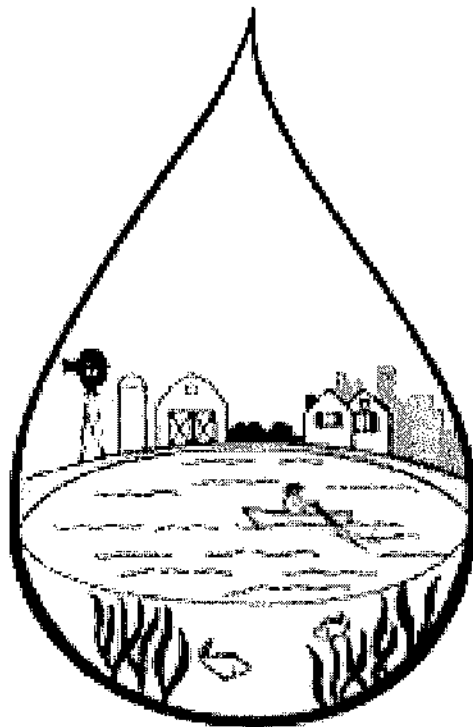


# **Prediction of Suspended Solids and Total Phosphorus Yields in the Red Cedar River Drainage System**



## **Wisconsin Department of Natural Resources Report to Red Cedar River Basin Project July 1999**

(including corrections made in 2010)



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## **1. Objective**

Water quality in the Red Cedar River Basin is impaired by excessive loadings of sediment and nutrients arising from point and nonpoint sources of pollution. An effort was made to estimate the suspended solids and phosphorus loadings from all sources of pollution within the basin. A process based computer model, Simulator for Water Resources in Rural Basins - Water Quality (SWRRBwq), was used to estimate sediment and phosphorus contributions from various agricultural, forested and urban land uses for the seven watersheds in the Red Cedar River Basin. The phosphorus loadings were also estimated from point sources and barnyards using Wisconsin Pollution Discharge Elimination System permits and Priority Watershed Project data, respectively. Finally, the sediment and phosphorus loadings from all watersheds were routed to Tainter Lake to determine the relative contribution of various pollutant sources and watersheds in the basin.

## **2. Description of the SWRRBwq model**

Simulator for Water Resources in Rural Basins - Water Quality was developed by the USDA-ARS (Arnold et al., 1990) to simulate hydrologic, sedimentation, nutrient and pesticide transport in large, complex rural watersheds. The model operates on a continuous daily time step and allows for subdivision of basins to account for differences in soils, land use, rainfall, etc. SWRRBwq was designed to predict the effect of management practices on water, sediment and pesticide yields with reasonable accuracy for ungaged rural basins throughout the United States. SWRRBwq has been tested on 11 large watersheds at eight Agricultural Research Service locations throughout the country. The results show that SWRRBwq is a versatile and convenient tool for use in planning and designing water resource projects.

SWRRBwq includes five major components: weather, sedimentation, nutrients, and pesticides. Processes considered include surface runoff, return flow, percolation, evapotranspiration, transmission losses, pond and reservoir storage, sedimentation and crop growth. A weather generator allows precipitation, temperature, and solar radiation to be simulated when measured data is unavailable. The precipitation model is a first order Markov chain model, while the air temperature and solar radiation are generated from a normal distribution. Sediment yield is

based on the Modified Universal Soil Loss Equation (MUSLE). Nutrient yield routines were taken from the EPIC model (Williams et al., 1985). The pesticide component is a modification of the CREAMS (Smith and Williams, 1980) pesticide model. SWRRBwq allows for simultaneous computations on each subbasin and routes the water, sediment, nutrients, and pesticides from the subbasin outlets to the basin outlet. Surface runoff volume is predicted using the SCS curve number adjusted for daily soil moisture content. Return flow is calculated as a function of soil water content and return flow time. Return flow travel times can be calculated from soil hydrologic properties or user inputs.

The percolation component uses a storage routing model combined with a crack-flow model to predict flow through the root zone. Evapotranspiration (ET) is estimated using Ritchie's ET model. Transmission losses in the stream channel are calculated as a function of channel dimensions, flow duration and effective hydraulic conductivity of the bed. Peak runoff rate prediction is based on a modification of the Rational Formula. The channel and floodplain sediment routing model is composed of two components operating simultaneously (deposition and degradation). Degradation is based on Bagnold's stream power concept, and deposition is based on the fall velocity of the sediment particles. The crop growth model computes total biomass each day during the growing season as a function of solar radiation and leaf area index (LAI). LAI is computed for each day from the maximum LAI and total above ground biomass. The ET component uses LAI to compute plant evaporation. Water and temperature stress factors are used as growth constraints.

SWRRbwq simulates crop growth for both annual and perennial plants. Annual crops grow from planting date to harvest date or until the accumulated heat units equal potential heat units for the crop. Perennial crops maintain their root systems throughout the year.

Lake and reservoir simulation can be applied when a single reservoir is simulated at the watershed outlet. The major components of the lake model are pollutant loading, outflow, settling, resuspension, burial, etc. The model can also track fate of pesticides from their initial application on the land to their final fate in the lake. This allows decision makers to directly

predict the influence of upland agricultural management decisions on lake water quality (Arnold et al., 1991). The lake and reservoir component was not used in this study.

### **3. Data acquisition for the Red Cedar River Drainage System**

The Red Cedar River drainage basin is a complex system with vast spatial and temporal variability in the different physical processes driving the system. Accounting for the interactions of these physical processes and their temporal-spatial variability is important in any attempt to model the behavior of a system. The data input requirements for the SWRRBwq model are significant; the acquisition and sources of data for this study are described throughout the report.

### **4. Red Cedar River Drainage System**

The Red Cedar River originates in Sawyer County and flows south through Barron and Dunn Counties as it drains into the Tainter Lake (Figure 1). The entire drainage area for Tainter Lake consists of seven watersheds. Five of the seven watersheds drain into the Lake through the Red Cedar River and the remaining two through the Hay River which discharges directly into the Lake. The general description of all seven watersheds is provided in Table 1.

Water quality problems due to excessive sediment as total suspended sediment (TSS) and total phosphorus (TP) loadings have been well documented throughout the entire drainage area (WDNR, 1979; WDNR, 1993, WDNR 1996). Tainter Lake is highly eutrophic and experiences severe summer algae blooms and poor water quality. The Red Cedar and Hay Rivers also experience siltation in various stream segments and dissolved oxygen problems in heavily vegetated stream reaches. The Wisconsin Department of Natural Resources recently conducted a reservoir water quality model study using the Corps of Engineers BATHTUB model to assess the impacts of phosphorus loadings on Tainter Lake (Schreiber, 1992). The results of the SWRRBwq model will be used to assess potential water quality improvements in Tainter Lake as a result of pollutant load reductions in the basin.

Figure 1. Red Cedar River Basin / Tainter Lake Drainage Area.

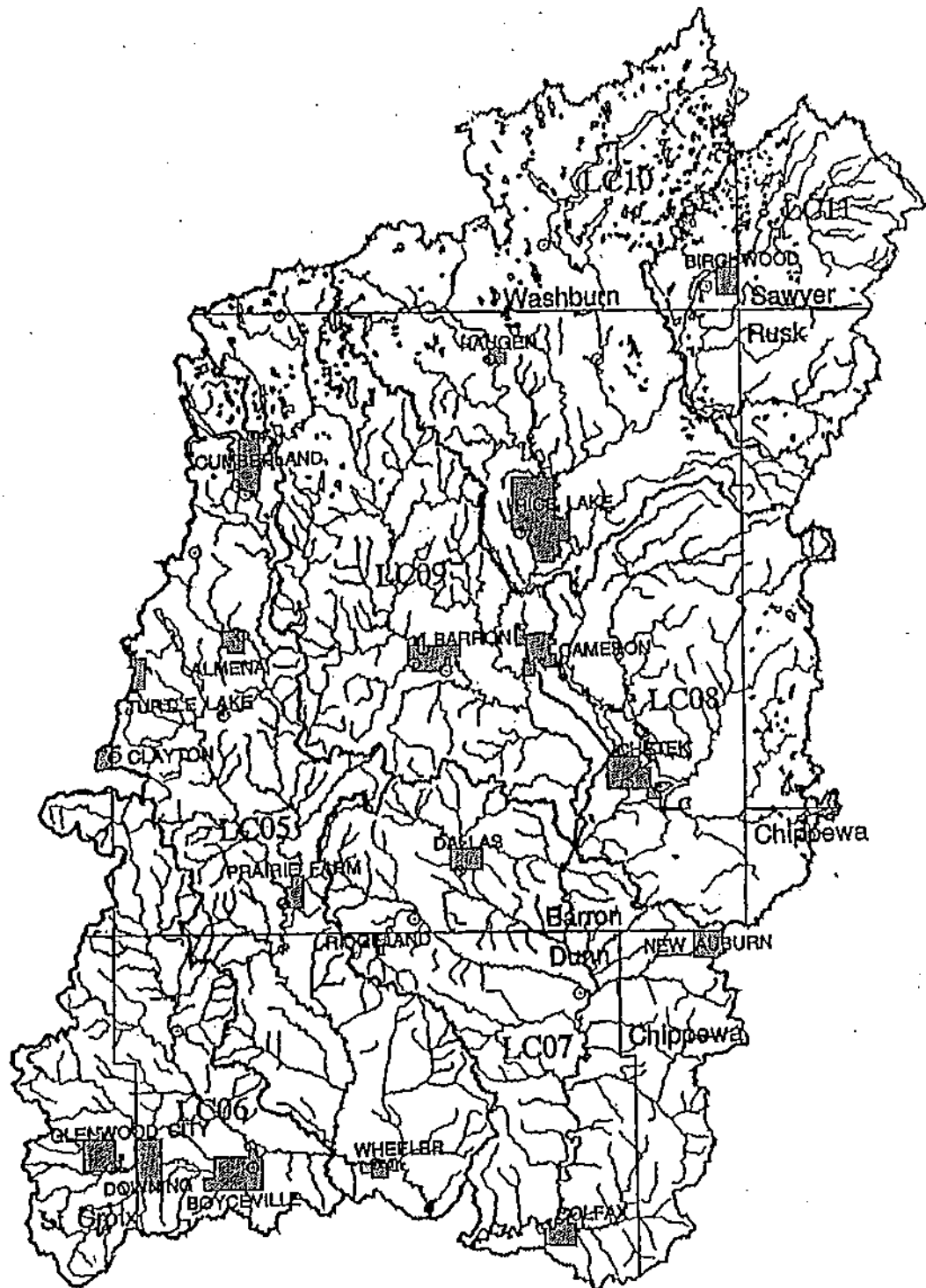




Table 1. Watersheds of the Red Cedar River Basin

Sr #	Watershed name	Water-shed #	Total area Sq.miles	Area in crop & pasture	% area in crop & pasture	Priority watershed status
1	Hay River	LC05	289.6	191.1	20.6	completed
2	South Fork Hay River	LC06	182	149.2	16.1	in implementation
3	Pine Creek & Red Cedar River	LC07	287.9	198.7	21.5	not selected
4	Lake Chetek	LC08	212	95.4	10.3	not selected
5	Yellow River	LC09	239.3	165.1	17.8	in planning
6	Brill & Red Cedar Rivers	LC10	297.7	116.1	12.5	not selected
7	Red Cedar Lake	LC11	140	10.1	1.1	not selected
	Total		1648.5	925.7	100	

## 5. Discretization of the Drainage System

Delineation of the entire drainage area to fit the model frame-work was a challenging task. With the help of the Dunn & Barron County Land Conservation Department (LCD) staff, the entire drainage area was divided into the following four land uses:

- Cropland: corn, oats and hay
- Pasture: pasture, idle/rangeland, grass
- Forest: woodlot and water
- Urban: dirt roads, grass, hard surface

To ensure the hydrologic integrity of the drainage system, each watershed was divided into 10 subareas based upon their drainage characteristics. The ten subareas for the South Fork Hay River Watershed are shown in Figure 2. Hydrologic delineations of the remaining six watersheds are shown in Appendix 1. Soils data were compiled for the entire drainage area using the Wisconsin STATSGO (USDA Publication #1492) database. Soils data indicated the presence of 3-12 soil types (e.g. Santiago, Amery, Gale, etc.) in each subarea. This could result in 12-48

unique land use-soil type combinations for each sub area. In order to keep the modeling effort within a manageable work load, all soil parameters within a subarea were averaged to develop a lumped soil parameter input file for each sub area.

Four input files were developed for every watershed with each file corresponding to one unique land use (cropland, pasture, forest or urban). The model was run for each input file to obtain TSS and TP delivery ratios in metric tons per hectare (MT/ha) and Kilograms per hectare (Kg/ha) at the mouth of each watershed, respectively. The delivery ratios from each file were unique to a particular land use in the watershed and were based upon the assumption that the entire watershed had only one land use. The overall TSS and TP loadings at the mouth of each watershed were then obtained by using the following area-weighting equation:

$$L_o = (D_A \times A_A) + (D_F \times A_F) + (D_P \times A_P) + (D_U \times A_U)$$

Where

$L_o$  = overall sediment or phosphorus loading in MT or Kg, respectively

$D_A$  = TSS/TP delivery (MT/ha or Kg/ha) assuming entire watershed to be agriculture

$D_F$  = TSS/TP delivery (MT/ha or Kg/ha) assuming entire watershed to be forest

$D_P$  = TSS/TP delivery (MT/ha or Kg/ha) assuming entire watershed to be pasture

$D_U$  = TSS/TP delivery (MT/ha or Kg/ha) assuming entire watershed to be urban

$A_A$  = Actual watershed area with agricultural land use

$A_F$  = Actual watershed area with forest land use

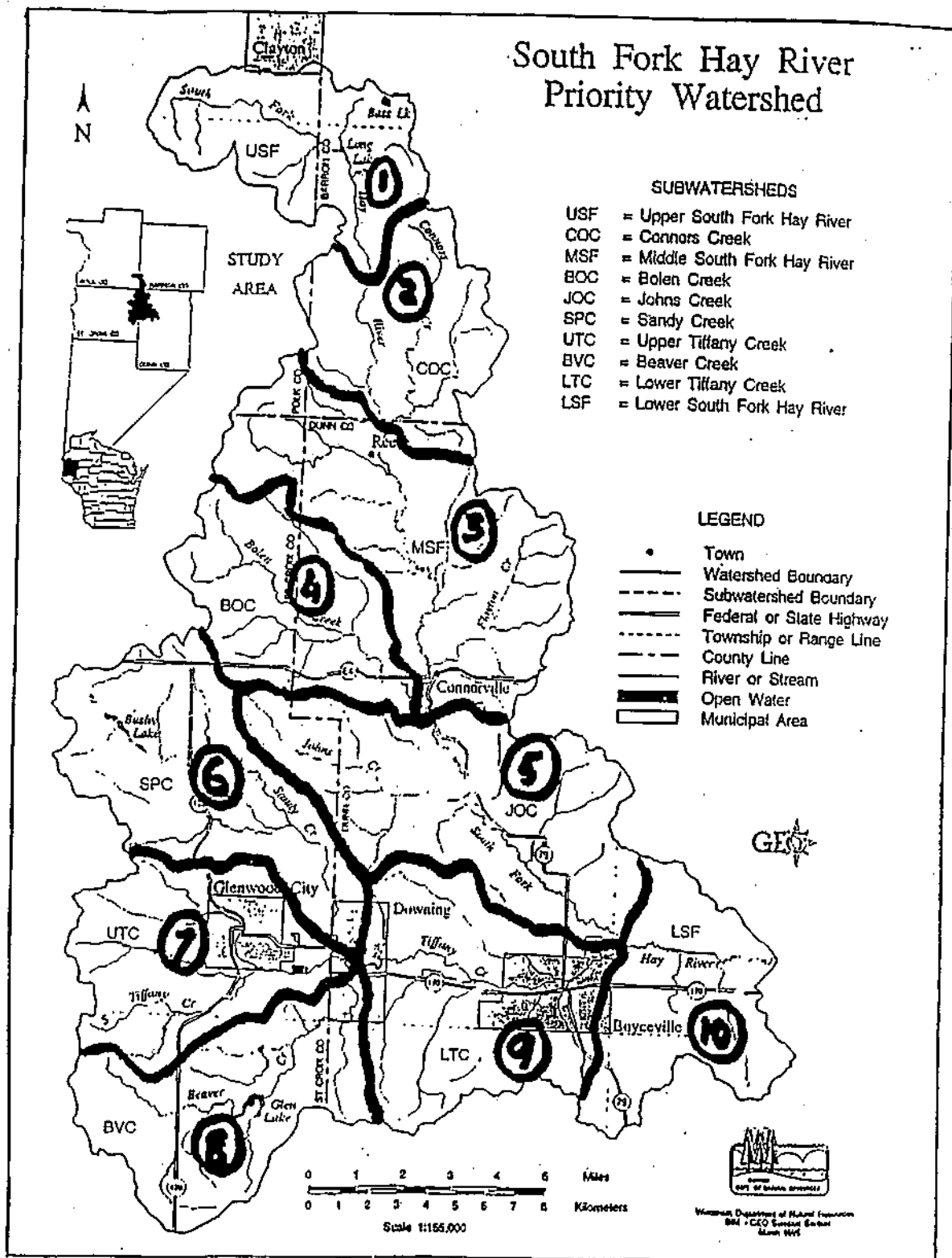
$A_P$  = Actual watershed area with pasture land use

$A_U$  = Actual watershed area with urban land use

No best management practices were assumed for the prediction of initial load estimates.

