SECTION 319 NONPOINT SOURCE POLLUTION CONTROL PROGRAM

INFORMATION/EDUCATION TRAINING/DEMONSTRATION PROJECT

FINAL REPORT

Manure Management BMPs Based on Soil Phosphorus: Evaluating Additional Soil/Runoff P Relationships

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Grant # C9998185-01

EXECUTIVE SUMMARY

PROJECT TITLE: Manure Management BMPs Based on Soil Phosphorus: Evaluating Additional Soil/Runoff P Relationships

PROJECT START DATE: November 01, 2005

PROJECT COMPLETION DATE: September 30, 2007

FUNDING:

	Original Budget	Expended
EPA 319	$97,033.00	$97,033.00
SD Corn Utilization Council		$10,000.00
East Dakota Water DD		$ 2,500.00
SD Soybean Council		$10,000.00
SD Farm Bureau		$ 7,500.00
SD Beef Industry Council		$ 5,000.00
TOTAL:	$97,033.00	$ 132,033

SUMMARY OF ACCOMPLISHMENTS:

The project goal was: "Reduce phosphorus (P) loading in South Dakota by characterizing the P loading contributions of eight additional South Dakota soils." The five soils evaluated previously and the eight soils evaluated during this study support the majority of CAFOs located in the state. The information gathered will help refine current manure application guidelines and improve stakeholder education and communication of strategies necessary for effective manure management. The information gained during this project will enhance South Dakota's understanding of P loading that originates from nonpoint source pollution and contribute to improving water quality of lakes statewide.

In partnership with the South Dakota State Soil Specialist, County Extension Educators, and farmer cooperators, correlations between soil test phosphorus (STP) and runoff P for eight additional South Dakota soils were evaluated using indoor rainfall simulation.

Similar to the results of the previous 319 P runoff project, this study found a linear relationship between STP and total dissolved phosphorus (TDP) in surface runoff among all soil types (r^2 = 0.65-0.99; $P < 0.005$). The relationship indicates that continued additions of either manure or fertilizer P will result in increased P loss to surface water resources, and that the soils are not infinite sinks for added P. In addition, the results of this study suggest that interpreting the risk of P loss to surface runoff is spatially dependent, i.e., it is dependent on the type of soil (chemical and physical character) and its interaction with runoff during rainfall simulation at the studied depth. The fact that a South Dakota soil contains a specific chemical or physical layer as part of its taxonomy has little influence on the soil's risk of P loss to surface runoff. Chemical and hydrologic properties of the soil at the 2 and/or 5 cm depth, which are the depths of greatest soil/runoff water interaction, are more immediately affected by management decisions and thus need full consideration when interpreting environmental P risks.

The Cooperative Extension Service was an integral component in transferring the information for this project. The SDSU CES has developed statewide contacts with livestock and other producers. This project used these CES programs and contacts to conduct information transfer about the improved manure management BMPs developed. During the first project segment, eight manure management workshops, eight manure and fertilizer training sessions and two press releases were conducted in 2003 and 2004. In the second phase of the project, 11 manure management workshops and 13 manure and fertilizer training sessions were conducted during 2005-2007. A total of 19 manure management workshops, 21 manure and fertilizer training sessions, and two press releases were conducted as part of the information transfer process. In addition, four water quality seminars related to the P runoff continuation project were conducted as part of the information transfer efforts.

The project goal was met. This information was also incorporated into the current manure management requirements for CAFOs in South Dakota. Unfortunately there is currently not a mechanism to measure the effect on surface waters in the state.

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INTRODUCTION

Financial support provided by the South Dakota Department of Environment and Natural Resources (SDDENR), South Dakota Agricultural Experiment Station, South Dakota Corn Utilization Council, East Dakota Water Development District, South Dakota Soybean Council, South Dakota Farm Bureau and the South Dakota Beef Industry Council, the Manure Management BMPs Based on Soil Phosphorus project at South Dakota State University funded research to acquire information needed to establish sound manure and fertilizer P application strategies, and aid with the development of manure application guidelines for South Dakota.

This project was a continuation of the previous P runoff project titled "Manure management BMP's based on soil phosphorus" (Schindler et al., 2005). From 2002 to June 2005, the first phase of the 319 funded P runoff project evaluated the soil P/runoff P relationships of five dominant South Dakota agricultural soils (Guidry et al., 2006; Schindler et al., 2005). The five soils evaluated comprised a significant portion of the glaciated regions of South Dakota. Soils evaluated included: Vienna (fine-loamy, mixed, superactive, frigid Calcic Hapludolls), Kranzburg (fine-silty, mixed, superactive, frigid Calcic Hapludolls), Poinsett (fine-silty, mixed, superactive, frigid Calcic Hapludolls), Moody (fine-silty, mixed, superactive, mesic Udic Haplustolls), and Barnes (fine-loamy, mixed, superactive, frigid Calcic Hapludolls). Guidry et al. (2006) found a significant linear relationship between STP and TDP concentration in runoff (Figure 1). These results closely mimic those generated by other researchers (Hooda et al., 1999; Pote et al., 1996; Sharpley, 1995; Schreiber, 1988), and suggest that South Dakota soils are not an infinite sink for P. The results also show that risk of P loss to sensitive water bodies accentuates as P is added to soil either as fertilizer or with a manure application.

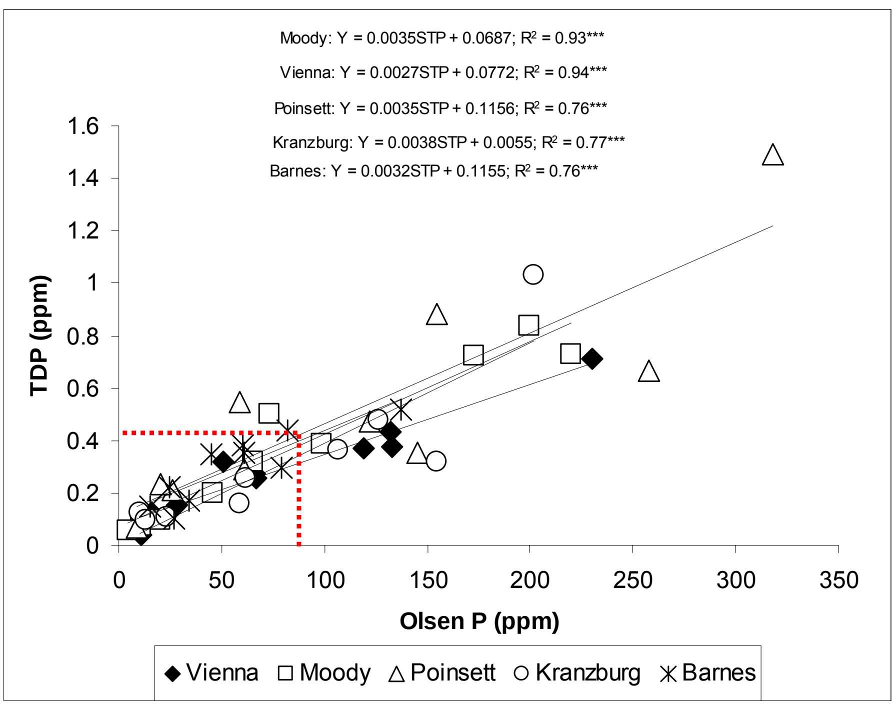

Figure 1. The relationship between total dissolved P (TDP) and Olsen-P for five dominant agricultural soils of Eastern South Dakota.

At the current identified critical P levels for surface runoff and soil P saturation (1 ppm total dissolved P (TDP) runoff and 25 percent P saturation, respectively (Sharpley et al., 1996), the data from the analysis of the five soils show that the current manure application guidelines used by SDDENR for the state of South Dakota (SDDENR, 2003) (at Olsen-P levels of >100 ppm, manure cannot be applied) should provide reasonable protection against water resource P contamination, since all soils exhibit TDP levels well below the 1 ppm critical value. Moreover, the 25 percent P sorption saturation level established by Dutch Scientists is generally accepted by researchers and environmentalists as the level at which greater P loss to water resources can be expected. Based on this assertion, the Kranzburg soil may reach as high as 200 ppm Olsen P before its exchange sites become 25 percent saturated (Figure 2), further illustrating that the current manure application guidelines are within the necessary limits for environmental preservation. This assertion is, however, predicated on the assumption that the nationally advocated critical level of 1 part per million (ppm) represents the critical level for South Dakota as the critical level of P to prevent water quality degradation is dependant on the nature of the receiving water body. For example, the primary productivity of rivers is generally much less responsive to increased nutrient loadings than the productivity of lakes (Wetzel, 2001). Vollenweider (1968) estimated that 0.07 g/m^2/yr was a permissible phosphorus loading for lakes. Values of 0.13 g/m^2/yr are considered "dangerous." "Dangerous," according to Vollenweider (1968) means that more rapid eutrophication may be expected tooccur. For lakes, concentrations of P in runoff as low as 0.03 to 0.05 ppm total P may have to be maintained to prevent eutrophication. Based on the soil P/runoff P relationships presented in Figure 14, TDP may reach the critical value even at STP levels considered low by agronomic standards (i.e., <10 ppm). In the case of the most sensitive water bodies, a threshold P limit below the agronomic optimum may be necessary to prevent eutrophication. State water quality professionals must determine what the "true" or "accepted" critical level is for South Dakota before these runoff relationships can be quantified.

