate the proportion of failing septic systems. The Minnesota Pollution Control Agency provides state summaries of these estimates at http://www.pca.state.mn.us/programs/ists/localgovernment.html#annualreports. Request county level data from a county Environmental Services Department or by calling the MPCA (1-800-657-3864). Ask lake associations if any septic system surveys have been done in the watershed.

Geese

Examples of how people count geese are in:

Cooper, J.A. 2006. 2006 Program Report. The Canada Goose Program. Page 24 of http://www.ci.roseville.mn.us/council/parks/packets/2006/061205.pdf

Cordts, Steve. 2005. The 2005 Minnesota Waterfowl Breeding Population Survey. Wetland Wildlife Populations & Research. http://files.dnr.state.mn.us/publications/wildlife/populationstatus2005/migratorybirds.pdf

Manny, B.A., W.C. Johnson, and R.G. Wetzel. 1994. Nutrient additions by waterfowl to lakes and reservoirs: Predicting their effects on productivity and water quality. Hydrobiologia. 279/280:121-132.

Scherer, N.M., H.L. Gibbons, K.B. Stoops and M. Muller. 1995. Nutrient loading of an urban lake by bird feces. Lake Reserv. Manage. 11(4): 317-327.

Road sanding

Contact the county highway department for information about the P content and quantity of sand applied to roads.

Permitted Dischargers

Data about National Pollutant Discharge Elimination System (NPDES) permitees is public and available from the Minnesota Pollution Control Agency (MPCA), but you may have to ask for help to acquire and interpret the numbers. Start with discharge data from the MPCA Environmental Data Access site at: http://www.pca.state.mn.us/data/eda/. Look for the discharge limits listed in the source's NPDES permit, additional emergency discharges, and data from the Discharge Monitoring Reports (DMR), which all permitees must submit.

Adjusting agricultural loading factors

At a watershed scale, agricultural land generally delivers less than 1 lb P/ac/yr to the end of the watershed. However, values measured in Midwestern watersheds vary from near zero to 6 lbs P/ac/yr. The highest values are measured during years of high precipitation or extreme runoff events. If rainfall is held constant, higher P loss would come from steeper land, land near waterways, erosive soils, erosive management practices, and land with surface manure or fertilizer applications. Furthermore, the size of the watershed matters. Higher per-acre P loads will be measured in runoff from a half-acre plot than in the drainage of a 200 mi^2 watershed where deposition and adsorption of P occur throughout the watershed. For example, rates of 18 lbs P /ac have been measured in runoff from small research plots.

Thus, agricultural loading factors for a watershed should be selected to match:

- Size of the watershed
- Ag management practices
- Soil and landscape characteristics

Even when all three of these features are kept constant, actual P loads will vary substantially from year to year depending on weather patterns.

Use the following steps to improve the estimate of phosphorus loss from ag land

1. **Subdivide agricultural land.**
   As much as possible, divide agricultural acreage into subcategories of cropping systems: row crops with manure applications, row crops with no manure applications, and pasture or perennials. Further subdivisions by cropping system or landscape types may be helpful. Default loading factors for these basic categories are shown in Table 1.

Table 1: PSAT default loading factors.

Row crops with manure applications	0.8
Row crops with no manure applications	0.6
Pasture or perennials	0.2
Mixed agriculture	0.5

See explanation of factors in "Documentation" on page 17.

2. **Use the Minnesota Phosphorus Index (MN P Index) to refine the loading factors.** The MN P Index (available at www.mnpi.umn.edu) analyzes P loss risk from a farm field. It can account for soil type, landscape, tillage practices, cropping systems, and manure application practices. For each ag land use category, create one or more scenarios that represent the typical farming systems in your watershed. Use the MN P Index to determine the P loss risk rating for each scenario. The MN P Index generates a P loss risk estimate for a field, not on a per-acre basis, but it can be used to suggest refinements to loading estimates. Use Table 2 to convert the MN P Index results to a loading factor to be used in column H of the Primary Sources sheet in PSAT.

