CHAPTER 1
INTRODUCTION

Project Background:

Through the promulgation of Administrative Code NR 217 in 1992, wastewater treatment facilities in Wisconsin were required to achieve an effluent standard for phosphorus of 1.0 mg/l for chemical treatment and 1.5 mg/l for biological treatment. The administrative code allows for alternative limits if it can be demonstrated that achievement of the 1 mg/l limit will not "result in an environmentally significant improvement in water quality and material progress towards the attainment and maintenance of associated water quality standards for the receiving water body…" (NR 217.04(2)(b)1.

As a result of NR 217, a group of municipal wastewater treatment facilities initiated the formation of a "partnership" – The Rock River Partnership (RRP) to assess water quality management issues within the Rock River Basin in an integrated watershed-based approach. The RRP is made up of a variety of interest groups and stakeholders within the Rock River Basin. Representative members include state agencies, municipal wastewater operators, industries, private citizens, and environmental organizations. Members of the partnership signed a Memorandum of Understanding (MOU) in 1997 to define the goals and responsibilities of the RRP.

Among items stated in the MOU is the WDNR "commitment to seek water quality solutions across all media and to not pursue additional reductions from point sources in phosphorus or other substances if reductions can be technically achieved at materially lower monetary cost through control strategies for non-point sources." To be successful, such an approach should take into consideration phosphorus loading from all sources (both point and non-point discharges) and seek geographically targeted, cost-effective, and holistic solutions to control phosphorus loading in the basin. In order to determine watershed-based solutions, the MOU outlined the following steps (MOU, January 1997):

- Determine if nutrients are a problem;
- Where are the nutrients coming from? What water quality standards or beneficial uses are impaired?
- Develop target reduction goals to restore beneficial uses.
- Develop menu of strategies to achieve reductions;
- Assign quantity of reductions likely to be achieved and unit costs for each strategy;
- Prioritize strategies in order of cost-effectiveness.
- Explore trades, cooperative agreements, funding techniques, or other mechanisms needed to implement mix of strategies.
- Select scenario (mix of most cost-effective strategies) reasonably likely to achieve target reduction goal.

For signers of the MOU, the WDNR agreed to suspend implementation of NR 217 pending the outcome of studies performed under the guidance of both the RRP and WDNR. A scope of work was developed to address issues raised in the MOU. Five specific tasks were identified and are listed below:

1. Computer modeling of the Rock River Basin to determine the relative sources of phosphorus and sediment
2. Monitoring of water quality characteristics at nine locations throughout the basin
3. Evaluation of the requirements for effluent trading
4. Evaluation of the costs for phosphorus removal from point and non-point sources
5. Assessment of the actual biological water quality at multiple locations in the watershed

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This document presents the methods, analyses, and results of the first task.

The Watershed Modeling Task: Purpose and Objectives:

This report documents the process used to analyze point and nonpoint sources of phosphorus in the Rock River Basin. The purpose and objectives of this task have been changed and altered somewhat as the practical limitations of a modeling effort at this scale (3,600 square miles) became realized, however, three goals have remained the same:

- Estimate an annual phosphorus load from external sources to the Rock River surface water system and the relative contribution of phosphorus loadings from nonpoint and point sources.
- Estimate the changes in annual phosphorus loadings from the application of global nonpoint source best management practices and point source controls.
- Compare the phosphorus loadings generated from the model to selected water quality monitoring stations within the basin (nine sites funded by RRP).

Annual phosphorus loads were evaluated for six different management scenarios. For nonpoint pollution, the scenarios involve modifications in tillage practices and nutrient management practices. These scenarios were selected because SWAT is able to simulate them and they represent global BMP practices. For point source controls, the application of NR 217 did not address granting of alternative limits; phosphorus discharge of applicable point sources was set to 1 mg/l. The scenarios are summarized in the table below.

TABLE 1.1
SUMMARY OF SCENARIOS MODELED WITH SWAT

Management Scenario	Nonpoint Source (cropland) Management		Point Source Management
	Tillage Practices	Nutrient Management	Effluent Concentrations
1	Current	Current	Current
2	Improved [1]	Current	Current
3	Current	Improved [2]	Current
4	Improved	Improved	Current
5	Current	Current	NR 217 levels [3]
6	Improved	Improved	NR 217 levels

[1] "improved tillage" assumes a global change of all conventional tilled fields to conservation tillage; and all existing conservation tilled fields to no-till.