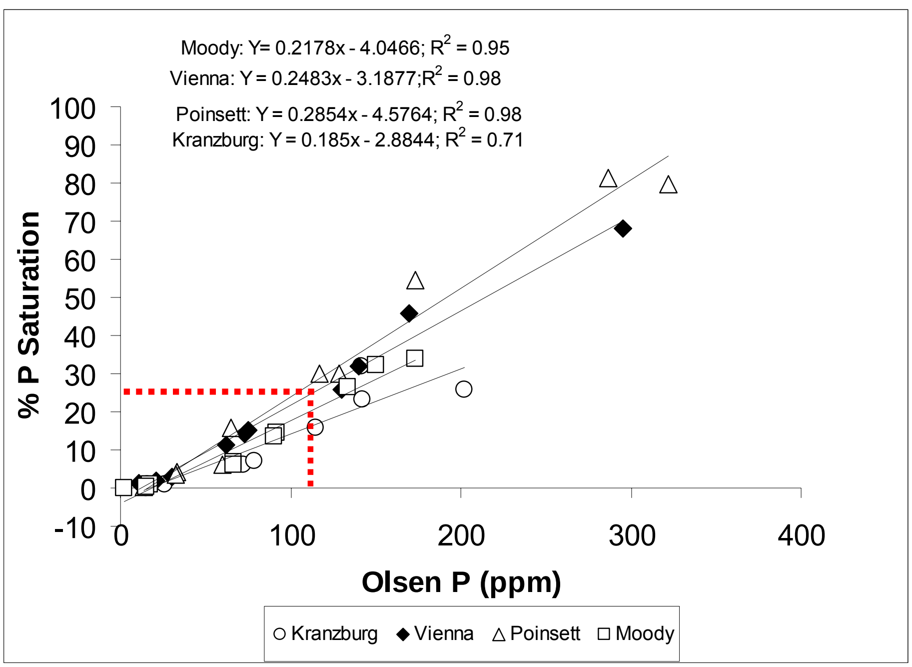

Figure 2. The relationship between P sorption saturation percent and Olsen-P for four dominant agricultural soils of Eastern South Dakota.

As depicted in Figure 1, slopes of the regression equations are similar, suggesting the rate of P release to surface runoff is nearly the same for all five soils evaluated in Phase I. Cattle producers and other environmental stakeholders in South Dakota have communicated there was a need to develop "irrefutable evidence" in favor of or against the current manure application guidelines. However, to provide such "evidence", an evaluation of the runoff P/soil P relationships for additional South Dakota soils was needed. The previous study evaluated five glacial till soils with similar diagenetic history (Guidry et al., 2006). All are mollisols formed under ustic (dry) to udic (humid) moisture regimes and calcium carbonate influences (e.g., Calcic Hapludolls). It was expected that the extent of P release to surface runoff from other South Dakota soils may not parallel that of the five soils evaluated, as they have different diagenetic histories. For example, the Pierre and Millboro soils of western South Dakota developed under weathered shale deposits and are classified as vertisol soils high in layer (phyllo) silicate clay. The Highmore, Williams, and Houdek soils are mollisols that with regions of illuvial accumulations of phyllosilicate clay or argillic horizons (Typic Argiustolls). The Aberdeen soil has both clay and exchangeable sodium accumulations in its subsurface horizons (Glossic Natrudolls).

P fixation is directly related to the amount of clay-sized particles. As innate chemical differences exist between the studied soils and the unstudied soils, it was hypothesized that these influence the fate and transport of P within these systems. It could not be assumed that the unstudied soils would respond the same in terms of their capacity to release P to surface runoff. It was, therefore, necessary to determine the relationship between runoff P and soil P for other dominant South Dakota agricultural soils. Doing so establishes a more complete data set that better describes the relationship between soil and runoff P for the state of South Dakota. The data is now available to verify the validity of or justify revisions to the current manure application guidelines.

According to the State of South Dakota Occurrence of Soil Series and Development of a Phosphorus Index map (Appendix 1), there are sixteen soil series that support the majority of South Dakota's permitted Confined Animal Feeding Operations (CAFOs). Phosphorus runoff/soil test P relationships were established for five of the sixteen in Phase I. All five of the soils completed in Phase I were located along a relatively narrow area along the I29 corridor. This left a very broad area of soils with high P accumulation potential that had not been evaluated for their P loss potential. This project collected ten samples ranging from low to high Olsen-P for each of eight soil series (i.e., the Aberdeen, Clarno, Egan, Highmore, Houdek, Millboro, Pierre, and Williams series) (Table 1). Soils were packed into runoff boxes and soil P/runoff P relationship developed using indoor rainfall simulation for each soil. The previous P runoff project has shown P concentration of indoor runoff to be highly correlated to the P concentration of field surface runoff (Guidry et al., 2006; Schindler et al., 2005).

All project activities, with exception of collection of soils from cropped fields to fill the runoff boxes, were conducted in the laboratory. Therefore, no environmental disturbances, other than soil collection, occurred.

Table 1. Classification and Olsen-P of the surface 5 cm of the Aberdeen (N=10), Clarno (N=9), Egan (N=10), Highmore (N=10), Houdek (N=10), Millboro (N=10), Pierre (N=10), and Williams (N=10) soils.

Soil Series‡	Soil Classification	Olsen-P	
		Range	Mean
		$mg\ kg^{-1}$	
Aberdeen	Fine, smectitic, frigid Glossic Natrudolls	10-293	96
Clarno	Fine-loamy, mixed, superactive, mesic Typic Haplustolls	6-133	55
Egan	Fine-silty, mixed, superactive, mesic Udic Haplustolls	9-280	103
Highmore	Fine-silty, mixed, superactive, mesic Typic Argiustolls	17-260	112
Houdek	Fine-loamy, mixed, superactive, mesic Typic Argiustolls	6-227	107
Millboro	Fine, smectitic, mesic Typic Haplusterts	13-107	51
Pierre	Fine, smectitic, mesic Aridic Leptic Haplusterts	10-235	82
Williams	Fine-loamy, mixed, superactive, frigid Typic Argiustolls	6-345	111

PROJECT GOALS, OBJECTIVES, AND ACTIVITIES

The project goal was, "Reduce P loading in South Dakota by characterizing the P loading contributions of eight additional South Dakota soils and improving manure management strategies by better understanding the relationships that exist among STP and runoff P." The information gained from the characterization will help refine current manure application guidelines and improve stakeholder education and communication of strategies necessary for effective manure management. The project enhances South Dakota's awareness of P loading to surface water resources and thus aids in reducing eutrophication of lakes statewide. A total of 13 benchmark soils have been characterized upon completion of this project segment.

The soils chosen for the study were located across the state of South Dakota and currently support the majority of CAFOs in the state (Appendix 1). This information will improve the level of technical assistance to improve manure application strategies statewide and will assist SDDENR in refining the current manure application guidelines. By attaining the goal, BMPs for improved manure management will be transferred to SD livestock producers, extension educators, commodity groups, and environmental stakeholders. This will reduce nonpoint source pollution of surface water in South Dakota. The project will enhance understanding of the sources of nonpoint source nutrient loading of South Dakota's water resources, and is essential for producer acceptance of phosphorus-based manure management.

The two major objectives of the project were met or exceeded.

1. Establish laboratory correlations among STP and runoff P for the Aberdeen, Clarno, Egan, Highmore, Houdek, Millboro, Pierre, and Williams soil series collected from across South Dakota that range in STP levels from low to high.

2. Provide manure management education to extension educators and livestock producers.

Activities completed to reach objective are described below. A milestone comparison (Table 4) appears at the end of this section.

Objective 1: Establish laboratory correlations among STP and runoff P for the Aberdeen, Clarno, Egan, Highmore, Houdek, Millboro, Pierre, and Williams soil series collected from across South Dakota that range in STP levels from low to high.