Insufficient data was available to determine the type or specific location of the land use practices.

Figure 2. Hydrologic Delineations of South Fork Hay River Watershed.



## **6. Input data to the SWRRBwq Model**

The input data file was developed for each watershed separately. The input data collection forms are described in Appendix 2. However, important data parameters are described as follows:

### *Crop Data*

Since each land use category contains various types of crops and crop rotations, accounting for the percentage area of these crops was important in estimating representative values of the different parameters in the model. The crop rotations were compiled with the help of Dunn & Barron County Land Conservation District (LCD) staff. A typical crop rotation in the basin can be corn-corn-oats-hay-hay-hay over a six year period. However, the model can only accept crop rotations for three years. Therefore, the three year crop rotations of corn-hay-hay, corn-corn-hay, and corn-oats-hay were selected for areas under cropland.

Various crop parameters are built into the model database for row crops, pasture, and forested areas. These parameters include potential crop heat units (degree-C), a biomass conversion factor (Kg/ha/MJ), water stress yield factor, a harvest index, and average annual C-Factor. Of all these parameters, the average annual C-Factor is one of the most critical parameters. The C-Factor is the crop management factor used to calculate sediment yield in the MUSLE equation. The C-Factor value is a function of cropping systems and tillage practices and is considered one of the more important factors in the sediment generation process. The daily crop management factor C in the SWRRBwq model is calculated as a function of average annual values and is a function of soil cover (residue plus above ground biomass). The C-Factors of 0.23-0.32 were used for row crops such as corn, soybeans, cotton and peanuts etc. The C-Factors for alfalfa and Pasture are 0.04 and 0.008, respectively. A range of 0.04-0.008 was used for the C-Factors in the forested areas.

### *SCS Curve Number*

The Curve Number is one of the most sensitive parameters in the SWRRBwq model. The surface flow generation is highly sensitive to the values of this parameter. The SCS curve

number is an empirical parameter used to evaluate land use, soil condition, agricultural practices, and antecedent moisture conditions. The range of this parameter is 0-100. The curve number for soil moisture condition II is the average between the dry condition I and the wet condition III. The selection of the SCS curve number was based upon the type of crop, cover condition and the hydrologic behavior of the soil. The curve numbers were compiled by the Soil Conservation Service and used in the model study as shown in Table 2. These values are built into the SWRRBwq model. Using a six year crop rotation, the following SCS curve numbers were selected for the model runs:

Forest	60
Pasture	69
Urban	72
Cropland	
Corn	78-80
Oats	72-75
Hay	70-72

#### *Roughness Coefficient*

The overland and channel roughness coefficient values effect the peak flow and sediment yield. When the overland roughness coefficient increases, the flow velocity decreases and flow needs more time to travel overland. As a result, the peak flow decreases in-turn decreasing the sediment yield. Overland roughness factors were selected as the following:

Crops	0.19
Forest	0.24
Pasture	0.30
Urban	0.12
Stream Channels	0.04

Table 2. SCS Runoff Curve Numbers for Antecedent Moisture Condition II.

Land Use		Condition	Hydrologic		Group	
Crop	Cover		----A----	----B----	----C----	----D----
Fallow	Straight Row		77	86	91	94
Row Crops	Straight Row	Poor	72	81	88	91
	Straight Row	Good	67	78	85	89
	Contoured	Poor	70	79	84	88
	Contoured	Good	65	65	82	86
	Contoured & Terraced	Poor	66	74	80	82
	Contoured & Terraced	Good	62	71	78	81
	Straight Row	Poor	65	76	84	88
Small Grain	Straight Row	Good	63	75	83	87
	Contoured	Poor	63	74	82	85
	Contoured	Good	61	73	81	84
	Contoured & Terraced	Poor	61	72	79	82
	Contoured & Terraced	Good	59	70	78	81
	Straight Row	Poor	66	77	85	89
	Straight Row	Good	58	72	81	85
Close-seeded legumes* or rotation meadow	Contoured	Poor	64	75	83	85
	Contoured	Good	55	69	78	83
	Contoured & Terraced	Poor	63	73	80	83
	Contoured & Terraced	Good	51	67	76	80
	*closed drilled or broadcast					
	Pasture or Range	Poor	68	79	86	89
		Fair	49	69	79	84
Meadow		Good	39	61	74	80
	Contoured	Poor	47	67	81	88
	Contoured	Fair	25	59	75	83
	Contoured	Good	6	35	70	79
		Good	30	58	71	78
	Woods	Poor	45	66	77	83
		Fair	36	60	73	79
Farmsteads		Good	25	55	70	77
			59	74	82	86
	Roads (dirt) *		72	82	87	89
Roads						
(Hard Surface) **			74	84	90	92
**including right-of-way						

\*A. (Low runoff potential). Soils having high infiltration rates even when thoroughly wetted and consisting chiefly of deep, well to excessively drained sands or gravels. These soils have a high rate of water transmission.

B. Soils having moderate infiltration rates when thoroughly wetted and consisting chiefly of moderately deep to deep, to moderately well to well drained soils with moderately fine to moderately coarse textures. These soils have a moderate rate of water transmission.

C. Soils having slow infiltration rates when thoroughly wetted and consisting chiefly of soils with a layer that impedes downward movement of water, or soils with moderately fine to fine texture. These soils have a slow rate of water transmission.

D. (High runoff potential). Soils having very slow infiltration rates when thoroughly wetted and consisting chiefly of clay soils with a high swelling potential, soils with a permanent high water table, soils with a claypan or clay layer at or near the surface, and shallow soils over nearly impervious material. These soils have a very slow rate of water transmission.

### *Planting and Harvest Dates*

These dates were suggested by the Dunn & Barron County staff as the following:

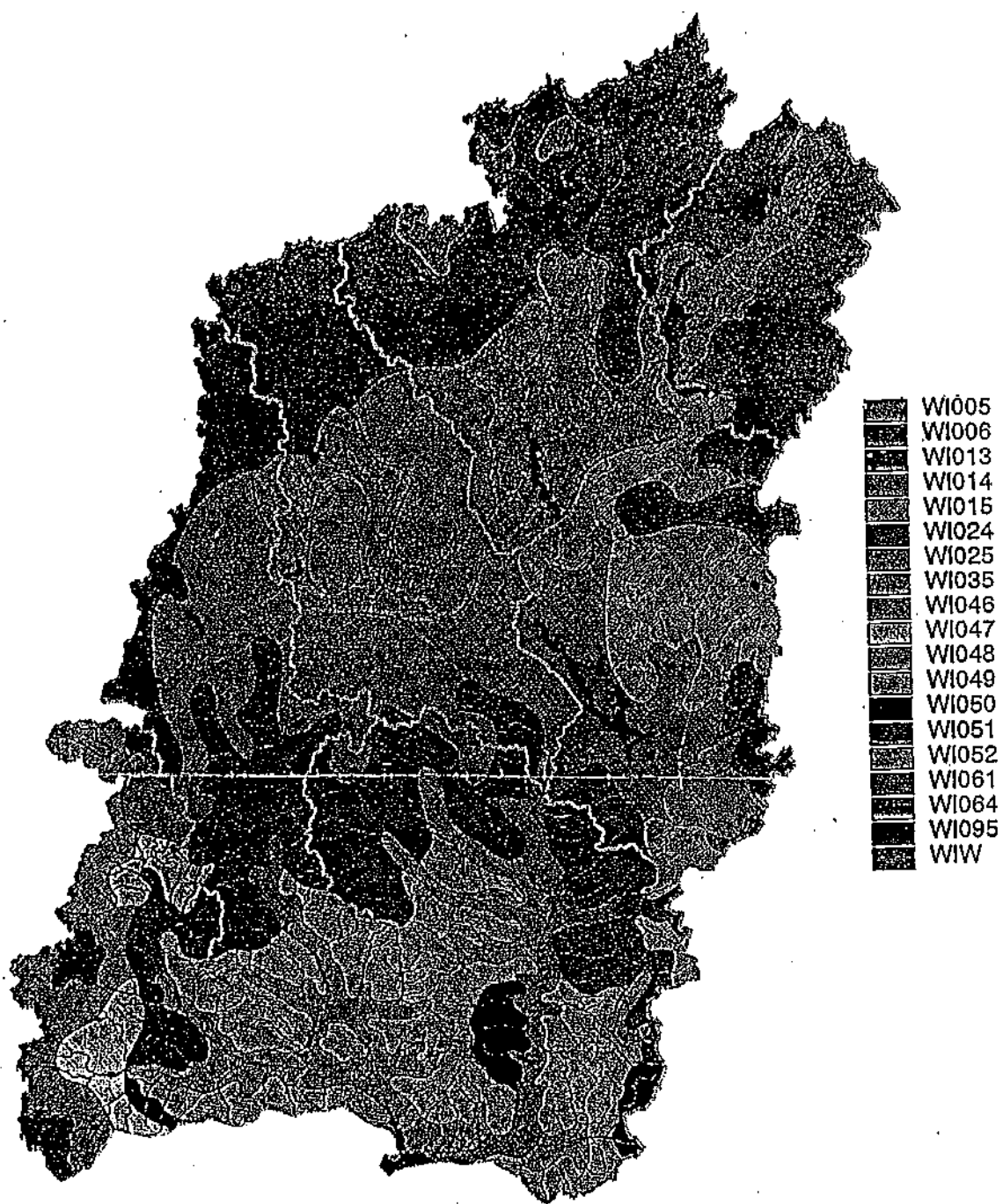
Planting Date	Harvesting Date
month/day	month/day
5/1	10/10

### *Soils Data*

Preliminary soils associations (e.g. Gale-Renova-Amery association) were obtained from Wisconsin STATSGO which is a general soils map of the state (Figure 3). Each soil association was a combination of three soils (such as Amery, Santiago, Gale etc.). Each of the seventy subareas in the basin could be a combination of one or more soil associations and therefore could have any combination of soils listed in Table 3. The values associated with various soils were obtained from the Soil-5 database which is built into the SWRRBwq model. The Soil-5 database was compiled by the Natural Resources Conservation Service (NRCS) Soil-5 Interpretation Records, and provides information on the characteristics and interpretive properties of all soils identified in the United States. This data has been collected and updated by NRCS for decades and contains the following properties and characteristics of more than 14,000 soils:

- number of soil layers
- USLE K factor
- Depth to the bottom of each layer
- Bulk density of soil layer
- Available water capacity of soil layer
- Saturated conductivity for soil layer
- Clay content
- Organic carbon percent for soil layer
- Initial NO<sub>3</sub> concentration
- Maximum root depth

**Figure 3. Soil Associations of the Red Cedar River**





**Table 3. Red Cedar River Soils and Soil Parameters**

Soil Name	USLE Factor K	% passing Seive #200	Layer 1 Density	Layer 1 Water Capacity	Layer 1 Conductivity	Layer 1 % Clay	Layer 1 Carbon
Alban	0.37	90	1.4	0.22	33.02	11	1.16
Amery	0.24	35	1.52	0.14	33.02	8	1.16
Antigo	0.37	90	1.4	0.22	33.02	11	1.16
Arland	0.24	37	1.45	0.14	33.02	9	1.16
Barronett	0.28	85	1.35	0.28	33.02	10	2.91
Chetek	0.24	32	1.6	0.08	330.02	2	0.58
Eleva	0.24	40	1.5	0.15	101.6	10	1.16
Elk mound	0.24	30	1.45	0.12	33.02	7	0.87
Friendship	0.17	21	1.57	0.1	330.2	5	0.76
Gale	0.37	90	1.45	0.11	101.6	3	0.76
Greenwood	0	0	0.35	0.6	152.04	0	37.79
Hixton	0.32	67	1.45	0.21	33.02	14	0.87
Magnor	0.37	82	1.45	0.21	33.02	11	1.16
Meehan	0.17	22	1.5	0.11	330.2	6	1.05
Menahga	0.15	20	1.35	0.11	330.2	6	0.76
Mehtomadi	0.15	22	1.5	0.11	330.02	8	0.58
Otterholt	0.37	80	1.47	0.23	33.02	12	1.74
Padus	0.24	37	1.52	0.13	33.02	6	0.87
Pence	0.24	32	1.42	0.13	101.6	7	0.47
Renova	0.37	82	1.35	0.23	33.02	23	0.87
Santiago	0.37	85	1.37	0.22	33.02	10	1.74
Seaton	0.37	97	1.15	0.23	33.02	18	1.16
Spencer	0.37	80	1.47	0.23	33.02	13	1.74
Tell	0.37	90	1.4	0.23	33.02	16	1.16
Urne	0.37	50	1.5	0.18	101.6	11	0.47
Vlasaty	0.37	87	1.4	0.23	33.02	22	1.16

All of these parameters were averaged for all of the predominant soils in each subarea. Representing this spatial distribution was crucial for a reasonable and accurate outcome. In addition, initial soil phosphorus concentrations of 0.0005 lb/lb of soil (Young et al., 1986 - AGNPS Model; Sims, 1992) were assumed in top two soil layers (10 mm and 76mm) for each subarea.

#### *Fertilizer and Manure Application Rate*

Values representing average phosphorus inputs from manure and commercial fertilizers were compiled from various literature sources, the Soils Testing Laboratory at the University of Wisconsin, Madison (personnel conversation with Dr. Sherry Combs and soil technicians at the lab), DNR staff, and the Livestock Waste Facilities Handbook.

A fertilizer application rate of 100 kg/ha/year was used for the cropland with the assumption that it was applied on the same date as the planting of the crop (Fox-Wolf Basin 2000 Technical Reports; nutrient management plans in north west wisconsin, DNR data). Unfortunately, the fertilizer application routine was not functioning in the SWRRBwq model. To overcome this problem (based upon personnel conversation with Dr. Jeff Arnold, author of SWRRBwq Model), the P-concentration in the soil was increased by 0.0003 lbs/lb-soil in order to account for the fertilizer application rate of 100 Kg/ha. Furthermore, phosphorus in commercial fertilizer was assumed to be bioavailable and was applied completed to the soluble pool for the model input.

In addition, it was estimated that soil phosphorus concentrations can increase to as high as 0.0013 lb/lb of soil due to long term manure additions (USDA, 1980). Other studies (Sims, 1992) also indicate an increase in soil concentration of 0.000996 lb-P/lb of soil (996 mg/Kg) due to long-term feedlot waste applications to cropland. Qiu, 1993 has also demonstrated a 2-4 fold increase in phosphorus levels and organic carbon content of soils due to long term manure application. For initial modeling runs, a conservative assumption was made that the manure application resulted in an increase in the phosphorus concentration of 0.0005 lb/lb-soil on the cropland. No increase in phosphorus was assumed for idle/pasture and forested lands. Phosphorus increase of 0.0005 lb/lb-soil was assumed for the urban areas due to lawn fertilizer

application.

The monitoring data collected in 1997 revealed extremely high concentrations of phosphorus associated with the sediment particles in cropland runoff (Paul La Liberte, Memorandum August 15, 1997). As a result of this study, the phosphorus concentrations in the top 10 mm layer were increased to 0.003 lb/lb-soil for the Hay River drainage area and 0.004 lb/lb-soil for the Red Cedar River drainage area. All final model runs were based upon these new enrichment ratios.

### *Topographic Data*

Topographic maps of scale 1:100,000 and 1:24,000 were used to extract slopes of agricultural lands, along with the lengths & slopes of stream channels. Drainage areas and areas in cropland in each watershed were compiled from the Lower Chippewa River Basin Plan and from personal communication with Dunn County LCD personnel. Channel characteristics such as width and depth were obtained with the help of the Dunn County LCD and DNR Western District staff. The routing channel for the simulation in each subarea was assumed to be the longest channel. This approximation was warranted by the SWRRBwq model. However, the Red Cedar River system contains numerous channels with varying lengths, widths and depths in each subarea. The density of these stream channels will have an effect on the flow, sediment and total phosphorus yields. Only the main and longest channel was used in each subarea although other segments of streams in the subareas can be used to improve channel routing characteristics.

### *Routing Characteristics within a Watershed*

The routing channel in the model is the distance from each subarea to the mouth of the watershed. Routing is conducted separately for each subarea, therefore, no interaction is assumed to occur between various subareas. The farthest point in each watershed was considered to be the mouth of each watershed. In addition, a number of lakes exist within the Red Cedar River Drainage system. Modeling the routing characteristics through each lake requires long-term monitoring and considerable effort which was beyond the scope of this project. Furthermore, the model can only incorporate lake/reservoir data for a lake which is located at the end of the watershed. Because the space and time behavior of a lake is complicated, a

simplifying assumption was made to use their trapping effect. A 50-90% reduction in sediment and in-turn particulate phosphorus was assumed to account for each large lake in the system and was accomplished in SWRRBwq by increasing the routing lengths for the subareas draining to the lakes. The trapping efficiency was estimated using an empirical model based on in-lake physical, chemical and biological processes, watershed runoff and phosphorus loading (Table 4).