Table 2: Converting MN P Index results to PSAT loading factors.

	MNPI results	PSAT loading factor
Very low	<1	0.1 – 0.2
Low	1 – 1.9	0.2 – 0.5
Medium	2 – 3.9	0.5 – 0.9
High	4 – 5.9	1.0 – 1.4
Very high	>6	>1.4

3. **Choose a range of loading factors.** Based on the results from Step 2 and other relevant watershed data (see Appendix: Ag P Load Data), choose low and high loading factors for each ag land use category. Calculate PSAT results for both. By presenting results for a low and high estimate of agricultural P loss, you can account for two sources of uncertainty: 1) Actual long term average P loads are unknown; use a range to illustrate the possible values. 2) P loads vary widely from year to year; use a range to illustrate possible values in low versus high runoff years.
   How much interannual variation can be expected? Of the watershed data used to support this model, on average, individual sites varied more than six-fold between high and low P loss years. These watersheds were all less than 200 sq. mi. MPCA (2004) used a factor of 3.2 difference between P loss in wet years vs. dry years for estimating P loading from agricultural land for the Upper Mississippi River Basin.

4. **Document your choices.** Provide a justification for the loading factors selected.

Cautions

Size of watershed

PSAT is intended for small to medium-sized watersheds. Loading factors for rural areas are based on data from watersheds less than 200 sq miles, so the PSAT should not be applied to larger watersheds. In urban watersheds (more than 30% urban development), the maximum watershed size should be limited to 20 square miles. This is because the urban runoff estimate is based on the Simple Method, which was originally designed for development lots less than 1 mile square

The tool could be applied to larger watersheds (e.g. 8-digit HUCs) if loading factors are adjusted accordingly. Consider applying the loading factors only to land within a 100 meters from surface water as described in the statewide phosphorus assessment (MPCA, 2004. Especially Appendices C and I.). The MPCA study used the coefficients shown in Table 3 for the Upper Mississippi River basin.

Table 3. Export coefficients for phosphorus load calculations for the Upper Mississippi River Basin.

	Kg/ha/y	Lb/a/y
Deciduous Forest	0.075	0.067
Evergreen Forest	0.123	0.109
Mixed Forest	0.13	0.116
Shrubland	0.129	0.115
Grasslands/ Herbaceous	0.169	0.150
Agriculture	0.39	0.35

From MPCA (2004): Table 8 of Appendix I, and Table 3 of Appendix C.

Relative, not actual loads

This tool is not a calibrated model so results represent relative contributions or relative changes. It cannot reproduce actual in-stream loads.

The load reductions on the “Management Practices” worksheets are sometimes calculated as a percent efficiencies. However, some are calculated separately using a different method than used to calculate primary and secondary loading. So use caution when comparing the two values (primary or secondary load versus load reduction from management practices. Use the load reduction estimates to illustrate the relative magnitude of reductions possible.

Annual averages

PSAT results are annual averages that give no indication of variation within or between years. When planning treatment, consider critical conditions during the year and plan for major events such as snowmelt or large runoff events

Uncertainty

Conservative assumptions in the model provide some margin of safety, however and explicit margin of safety should be incorporated where specific targets are to be met, such as in a TMDL study.

High soil test P

PSAT cannot account for high soil test P levels in rural land near water bodies. The MNPI should be used in these situations to estimate risk.

Forest P loads

Forest P loads are assumed to be minimal in the PSAT calculations, but high loads are possible from isolated locations with high compaction or high snowmelt runoff.

Internal loading

PSAT does not consider internal loading as a source of P.

Form of P

PSAT does not differentiate between dissolved and particulate P. The tool only considers total P on the assumption that all P has the potential to become available.

Watershed P loading

PSAT is a model of lake P loading, not watershed P loading. For example, P may buildup in a watershed under septic tanks and in fields with heavy manure applications. But if there is no transport mechanism, the P may not be carried to the lake to increase lake loading.