According to the State of South Dakota Occurrence of Soil Series and Development of a Phosphorus Index map (Appendix 1), there are eight additional soil series that support the majority of South Dakota's permitted CAFOs. These soils are the Aberdeen, Clarno, Egan, Highmore, Houdek, Millboro, Pierre, and Williams series) (Table 1). Ten conventionally tilled cropland areas were identified for each of the eight benchmark soils. The sites had similar slope and topography and varied from low to high agronomic STP. Approximately 40 surface soil samples (0-5 cm) were collected and prepared for a routine Olsen-P analysis (Olsen et al., 1954; Soil Testing Procedures, 1995) by the Soils Testing Laboratory at South Dakota State University. The routine analyses were used to identify the 10 evaluation sites for each soil series. Bulk soil samples were collected from each of the 10 evaluation sites, air-dried, sieved, packed into runoff boxes to similar bulk densities, and subjected to indoor rainfall simulation (Guidry et al., 2006; Schindler et al., 2005).

The indoor protocol for the National Research Project for Simulated Rainfall-Surface Runoff Studies was followed to complete Objective 1 (Appendix 2). A rainfall simulator, constructed according to the National protocol (Appendix 2) by Joern Inc., Purdue University, was used

Figure. 3. Rainfall simulator used for P runoff evaluations.

(Figure 3). Runoff boxes were constructed according to the National protocol (Appendix 2) and used to conduct indoor rainfall simulation to establish STP and runoff P (dissolved and sediment P) correlations. Each of the 10 bulk soils representing the eight benchmark soils (77 bulk soils total) were packed into the runoff boxes to approximate field bulk density in accordance with National Protocol (Appendix 2). The runoff events were evaluated in triplicate. Rainfall simulation, runoff collection, and chemical analyses were performed according to the National protocol (Appendix 2). Unfiltered (total P) and filtered (total dissolved P) runoff samples were analyzed for total P content by sulfuric acid/persulfate digestion and ascorbic acid reduction as described in section 4500-P of Standard Methods for the Examination of Water and Wastewater (American Public Health Association, American Water Works Association, and Water Pollution Control Federation, 1998) by South Dakota State University (SDSU) Analytical Services.

Relationships between STP and surface runoff P were determined by regression analysis. Regressions and correlation coefficients were determined for each benchmark soil using SAS software for Windows version 9.1 (SAS Institute, 2003).

Task 1: Identify 10 evaluation field sites that have similar slope and topography and vary from low to high agronomic STP for each of 8 benchmark soils.

Product 1: Eighty (80) evaluation sites (10 sites/benchmark soil x 8 benchmark soils).

Seventy-seven (77) evaluation sites (10 sites/benchmark soil x 5 benchmark soils and 9 sites/benchmark soil x 3 benchmark soils) evaluation sites were identified. The identification of field evaluation sites was accomplished by collecting enough surface soil samples (0-15 cm) for the Aberdeen, Clarno, Egan, Highmore, Houdek, Millboro, Pierre, and Williams series that 10 sites could be identified for soil collection and laboratory simulation study. Similar to the 2002-2005 P runoff field study (Schindler et al., 2005), a Global Positioning System with a hand-held Geographical Information Software was used to locate and record field positions.

Milestones: *Planned* – Identification of 10 evaluation sites per benchmark soil (total evaluation sites = 80) will be completed by July 1, 2006.

Actual – Ten evaluation sites per each of 5 benchmark soils and 9 evaluation sites per 3 benchmark soil (total evaluation sites = 77) were completed by May 2007. Additional time was needed to identify collection sites because of the difficulty of identifying a wide range of STP concentrations, especially at the high end for the Pierre and Millboro soils. Field conditions such as recent manure or fertilizer applications which excluded sites from use also affected collection of bulk samples.

Task 2: Conduct indoor rainfall simulation and analyze soil and runoff water samples.

Product 2: Collect bulk composite surface soil samples (0-5 cm) from the 10 field sites established for each of the eight benchmark soils to pack into soil boxes (total of 80 bulk samples), and determine the soil chemical properties.

Seventy-seven bulk composite surface soil samples (0-5 cm) from the identified field sites for each of the benchmark were collected and analyzed for select chemical properties.

Milestones: *Planned* – All bulk soil samples collected and analyzed by July 2006.

Actual –Seventy-seven bulk composite surface soil samples (0-5 cm) from the identified field sites for each of the benchmark soil were collected and analyzed for the selected chemical properties by May 2007.

Product 3: Assess soil P/runoff P relationships for the eight benchmark soils using indoor simulated rainfall.

Soil test phosphorous and runoff P correlations based on laboratory simulations for the Aberdeen, Clarno, Egan, Highmore, Houdek, Millboro, Pierre, and Williams soil series were completed. Ten field sites per soil series, with the exception of the Millboro, Pierre, and Clarno soils, which consisted of nine evaluations sites, were evaluated. Samples were collected from the field, packed into runoff boxes (Figure 4), and subjected to indoor rain simulation according to the National Protocol (Figure 5 and Appendix 2). Five soil series x 10 sites per series (except Millboro, Pierre, and Clarno at 9 sites) = 77 sites and 8 STP/runoff P correlations (Figures 6-13).

Figure 4. Runoff boxes used for indoor rainfall simulation.

Milestones: *Planned* – Runoff boxes will be built during November and December 2005. Approximately 67 percent of the soils will be evaluated during 2005-2006 and 33 percent during 2006-2007. All evaluations will be completed by February 2007. A total of 960 runoff samples will be analyzed by December 2006.

Actual –Ten runoff boxes were constructed during November (Figure 4). All eight soils were evaluated by April 2007. Approximately 1,056 samples were analyzed for total P and Total dissolved P. This number includes a 10 percent increase for QA/QC (Table 2).

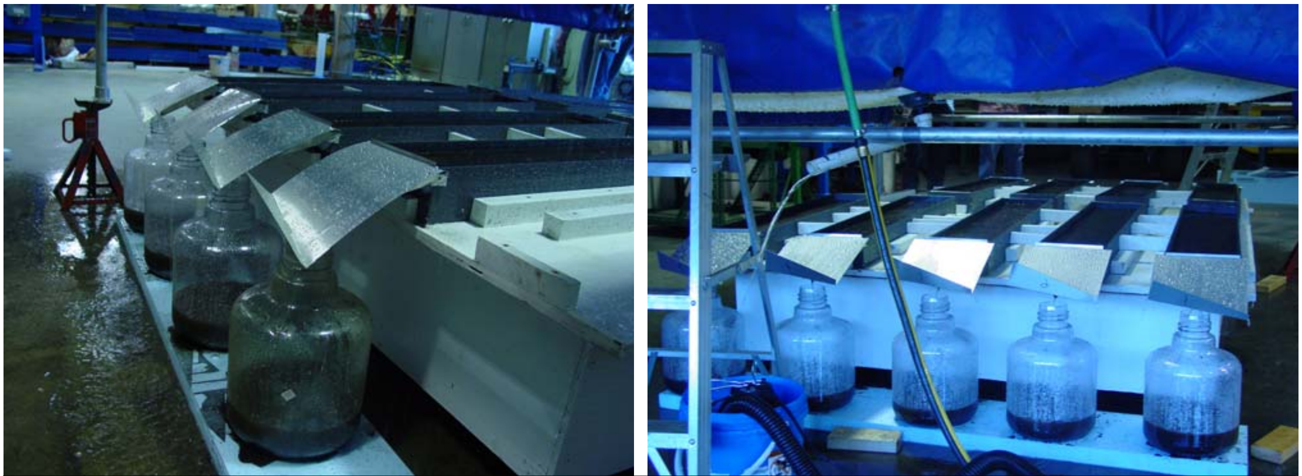

Figure 5. Surface runoff collection during indoor rainfall simulation.

Figures 6-13 and Table 2 show the relationship between STP and surface runoff TDP for the Aberdeen, Clarno, Egan, Highmore, Houdek, Millboro, Pierre, and Williams soil series as determined by indoor rainfall simulation. A strong linear relationship between STP and TDP exists among all soil types (r^2 = 0.65-0.99; P < 0.005). The relationship indicates that continued additions of either manure or fertilizer P will result in increased P loss to surface water resources, and that the soils are not infinite sinks for added P. Results are similar to those of the previous 319 P runoff project where the Vienna, Kranzburg, Poinsett, Barnes, and Moody series were evaluated and determined to possess a positive, linear relationship between STP and TDP (Schindler, et al., 2005; Guidry et al., 2006). Other investigators have reported similar results (Vadas et al., 2005).