#### *Weather Data*

The SWRRBwq model uses a in-built weather generator that provides statistics on various weather parameters at hundreds of stations throughout the U.S. These weather statistics are based on a 30 year record of weather information at each station. In Wisconsin, the model has weather data available at 21 stations. None of these stations were located in the Red Cedar River Basin, however, weather stations at St. Croix Falls and Weyerhauser were in the proximity to the Basin, and had long term weather data. The National Oceanic and Atmospheric Administration (NOAA) was contacted for additional weather data within the basin but very limited data was available for the study area. In the absence of long term data in the basin, the weather parameters at St. Croix Falls and Weyerhauser were averaged and the averaged parameters such as monthly rainfall, solar radiation, daily maximum and minimum temperature were used for the entire study area. This assumption might not account for all temporal variability in precipitation and temperatures but the model was used to estimate the pollutant loadings for a nine year period and for a nine year scenario. The simulated rainfall and temperature data at the two stations should be adequate to represent more long-term conditions. The other weather data included in the weather files was:

- frequency of 0.5 hour rainfall
- frequency of a six hour rainfall
- frequency of a wet day after a dry day
- frequency of a wet day after a wet day

Table 4. Red Cedar Basin Reservoir Trap Efficiency Using Brune's Curve  
Total Phosphorus Retention Using the Reckhow, 1979 Model

County	Lake Name	Lake Area (Ac)	Mean Depth (Ft)	Lake Volume AF	Direct Drainage Area (Ac)*	Direct Drainage Area (Mi <sup>2</sup> )	Runoff (In)	C/I Ratio	Brune's Curve Trapping	Total Phos. Retention
Barron	Chetek Lake Chain	3387	9.36	31690	83513	135.0	12.0	0.38	95%	56%
Barron	Rice Lake	939	9.00	8451	70272	109.8	10.5	0.14	85%	28%
Barron	Red Cedar Lake	1845	10.00	18450	20252	31.6	11.0	0.99	97%	60%
Barron	Bear Lake	1348	20.00	27160	11658	18.2	11.0	2.54	98%	83%
Sawyer	Lake Chatec Chain	2583	16.70	43087	45319	70.8	9.5	1.20	97%	84%
Washburn	Long Lake	3290	26.00	85540	26450	41.3	12.0	3.23	99%	84%

\* Lake Area subtracted from the drainage area.

### *Tillage*

The model provides the following four options for tillage operations on cropland:

- fall plow
- spring plow
- conservation tillage
- zero tillage

Based upon discussions with Dunn County LCD staff, the spring plow option was used for all areas of Dunn County. In Barron County, a combination of spring plow (60%), fall plow (10%) and conservation till (30%) was used. Two options were available to represent the vegetation in the SWRRBwq model: annual or perennial. Crops such as corn and oats were considered annual while forest and cropland with hay were assumed perennial.

### **7. Point Source Loadings**

All point sources that currently (for the year 1997) discharge into the Red Cedar River drainage systems were identified. Discharge Monitoring Records were used to estimate the yearly or seasonal loadings for all facilities. The summary of point source loadings in the basin is described in Appendix 3.

### **8. Barnyard Loadings**

A detailed inventory of the number of barnyards, and number & types of animal units was not available for each watershed. The total number of barnyards was available for the South Fork Hay River Watershed (Mechelke et al., 1992), the Red Cedar River & Pine Creek Watershed (Mechelke et al., 1992), and the Yellow River Watershed Priority Watershed Report (WDNR, 1993). The data from these three watersheds was used to estimate the average number of barnyards for the remaining four watersheds. Barnyard density (# barnyards/ha) was calculated for the three watersheds: South Fork Hay, Red Cedar & Pine, and Yellow River watersheds. Then, the number of barnyards in the remaining four watershed were estimated by multiplying the cropland area in each watershed by this barnyard density. Finally, after discussions with the Dunn and Baron County staff, these numbers were revised to reflect the most recent number of barnyards in each of the seven watersheds in the basin.

Based upon discussions with the DNR staff in the Bureau of Watershed Management, an average loading of 22.2 lbs/year was assumed from each barnyard in the study area. Several priority watershed projects have shown that the average loadings/barnyard (from a 10 year storm) for an entire watershed in different parts of the state (Yellow River, Black Earth Creek, Duncan Creek) range from 8-10.5 lbs/storm (Mechelke et al., 1992). Therefore, it was a reasonable assumption to assign an average phosphorus loading to a barnyard in the basin. In addition, water quality monitoring has demonstrated that as much as 50% of the barnyard load can be in the form of available phosphorus. Therefore, an assumption was made that 50% of the total phosphorus from barnyard runoff was in the form of available phosphorus.

#### **9. Load Routing from Individual Watersheds to Tainter Lake**

The phosphorus load at mouth of each watershed consisted of particulate phosphorus (runoff associated-P from uplands and barnyards) and available (or dissolved) phosphorus. The available phosphorus was the sum total of the following:

- a. Dissolved fraction of the total phosphorus associated with runoff from all land uses such as cropland, urban, pasture, and forest.
- b. Point source phosphorus (an assumption was made that it was all soluble).
- c. Forty percent of barnyard runoff (an assumption was made that 40% of all barnyard runoff was in the available form).

For routing phosphorus from the watersheds to Tainter Lake, only particulate phosphorus was routed. Particulate phosphorus from the barnyards was first routed to the mouth of each watershed and then from the mouth of a watershed to Tainter Lake. It was also assumed that due to the relatively short routing distance and travel time in the drainage area, 100% of the dissolved phosphorus from each watershed reached the mouth of Tainter Lake.

To develop the routing procedure from the outlet of each watershed to Tainter Lake, sediment and sediment attached phosphorus delivery ratios were needed. The Fox Wolf Basin 2000

Technical Report (1993) describes the channel delivery ratios that represent the ratio of routed TSS & TP loads reaching basin outlet to the unrouted loads as a function of distance (Figure 4). These values were obtained by conducting TSS & TP monitoring in the channels within various subareas and main routing channels in the entire Wolf River drainage system. Table 5 represents the routing distances for all seven watersheds along with channel delivery ratios for TSS and particulate phosphorus loads in the Red Cedar River system.



Figure 4. Sediment & Phosphorus Routing in the Channels as a Function of Distance

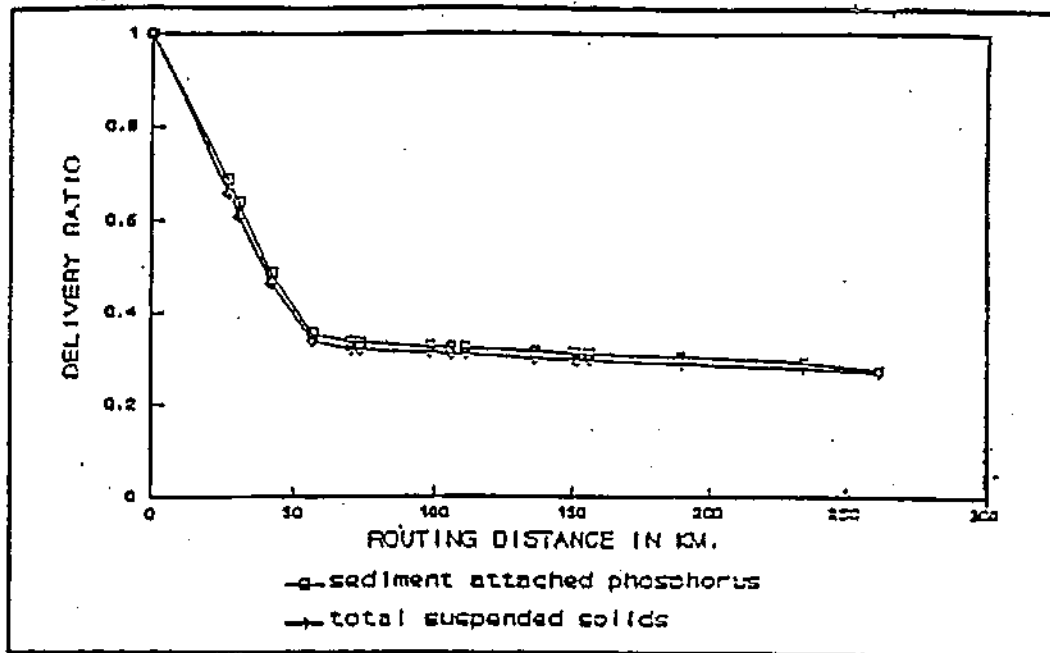


Table 5. Channel Delivery Ratios for seven watersheds in Red Cedar River Basin

Watershed name	Watershed #	Routing Distance to Tainter Lake (Km)	TSS Delivery Ratio	Particulate-P Delivery Ratio
Hay River	LC05	0.0	1.00	1.00
South Fork Hay River	LC06	32.5	0.71	0.68
Pine Creek & Red Cedar River	LC07	0.0	1.00	1.00
Lake Chetek	LC08	64.8	0.35	0.33
Yellow River	LC09	64.8	0.35	0.33
Brill & Red Cedar	LC10	86.2	0.32	0.30
Red Cedar lake	LC11	93.8	0.32	0.30

## 10. Results

The SWRRBWq model results for the simulated average annual sediment and phosphorus loadings from the cropland, pasture/idle land, forest and urban areas are listed in Tables 6 & 7. Table 6 lists the average annual subwatershed and watershed yields, and corresponding loadings from the four land uses in the basin. Table 7 represents a comparison of areas, average annual sediment and phosphorus loadings from various land uses in the seven watersheds. Table 8 represents the average annual sediment, particulate and dissolved phosphorus loadings from all sources (upland runoff, barnyards and point sources) at the mouth of each watershed. The routed average annual sediment and total phosphorus loadings from individual watersheds to Tainter Lake are also shown in Table 8. All dissolved (available) phosphorus was routed 100% to Tainter Lake. The particulate phosphorus and sediment was routed to Tainter Lake using routing ratios from Table 5.

Table 6. SWRRBwq Modeling Results for TSS & TP Loadings.

Watershed Name	Watershed #	Land Use	Area	Subwatershed TSS Yield MT/ha	Watershed TSS Yield MT/ha	Watershed TP Yield Kg/ha	Subwatershed TSS Load MT	Watershed TSS Load MT	Watershed TP Load Kg
Hay River	LC05	Cropland	23369	3.456	0.487	1.344	80763	11381	31408
		Forest	34336	0.257	0.056	0.14	8824	1923	4807
		Pasture	15679	0.388	0.036	0.15	6083	564	2352
		Urban	1621	1.948	0.292	0.7	3158	473	1135
		Total	75006				98829	14341	39702
South Fork Hay	LC06	Cropland	17188	3.096	0.618	1.092	53214	10622	18769
		Forest	16867	0.33	0.107	0.09	5566	1805	1518
		Pasture	11559	0.348	0.049	0.18	4023	566	2081
		Urban	1351	1.822	0.341	0.74	2462	461	1000
		Total	46967				65264	13454	23368
Pine Creek & Red Cedar	LC07	Cropland	32031	3.392	0.447	1.068	108649	14318	34209
		Forest	20371	0.09	0.026	0.16	1833	530	3259
		Pasture	21421	0.372	0.031	0.18	7969	664	3856
		Urban	663	1.863	0.221	0.7	1235	147	464
		Total	74486				119686	15658	41788
Lake Chetek	LC08	Cropland	12107	2.82	0.349	0.96	34142	4225	11623
		Forest	33442	0.139	0.034	0.14	4648	1137	4682
		Pasture	8138	0.381	0.036	0.18	3101	293	1465
		Urban	1219	1.835	0.262	0.69	2237	319	841
		Total	54908				44128	5975	18611
Yellow River	LC09	Cropland	24614	3.66	0.476	1.365	90087	11716	33598
		Forest	19370	0.066	0.02	0.1	1278	387	1937
		Pasture	16509	0.359	0.04	0.16	5927	660	2641
		Urban	1483	1.751	0.268	0.62	2597	397	919
		Total	61978				99889	13161	39096
Brill & Red Cedar	LC10	Cropland	16580	3.088	0.35	1.274	51199	5803	21123
		Forest	48183	0.103	0.031	0.12	4963	1494	5782
		Pasture	11120	0.358	0.061	0.17	3981	678	1890
		Urban	1220	1.775	0.364	0.71	2166	444	866
		Total	77104				62308	8419	29661
Red Cedar Lake	LC11	Cropland	648	2.89	0.3	0.975	1873	194	632
		Forest	34641	0.06	0.031	0.06	2078	1074	2078
		Pasture	324	0.248	0.061	0.16	80	20	52
		Urban	647	1.84	0.215	0.72	1190	139	466
		Total	36260				5222	1427	3228

Table 7. SWRRBwq Modeling Results for Various Land Uses

Watershed Name	Watershed #	Category	Unit	Cropland	Forest	Pasture	Urban	Total
Hav River	LC05	Area	Ha	23369	34336	15679	1621	75006
South Fork Hav	LC06	Area	Ha	17188	16867	11559	1351	46967
Pine Creek & Red Cedar	LC07	Area	Ha	32031	20371	21421	633	74486
Lake Chetek	LC08	Area	Ha	12107	33442	8138	1219	54908
Yellow River	LC09	Area	Ha	24614	19370	16509	1483	61978
Brill & Red Cedar	LC10	Area	Ha	16580	48183	11120	1220	77104
Red Cedar Lake	LC11	Area	Ha	648	34641	324	647	36260
Total		Area	Ha	126537	207210	84750	8174	426709
Hav River	LC05	TP Load	Kg	31408	4807	2352	1135	39702
South Fork Hav	LC06	TP Load	Kg	18769	1518	2081	1000	23368
Pine Creek & Red Cedar	LC07	TP Load	Kg	34209	3259	3856	464	41788
Lake Chetek	LC08	TP Load	Kg	11623	4682	1465	841	18611
Yellow River	LC09	TP Load	Kg	33598	1937	2641	919	39096
Brill & Red Cedar	LC10	TP Load	Kg	21123	5782	1890	866	29661
Red Cedar Lake	LC11	TP Load	Kg	632	2078	52	466	3228
Total		TP Load	Kg	151362	24063	14337	5691	193454
Hav River	LC05	TSS Load	MT	11381	1923	564	473	14341
South Fork Hav	LC06	TSS Load	MT	10622	1805	566	461	13454
Pine Creek & Red Cedar	LC07	TSS Load	MT	14318	530	664	147	15658
Lake Chetek	LC08	TSS Load	MT	4225	1137	293	319	5975
Yellow River	LC09	TSS Load	MT	11716	387	660	397	13161
Brill & Red Cedar	LC10	TSS Load	MT	5803	1494	678	444	8419
Red Cedar Lake	LC11	TSS Load	MT	194	1074	20	139	1427
Total		TSS Load	MT	58259	8350	3445	2380	72435

Table 8. Total Phosphorus Loadings in Seven Watersheds.

Watershed Name	Watershed #	Runoff TP Load Kg	Runoff PP Load Kg	Runoff DP Load Kg	# Barnyards	Barnyard TP Load Kg	Barnyard PP Load Kg	Barnyard DP Load Kg	Point S. DP Load Kg	Combined TP Load Kg	Combined PP Load Kg	Combined DP Load Kg
Hay River	LC05	39702	22279	17423	279	2806	1403	1403	6839	49346	23682	25664
South Fork Hay	LC06	23368	11199	12169	205	2062	1031	1031	1484	26913	12230	14683
Pine Creek & Red Cedar	LC07	41788	17695	24093	382	3842	1921	1921	837	46465	19616	26849
Lake Chetek	LC08	18611	6353	12258	144	1448	724	724	1306	21364	7077	14287
Yellow River	LC09	39096	17747	21349	294	2957	1478	1478	3033	45084	19225	25859
Brill & Red Cedar	LC10	29661	13032	16629	198	1991	996	996	2375	34028	14028	20000
Red Cedar Lake	LC11	3228	739	2489	8	80	40	40	0	3308	779	2529
Total		195454	89044	106410	1510	15186	7593	7593	15874	226508	96637	129871

Table 9. Sediment and Phosphorus Loadings Routed to Tainter Lake.

Watershed Name	Watershed #	Unrouted TP Load Kg	Unrouted PP Load Kg	Unrouted DP Load Kg	Routed PP Load Kg	Routed TP Load Kg	Unrouted TSS Load MT	Routed TSS Load MT
Hay River	LC05	49346	23682	25664	23682	49346	14341	14341
South Fork Hay	LC06	26913	12230	14683	8316	22999	13454	9552
Pine Creek & Red Cedar	LC07	46465	19616	26849	19616	46465	15658	15658
Lake Chetek	LC08	21364	7077	14287	2335	16622	5975	2091
Yellow River	LC09	45084	19225	25859	6344	32203	13161	4606
Brill & Red Cedar	LC10	34028	14028	20000	4208	24208	8419	2694
Red Cedar Lake	LC11	3308	779	2529	234	2763	1427	457
Total		226508	96637	129871	64735	194606	72435	49400

Figure 5 represents the sediment and phosphorus loadings delivered to the mouth of each watershed along with the land uses for the entire basin. The relative sediment and phosphorus contribution of the seven watersheds to Tainter Lake is shown in Figure 6. The output files from the SWRRBWq Model generate sediment loadings in each subarea before routing it to the mouth of each watershed. Using this information, Figure 7 was developed to identify the subareas with high sediment export within each watershed. Figures 8 through 14 represent the loading estimates (routed to the mouth of each watershed) and land uses for each of the seven watersheds in the basin. Figure 15 represents the relative contribution of total phosphorus and sediment from different types of land use in the basin.