Documentation

Development of PSAT

The Phosphorus Source Assessment Tool is a modification of the Watershed Treatment Model (WTM) created by the Center for Watershed Protection. (See References, page 21, for download instructions.) Several significant modifications were made:

- The WTM was designed primarily to assess stormwater runoff from urbanized watersheds. Several agricultural land use categories were added to make it more useful in rural watersheds.
- Default loading factors were changed based primarily on data from Minnesota and Wisconsin.
- The PSAT focuses on phosphorus. Components for nitrogen and bacteria were removed from the WTM.
- A new results reporting worksheet was added with pie graphs of the results.

The name was changed to the Phosphorus Source Assessment Tool to reflect these changes, to emphasize that this tool is not a calibrated model, and because we are not emphasizing the treatment component of the model.

Other modifications to the WTM include:

- Adding the option to account for septic systems that are an imminent threat to public health and safety (ITPHS) because counties routinely survey ITPHS systems along with failing and complying systems.
- Adding the option to input subsoil P levels. This value, instead of surface soil P, is used in the channel erosion estimate.
- Deleting the combined sewer overflow component because combined sewers have been all but eliminated from Minnesota.
- In the livestock calculation, deleting poultry because they are virtually never on exposed lots, and adding horses because they occasionally are concentrated near water sources.
- Adding the option to indicate the P content of road sand. WTM did not consider road sand to be a source of P.
- Deleting the lawn subsurface flow component because it has little significance for phosphorus.

Urban land uses

Phosphorus loss from urban land (residential, commercial, roadway, and industrial) is calculated by using the Simple Method to estimate runoff based on percent impervious area and multiplying by a P concentration. The Simple Method is:

Load (lb P per acre) = mg P/L * Rainfall (in) * 0.9 * (0.05+0.009* %imperv) * 0.226

(0.226 is a unit conversion factor)

Default event mean concentrations (Table 4) are based on Bannerman et al. (1992 and 1993), documentation for the WTM (Caraco 2001)

Table 4. PSAT default P concentrations in urban runoff.

Urban land use	Default P concentration in runoff
Roadways	0.5 mg/L
Commercial	0.3 mg/L
Industrial	0.4 mg/L
Residential	0.4 mg/L

Rural land uses

Phosphorus loss from non-urban lands is calculated using default loading factors (column K) in pounds of P per acre. No estimate of runoff is made.

Loading factors are estimates of the annual amount of phosphorus delivered to the lake or other endpoint of a watershed, divided by the total number of acres in the watershed. In reality, phosphorus comes from critical areas in the landscape and does not flow equally from all areas.

Agricultural land uses

P loading from agricultural land was based on the studies described in Table 5, and on analyses done with the MN Phosphorus Index (MN PI). A scenario representing land use in two Nicollet County watersheds (Birr 2006) was analyzed in the MN PI. The resulting risk factor (3.3) was four times the measured P loss of 0.8 lbs P/acre. Thus, we assumed that actual P loss is 0.24 times a MNPI risk factor. We modeled typical ag scenarios with and without manure and used the 0.24 factor to convert MNPI results for each scenario to the loading factors used in PSAT. P loss risk from row crops with manure applications varied widely depending on the amount and method of application.

Table 5. Basis for agricultural loading values.