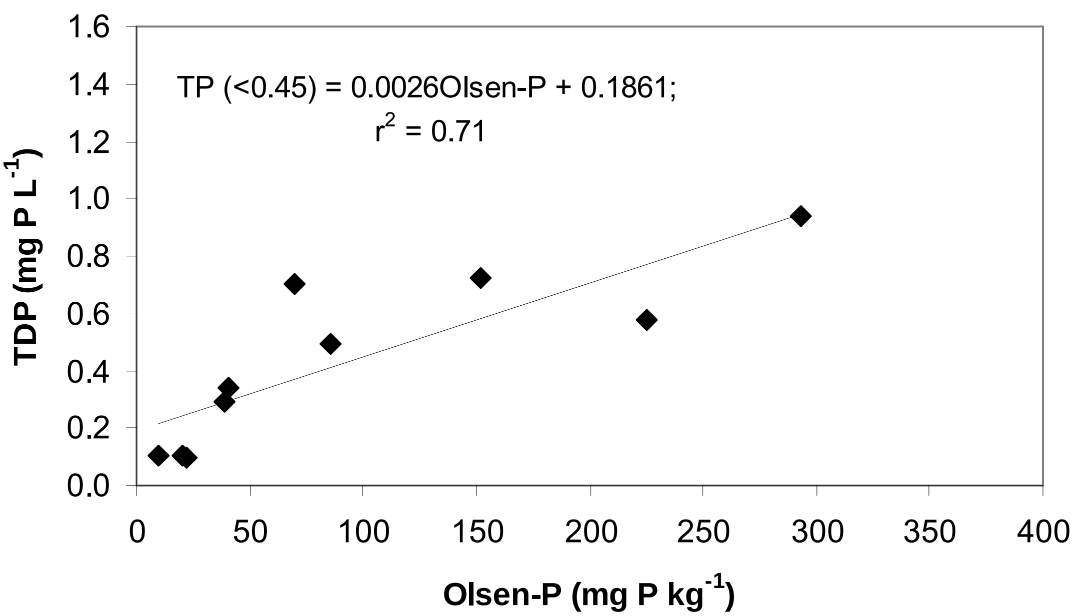

Figure 6. Relationship between total dissolved P (TDP) concentration in surface runoff and Olsen-P (mg kg^{-1}) for the **Aberdeen** soil series at the 0-5 cm soil depth. Evaluation derived via indoor rainfall simulation.

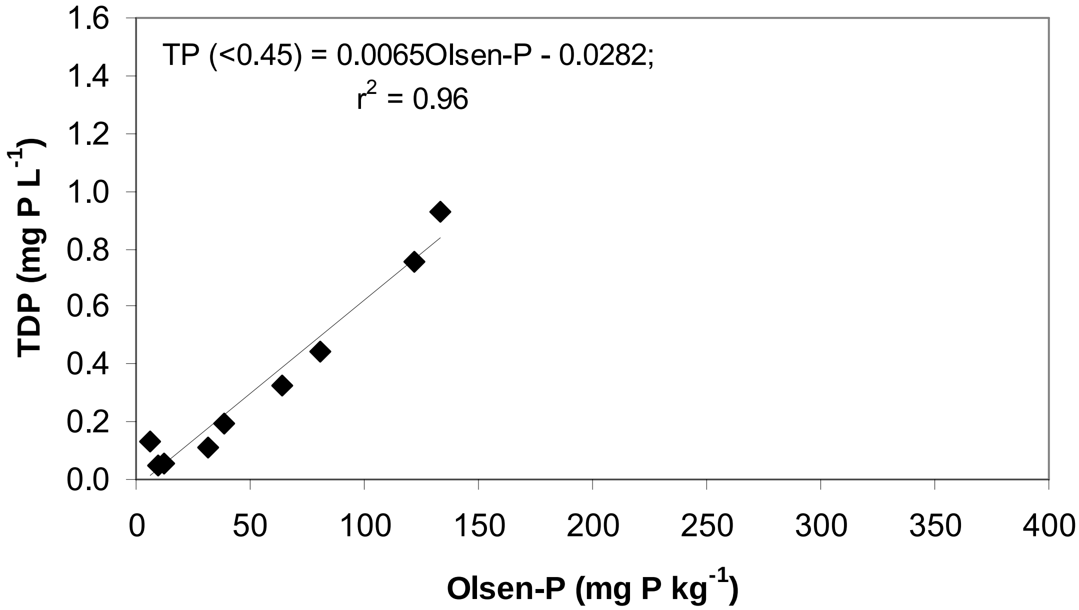

Figure 7. Relationship between total dissolved P (TDP) concentration in surface runoff and Olsen-P (mg kg^{-1}) for the **Clarno** soil series at the 0-5 cm soil depth. Evaluation derived via indoor rainfall simulation.

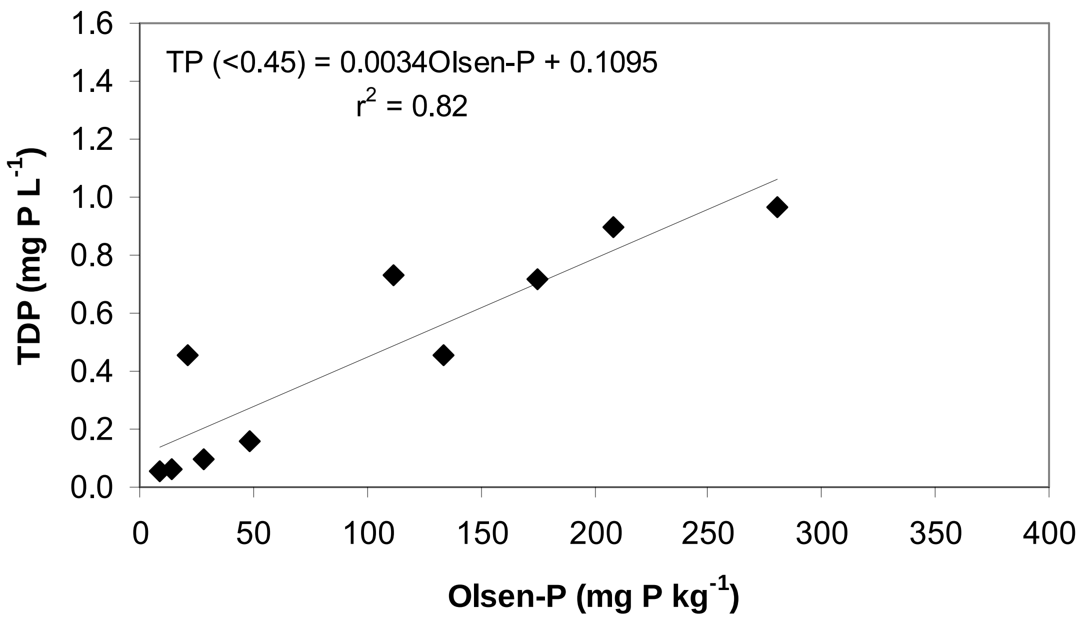

Figure 8. Relationship between total dissolved P (TDP) concentration in surface runoff and Olsen-P (mg kg^{-1}) for the **Egan** soil series at the 0-5 cm soil depth. Evaluation derived via indoor rainfall simulation.

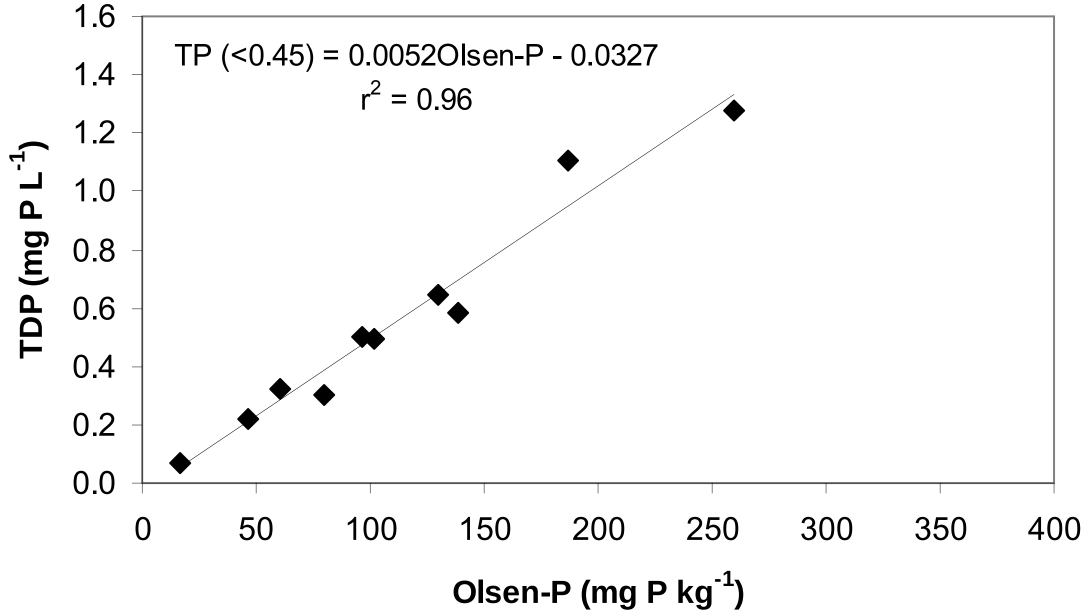

Figure 9. Relationship between total dissolved P (TDP) concentration in surface runoff and Olsen-P (mg kg^{-1}) for the **Highmore** soil series at the 0-5 cm soil depth. Evaluation derived via indoor rainfall simulation.