## **11. Discussion**

The sediment and phosphorus loads were estimated at the mouth of each of the seven watersheds and were then routed to Tainter Lake. Therefore, the discussion of the modeling results is divided into loads routed to the mouth of each watershed and loads routed to Tainter Lake.

### *Loads Routed to the mouth of each watershed:*

A long term average annual sum of all the sediment and total phosphorus loads delivered to the mouths of the seven watersheds in the Red Cedar Basin is estimated at approximately 72,000 MT and 226,500 Kg, respectively (Table 8 & 9). In all watersheds, except for the Red Cedar Lake Watershed, cropland represents the largest source of sediment and phosphorus loading (Figures 8-14). Forested areas represent the largest source of phosphorus loadings in the Red Cedar Lake watershed as it is the predominant land use in the watershed as well. The point source contribution of the total load varies among the seven watersheds; point source loads being the highest in the Hay River Watershed (nearly 16%) to negligible in the Red Cedar Lake Watershed.

Of the seven watersheds, the Pine Creek and Red Cedar River Watershed (LC07), Hay River Watershed (LC05), and Yellow River Watershed (LC09) are the three highest contributors of phosphorus load from runoff (Table 6). The phosphorus loadings for these three watersheds are

Figure 5. Total Phosphorus and Sediment Loads Routed to Tainter Lake Including Barnyards and Point Sources.

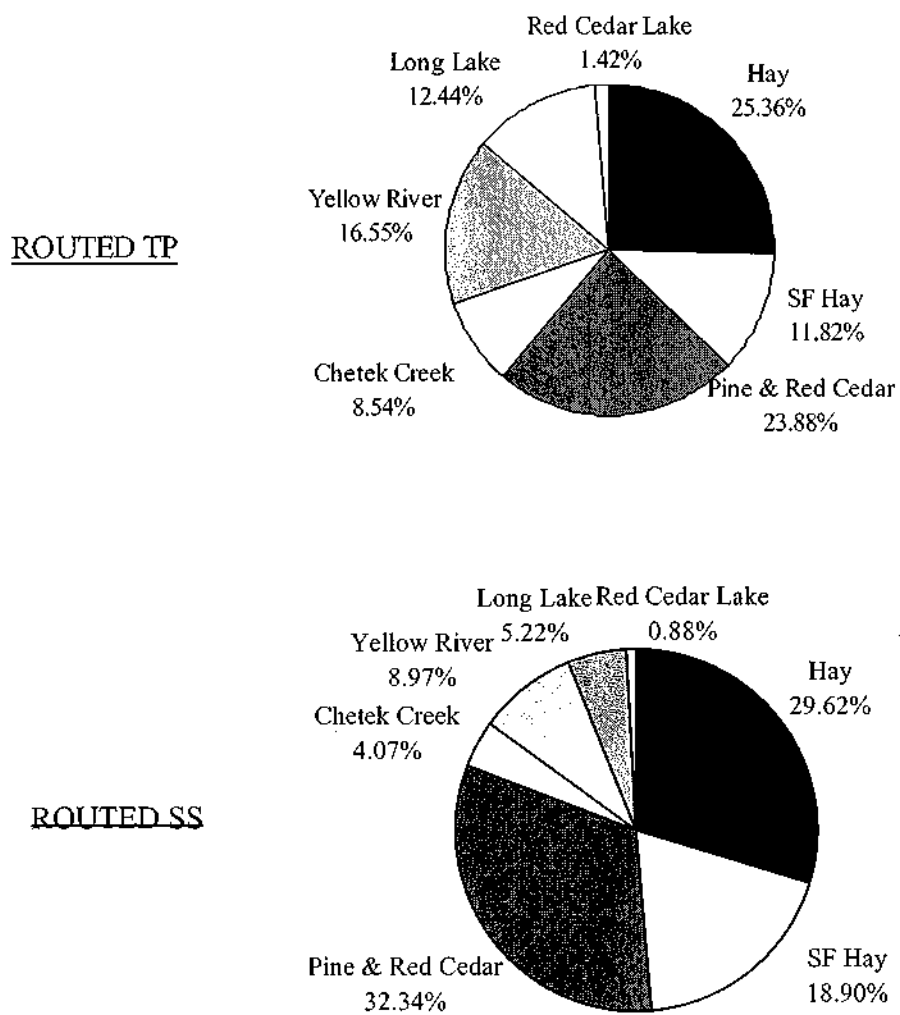
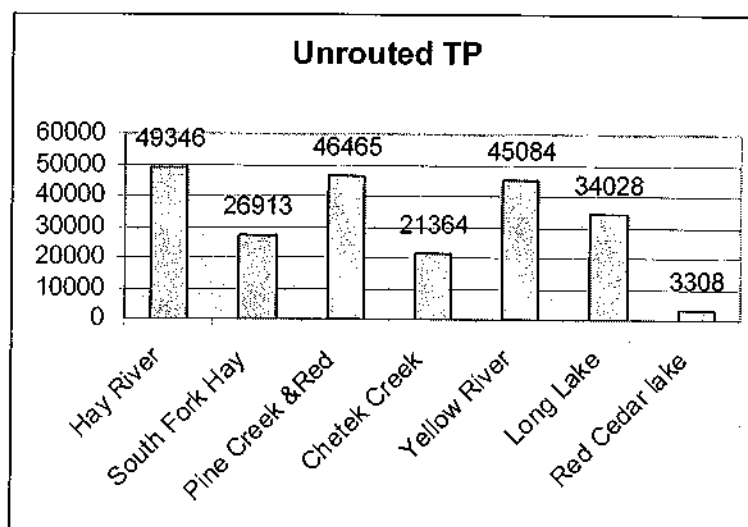
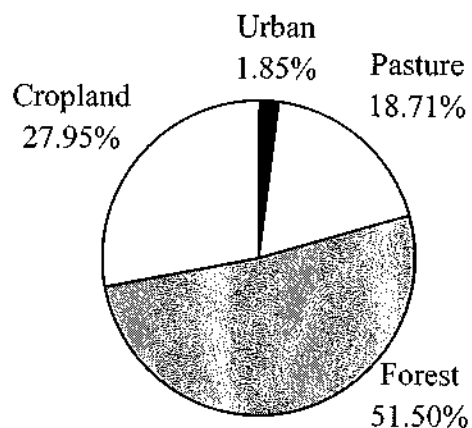


Figure 6. Land Use, Sediment and Phosphorus Loadings From All Seven Watersheds Including Point Sources and Barnyards.

# LAND USE



# UNROUTED SS

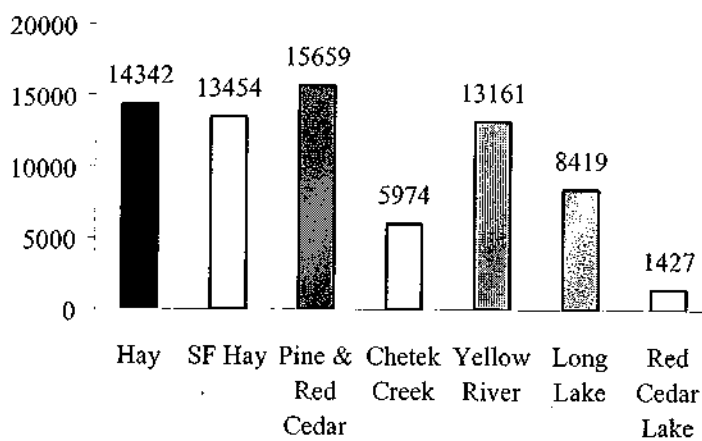




Figure 7. Critical subareas in the Red Cedar River Basin with Highest Sediment Erodibility.

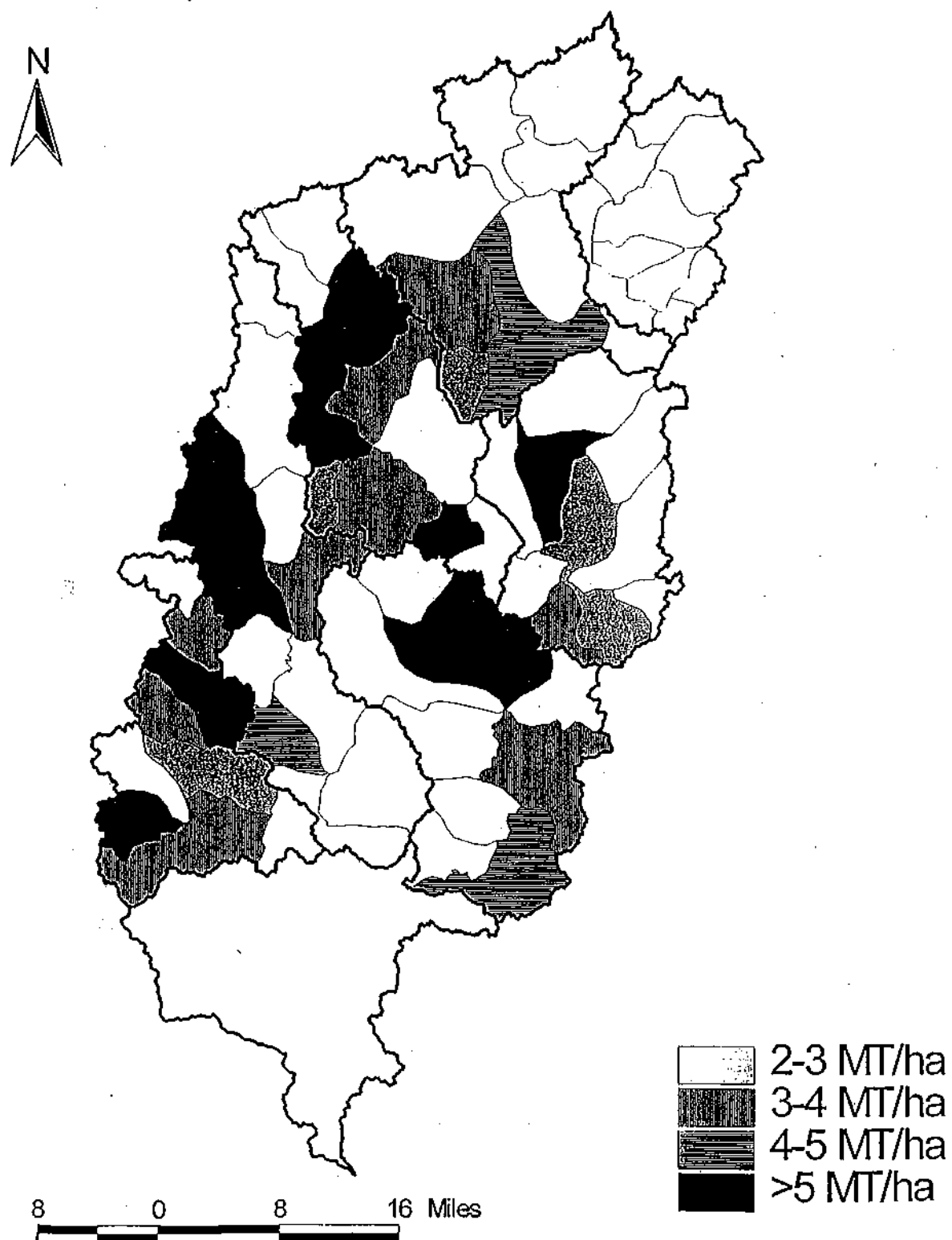


Figure 8. Hay River Watershed (LC05) Land Use, Sediment and Phosphorus Loads.

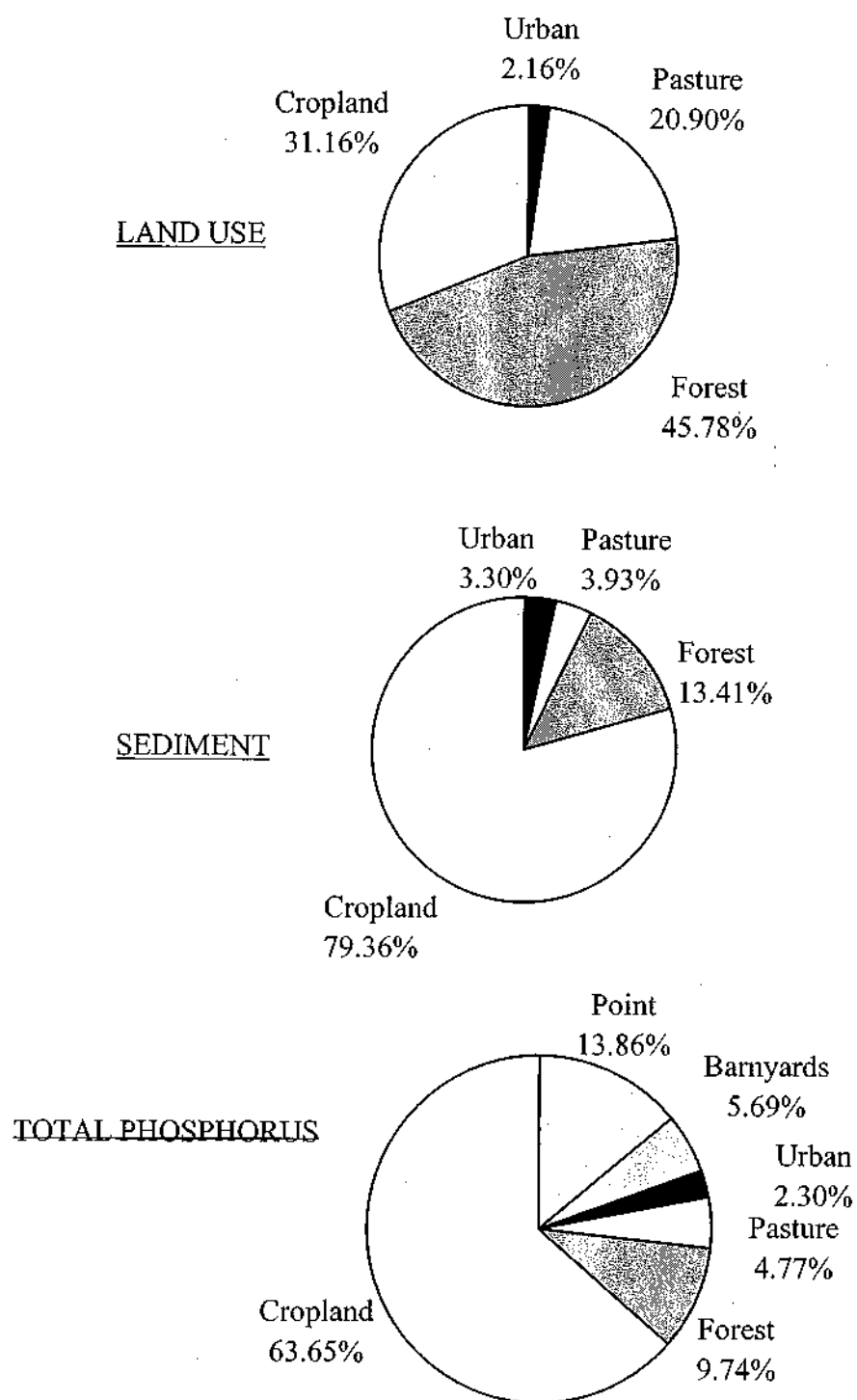


Figure 9. South Fork Hay River Watershed (LC06) Land Use, Sediment and Phosphorus Loads.