Value	Description of source
0.8 lb/a	The average of total P loads from 13 studies of cropland in the Midwest larger than 1 hectare from the MANAGE database (Harmel, et al. 2006). All sites were corn and/or soybeans, 4 to 150 acres. Averages ranged from 0.12 to 1.6 lb/ac. Four of the 5 sites that were >1 lb/ac were from MO which has higher precip than MN. P loads decrease as field size increases, so studies on very small plots were eliminated, including those in Morris MN in the late 1960's (Young et al. 1977; Burwell at al. 1975) where rates of 5 to 33 kg/ha were measured.
0.8 lb/a	Average of two 2800-acre watersheds in Nicollet County MN measured for three years (Birr 2006). Annual measurements ranged from 0.55 to 1.2 lb/ac. No association observed between P load and increased BMPs in one of the watersheds. (BMPs included switching from fall moldboard (MB) to chisel (FC) plowing, replacing open inlets, and nutrient management planning.) Management was generally corn/soybean rotation, 20% of acres got manure, 25% of acres had fall MB, 66% had FC.
1 lb/a	Average P load from 20 Wisconsin watersheds with >80% agricultural land, ranging from 2 to 200 sq. mi. (Corsi et al. 1997). P loads from agricultural watersheds tended to be higher than loads from either urbanized watersheds or predominantly forested/water watersheds. Values over 1 lb/a generally came from sites in the steeper driftless area of southwest WI.
0.4 lb/a	Agricultural loading factor used for the Upper Mississippi River Basin in the MPCA study of statewide phosphorus sources (Barr 2004).
0.89 lb/a	Loading factor used in WiLMS (Panuska and Kreider 2003) as the "most likely" value for row crop agriculture. "Low" and "high" values used in WiLMS were 0.45 and 2.67, respectively. Their values are based on data from smaller watersheds, i.e. ~20 sq. mi. WiLMS is a model used in Wisconsin for similar purposes as PSAT.
0.2 lb/a	The average of total P loads from five studies of pasture runoff in the Midwest from the MANAGE database (Harmel, et al. 2006). One site was 43 ha, the remainder were 6.3 ha or less. So these results are probably high for the scale of a lake watershed. Three were rotationally grazed (0.1-0.28 lb/ac). Two studies in the database were excluded because the pastures were used as winter feeding lots. Total P losses from these sites were 0.9 and 1.7 lb/ac. Another study was excluded because it was alfalfa in rotation with corn and oats (0.7 lb/ac).
0.27 lb/a	The loading factor used in WiLMS (Panuska and Kreider 2003) as the "most likely" value for pastures. "Low" and "high" values were 0.09 and 0.45, respectively.

Rural development

The P loading factor of 0.2 lb/a/yr is the result of the Simple Method (explained on page 18**Error! Bookmark not defined.**) assuming 5% impervious cover, 26 inches of precipitation, and 0.4 mg P /L. This value makes sense because it is higher than forest losses but lower than low density residential losses.

WiLMS (Panuska and Kreider 2003) used a loading factor of 0.09 lb/a as the "most likely" value for rural residential acres (define as larger than one-acre lots). "Low" and "high" values are 0.04 and 0.22, respectively.

Forest, brush, and grassland

PSAT uses a single loading factor of 0.1 lb/a for all areas of natural vegetation. The MPCA phosphorus study (Barr 2004) used loading factors of 0.07 to 0.15 lb/a for natural plant communities, but only considered acreage within 100 m of water. WiLMS (Panuska and Kreider 2003) used a loading factor of 0.08 lb/a as the "most likely" value for forest land, and 0.04 and 0.16 as the "low" and "high" values.

Open water / Atmospheric deposition

The P loading factor of 0.2 lb/a for open water at the bottom of the watershed represents inputs from atmospheric deposition. The BATHTUB model uses a default value for atmospheric deposition of 0.27 lb/a. The MPCA phosphorus study (Barr 2004) uses a value of 0.15 lb/a for the Upper Mississippi River Basin. WiLMS (Panuska and Kreider 2003) used values of 0.1 lb/a and 0.3 lb/a for wetlands and lakes, respectively. WiLMS does not differentiate by location in the watershed.

Septic systems

Phosphorus concentrations in septic tank effluent of 1, 3, and 5 mg/L for conforming, failing and ITPHS systems, respectively, were suggested by University of Minnesota septic system specialists (Sara Christopherson, personal communication). The value of 1 mg/L for conforming systems is reasonable for coarse soils but is probably high for finer soils.

Default rates of 25% of septic systems failing and 5% systems ITPHS (Imminent Threat to Public Health and Safety) are averages for central Minnesota counties from 2005 annual reports.

The default value of 70 gallons of waste per person day was retained from the Watershed Treatment Model. It is slightly higher than the estimate of 60.4 gallons from Mayer et al. (1999).