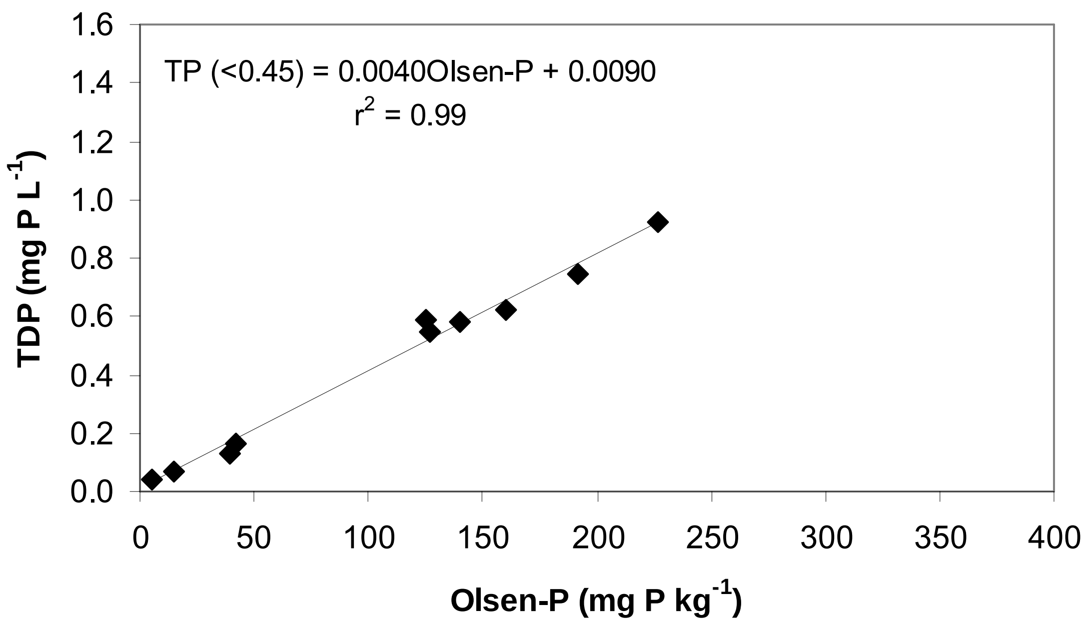

Figure 10. Relationship between total dissolved P (TDP) concentration in surface runoff and Olsen-P (mg kg^{-1}) for the **Houdek** soil series at the 0-5 cm soil depth. Evaluation derived via indoor rainfall simulation.

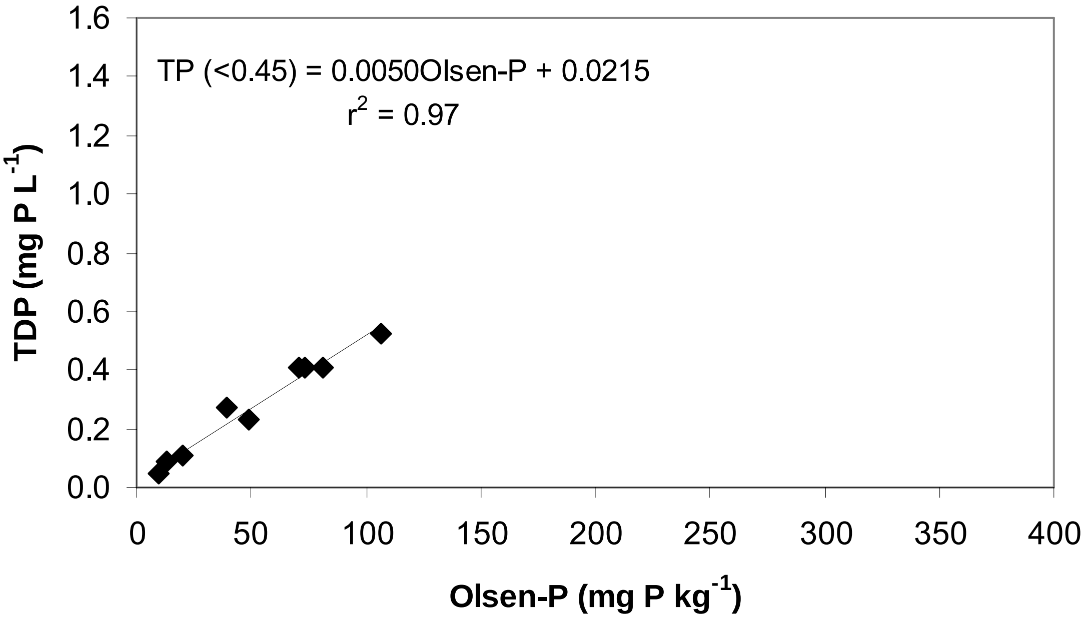

Figure 11. Relationship between total dissolved P (TDP) concentration in surface runoff and Olsen-P (mg kg^{-1}) for the **Millboro** soil series at the 0-5 cm soil depth. Evaluation derived via indoor rainfall simulation.

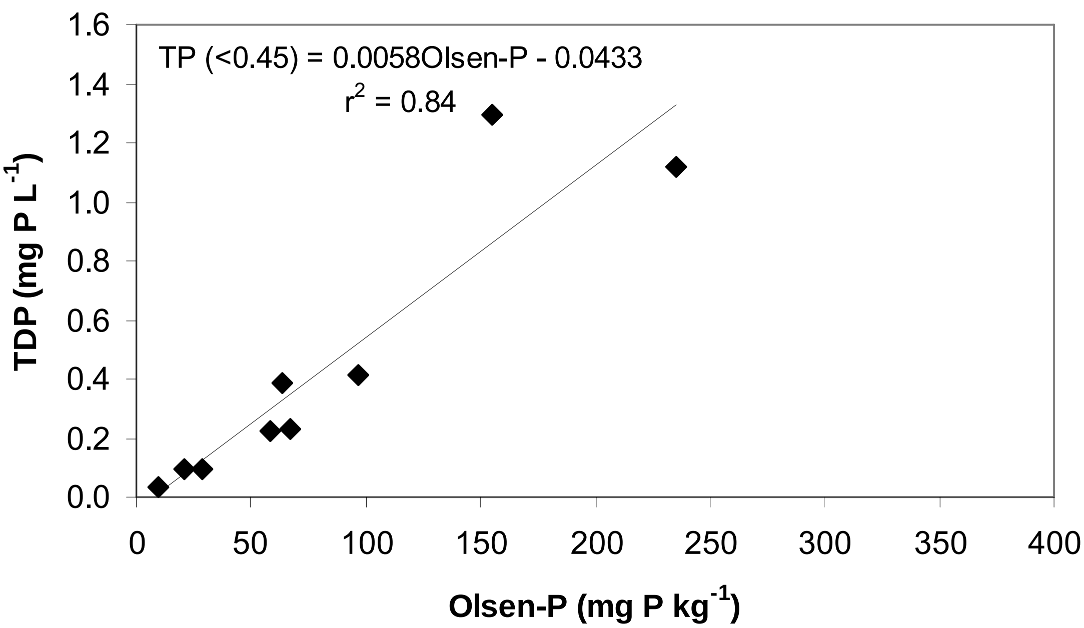

Figure 12. Relationship between total dissolved P (TDP)] concentration in surface runoff and Olsen-P (mg kg^{-1}) for the **Pierre** soil series at the 0-5 cm soil depth. Evaluation derived via indoor rainfall simulation.