[2] "improved nutrient management" assumes a global change that all cropland has phosphorus fertilization application based on UW-Extension average recommended rates.

[3] "NR 217 levels" assumes that all permitted wastewater discharges meet the phosphorus discharge limit of 1 mg/l. Due to variability and uncertainty, the use of alternative limits, such as 1.5 mg/l for biological phosphorus removal, were not addressed.

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Limitations of the Modeling Process and Results

To be useful to the RRP, the modeling effort had to address the entire Rock River basin. Much development is occurring in modeling tools for use at such a scale. The SWAT model chosen for this effort was continually modified during the course of this effort. Details of the effort were not able to be included in the scope of work due to the large amount of unknowns. Details were worked out in a series of monthly technical meetings of a modeling subcommittee made up of representatives from Earth Tech, Strand Associates, WDNR, RRP, USGS, and SWAT model developers.

Due to budget and time constraints, an exhaustive study could not be performed. Detailed in-stream water quality modeling involving fate and transport was not simulated. Once in the aquatic system, sediment and nutrients were modeled conservatively with minimal interactions using default QUAL2E routines. Data was collected from available sources and agricultural practices were limited to standardized practices. To minimize the potential for inappropriate use of output data from the modeling effort, it is important to keep in mind the limitations of the model. These limitations are identified below:

- The model will not target specific sites (for example: cropped fields) for effluent trades.
- The model will not "route" phosphorus beyond the sub-watershed level and will not predict the effects of in stream phosphorus loads on overall water quality.
- There is a significant degree of uncertainty associated with the output from nonpoint source models, however, this modeling effort will provide a general indication of the annual phosphorus load for a sub-watershed for a given set of conditions.
- An exhaustive evaluation of nonpoint control options was not made. The control options were limited to 1) modifications of fertilizer application rates; and 2) changes in tillage practices. Additional phosphorus reductions could be gained through the application of other BMPs such as buffer strips, various urban control practices, artificial wetlands, and other applicable practices.

It should be stated that the uncertainty in modeling nonpoint sources of sediment (erosion) and phosphorus is high relative to the calculation of point source phosphorus discharges. The erosion of sediment and phosphorus is influenced by both spatial and temporal variability. This is in part due to the error and uncertainty in spatial/temporal databases, which arises from both the characterization and measurement of natural events. These errors propagate through spatial operations mixing with additional errors from the estimation of additional factors such as:

- ♦ intermediate features (i.e. slope, percent residue, etc.)
- ♦ processing techniques (i.e. crop growth model, ET calculations, etc.),
- ♦ conceptual errors (i.e. use of 1992 land use with 1998 climate and monitoring data), and
- ♦ numerical limitations (rounding errors).

Errors in the modeling process, in terms of both parameter estimates and imperfect representation of properties/processes further contributes to uncertainty. This uncertainty implies that modeling results need to have limitations placed on the conclusions that are derived.

Phosphorus Sources and Impacts

Phosphorus loads into surface water systems can be divided into two principal sources: nonpoint and point. Nonpoint sources include agricultural runoff from fields, urban runoff, milk house waste, barnyards, and natural geological inputs conveyed principally through groundwater. Point sources are comprised of public and private wastewater treatment plants and industries including cheese and dairy facilities and canneries.

Phosphorus, an essential element for all living plant life, can be the growth limiting factor for algae and other aquatic vegetation in surface waters. When phosphorus enters surface waters in substantial amounts, it can become a pollutant by contributing to nuisance growth of algae and other aquatic plants and, thus, accelerate eutrophication. There is a general conclusion that of all the nutrients necessary for algae and aquatic plant growth, it is the phosphorus level in fresh water bodies that controls excessive growth. While the direct human health risks of eutrophication are not well documented (Sharpley et. al., 1993), the process can cause odor, fish kills, habitat destruction, and a general degradation of the aesthetic and recreational value of the natural environment.

The critical concentration of phosphorus that accelerates growth of algae and other aquatic plants in Midwestern lakes is very low. Daniel et. al., 1998, suggests levels in lakes can be 0.01 ppm and above for dissolved phosphorus and 0.02 ppm and above for total phosphorus. The required concentration of phosphorus in the soil solution for normal plant growth is usually 0.20 to 0.30 ppm. Thus, often the P concentration in the runoff leaving agricultural fields frequently exceeds the critical value for aquatic plant growth. The concentration and amount of phosphorus in the runoff including sediment depends a great extent on crop production practices. In Wisconsin, historical cropping factors have caused a surplus of phosphorus in the soil profile. Estimates indicate 50 years or more of excess phosphorus in the soil profile. Since 1970, phosphorus additions (generally in the form of fertilizers and/or livestock manure) have exceeded removals, (crop harvesting) however, reductions in fertilizer use and reductions in the number of dairy cattle in Wisconsin has reduced this imbalance (Bundy, 1998).