People generate about 2 lbs of P per person per year. This ends up in the septic tank, in the soil, in the water, or exported from the area.

Livestock

The manure P delivery factor was set at 3% on David Schmidt’s suggestion and to better match results from the MinnFARM model (David Schmidt, UMN manure feedlot specialist, personal communication).

Geese

PSAT assumes an annual P production of 0.8 lbs per goose, which is the average of the two data sources: Scherer et al. (1995) and Manny et al. (1994). Scherer et al. used the following estimates: P is 1.87% of goose droppings (dry weight), geese average 8 lbs live weight, and annual P production per bird is 1.23 lbs or 0.15 lbs P per lb of live weight. Manny et al. estimated an average live bird weight of 5.6 lbs (measured during molting in 1955) and 0.07 lbs of P per lb of live weight.

Scherer et al. found little link between the amount of waterfowl and water quality. They pointed out that nutrients cycle through the birds quickly, so much of the P comes from food that was eaten in or very near the lake, i.e., goose droppings may be more internal than external loading.

Cormorants and pelicans were not considered because no information about their effects was readily available.

Marine toilets/recreation

The estimate of direct human waste includes two separate calculations. The first follows the assumptions of the Watershed Treatment Model (WTM) for estimating dumping from marine toilets. The WTM assumes 8 gallons of waste per person per day with 10 mg/L phosphorus.

The second calculation is based on monitoring done on Granite Lake in January and February of 2007 (Wright County, Lake ID#086-0217; Raymond Rau, personal communication). They observed an average of 3.8 urine spots near each ice fishing site (ice house or cluster of holes) per week. According to Etnier et al. (2005), human waste contains 365 g P (67%) in urine and 183 g P (33%) in feces per year. Thus, assuming four urinations per day (no reference), each urine spot would contribute 0.25 g P.

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To download the WTM, go to http://www.stormwatercenter.net/. Click on Monitor/Assess, then click on Watershed Treatment Model near the top of the page.
For WTM documentation, go to the Center for Watershed Protection's list of Technical Manuals at http://www.cwp.org/PublicationStore/TechResearch.htm.

Acronyms

CWP	Center for Watershed Protection (www.cwp.org)
du	dwelling units
gpcd	gallons per capita per day
gpd	gallons per day
HDR	high density residential
HUC	Hydrological Unit Code (http://www.dnr.state.mn.us/watersheds/index.html)
ITPHS	Imminent Threat to Public Health and Safety (Refers to a septic tank that drains effluent directly into surface water or to the ground surface.)
LDR	low density residential

LMIC	Land Management Information Center
MDR	medium density residential
mg/L	milligrams per liter (equivalent to ppm)
MinnFarm	Minnesota Feedlot Annualized Runoff Model (http://www.manure.umn.edu/applied/open_lots.html)
MNPI	Minnesota Phosphorus Index (www.mnpi.umn.edu)
MPCA	Minnesota Pollution Control Agency
MPSAT	See PSAT.
NPDES	National Pollutant Discharge Elimination System (An EPA program that regulates discharges of pollutants from point sources such as waste water treatment plants or industrial waste.)
P	phosphorus
ppm	parts per million. In the case of nutrient concentrations in water, ppm is equivalent to mg/L.
PSAT	Phosphorus Source Assessment Tool, also called the Minnesota PSAT (MPSAT)
sf	square feet
SSO	Sanitary Sewer Overflow (leaking into and out of sanitary sewer systems)
TMDL	Total Maximum Daily Load (the level of a pollutant input that will maintain the desired level of water quality in a water body)
TP	Total phosphorus
TSS	Total suspended solids
WDNR	Wisconsin Department of Natural Resources
WiLMS	Wisconsin Lake Modeling Suite (Panuska and Kreider, 2003)
WTM	Watershed Treatment Model (http://www.stormwatercenter.net/)