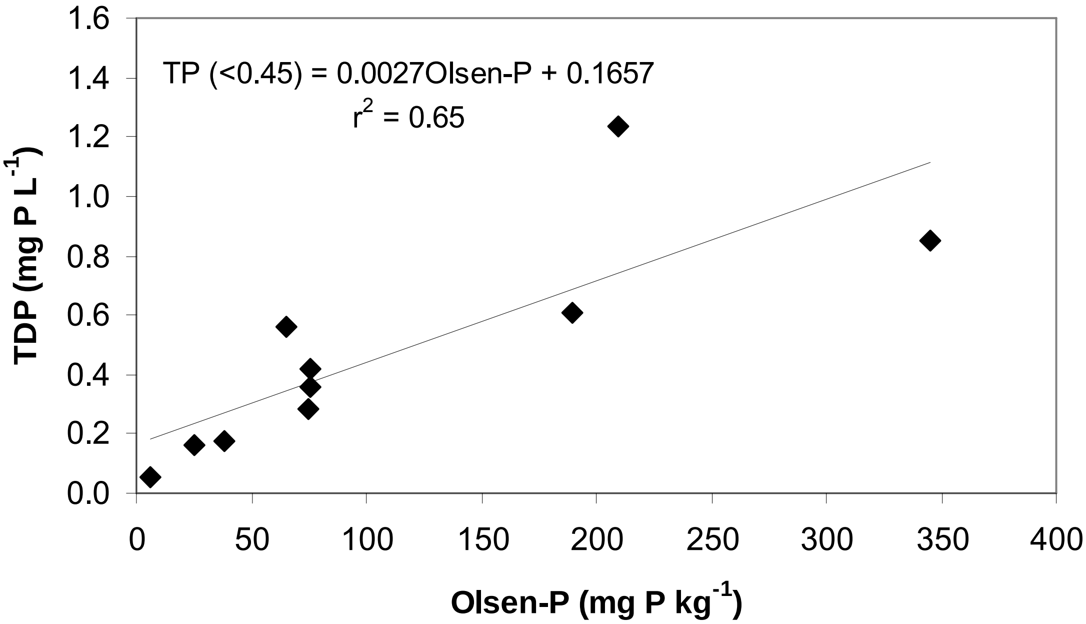

Figure 13. Relationship between total dissolved P (TDP) concentration in surface runoff and Olsen-P (mg kg^{-1}) for the **Williams** soil series at the 0-5 cm soil depth. Evaluation derived via indoor rainfall simulation.

Figure 14 depicts the SAS output when Olsen-P (mg kg^{-1}) is used as the predictor of TDP concentration in surface runoff. Visual inspection of Figure 14 suggests that some significant differences exist between the intercepts and slopes among the soil series. Differences in intercept suggests factors other than extractable P contributes to TDP in surface runoff, while differences in slope indicates that soils release P to surface runoff at varying rates and thus may require different P management strategies.

Statistical comparisons of model intercepts that were significantly different include: Aberdeen vs. Clarno, Aberdeen vs. Highmore, Aberdeen vs. Pierre, and Pierre vs. Williams (Table 2). With the exception of the Clarno, Highmore, and Pierre soils, all model intercepts were positive. According to Schroeder et al. (2004), positive intercepts could imply that an amount of TDP other than what was generated from STP was contributing to the overall TDP concentrations in the runoff. The added source of TDP was likely due to dissolvable organic P associated with plant residues that were inadvertently left on the field plot surface. Sharpley (1981) reported that P released from the plant canopy accounted for as much as 18-94 percent of P lost in surface runoff. The negative intercepts of the Clarno, Highmore, and Pierre soils suggest that the Olsen method extracted more P from the soil than the runoff water (Schroeder et al., 2004). These effects are likely the result of soil-specific interactions that govern P release to runoff water and any P contribution from prior and/or existing plant materials.

The slope or the extraction coefficient of regression equations estimate the rate of P released to surface runoff (Sharpley, 1995). Slopes ranged from 0.0026 to 0.0065 among the studied soils (Table 2), and were similar to the previous study of eastern South Dakota soils conducted by this research team (Schindler, et al., 2005; Guidry et al., 2006). Significant differences, however, did exist among the studied soils. For example, differences in slopes existed between the Aberdeen and Clarno, Aberdeen and Highmore, Aberdeen and Pierre, Clarno and Egan, Clarno and Houdek, Clarno and Millboro, Egan and Highmore, Egan and Pierre, Highmore and Williams, and Pierre and Williams soil series (Table 2).

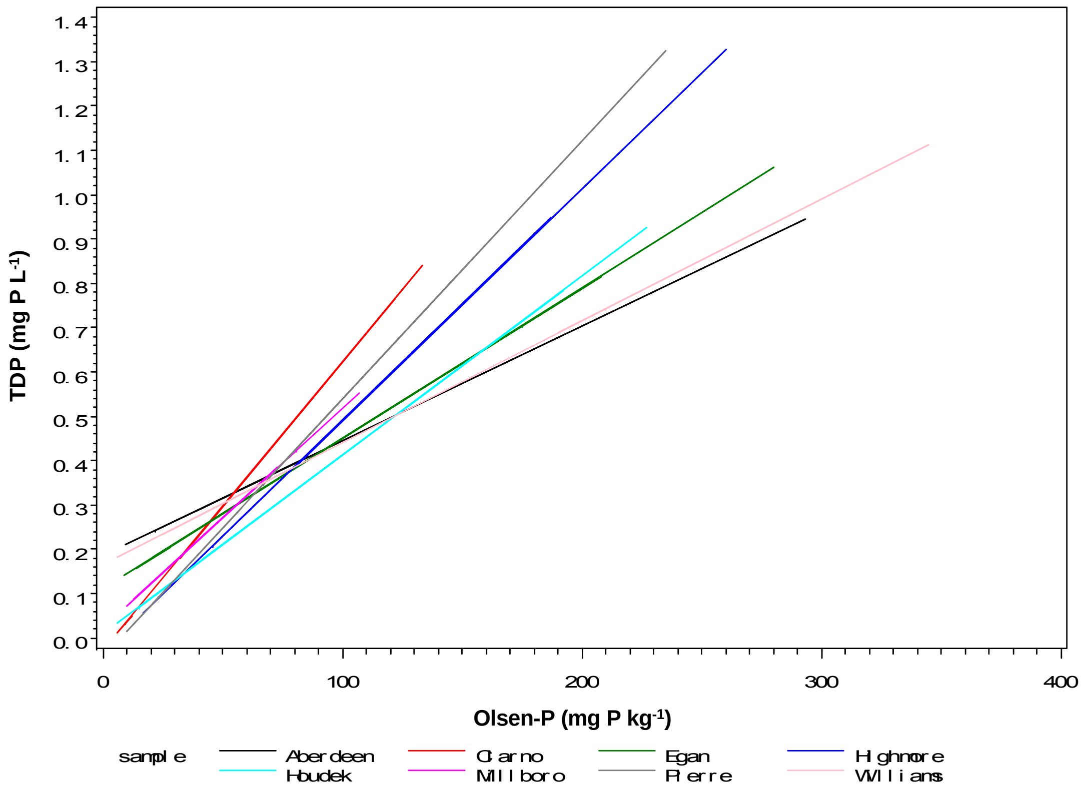

Figure 14. SAS output showing the predicted relationship between total dissolved P (TDP) concentration in surface runoff and Olsen-P (mg kg^{-1}) for the studied soil series at the 0-5 cm soil depth. Evaluation derived via indoor rainfall simulation.

It would be desirable to be able to group soils according to their risk of P release to water resources when developing a P-index for South Dakota. Based on the results of this study, two such groups may be suggested; however the categories are not clearly delineated. For instance, based on the statistical evaluation of extraction coefficients (or slopes) (Table 2) and visual interpretation (Figure 14), the Aberdeen, Egan, Houdek, and Williams soils seemed to "fit" one group (e.g. group "A"; lower risk of TDP loss), and the Clarno, Highmore, Houdek, Millboro, and Pierre soils seemed to "fit" a second group (e.g. group "B"; higher risk of TDP loss). Both the Houdek and Millboro soils could have been placed into either group given their slope similarities to soils of each group (Table 2). The Vienna and Barnes, and the Kranzburg and Poinsett soils, with slopes of 0.0025 and 0.0039, and 0.0059 and 0.0045 based on indoor rainfall simulations (Guidry et al., 2006), of soils studied during a previous P runoff study at South Dakota State University (Schindler, et al., 2005), could be placed into groups A and B, respectively.