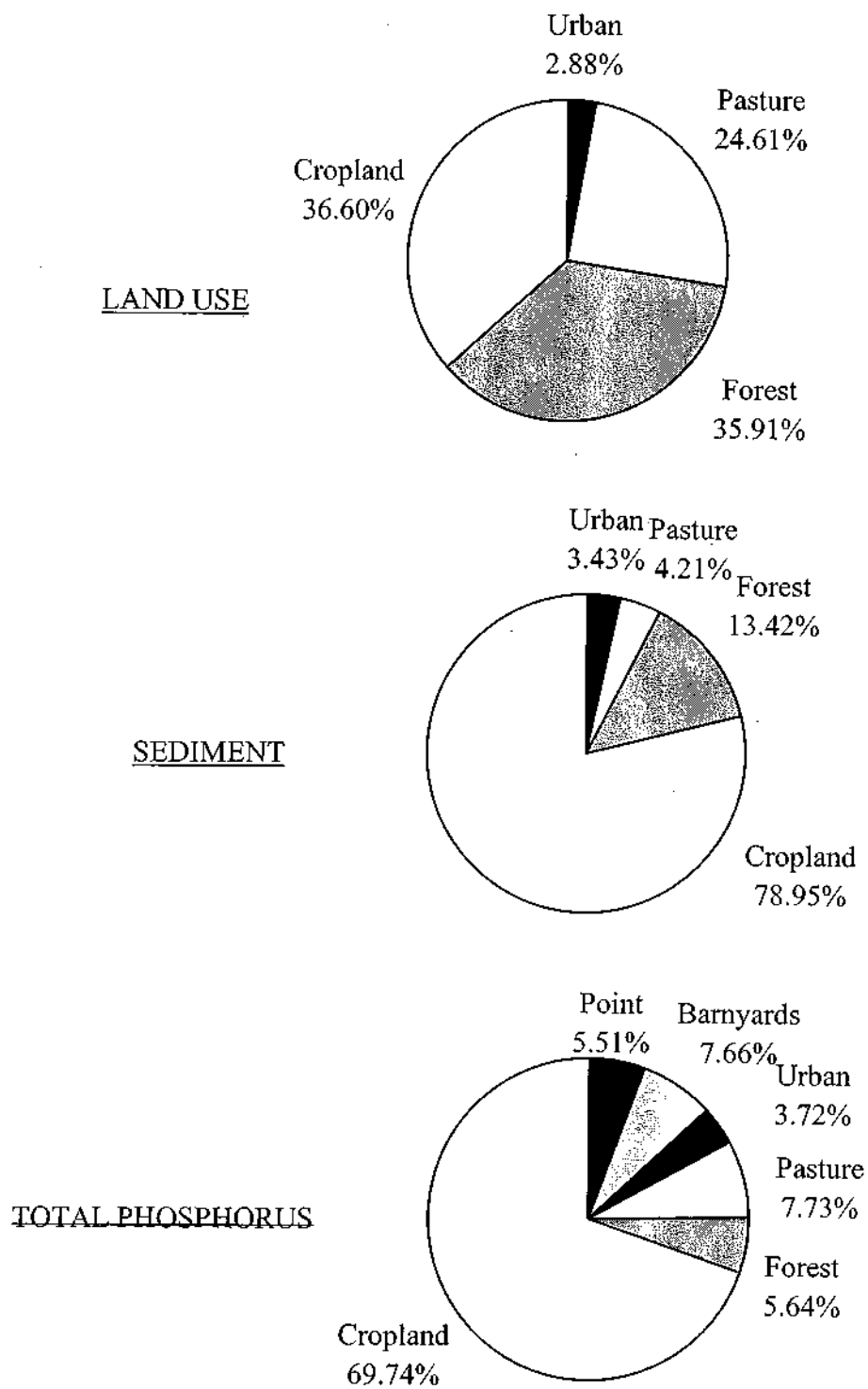


Figure 10. Pine Creek & Red Cedar River Watershed (LC07) Land Use, Sediment and Phosphorus Loads.

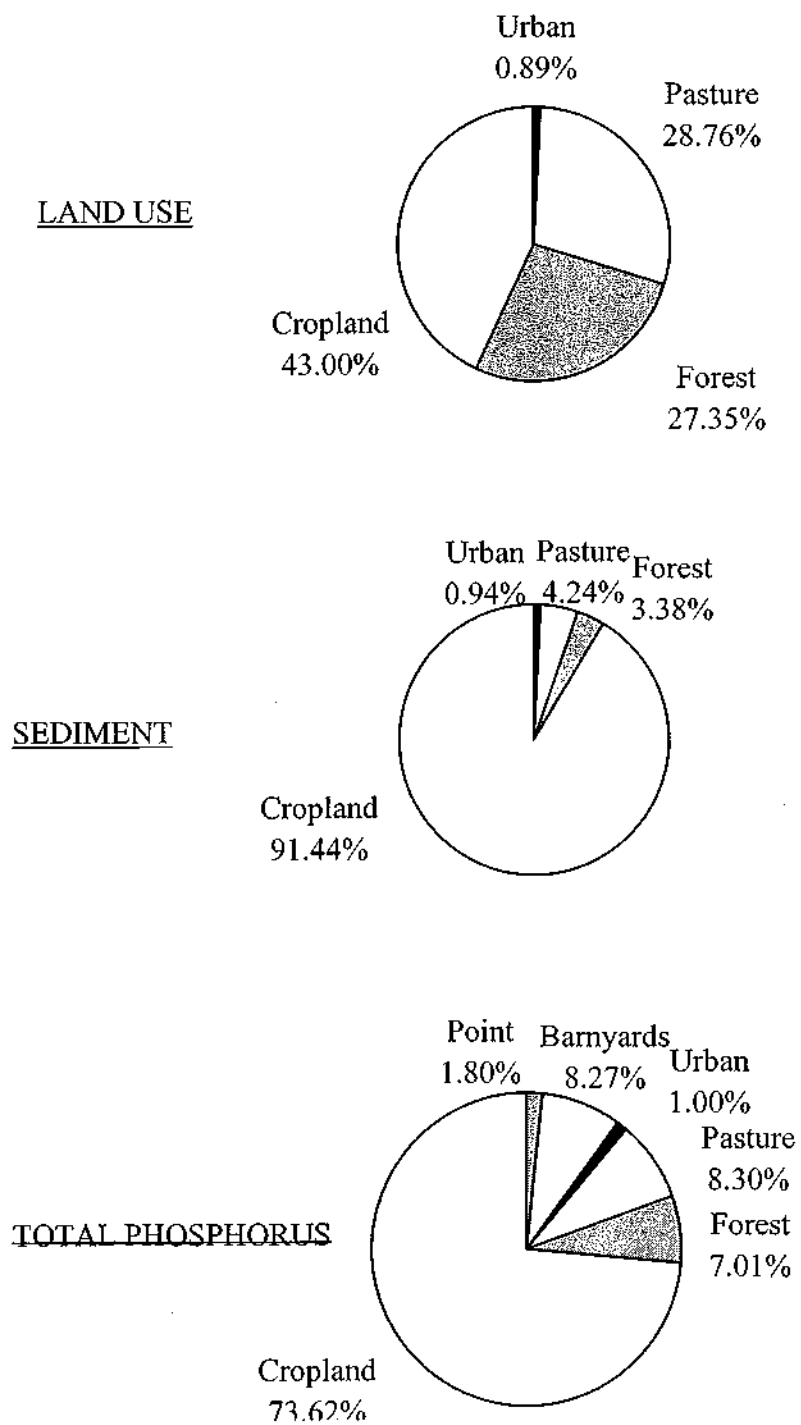
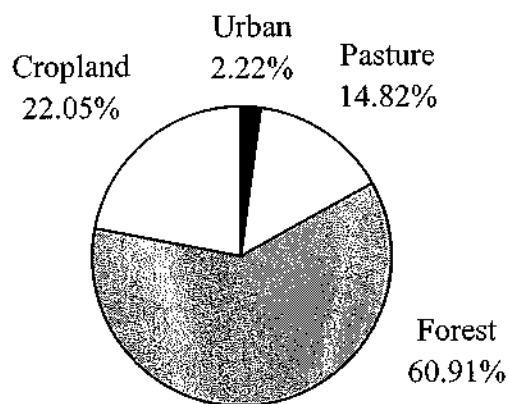
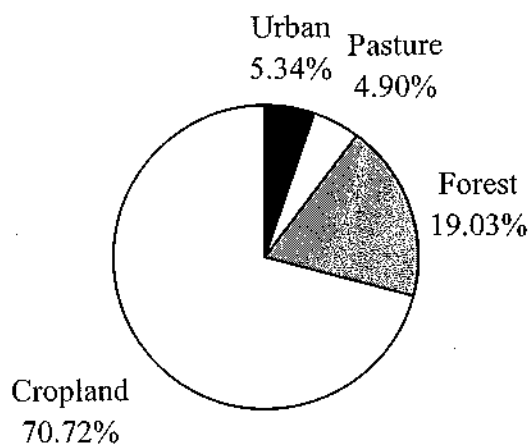


Figure 11. Chetek Creek Watershed (LC08) Land Use, Sediment and Phosphorus Loads.

LAND USE



SEDIMENT



TOTAL PHOSPHORUS

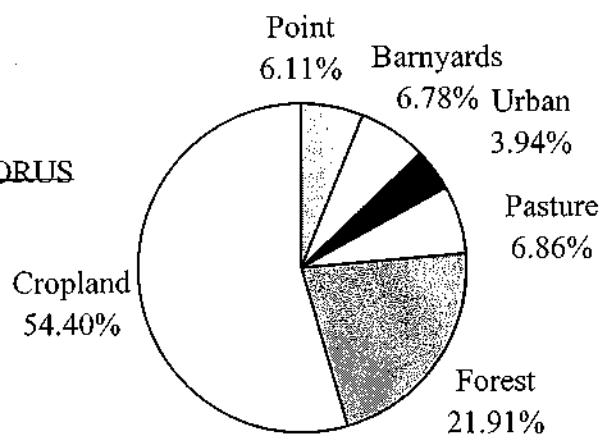


Figure 12. Yellow River Watershed (LC09) Land Use, Sediment and Phosphorus Loads.

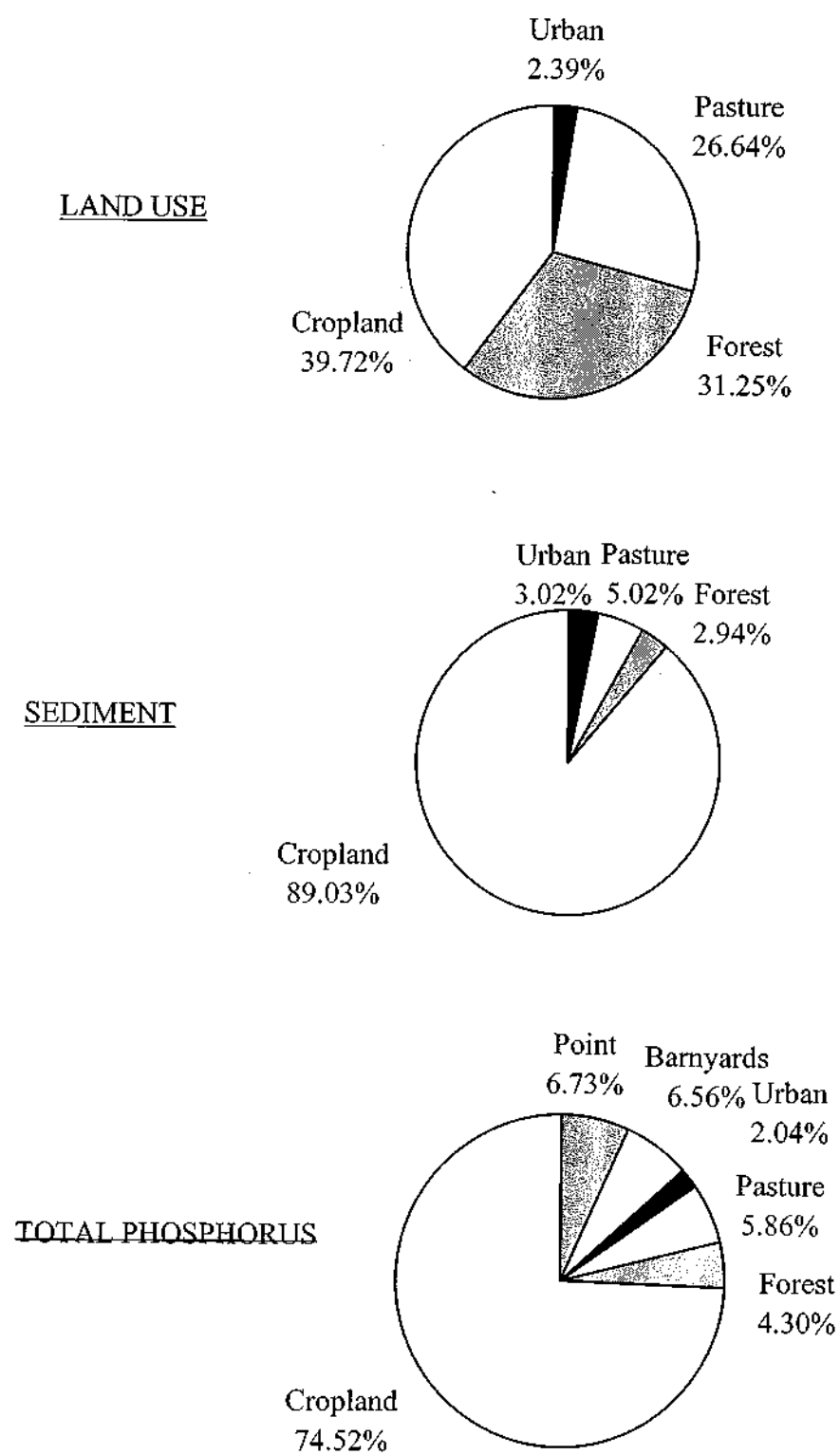
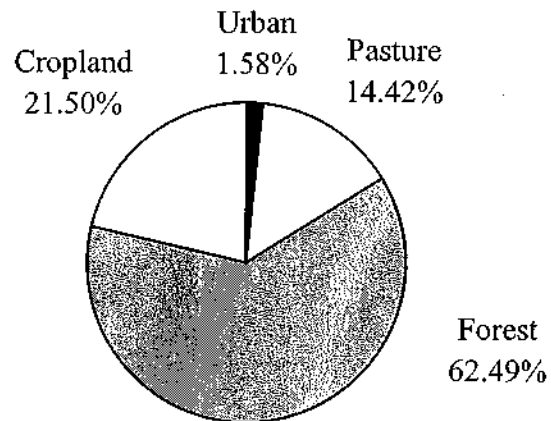
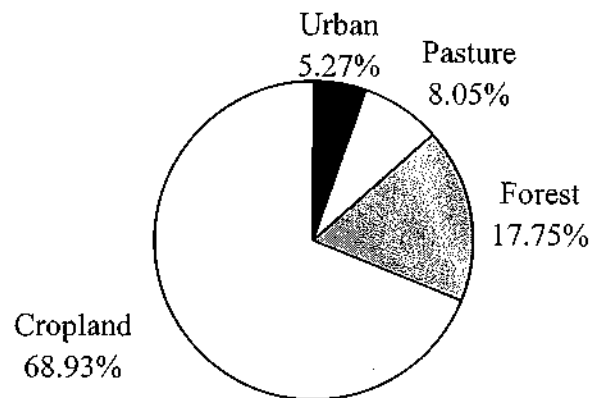


Figure 13. Brill & Red Cedar River Watershed (LC10) Land Use, Sediment and Phosphorus Loads.

LAND USE



SEDIMENT



TOTAL PHOSPHORUS

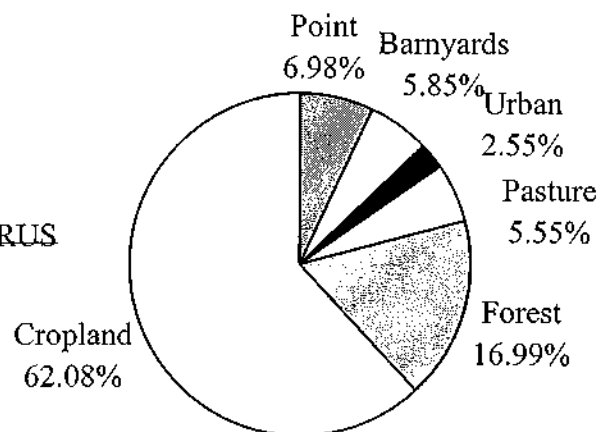
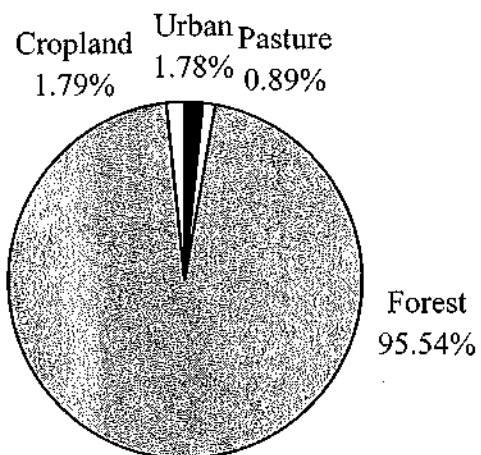
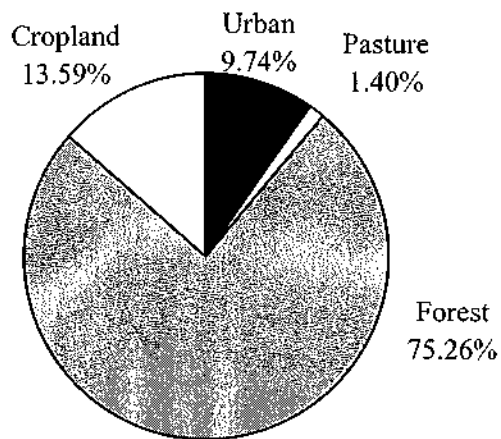


Figure 14. Red Cedar Lake Watershed (LC11) Land Use, Sediment and Phosphorus Loads.