Appendix: Ag P Load Data

Watershed-scale phosphorus loss data

Region	Watershed description	Watershed area	lbs P / ac-yr			Source	Site ID
		ac	average	min	max		
Southeast WI	Older loamy and sandy soils; steep, thin drift. 95% agricultural	6400	0.08	0.06	0.09	Corsi et al., 1997	25
WI, eastern forest	Red calcareous clay; lacustrine, till. 87% ag, 10% forest and wetland.	69759	0.13			Corsi et al., 1997	32
Southeast WI	Dairy and specialty crops. Irregular moraines. 96% ag.	47103	0.24	0.13	0.82	Corsi et al., 1997	37
Southeast WI	Older loamy and sandy soils; steep, thin drift. 86% ag, 13% urbanized.	10752	0.30	0.22	0.68	Corsi et al., 1997	27
WI, eastern forest	Red calcareous clay; lacustrine, till. 86% ag, 8% forest and wetland, 6% urbanized.	6080	0.38	0.13	0.92	Corsi et al., 1997	30
Southeast WI	Dairy and specialty crops. Irregular moraines. 85% ag, 8% urbanized, 6% wetland.	23168	0.44	0.28	1.04	Corsi et al., 1997	34
Southeast WI	Dairy and specialty crops. Irregular moraines. 85% ag, 10% urban.	5120	0.51	0.31	0.71	Corsi et al., 1997	28
Southeast WI	Dairy and specialty crops. Irregular moraines. 85% ag, 15% urban.	3648	0.53			Corsi et al., 1997	33
WI, driftless	Steep slopes. A lot of forage and pasture. 82% ag, 17% forest.	6720	0.54	0.10	1.59	Corsi et al., 1997	9
Southeast WI	Dairy and specialty crops. Irregular moraines. 93% ag, 7% forest.	1984	0.72	0.13	2.19	Corsi et al., 1997	36
Southeast WI	Dairy and specialty crops. Irregular moraines. 90% ag, 8% urban.	11712	1.02	0.29	2.25	Corsi et al., 1997	31
WI, Driftless area	Steep slopes. A lot of forage and pasture. 99% ag.	18240	1.07			Corsi et al., 1997	23
WI, eastern forest	Red calcareous clay; lacustrine, till. 99% ag.	9472	1.07	0.97	2.81	Corsi et al., 1997	24
Southeast WI	Older loamy and sandy soils; steep, thin drift. 89% ag, 6% forest and wetland.	127358	1.13			Corsi et al., 1997	35
WI, Driftless area	Steep slopes. A lot of forage and pasture. 99% ag.	27136	1.28	1.13	5.73	Corsi et al., 1997	20
WI, Driftless area	Steep slopes. A lot of forage and pasture. 99% ag.	5952	1.45	0.72	2.19	Corsi et al., 1997	7
WI, Driftless area	Steep slopes. A lot of forage and pasture. 100% ag	6144	1.50	0.38	6.19	Corsi et al., 1997	16
WI, N. Cent. forest	Moraines, sandy outwash. 92% ag, 8% forest.	2688	1.55	0.60	2.50	Corsi et al., 1997	6
WI, Driftless area	Steep slopes. A lot of forage and pasture. 100% ag	3456	1.89	1.06	2.73	Corsi et al., 1997	19
WI, Driftless area	Steep slopes. A lot of forage and pasture. 100% ag	1792	2.05	0.85	0.32	Corsi et al., 1997	18
WI, Driftless area	Steep slopes. A lot of forage and pasture. 100% ag	9600	2.38	1.17	3.58	Corsi et al., 1997	17
Dane County, WI	Dairy. 90% ag.	256	0.68			Panuska and Lillie, 1995	4
Southeast WI	Dairy and specialty crops. Irregular moraines. 93% ag.	26304	0.49	0.26	0.72	Panuska and Lillie, 1995	5
Southeast WI	Dairy and specialty crops. Irregular moraines. 94% ag.	8128	0.76			Panuska and Lillie, 1995	6
Southeast WI	Dairy and specialty crops. Irregular moraines. 95% ag.	15616	0.47	0.29	0.65	Panuska and Lillie, 1995	7
Southeast WI	Dairy and specialty crops. Irregular moraines. 72% ag.	13939	0.49	0.48	0.50	Panuska and Lillie, 1995	31
WI, N. Cent. forest	Moraines, sandy outwash. 84% ag, 13% water.	813	0.68			Panuska and Lillie, 1995	34