The main mechanism by which phosphorus is transported from agricultural lands into waterbodies is by runoff and soil erosion (Sharpley et. al., 1994). This loss occurs either as dissolved phosphorus (soluble) or as particulate phosphorus (attached to sediment particles). The loss of soluble phosphorus occurs in surface water runoff or leaching and is comprised mostly of orthophosphate, which is immediately bioavailable for algae uptake. Particulate phosphorus is associated with eroded soil and organic matter particles. Particulate phosphorus can be 75 to 90 percent of the total phosphorus transported in runoff (Schuman et al., 1973; Sharpley et al., 1993).

Although phosphorus transported by sediment loss may be greater than dissolved phosphorus loss, only a portion of sediment P is bioavailable for plant uptake (Sonzogni, 1982; Sharpley and Smith, 1991; Sharpley, 1993). The availability of particulate phosphorus is variable, and depends on the phosphorus concentration or saturation of the sediment along with several environmental factors in the waterbody. In general, the phosphorus concentration in eroded sediment is greater than in the soil from which it came.

When agricultural runoff enters streams the bioavailable phosphorus may increase or decrease depending on whether phosphorus is adsorbed or desorbed by stream sediments. Sediments with a high phosphorus concentration that enter a waterbody can contribute bioavailable phosphorus by desorption, which is most often associated with anoxic conditions. The effect of bioavailable phosphorus entering lakes or surface impoundments on eutrophic growth depends greatly on the characteristics of the lakes. Turbidity, depth of water, flushing rate, whether stratification occurs under normal conditions, temperature, and background phosphorus level of the lakes affect the growth of algae and other aquatic vegetation. In general, phosphorus control strategies have greatest benefit on deeper, stratified lakes with high flushing rates (less than a seven to ten day residence time) and low background phosphorus levels.

Cropping practices affect the concentration and amount of bioavailable phosphorus in runoff leaving agricultural fields. Cropland erosion control practices reduce the amount of particulate phosphorus but generally increase the concentration of dissolved phosphorus in the runoff. Surface applied phosphorus (chemical fertilizers or manure) without incorporation increases loss of dissolved phosphorus, compared to phosphorus applications that are incorporated. Generally, the concentration of dissolved phosphorus in runoff from no-till cropland is higher than from tilled land, but loss of particulate phosphorus is less

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(Sharpley et. al., 1993). Research at UW-Madison has also noted an increase in soluble phosphorus loads from no-till cropland over tilled cropland (Larry Bundy, UW-Madison Soils Dept.).

Urban areas have just as great an impact as agricultural areas on phosphorus and sediment loads. Urban areas tend to produce about 1.3 to 1.4 times more surface runoff and also tend to reduce groundwater infiltration over rural areas (Legg et. al., 1996). In addition, considerable amounts of pollutants in the form of nutrients, salt, metals, petroleum, phosphorus and sediment can be generated from urban areas. On average, Bannerman et al (1996) found Wisconsin urban sites with median and mean TSS concentration of 120 mg/l and 237 mg/l respectively. A second publication showed locations in Madison, WI producing a median and mean of 93 mg/l and 106 mg/l respectively (Waschbusch, 1995).

Unlike nonpoint source loads that are precipitation driven, point sources provide a continual phosphorus load. Point source loads tend not to fluctuate during flows however during large events bypass can occur resulting in the discharge of raw sewage. This tends to occur in combined sewer systems. The contribution of phosphorus from point sources depends on the type of point source, the flow rate from the point source, and treatment method employed by the point source. In general, the total biological available phosphorus from a point source without phosphorus treatment in place is around 70% with the remaining 30% as non-available P or organic P (unpublished memo, Strand Associates, 1999).

Project Setting:

General Background and Hydrology

The Rock River Basin lies within the glaciated portion of south central Wisconsin. The basin is bounded on the east by the Niagara escarpment and the eastern terminal moraine, which was formed by the Green Bay lobe during the last glaciated period in Wisconsin. The most dominant geologic features are the extensive drumlin fields in Dodge County and portions of Dane, Columbia and Jefferson counties.