LAND USE



SEDIMENT



TOTAL PHOSPHORUS

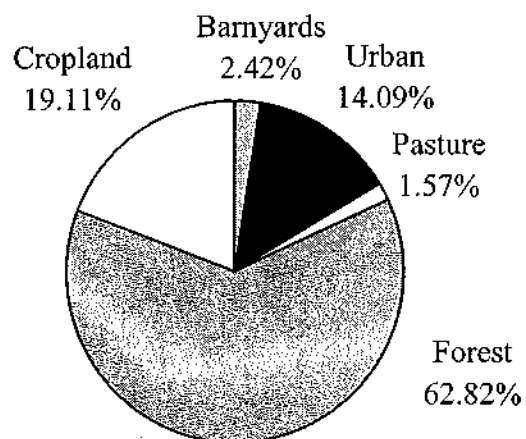
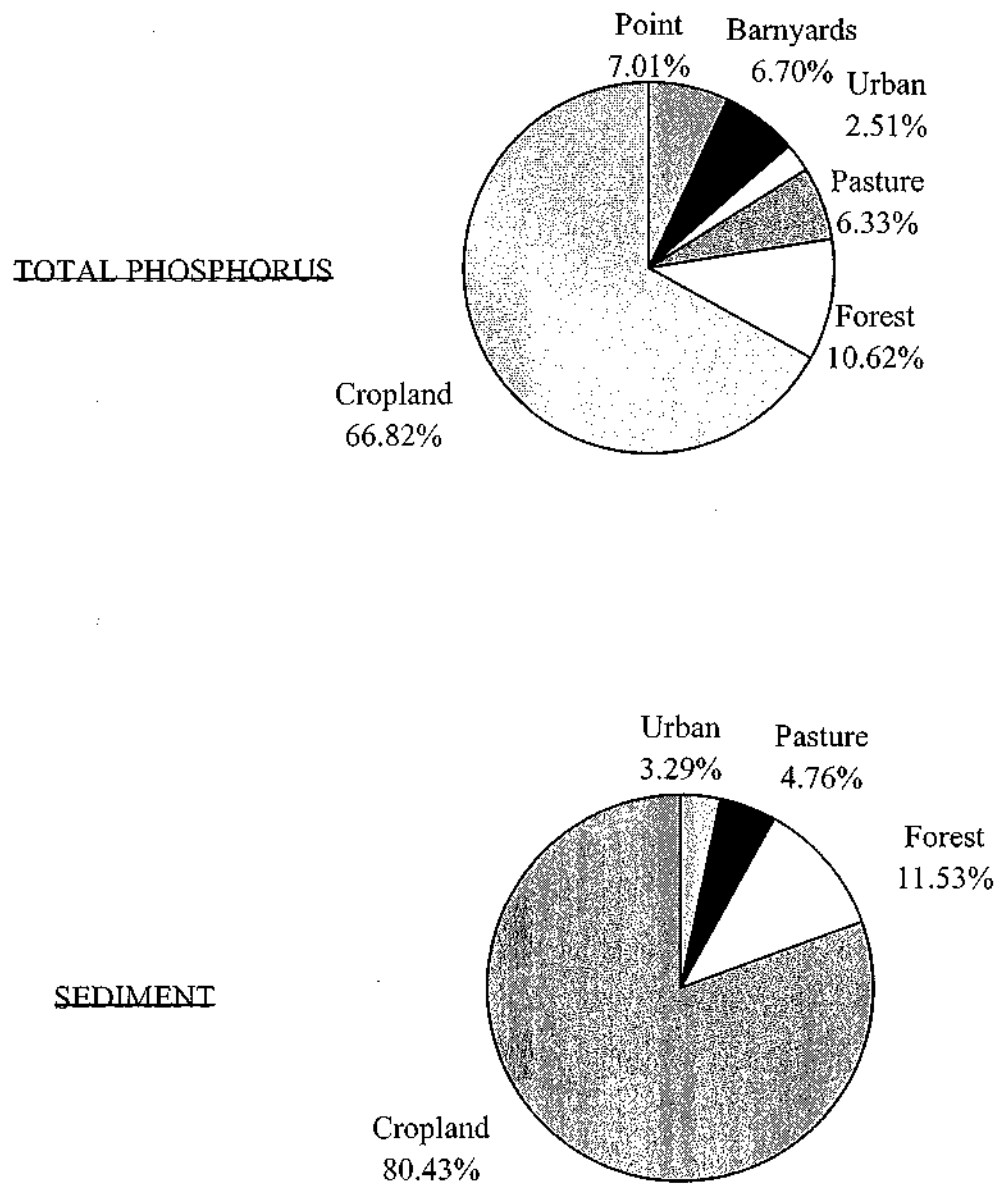




Figure 15. Total Phosphorus and Sediment Loads From Each Land Use Routed to Tainter Lake.



quite comparable and are estimated at nearly 40,000 Kg for each watershed (this load does not include the loading from the point sources or barnyards in each watershed).

#### *Loads Routed to Tainter Lake:*

As indicated in Tables 8 & 9, nearly 49,000 MT of sediment and 195,000 Kg of phosphorus make it to Tainter Lake in an average annual basis. Cropland runoff represents nearly 82% of the total sediment load and 64% of the total phosphorus load (Figure 15) reaching Tainter Lake. The forested area also represents a significant source of phosphorus loading to Tainter Lake contributing nearly 11%. Point sources and barnyards each represent nearly 7% of the total phosphorus load reaching Tainter Lake.

The Hay River Watershed (LC05) and Pine River & Red Cedar River Watershed (LC07) contribute nearly 62% of the sediment load (Figure 5) to Tainter Lake. These two watersheds not only produce high sediment loads but they are also delivered directly into the lake which in-turn makes their contributions significant. These two watersheds along with the South Fork Hay Watershed (LC06) contribute nearly 80% of the sediment load reaching Tainter Lake. The remaining four watersheds contribute less than 20% of the total sediment load due to the greater routing distance and corresponding lower deliveries to Tainter Lake.

The Hay River (LC05), and Pine River & Red Cedar River (LC07) watersheds represent the two largest contributors of phosphorus loading, discharging nearly 50% of the total annual phosphorus load to Tainter Lake. The Yellow River (17%), South Fork Hay (12%) and Long Lake (12%) watersheds are also significant contributors of phosphorus to Tainter Lake.

#### *Validation of the SWRRBwq Modeling Results*

The results of this effort match reasonably well with the information and data available from other monitoring and modeling studies in Wisconsin. Panuska et al. (1995) have shown that the most likely phosphorus loadings from agricultural and forested areas are 1.0 Kg/ha and 0.09 Kg/ha, respectively, in Wisconsin. These yields are based upon long term monitoring of a number of stations throughout Wisconsin. The SWRRBwq model results show that the range in average annual total phosphorus yield is 0.96-1.4 Kg/ha for forested land, and is 0.06-0.14 Kg/ha for cropland. In addition, the SWRRBwq loadings for each land use category are similar to those

from this statewide study.

Mechelke (1992) developed land use based phosphorus loads for the South Fork Hay River Watershed (LC06), and Pine and Red Cedar River Watershed (LC07) using EPA recommended phosphorus export coefficients. A comparison of Mechelke's results with the SWRRBwq results is shown in Table 10. The SWRRBwq results match well with results of this study. The results compare well not only for the total loads but also for the yields (lbs/ha) from cropland and forested areas in each of the two watersheds .

Table 10. Comparison of Mechelke, 1992 study and SWRRBwq Results

Parameter	Units	Mechelke, 1992 Results	SWRRBwq Results
S.F. Hay (LC06) Watershed total P-loads from cropland, forested, urban and pasture	Kg/year	29,022	23,367
Pine and Red Cedar Creek (LC07) Watershed Total P-loads from Ag., forested, urban and pasture	Kg/year	44,828	41,786
P-yield from Croplands (assuming Corn-Hay-Hay rotation)	Kg/ha	0.93	0.96-1.37
P-yield from Forested areas	Kg/ha	0.035	0.06-0.16

The nine year annual average sediment and phosphorus loadings predicted using the SWRRBwq model are comparable to the 1990 monitoring results at the two inlets to Tainter Lake. The monitoring results estimate the sediment and phosphorus loads at approximately 27,000 MT and 318,000 Kg, respectively to Tainter Lake for the year 1990. The nine year modeled average for sediment and phosphorus loads is 49,000 MT and 195,000 Kg, respectively.

The difference in the modeled and monitored results can be explained by the fact that the monitoring loads represent only one year of load while the modeling results represent long term average annual loads. In addition, 1990 was an atypical year during which 40% of the total load was delivered during a single storm event. Furthermore, the enrichment ratio (phosphorus in lbs /sediment in MT) was nearly 23.5 for the monitored year 1990. This ratio is exceptionally high

when compared with these ratios from other geographic areas in the state. The ratio for the modeling results is nearly 10 lbs/MT which is well within the range of the ratios observed at the master monitoring stations throughout the state.

### **13. Conclusions**

The following conclusions can be drawn from the results of this study.

- On an average annual basis, almost 500,000 MT of sediment is delivered to the seventy subwatersheds of the Red Cedar River Basin, of which approximately 49,000 MT (10%) is delivered to Tainter Lake.
- On an average annual basis, the total sediment delivered to the outlets of the seven watersheds of the Red Cedar River Basin is about 72,000 MT, of which approximately 49,000 MT is delivered to Tainter Lake.
- On an average annual basis, the total phosphorus delivered to the outlets of the seven watersheds of the Red Cedar River Basin is nearly 226,500 Kg, of which approximately 195,000 Kg is delivered to Tainter Lake.
- Cropland represents the largest and most dominant source of sediment and phosphorus loading in the Red Cedar River Basin to Tainter Lake. Barnyards also represent a significant source of phosphorus in the basin.
- On an average annual basis, point sources represent 7% of the total phosphorus load reaching Tainter Lake from all sources.
- The sediment loadings from each of the seven watersheds to Tainter Lake is strongly influenced by the proximity of each watershed to Tainter Lake. The Hay River Watershed (LC05), Pine River & Red Cedar River Watershed (LC07), and South Fork Hay Watershed (LC06) contribute nearly 80% of the sediment loads to Tainter Lake as they have little or no routing distance to the lake.

- The phosphorus loading from each watershed to Tainter Lake is also dependent upon the routing distance of each watershed to the lake, however, other factors such as the soluble fraction of total phosphorus in the runoff, point source loads, number of barnyards etc. play an important role. Unlike the sediment loads, the majority of which are contributed by only three watersheds, the majority of the phosphorus loadings to the Tainter Lake are distributed across six of the seven watershed.
- The phosphorus enrichment ratios in the Red Cedar River Basin, as indicated by the instream monitoring conducted in the years 1990 and 1995, are very high when compared to the ratios from other parts of the state. This is most likely a result of the long term application of fertilizer and manure to the croplands in the basin.
- The presence of excessive amounts of phosphorus in the top layers of cropland soils results in very high phosphorus yields in the basin. The phosphorus exports in the Red Cedar River Basin are considerably higher than those in the other parts of the state with similar sediment loadings.

#### **14. Recommendations**

Based upon the conclusions of the study, the following actions are recommended.

1. The cropland soils in the basin be assessed for phosphorus enrichment, and fertilizer and manure application rates be controlled to avoid excessive application of phosphorus.
2. Land spreading from point and nonpoint sources should be restricted to fields with the least erodibility (with consideration of the areas identified in this study).
3. Best management practices for the control of upland erosion from cropland be targeted towards the critical areas identified in this study.
4. To reduce sediment loadings to Tainter Lake the three watersheds, LC05, LC06 and LC07 be given the highest priority for BMP application as these three watersheds contribute the majority of the sediment load.

5. Additional monitoring be conducted at the two inlets to Tainter Lake for a minimum period of two years to assist in developing representative long term loadings and enrichment ratios in the Red Cedar River Basin.
6. All major lakes in the basin such as Red Cedar Lake, Long Lake, Chetek Lake and Lake Chetac be monitored to develop a better understanding of the loadings to these lakes and their trapping efficiencies.
7. Trading opportunities between point and nonpoint source should be explored as the point sources represent a small fraction of the total phosphorus load in the basin. The results of this study can be used to direct point/nonpoint source trades to areas with the highest concentration of nonpoint sources of pollutants.

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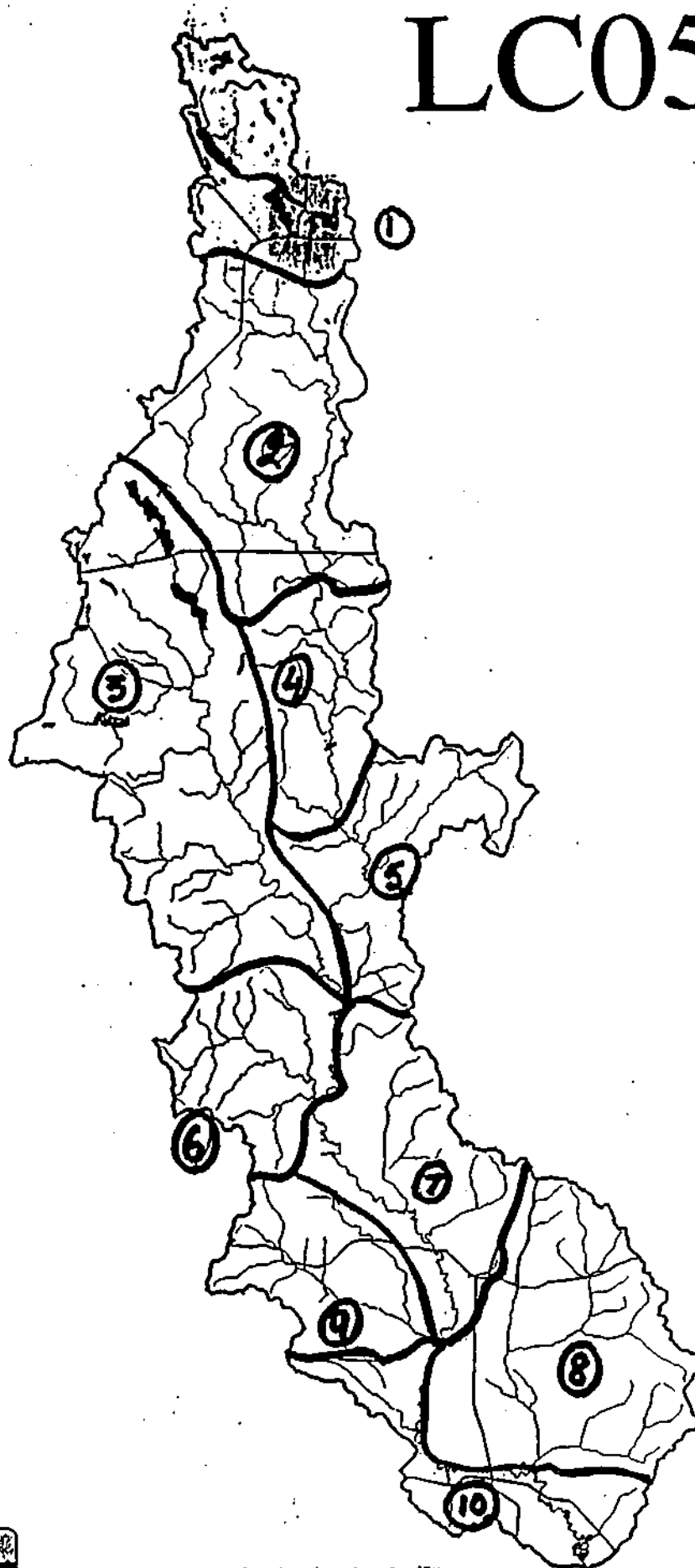
## **Appendix 1.**

### **Watershed Delineations**

LC05	Hay River
LC06	South Fork Hay River (See Figure 2.)
LC07	Pine Creek & Red Cedar River
LC08	Lake Chetek
LC09	Yellow River
LC10	Brill & Red Cedar Rivers
LC11	Red Cedar Lake