Treynor, IA	Corn, conventional tillage, terracing.	60	0.22	0.02	0.54	Alberts et al., 1978
Treynor, IA	Corn, conventional tillage, contour farming	33.6	0.41	0.07	1.15	Alberts et al., 1978
Treynor, IA	Corn, conventional tillage, contour farming	30	0.62	0.08	1.89	Alberts et al., 1978
Pottawattamie County, IA	Corn, conventional tillage, contour farming	33.6	0.86	0.53	1.18	Burwell et al., 1975
Eastern SD	Alfalfa, bromegrass pasture	4.1	0.09			Harms et al., 1974
Eastern SD	Pasture	6.3	0.22			Harms et al., 1974
Coshocton, OH	Kentucky Bluegrass, Orchardgrass, Rotationally Grazed		0.09			Owens et al. 2003
Coshocton, OH	Kentucky Bluegrass, Orchardgrass, Rotationally Grazed		0.15			Owens et al. 2003
Coshocton, OH	Kentucky Bluegrass, Orchardgrass. Summer grazed, winter feeding lot.		0.89			Owens et al. 2003
Coshocton, OH	Kentucky Bluegrass, Orchardgrass. Summer grazed, winter feeding lot.		1.66			Owens et al. 2003
Treynor, IA	Bromegrass, rotationally grazed	43	0.25	0.07	0.45	Schuman et al., 1973
Knox County, MO	Soybeans, No Till, contour farming, waterway	4.44	0.31	0.27	0.36	Udawatta et al., 2004
Knox County, MO	Soybeans No Till, waterway	4.44	1.16	0.45	2.31	Udawatta et al., 2004
Knox County, MO	Corn No Till, waterway	4.44	1.47	0.27	3.20	Udawatta et al., 2004
Knox County, MO	Corn No Till, contour farming, waterway	4.44	1.60	1.51	1.78	Udawatta et al., 2004
Knox County, MO	2 yr corn-soybean rotation. Conservation tillage, waterway.	1.65	0.89			Udawatta et al., 2002
Knox County, MO	2 yr corn-soybean rotation. Conservation tillage, waterway.	3.16	0.98			Udawatta et al., 2002
Chickasha, OK	Wheat	5.3	1.42	0.53	3.82	Reckhow et al., 1980
Swift Current, Saskatchewan	Spring wheat, summer stubble, 2-yr rotation	5	0.31	0.09	0.53	Reckhow et al., 1980
	Spring wheat, summerfallow	5	1.20	0.36	2.05	Reckhow et al., 1980
	Spring wheat, fall fertilized summerfallow	5	2.58	0.18	4.98	Reckhow et al., 1980
Coshocton, OH	Winter grazed, summer rotational, orchardgrass and bluegrass cover	1	3.20			Reckhow et al., 1980
Coshocton, OH	Summer grazed	1	0.76			Reckhow et al., 1980
Chickasha, OK	Continuous grazing, little bluestem cover, active gullies	11.1	1.30	0.24	3.44	Reckhow et al., 1980
Rhode River Watershed, MD	Continuous grazing with some supplementary winter feeding, some hay production	351.2	3.38			Reckhow et al., 1980
Chickasha, OK	Rotation grazing little bluestem cover, good cover	11	0.22	0.02	1.28	Reckhow et al., 1980
Chickasha, OK	Continuous grazing	7.8	4.36			Olness et al., 1980
Chickasha, OK	Continuous grazing	11.1	0.68			Olness et al., 1980
Chickasha, OK	Rotationally grazed pasture	9.6	2.75			Olness et al., 1980
Chickasha, OK	Rotationally grazed pasture	11	0.18			Olness et al., 1980