The Rock River Basin (in Wisconsin) covers approximately 3,750 square miles. It includes part or all of eleven counties: Dodge, Jefferson, Rock, Dane, Columbia, Fond du Lac, Washington, Walworth, Waukesha, Green and Green Lake. The basin has approximately 3,900 total river miles of which about 1,920 miles are classified as perennial rivers. The overall gradient of the Rock River is very flat. There are 443 lakes and impoundments in the watershed with a total area of approximately 57,900 acres. The largest surface water features in the basin are Horican Marsh, Beaver Dam Lake, Lake Sinissippi, Lake Koshkonong, the Madison chain of lakes, Oconomowoc Lake, and Lake Delavan.

For administrative purposes, the basin has been divided into two management units by the WDNR, the Upper (1,895 square miles) and Lower (1,856 square miles) Rock River Basins. The WDNR further subdivided these basins into 28 watersheds with 15 in the Lower Rock River Basin and 13 in the Upper Rock River Basin. For the purpose of modeling, these watersheds were further subdivided into 116 sub-watersheds. Figure 1.1 shows the location of the watersheds and sub-watersheds within the Rock River Basin and Table 1.2 provides a summary of the watersheds.

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WDNR Watershed and SWAT sub-watersheds

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TABLE 1.2: SUMMARY OF DNR WATERSHEDS IN THE ROCK RIVER BASIN

WDNR Watershed ID	WDNR Watershed Name	SWAT Model ID	Area (sq. mi.)
LR01-012	Turtle Creek	LR01	288
LR02-012	Blackhawk Creek	LR02	108
LR03-012	Bass Creek	LR03	113
LR04-012	Rock River/Milton	LR04	49
LR05-012	Marsh Creek	LR05	44
LR06-012	Yahara River and Lake Kegonsa	LR06	126
LR07-012	Badfish Creek	LR07	84
LR08-012	Yahara River and Lake Monona	LR08	94
LR09-012	Yahara River and Lake Mendota	LR09	113
LR10-012	Six Mile and Pheasant Branch Creeks	LR10	119
LR11-012	Lower Koshkonong Creek	LR11	266
LR12-012	Upper Koshkonong Creek	LR12	104
LR13-012	Bark River	LR13	186
LR14-012	Whitewater Creek	LR14	75
LR15-012	Scuppernong River	LR15	87
UR01-011	Middle Rock River	UR01	95
UR02-011	Lower Crawfish River	UR02	178
UR03-011	Beaver Dam River	UR03	290
UR04-011	Calamus Creek	UR04	30
UR05-011	Maunesha River	UR05	126
UR06-011	Upper Crawfish River	UR06	161
UR07-011	Johnson Creek	UR07	45
UR08-011	Sinissippi Lake	UR08	235
UR09-011	Oconomowoc River	UR09	131
UR10-011	Ashippun River	UR10	69
UR11-011	Rubicon River	UR11	79
UR12-011	Upper Rock River	UR12	258
UR13-011	East Branch Rock River	UR13	199

Land Use

Land use in the Rock River Basin ranges from rural-agriculture to high density urban. A comparison of current land use to original or pre-settlement conditions indicates a dramatic shift in land use over the past 200 years. Historically, the southern portion of the state was primarily oak savanna, wetlands, mesic prairie, and lowland forests. Today, the basin is primarily composed of highly productive agriculture land, which can be attributed to the rich fertile soils left by the Pleistocene glaciation. Principal soil types in this region are Dodge, Miami, Morley, Casco, Plano, Warsaw and Varna soil associations in upland areas. Soil associations in wetland areas are Pella, Poygan and Brookston (Hole, 1976).

Prior to the rise of agriculture, the basin contained thousands of acres of wetlands supporting diverse ecosystems ranging from shallow wet meadows and prairies, to lowland wet forests, to deepwater marshes. Agriculture, urban development, and transportation development have destroyed a large portion

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of the original wetland acreage. Most of the original wetlands in the basin have been drained and ditched for agriculture or filled for development.

The breakout of current land use in the basin is summarized in Table 1.3.