# LC05

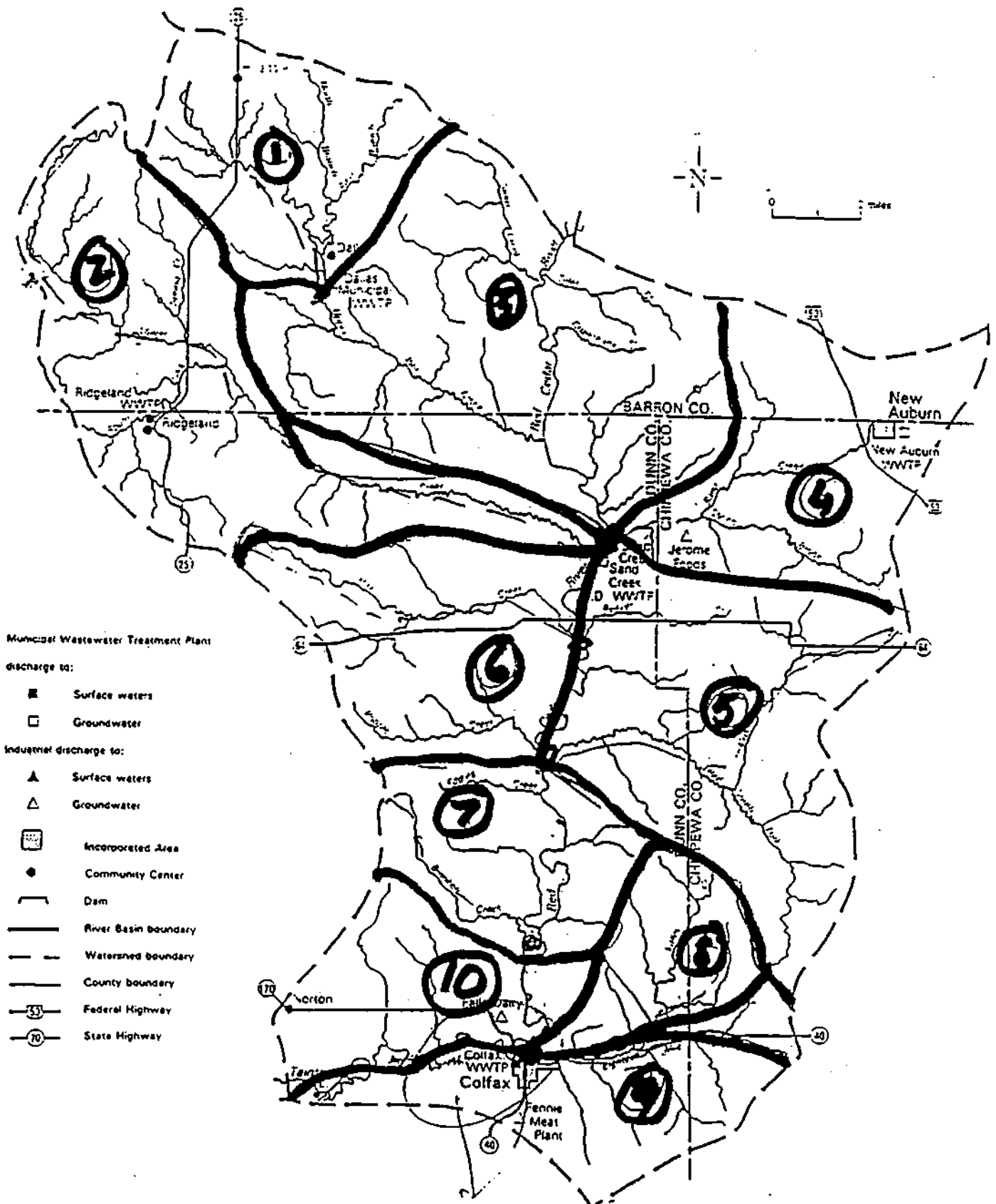


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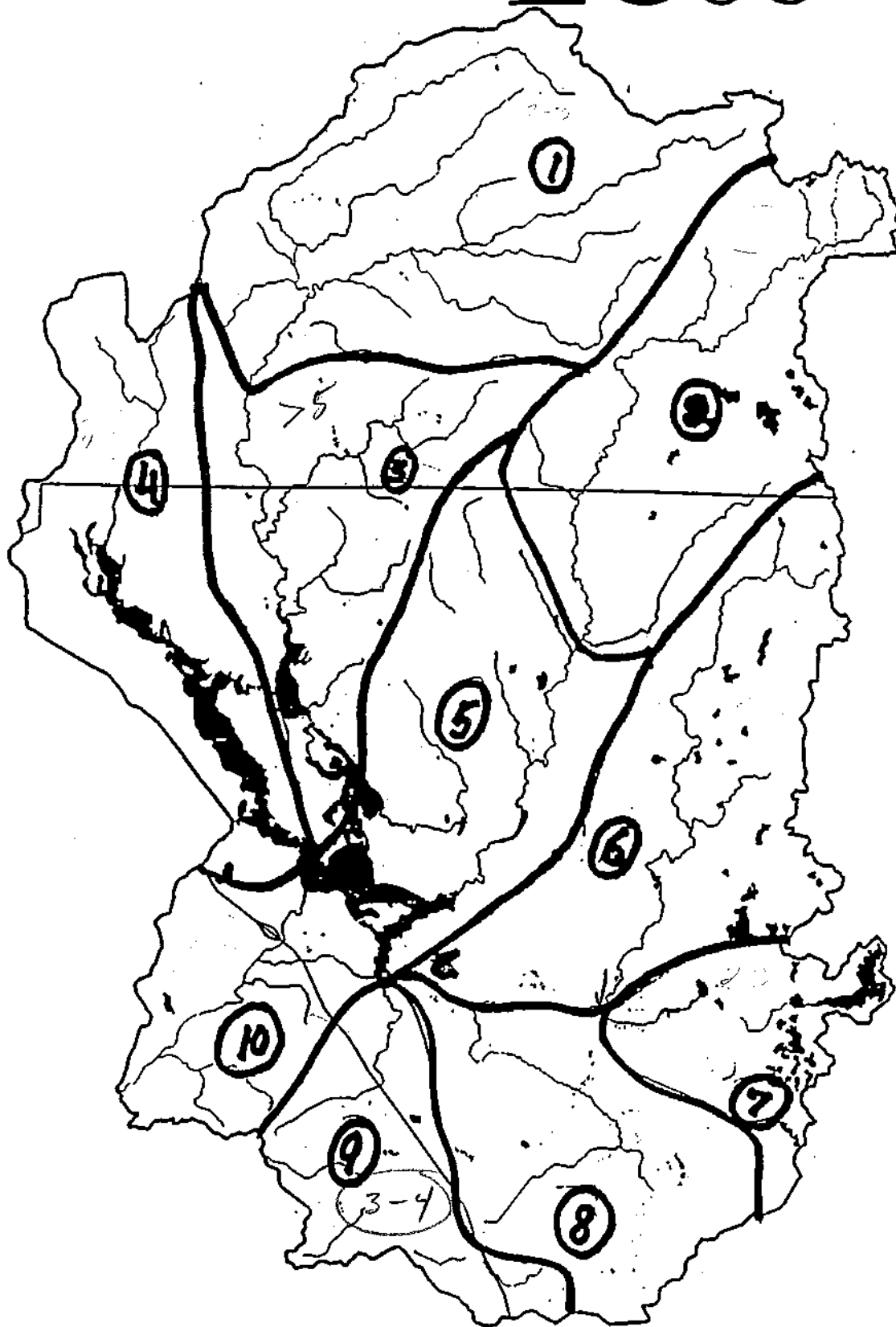
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0 1 2 3 4 5 6 7 8 Kilometers  
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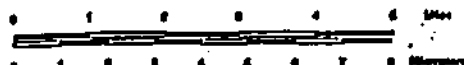
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# LC08



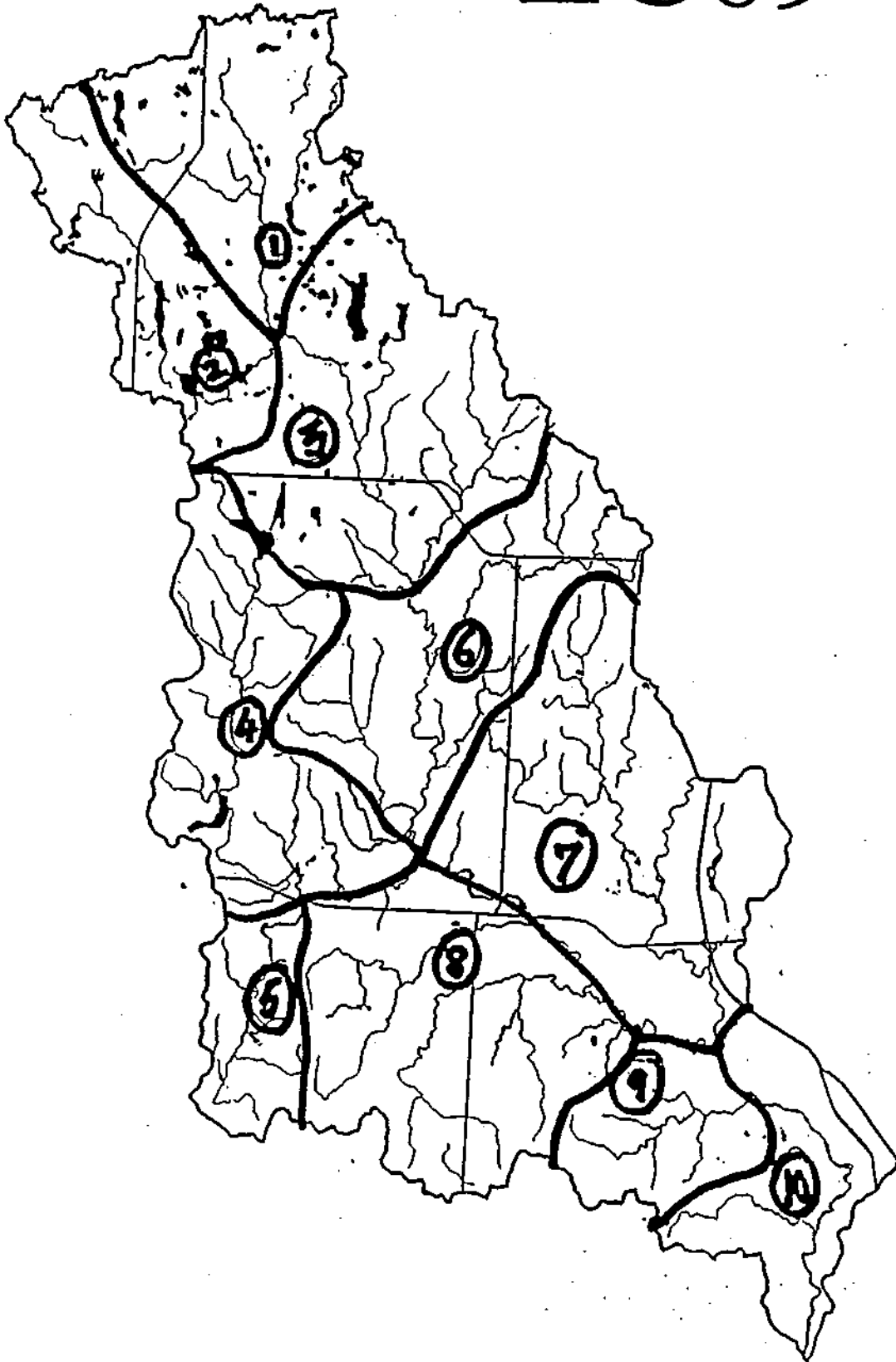
Bureau of Water Resources Management



Nominal Scale 1:105005



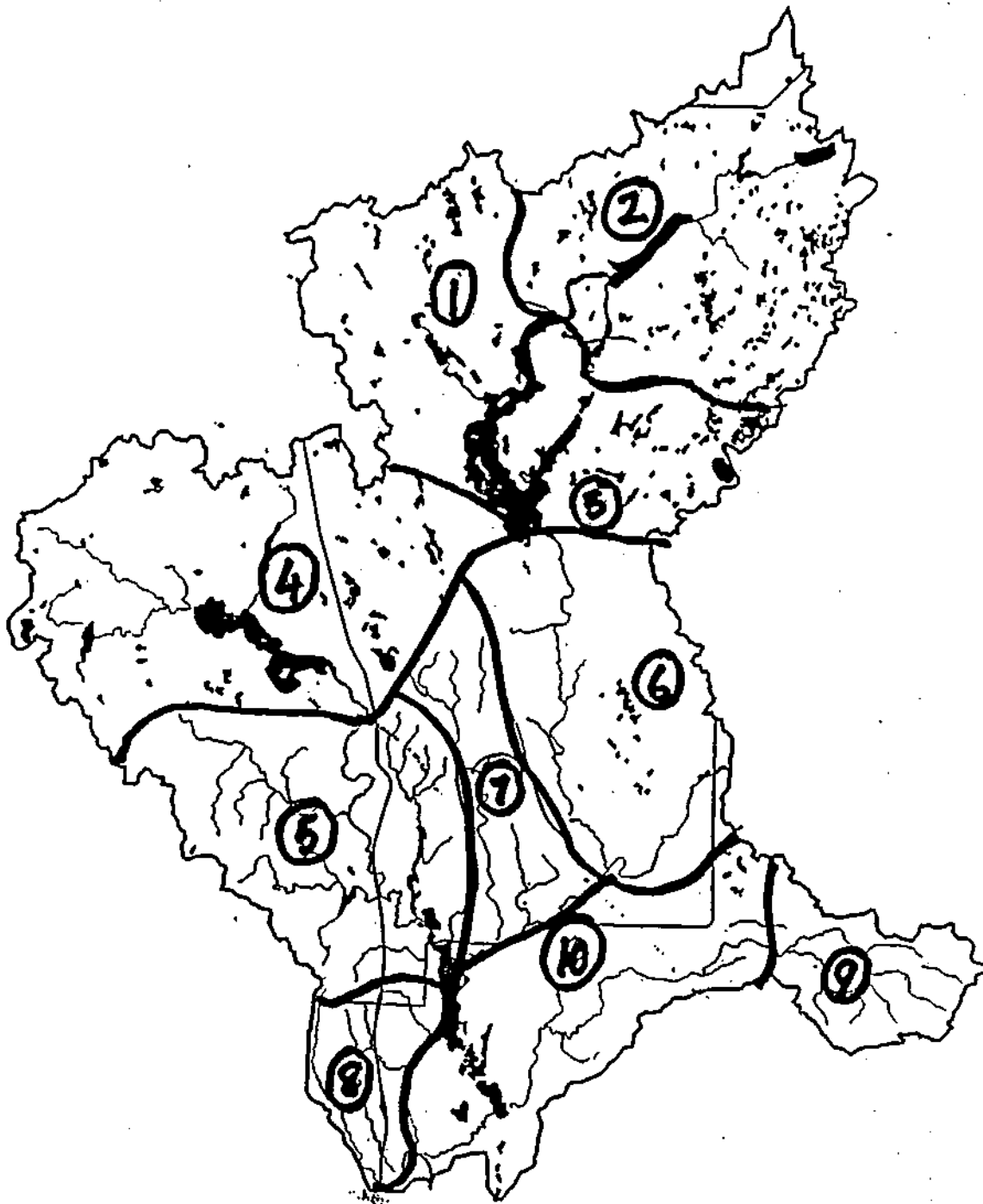
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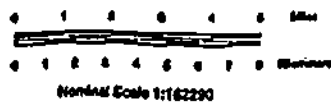
Bureau of Water Resources Management



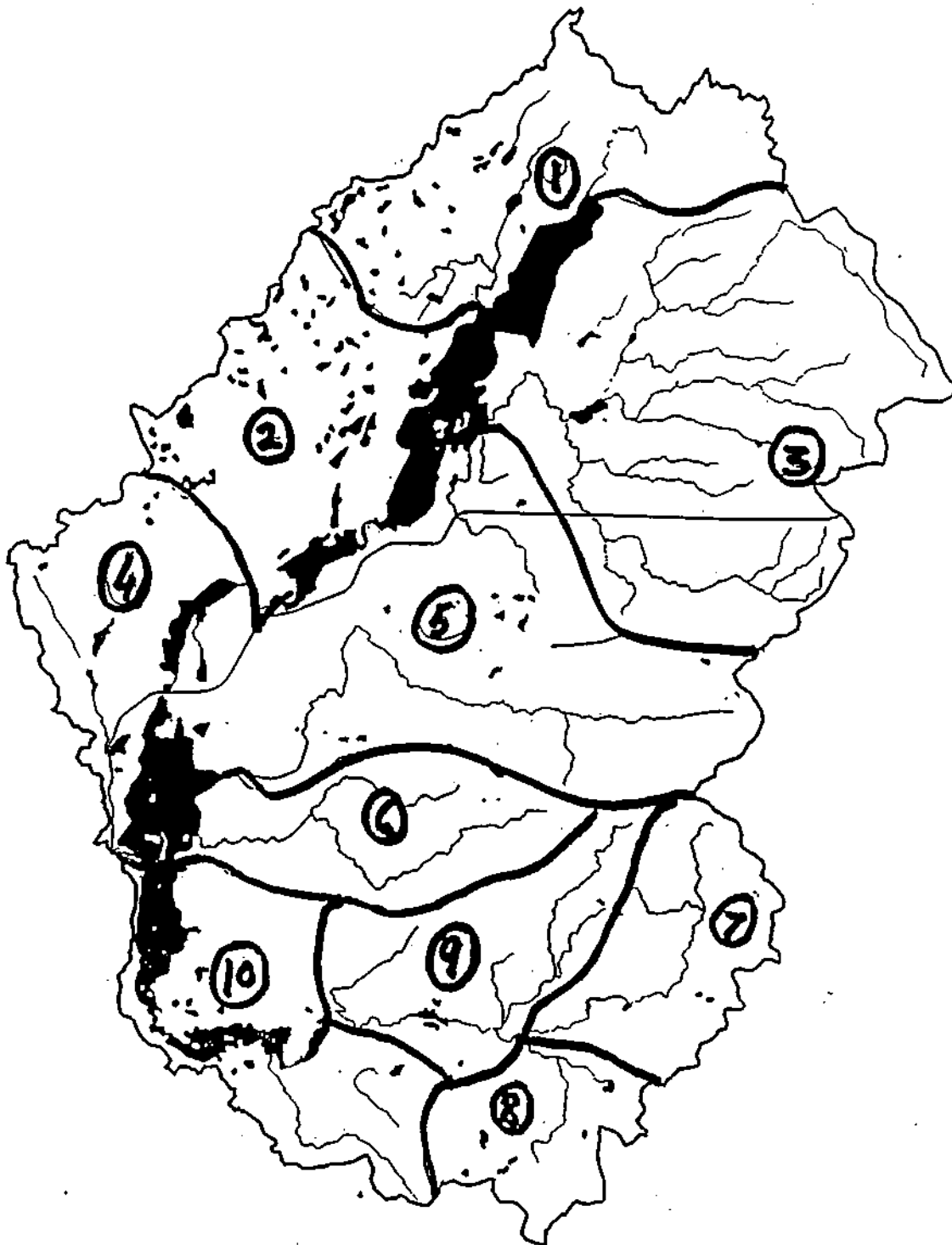
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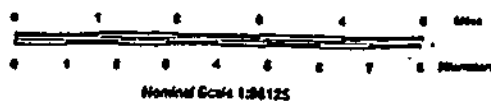
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# LC11