At first glance, it appeared a generalization could be made between soil classification and risk of P loss to surface runoff, but a closer inspection revealed inconsistency. For instance, soils that were classified as either: i) vertisols (i.e., soils that are high in clay content), or ii) having argillic horizons (i.e., soils that posses a subsurface horizon with a significantly higher percentage of phyllosilicate clay than the overlying soil material, but where the horizon could be exposed at the surface later by erosion) (USDA-NRCS, 1999), seemed to fit the "higher risk" category, group B. These soils included the Highmore and Houdek (possess argillic horizons), and the Millboro and Pierre soils, which were considered vertisols. Conversely, however, all remaining soils, except the

Williams soil, were classified as mollisols and did not contain an argillic horizon and thus would be placed in the "low risk" category, group A, as evidenced by relatively low extraction coefficients. The inconsistencies arise with the Clarno, Williams, Kranzburg, and Poinsett soils. The Williams soil is a mollisol containing an argillic horizon, similar to that of the Houdek and Highmore soils, but with a low slope would be grouped in the "low risk" category. The Clarno soil is a typical mollisol with no argillic horizon, but yet maintained the highest slope (m = 0.0065) and greatest risk of P loss to surface runoff (Table 2). The Kranzburg and Poinsett soils are mollisols that contain a calcic rather than argillic horizon within 100 cm of the soil surface, but would be placed in group B based on relatively high slopes (Table 2). The Kranzburg and Poinsett soils contained the highest amount of clay (i.e., 29.8 percent and 32.3 percent, respectively) relative to the Vienna and Barnes soils (Guidry et al., 2006).

Table 2. Mean runoff quality properties and regression parameters relating soil test phosphorus (STP) (mg P kg^{-1} as Olsen-P) with surface runoff total dissolved P (TDP) (mg P L^{-1}) for the Aberdeen (N=10), Clarno (N=9), Egan (N=10), Highmore (N=10), Houdek (N= 10), Millboro (N=9), Pierre (N=9), and Williams (N=10) soils using indoor rainfall simulation. STP and surface runoff TDP relationships are based on 0-5 cm bulk soil samples.

	Surface runoff type				
Soil Series	TDP†	TP†	slope	intercept	Model r^2
	mg L^{-1}				
Aberdeen	0.44a	0.3a	0.0026a‡	0.1861a	0.71(0.002)§
Clarno	0.33a	4.0c	0.0065bij	-0.0282bf	0.96(<0.0001)
Egan	0.46a	3.5d	0.0034ae	0.1095abf	0.82(0.0003)
Highmore	0.55a	5.8bc	0.0052cik	-0.0327bcf	0.96(<0.0001)
Houdek	0.44a	3.9c	0.0040afk	0.0090abf	0.99(<0.0001)
Millboro	0.28a	7.3abc	0.0050agk	0.0215abf	0.97(<0.0001)
Pierre	0.43a	6.1bc	0.0058dik	-0.0433bd	0.84(0.0005)
Williams	0.47a	8.3ab	0.0027ahj	0.1657aef	0.65(0.0048)

† Values represent the mean of duplicate values for two consecutive 30-min runoff events at soil field capacity.
‡ Values within a column followed by the same letter are not significantly different at $P \geq 0.05$.
§ Value in parentheses is the *P*-value associated with coefficient of determination, r^2.

From the results of this study, it appears that interpreting the risk of P loss to surface runoff is spatially dependent, i.e., it is dependent on the type of soil (chemical and physical character) and its interaction with runoff during rainfall simulation at the studied depth. Therefore grouping South Dakota soils according to their risk of P loss to surface runoff based solely on their classification does not appear to be valid. Chemical and hydrologic properties of the soil at the 2 and/or 5 cm depth (i.e., depths of greatest soil/runoff water interaction and thus environmental concern) are more immediately affected by management decisions and cropping history. A South Dakota soil classified as having a layer of illuviated clay, for example, does not necessarily equate to a high risk of P loss.

Objective 2: Provide manure management education to extension educators and livestock producers.

As with the previous P runoff study (Schindler et al., 2005) and a current watershed project, the Cooperative Extension Service (CES) was a key project partner of this project. The SDSU CES has developed statewide contacts with livestock and other producers. This project used these CES programs and contacts in so much as possible to transfer information about the improved manure management BMPs developed. Taking advantage of SDSU outreach programs helped to prevent duplication of effort and provide efficient use of resources.

As during the previous project segment, the SDSU soil extension specialist presented the information gained from this project at 1) annual soil testing workshops for ag consultants and fertilizer dealers in Brookings, Parker, Pierre and Aberdeen, 2) winter manure application training workshops for people applying for state CAFO permits in Pierre and Huron, and 3) the annual Certified Crop Advisor CEU workshop in Sioux Falls.

As the work was conducted in the laboratory, field demonstrations were not part of this project. However, opportunities did exist for extension educators, area livestock producers, and environmental stakeholders (public) to observe data collection in the laboratory. Results from laboratory simulations were summarized in brochures and were sent to commodity group representatives, and made available through the Water Resources Institute, Cooperative Extension Service, and Soil Testing Laboratory at South Dakota State University.

Task 3: Transfer indoor STP and runoff P (dissolved and sediment P) correlation information.

Product 4: *One thousand* copies of educational brochures. These media would explain the laboratory results produced and would be distributed to livestock producers, extension educators, and various environmental stakeholders. Information in these brochures would explain the soil P/runoff P relationships of eight dominant soils in South Dakota, and how the relationships compare to the previously studied glacial till soils of eastern South Dakota.

Five hundred copies of an educational brochure were printed midway through the project for distribution to commodity groups and for handouts and presentations at meetings. Two members of the Phosphorus Management Group (PMG), Mike Schmidt and Wayne Smith made presentations to the Beef Industry Council, SD Farm Bureau, and the SD Soybean Promotion & Research Board. Copies of the fact sheet were provided to the SD Pork Producers Council and the SD Corn Utilization Council.

Milestones: *Planned* – Approximately 500 copies of brochures showing the results of the first 5 soils would be produced and distributed during May and June 2006, and another 500 copies developed and distributed during December 2006 and January 2007.

Actual – The number of copies of brochures produced was fewer and the dates of production were later than planned. Brochures were produced in the amount needed for a specific event to insure that information was as current as the data allowed. Additional educational brochures are being developed based on recommendations of the PMG. One will include a complete set of data from all 13 soils without interpretation. A second brochure will present a summary of the data and discuss the significance of the data to livestock producers and recommendation on manure management BMPs to reduce impacts to water resources. It is anticipated that at least 500 copies will be produced.

Product 5: Six manure management workshops, and manure and fertilizer training sessions.

Eleven manure management workshops, 13 manure and fertilizer training sessions, and 4 water quality seminars were held. A summary of the workshops, sessions, and activities are in Table 3.

Milestones: *Planned* – Conduct six P management workshops and eight manure/fertilizer training sessions for years 2006 and 2007.

Actual – Eleven manure management training workshops for individuals with CAFOs requesting a state permit were held during 2005-2007. Locations and the number of individuals attending are shown in Table 3. Thirteen manure and fertilizer training sessions were also held (Table 3). In addition to the workshops and training sessions, four water quality seminars were presented (Table 3).

Table 3. **Manure Management BMPs Workshop Presentations**

Date	Place	Presented To	Manure Training Attendance	Fertilizer Training Attendance	Water Quality Seminar Attendance
1/17/2006	Huron	CAFO permitting	25		
2/8/2006	Wall	Farm Show		20	
2/9/2006	Martin	Farm Show		20	
2/14/2006	Pierre	Environmental and Groundwater Conference			75
3/2/2006	Brookings	SDSU Swine Production Class		40	
3/19/2006	Brookings	SDSU Ag Waste Management Class	25		
4/5/2006	Huron	Technical Service Provider training	30		
4/12/2006	Huron	Solid Waste Management Assn.	40		
4/17/2006	Mitchell	Master Gardner's		27	
4/18/2006	Winner	Master Gardner's		27	
4/19/2006	Yankton	Master Gardner's		27	
4/24/2006	Sisseton	Master Gardner's		27	
4/26/2006	Pierre	CAFO permitting	25		
5/2-3/2006	White River	Sun Prairie Hog Farms		8	
5/17/2006	Watertown	Master Gardner's		25	
6/1/2006	Rapid City	Master Gardner's		25	
6/2/2006	Pierre	Master Gardner's		25	
7/18/2006	Huron	CAFO permitting	25		
10/24/2006	Huron	CAFO permitting	25		
11/2/2006	Brookings	Eastern SD Water Conference			40
11/29/2006	Marshall, MN	Undergraduate Research Conference			30
12/12-13/2006	Mitchell	No-Till Clinic		180	
1/12/2007	Watertown	Agvise Soil Testing Lab	80		
1/18/2007	Huron	CAFO permitting	30		
2/22/2007	Huron	NRCS		20	
3/9/2007	Huron	Professional Soil Scientists of SD			20
3/22/2007	Brookings	SDSU Ag Waste Management Class	25		
4/26/2007	Brookings	CAFO permitting	30		
		TOTAL Number:	**11**	**13**	**4**
		TOTAL Attendance:	**305**	**471**	**165**

Product 6: Prepare P manure management project mid-year annual and final report describing STP and runoff P relationships for eight benchmark soils of South Dakota, and submit information to scientific journals for publication.