TABLE 1.3: SUMMARY OF LAND USE WITHIN THE ROCK RIVER BASIN

Land Use	Area (Sq. mi.)	Percent of Basin
Agricultural (croplands)	2,325	62%
Grassland and Pasture	413	11%
Forest/Woodlands	375	10%
Wetlands and Open Water	337	9%
Urban and other development	300	8%

While urban areas continue to expand particularly around Madison, Janesville, Beloit, and the Delafield-Hartland area, the predominant land use in the basin remains agriculture. The dominant agricultural practices in the basin vary from continuous corn and corn–soybean rotations in the south, to a mix of dairy, feeder operations, cash-cropping, and muck farming in the north.

Water Resources

Most of the lakes and impoundments in the basin are negatively affected by point and nonpoint pollution. In many cases, the impoundment itself is causing negative impacts on water quality. Impoundments generally trap sediment, stagnate water, increase water temperatures, and impede the free movement of aquatic species. The Rock River Basin has over 200 impoundments of varying sizes ranging from small mill ponds to the locks connecting Lake Monona and Lake Mendota. Millponds are common in south and southwestern Wisconsin. Dating back to the mid-to-late 1800s, dams were built and maintained for flood control, grain milling, and logging. In the 1900s, many millpond dams were built or modified to provide hydropower. Over the decades, millponds have become important recreational and aesthetic resources to the communities in which they exist. However, because of their physical characteristics, millponds require intensive management to maintain moderate water quality. Millponds tend to experience sedimentation, unbalanced populations of rough fish, turbidity, nuisance algae blooms and/or high concentrations of aquatic "weeds" (macrophytes).

Urbanization has also affected the basin's lakes. Most lakes in the basin are very fertile, shallow, and eutrophic or hypereutrophic (excessive growth of blue-green algae). The lakes are generally very turbid and experience excessive aquatic plant growth and/or algae blooms. As explained above, the high fertility is due in part to excess sediments and nutrients from land use changes and historical wastewater discharges.

Excess sediment that settles on the river and lake bottom smothers macroinvertebrates and fresh water mussels, clogs up rocky substrate necessary for aquatic habitat, and increases the turbidity of the water column. Sediment that reaches streams and lakes may also carry nutrients, heavy metals and other pollutants attached to the sediment particles. Elevated nutrients concentrations can result in excessive growth of algae or macrophytes. This excessive growth can lead to diurnal dissolved oxygen fluctuations caused by plant respiration and photosynthesis. The decomposition of algae after a bloom can rob the water column of dissolved oxygen needed by aquatic organisms, including fish.

Heavy metals delivered to surface waters from polluted runoff or direct discharges may contribute to the presence of toxicity of the receiving water, depending on a number of variables (pH, dissolved oxygen levels, alkalinity, etc.).

Model Selection:

Several watershed pollutant loading models were evaluated for the modeling task. These models included WINHUSLE (DNR's priority watershed model), AgNPS, SWAT, XP-SWMM, HSPF, and Unit Area Loadings. The selection of SWAT was a decision agreed upon by the Rock River work planning subgroup which included representatives from wastewater operations, Earth Tech (at that time Rust E&I), Strand Associates, and WDNR. Based on discussions at meetings held on June 2nd and August 6th, 1997, the SWAT model (version 98.1) was selected to model the Rock River Basin for the pollutant trading pilot project. The following criteria were considered in selecting the SWAT model for the Rock River application:

- The model's output met the project's objectives,
- Much of the information requirements were available from existing sources,
- The scale and level of effort to conduct the modeling met the project's schedule and budget, and
- The WDNR had used versions of SWAT in previous projects.

SWAT is the continuation of a long-term effort of nonpoint source pollution modeling with the USDA-Agricultural Research Service (USDA-ARS). The merging of two previous models (SWRRB and ROTO) into one basin scale model resulted in the development of the SWAT model. The objective of the model is to predict the effect of different cropland management techniques on water, sediment, and agricultural chemical yields in large ungaged basins. To satisfy these objectives, SWAT is a continuous time model (daily time step) which looks at the effects of weather, surface runoff, evapotranspiration, crop growth, irrigation, groundwater flow, nutrient and pesticide loading, and water routing and transfer on the long-term impacts of varying management practices. A subconsultant to Earth Tech, Paul Baumgart (Fox-Wolf 2000), made several modifications to SWAT 98.1 to better reflect conditions in Wisconsin.

It was agreed that the SWAT *Arcview*™ GIS Interface (AVSWAT) would not be utilized for this study. It was only available in a "beta" version at the time and was not supported. It was agreed that the potential time savings that this interface may create during the modeling effort did not outweigh the potential for errors in the interface that may create more problems and require additional time to find and correct.

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