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**Appendix 2.**  
**SWRRBwq Input Data**



Information Input and Format	Variables	Definitions	Units	Typical Range	Where Information Is Obtained
1. Title 20A4	TITLE				User specifies
2. Program control codes 2014	NBYR	Number years of runoff simulation		1-100	User specifies
	IYR	Beginning year of runoff simulation		1-2000	"
	LU	Number of subareas in basin		1-10	"
	IPD	Print code--0 = monthly, 1 = daily, 2 = yearly		0-2	"
	NSIM	Code for rainfall input--1 = measured entire basin, 2 = simulated single, 3 = measured multiple, 4 = simulated multiple for entire basin		1-4	"
	MSIM	Code for temperature input--1 = measured temperature, 2 = simulated single temperatures for entire basin, 3 = measured temperature for each subbasin, 4 = simulated temperature for each subbasin		1-4	"
	IGN	Number of times random number generator cycles before simulation begins		0-100	"
	IWST	Code for stat collection monthly water yield-- 0 = no, 1 = yes		0-1	"
	ISST	Code for stat collection monthly sediment yield-- 0 = no, 1 = yes		0-1	"
	IRES	Reservoir code--0 = reservoir simulation for subbasin, 1 = reservoir at basin outlet		0-1	"
	IGRAF	Graphics code 0 = no graphics, 1 = graphics can be viewed at runtime		0-1	"
	IRAIN	Code for writing generated/measured rainfall to specified file--0 = do not write, 1 = write		0-1	"
	ITEMP	Code for writing generated/measured maximum and minimum temperatures to specified file--0 = do not write, 1 = write		0-1	"
	IRESQ	Lake water quality inputs--0 = do not read inputs, 1 = read inputs		0-1	"
	IDAF	Beginning day of simulation	julian days	0-366	"
	IDAL	Last day of simulation	julian days	0-366	"

Information Input and Format	Variables	Definitions	Units	Typical Range	Where Information Is Obtained
3. General data 10F8.3	DA P2 BFF BRT FFC	Basin area Rainfall correction factor Baselflow factor Basin lag time Initial soil water storage as a fraction of field capacity	km <sup>2</sup>   days	1-5000 .5-1.5 0-1 0-120 0-1	User specifies " Table III.4 User specifies "
4. Sub-basin centroid coordinates 10F8.3	XIJ YIJ	X-centroid coordinates of subbasins Y-coordinates of subbasins	km km	0-200 0-200	User specifies "
5. * General weather data 10F8.3	TP5 TP6 TP24 YLT	TP-40 10-yr frequency 0.5 h rainfall TP-40 10-yr frequency 6.0 h rainfall Number years record max 0.5 h rain Latitude of watershed	mm mm  deg	5.0-150 25-200 5-100 -90-90	Table II.1 " " "
6. * Temperature data 12F6.3	OBMX OBMN VOBMX VOBMN CVT	Average monthly maximum air temperature Average monthly minimum air temperature If MSIM = 4, average monthly maximum air temperature If MSIM = 4, average monthly minimum air temperature Coefficient of variation for monthly temperature	*C *C *C *C "	-10-42 -30-30 -10-42 -30-30 0-1	Table II.1 " " "
7. * Solar radiation data 12F6.3	OBSL	Monthly average daily solar radiation	ly	20-750	Table II.1
8. * Monthly rainfall data 12F6.3	WI	Monthly maximum 0.5 h rainfall	mm	0-125	Table II.1
9. * Precipitation parameters 12F8.3	PRW(1) PRW(2) WLV RST(1) RST(2) RST(3)	Monthly probability of wet day after a dry day Monthly probability of a wet day after a wet day Days of precipitation in a month Monthly mean of daily precipitation Monthly standard deviation of daily precipitation Monthly skew coefficient of daily precipitation	 mm mm mm mm mm	.001-.95 .01-.95 0-31 0-500 .05-200 1-7	Table II.1 " User specifies Table II.1 " "

\* These data will be brought in with the GETWEAT command if automatic entry is used.

			Range	Is Obtained
10. Entire basin data 10F8.3	CHL1(11) CHS(11) CHN(11) OVN(11) SL(11) STP(11)	Channel length for entire basin Average channel slope entire basin Channel n value entire basin Overland flow N value entire basin Average slope length for entire basin Average slope steepness for entire basin	km m/m  m m/m	Appendix VI " Table III.2 " Appendix VI
11. Entire basin pesticide data 14, A16, F11.1, F8.2, 2F8.1, F8.2, F8.1	NPTOT PNAME SKOC WOF HL SKK EFA WSOL	Number of pesticides simulated Pesticide name Soil partition coefficient pesticide Wash off fraction Half life on foliage Half-life on ground Application efficiency Water solubility	1-5  1-999900000. 0-1 0-200 0-365 0-1 ppm	User specifies Table C-1 " " " " "
12SB. Basin data 10F8.3	FLU CN2 SALB SNO CHL1 CHS CHK1 CHW1 CHN OVN RT CSS ECP SL STP	Fraction of basin in each subarea SCS runoff curve number--condition II Soil albedo Initial water content of snow Channel length from most distant point to subbasin outlet Average channel slope Effective hydraulic conductivity in channel alluvium Average main channel width Channel n value Overland flow N value Return flow travel time Sediment concentration in return flow USLE erosion control practice factor P Average slope length for each sub-basin Average slope steepness for each sub-basin	0-1 5-95 .05-20 0-150 mm km m/m mm m days ppm m m/m	User specifies Table III.1 User specifies " Appendix VI " Table III.3 User specifies Table III.2 " User specifies " Table IV.1 Appendix VI "

Information Input and Format	Variables	Definitions	Units	Typical Range	Where Information Is Obtained
13SB. Routing data (sub- basin to basin outlet) 10F8.3	CHW2	Average channel width	m	1-1000	Appendix VI
	CHD	Average channel depth	m	.5-30	
	CHSS	Channel slope	m/m	.0001-10	
	CHL2	Channel length	km	.05-200	Table III.2
	CHNN	Channel n value		.01-.3	
	CHK2	Effective hydraulic conductivity in channel alluvium	mm/hr	0-150	
	CHXK	USLE soil factor K for channel		.05-.60	Appendix V
	CHC	USLE soil factor C for channel		.001-1	
14SB. Pond data 10F8.3	FP	Fraction of each subbasin that flows into ponds		0-1	User specifies
	SAX	Total surface area of all ponds in each subbasin	ha	0-1000	
	VMX	Runoff volume from pond catchment area required to fill empty ponds (depth over the pond upstream drainage area)	mm	0-100	
	VM	Initial pond volumes (depth over the pond upstream drainage area)	mm	0-100	
	SEPP	Seepage through dam	m <sup>3</sup> /day	0-300	
	CS	Initial sediment concentration	ppm	0-5000	
	CFP	Normal sediment concentration	ppm	0-5000	
	HC	Hydraulic conductivity of pond bottoms	mm/hr	0-1	
15SB. Reservoir data 10F8.3	FR	Fraction of each subbasin that flows into reservoirs		0-1	User specifies
	SAF	Total reservoir surface area at emergency spillway	ha	0-3000	
	VRF	Runoff volume from reservoir catchment area required to fill emergency spillway (depth over the reservoir upstream drainage area)	mm	0-300	
	SAS	Total reservoir surface area at principle spillway	ha	0-1000	
	VRS	Runoff required to fill to principle spillway (depth over the upstream drainage area)	mm	0-100	
	VR	Initial reservoir volumes (depth over the reservoir upstream drainage area)	mm	0-100	
	RHR	Average principle spillway release rate	m <sup>3</sup> /s/km <sup>2</sup>	0-1	
	SEPD	Seepage through dam	m <sup>3</sup> /day	0-300	
	CSR	Initial sediment concentration in reservoirs	ppm	0-5000	
	CFR	Normal sediment concentration in reservoirs	ppm	0-5000	
	HCR	Hydraulic conductivity of reservoir bottoms	mm/h	0-1	

Information Input and Format	Variables	Definitions	Units	Typical Range	Where Information Is Obtained
16SB. Pesticide data 10F8.3	FFP	Initial pesticide on foliage	kg/ha	0-5	User specifies
	GP	Initial pesticide on ground	kg/ha	0-5	"
	ERP	Enrichment ratio for pesticide		1-5	"
17SB. Nutrient and pesticide data (upper soil layer) 10F8.3	CBN*	Organic carbon	%	0-6	User specifies
	CON	Organic N concentration	g/m <sup>3</sup>	0-10000	"
	CP	Phosphorus concentration	g/m <sup>3</sup>	0-4000	"
	CLP	Concentration of labile P	g/m <sup>3</sup>	0-100	"
18SB.* Subbasin soil data 2014 and 10F8.3	NS	Number of soil layers for each soil		2-10	User specifies
	EK	USLE soils factor K		.05-.60	Appendix V
	SIL	Pass #200 sieve	%	0-100	"
	Z	Depth to bottom of layers	mm	10-3500	"
	POR	Bulk density	t/m <sup>3</sup>	.05-2.6	"
	T4	Available water capacity	mm/mm	0-1.0	"
	SC	Saturated conductivity	mm/h	0.200	"
	CLA	Clay content	%	0-100	"
	WNO	Initial NO3 concentration	g/m <sup>3</sup>	0-100	"
	SIL	Pass #200 sieve	%	0-100	"
	PSZ	Particle size distribution	fraction	0-1	"
	RD	Maximum rooting depth	mm	10-3500	Appendix V

\*These data will be obtained when using the GETSOIL command in UTIL after running the separate SOILS retrieval program.

Information Input and Format	Variables	Definitions	Units	Typical Range	Where Information Is Obtained
19SB. Crop data 14, F4.1	NCR	Number of crops in rotation		1-3	User specifies
	MO	Month of planting	mos	1-12	"
	IDA	Day of month of planting	days	1-31	"
	CNP	New CN2 at planting		5-95	Table III.1
	MOH	Month of harvest	mos	1-12	User specifies
	IDH	Day of month of harvest	days	1-31	"
	CNH	New CN2 at harvest		5-95	Table III.1
314, 5F8.2	IRD	Vegetation--1 = annual (crops), 2 = perennial (forest, range, meadow, etc.)		1-2	"
	ITIL	Code for tillage operation--1 = fall plow, 2 = spring plow, 3 = conservation tillage, 4 = zero tillage		1-4	"
	LEG	Legumes--1 = non-legumes, 2 = legumes		1-2	"
	PHU	Potential heat units	°C	500-3000	"
	BE	Biomass conversion factor	kg/ha • m <sup>2</sup> /MJ	10-50	"
	WSYF	Water stress yield factor		.0-2	"
	HI	Harvest index (potential)		.01-.95	"
2F8.3	CVM	Average annual C factor for subbasin		.001-.5	"
	BLAI	Maximum LAI for sub-basin		.5-7	"
	RSD	Initial residue cover	kg/ha	0-20000	"
20SB. Treatment data 614, 7F8.3	MON	Month nitrogen and phosphorus applied	mos	1-12	User specifies
	IDY	Day nitrogen and phosphorus applied	days	1-31	"
	FN	Amount of nitrogen applied	kg/ha	0-200	"
	FPH	Amount phosphorus applied	kg/ha	0-200	"
21SB. Treatment data 614, 7F8.3, 14	MOT	Month pesticide data applied	mos	1-12	User specifies
	IDD	Day pesticide data applied	days	1-31	"
	PA	Amount of pesticide applied	kg/ha	0-5	"
	IPST	Which pesticide applied		1-10	"



	Range	Is Obtained
22SB. Irrigation data 614, 7F8.3		
(1) Automatic by water stress IRR Irrigation code--1 = automatic by water stress, -1 = Input date and amount, 0 = no irrigation	-1-1.	User specifies
WSF Wwater stress when Irrigation applied	0-95	"
EFI Irrigation runoff ratio	0-1.0	"
(-1) Input data and amount		
MOO Month Irrigation applied	1-12	User specifies
IDE Day Irrigation applied	1-31	"
AI Amount Irrigation applied	0-1	"
(0) No Irrigation IRR = 0		"
Rainfall File		
Daily measured rainfall Separate file 5X, 15F5.1	Daily precipitation for each subbasin mm 0-250	"
Temperature File		
Maximum/minimum temperatures Separate file 5X, 15F5.1	Daily maximum/minimum temperatures for each subbasin °C -50-54	"
Statistics File		
Monthly measured water and sediment values Separate file 2F8.2	mm 0-250	"

Information Input and Format	Variables	Definitions	Units	Typical Range	Where Information is Obtained
Lake water quality Separate file	Lake Water Quality				
	CPEST1	Initial pest concentration	mg/m <sup>3</sup>	0-50000	User specifies
	VREAC	Reaction coefficient	1/day	0-10	"
	WVOL	Volatilization coefficient	m/day	0-10	"
	VPART	Partition coefficient	m <sup>3</sup> /day	0-10	"
	VSETL	Settling velocity	m/day	0-10	"
	VRSUP	Resuspension velocity	m/day	0-1	"
	VMIK	Mixing velocity	m/day	0-10	"
	CPEST2	Initial pesticide concentration in bottom sediments	mm/m <sup>3</sup>	0-50000	"
	VREACT2	Reaction coefficient	1/day	0-10	"
	VBURY	Burial velocity	m/day	0-10	"
	DACT	Depth of active sediment layer	m	0-1	"
	VSETLP	Phosphorus settling rate	m/day	0-1	"
	PHOSL	Initial total phosphorus concentration in lake	mg/L	0-50000	"
	ISUBL	Subbasins VX to use in lake balance		0-10	"
	UMW	Average monthly wind speed	m/s	0-20	"
	EFFLO	Average daily effluent flow	m <sup>3</sup> /day	0-10000	"
	EFFLT	Average temperature of effluent	°C	-6-90	"
	FLOWT	Average temperature of natural inflow	°C	-6-50	"
TD		Average monthly dewpoint temperature	°C	-6-45	"
	TLAKE	Initial lake temperature	°C	-6-45	"

**Appendix 3.**  
**Point Source Average Annual Loadings**

# Red Cedar River Basin Point Source Average Annual Phosphorus Loads (lbs/yr).

Facility	Permit #	Watershed	Discharge Type	Receiving Water	1990	1994	1997	Est2000+
Almena	23183	LC05	Seasonal	Hay River	992	600	842	842
Cumberland	20354	LC05	Continuous	Hay River	12591	2801	3245	2821
Crystal Lake	35114	LC05	Seasonal	Unnamed	2141	1708	2428	110
Prairie Farm	25178	LC05	Continuous	Hay River	194	397	328	328
Stella Foods	50725	LC05	Continuous	Hay River	176	0	0	0
Turtle Lake	25631	LC05	Seasonal	Moon Creek	8953	11930	7828	1204
Wheeler	60852	LC05	Seasonal	Hay River	0	313	375	375
Boyceville	60330	LC06	Continuous	Hay River	0	2167	2196	2196
Glenwood City	60381	LC06	Continuous	Tiffany Creek	951	983	1069	1069
Colfax	23663	LC07	Seasonal	Red Cedar River	1722	1079	1486	1486
Dallas	23698	LC07	Continuous	Upper Pine Creek	0	304	317	317
Ridgeland	21296	LC07	Seasonal	Lower Pine Creek	27	27	38	38
Chetek	21598	LC08	Continuous	Chetek River	1997	1890	2873	830
Turkey Store	70408	LC09	Continuous	Yellow river	1694	8342	6672	1334
Rice Lake	21865	LC10	Continuous	Red Cedar River	11384	11150	5224	5224
Total					42882	43691	34921	18174

**Appendix 4.**  
**Sensitivity of Sediment and P Yields to Selected Inputs**  
**to the SWRRWQ Model**

Sensitivity of Sediment and P Yields to Selected Inputs to the SWRRWQ Model.

Line No.	Parameter	Input Value	Sediment Yield	Sed. Att. P	Soluble P
		t/ha	t/ha	kg/ha	kg/ha
1	Soil	0.12	1.12	0.21	0.21
2	Loss	0.20	1.83	0.40	0.21
3	Ratio C	0.28	2.81	0.61	0.21
4	Tillage Operation	Fall Plow	1.83	0.40	0.21
5		Spring Plow	0.69	0.11	0.20
6		Reduced Till.	0.59	0.09	0.21
7		No-Till	0.57	0.09	0.21
8	Manning n (Overland flow)	0.10	1.85	0.40	0.21
9		0.15*	1.83	0.40	0.21
10		0.20	1.81	0.40	0.21
11	CN After Planting	74	0.84	0.16	0.12
12		79	1.26	0.25	0.16
13		84*	1.83	0.40	0.21
14	USLE K Erodibility	0.30	1.48	0.32	0.17
15		0.34	1.68	0.37	0.19
16		0.37*	1.83	0.40	0.21
17	Initial Residue	1000	2.00	0.43	0.21
18	Residue	4484*	1.83	0.40	0.21
19	Cover	8750	1.68	0.39	0.21

\* = Standard conditions for corn, corn, oats/alfalfa, alfalfa, alfalfa, alfalfa crop sequence on Kewaunee silt loam soil, with 4% slope about 45 m long. The field is plowed in the fall with conventional tillage. Input organic-P = 145 kg/ha, input labile-P = 30 g/m<sup>3</sup>, and fertilizer-P = 46 kg/ha.