Three mid-year, annual, and final reports were prepared. An additional progress report was submitted to fulfill requires of the U. S. Geological Survey 104 program.

Milestones: *Planned* – Prepare semi-annual reports in April 2006. Annual reports prepared during September 2006. Ten copies of a final report by May 31, 2007. At least one manuscript will be prepared and submitted for publication in a refereed, scientific journal.

Actual – Mid-year report for Oct. 2005 through March 2006 titled “Manure Management BMPs Continuation” and Annual report for April 2006 through September 2006 were prepared and submitted to the SDDENR. One copy of this final report will be submitted to the SDDENR by September 30, 2007. Ten additional copies will be made available for distribution. A progress report titled “Establishing a Relationship between Soil Test P and Runoff P for a South Dakota Soil Using Simulated Rainfall” was prepared for the report to the U. S. Geological Survey 104 program during June 2006. One manuscript was submitted to the Journal of Environmental Quality for publication during August 2007.

Table 4. Planned and actual milestones, products, and completion dates. †

Objective/Task/Products	**Quantity‡ Planned /(Actual)**	**Year 1**												**Year 2**											
		Oct. 2005 - September 2006												**Oct. 2006 – September 2007**											
Objective 1		**10**	**11**	**12**	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**	**12**	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**
Task 1: Identify soil sites for 8 benchmark soils:																									
Product 1: Evaluation sites	80 (79)	X O	X O					O	X O	X O	X O	O	O	O						O	O				
Task 2: Conduct indoor Rain simulation																									
Product 2: Collect bulk soils/obtain soil chemical information	80 (79)	X O	X O						X O	X O	X O	O	O	O						O	O				
Product 3: Assess runoff/soil P relationship	960 (1056)			X O	X O	X O	X O	X O				X O	X O	X O	X O	O	O	O	O	O					
Objective 2																									
Task 3: Information Transfer																									
Product 4: Develop brochures	1000 (500)								X O	X O						X	X								
Product 5: P Mgt. workshops/training seminars																									
Workshops	6 (6)				O		X	X O	X	X	O			O		X	X	X	X	X					
Manure/fertilizer training/Seminars	8 (12)					O	X O	X	X O	X O					O	X O	X	X	X	X					
Product 6: Prepare semi-annual, annual and final reports and manuscripts	12 (12) rpts. 1 (1) man.								X O					X O							X O	O	O	O	O
Phosphorus Management Group meetings	3 (2)				X					X O							X O								

† X = Planned completion dates; O = Actual completion dates

‡ Values in Parentheses are the actual quantity.

COORDINATION EFFORTS

South Dakota State University (SDSU) was the project sponsor. The SDSU Chemistry and Biochemistry Department, Soil and Plant Testing Laboratory (Plant Science Department), Cooperative Extension Service, and the SDSU Water Resources Institute, provided staff, grant funds and facilities to complete the project. Other federal and local agencies and organizations contributed technical and financial resources to complete the project. The contributions of each are outlined below.

South Dakota Department of Environment and Natural Resources

Staff from the South Dakota Department of Environment and Natural Resources (DENR) administered the project grant and provided oversight of project activities by reviewing mid-year and annual reports and attend project demonstrations. DENR staff also kept other agencies informed by providing project updates to the Nonpoint Source Task Force.

The DENR was also tasked with developing requirements for P-based nutrient management for South Dakota. Information gained about phosphorus loss in runoff was used to develop administrative rules for the General NPDES livestock facility permit that was adopted during 2003. The permit requirements have been more acceptable to producers since the original P runoff data was collected in South Dakota.

South Dakota Ag Experiment Station

The South Dakota Ag Experiment Station (AES) provided the initial finding that allowed for the purchase of a rain simulator that met the requirements of the national protocol for rain simulation research. The AES also contributed to the project by supporting the stipend and laboratory studies of one Ph.D. student in the Atmospheric, Environment, and Water Resources program during the 2002-2005 P runoff project (Schindler et al., 2005). The graduate student's contribution was the foundation for the continuation project.

United States Department of Agriculture (USDA)—Natural Resources Conservation Service (NRCS)

NRCS provided technical assistance with locating field sites and verification of soil types during selection of individual plots. NRCS staff was often the initial contact with landowners who that allowed access to their land for soil sampling and collection. The local contacts and knowledge of soils contributed by NRCS were important to the success of this project. NRCS intends to use the information gained from this project and that from the previous P runoff project (Schindler et al., 2005) to develop a P-index for South Dakota.

State-wide Producer Groups

The South Dakota Farm Bureau, South Dakota Corn Utilization Council, South Dakota Soybean Promotion and Research Council, East Dakota Water Development District, and South Dakota Beef Industry Council each contributed to the development of this project by recognizing the need to collect data on the water quality effects of phosphorus in the soil and develop an outreach program that would help livestock producers in South Dakota maintain production while minimizing effects on water quality. These organizations provided funds to match the 319 grant awarded for the project. The funds were used for contractual services (including analytical services and soil testing) and publication costs (including publication costs and manuscripts). The contributions not only helped further the understanding of the sources of nonpoint source nutrient loading of South Dakota's water resources, but were essential for producer acceptance of phosphorus-based manure management.

Local Producers

The project would not have been possible without the cooperation of the state's livestock producers who allowed project staff access to their land to sample and collect soils. The producers were willing to provide historical data or any farm management information that would facilitate project completion and data interpretation. Many of the producers had keen interest in the outcome and findings of the project and asked good questions regarding how findings would be used.

South Dakota State University and Cooperative Extension Service

The Cooperative Extension Service was a project team member. The South Dakota Soil Extension Specialist was the main contact with livestock producers statewide for the dissemination information regarding the research. Educational seminars/short courses, field day events, and formal instruction were used to transfer information to area livestock producers, extension educators, undergraduate animal science students, and the general public. The specialist was also instrumental in development of BMPs and manure management regulations adopted by SDDENR which were based on results from this project.

Many South Dakota County Extension Educators participated in the project by helping identify and contact local producers. The Extension Educators were often the first point of contact. The educators were knowledgeable of potential cooperating producers, their farming enterprise, fields and soil types, and which field sites may be the most useful to the project.

The Phosphorus Management Group:

SDSU staff and livestock and grain producers met several times during 2001 to discuss ways to collect scientifically defensible information relative to the soil P issue. The attendees included the South Dakota Cattlemen's Association (SDCA), Pork Producers, Soybean growers, South Dakota Farm Bureau and SDSU staff. This ad hoc group, referred to as the Phosphorus Management Group (PMG), met as a subgroup during this project segment to discuss the results and how they should be disseminated. A topic at one of these meetings was the need for additional research particularly on the issue of winter spreading of manure.

PROJECT GOALS AND MILESTONES NOT MET

The most significant change in the project was the request for a no-cost extension to allow for collection of additional bulk soil samples to complete all eight soil series. For some soils it was difficult to find bulk samples with a wide range of STP. Three soil series had only 9 of the planned 10 analyzed due to redundant STP. A second factor in the project extension was the departure of the lead researcher for other employment during July 2006. Arrangements were made to keep the individual involved in the project through a contractual agreement to complete data analysis and draft reports and manuscripts. A no-cost extension was requested and granted with a new completion date of September 30, 2007 to accommodate the arrangement. All reports were submitted as planned in the amended workplan.

PROJECT BUDGET

The project was funded by an EPA Clean Water Act Section 319 Grant provided through the South Dakota Department of Environment and Natural Resources (DENR). Matching funding included state funds administered through South Dakota State University (SDSU) Plant Science Department, SDSU Agricultural Experiment Station, and the Water Resources Institute. Additional matching funds were provided through the South Dakota Corn Utilization Council (SDCUC), South Dakota Pork Producers Council (SDPPC), South Dakota Farm Bureau, South Dakota Soybean Promotion and Research Council, East Dakota Water Development District, and South Dakota Beef Industry Council. Table 4 shows the original and actual expenditures and funding sources for the Manure Management BMPs Based on Soil Phosphorus: Evaluating Additional Soil/Runoff P Relationships. Detail explanations of the funding sources and their contributions follow.

RECOMMENDATIONS

As shown in Table 3, statistically significant differences were found between several of the 13 soils studied. However it can be questioned if the differences are of practical significance. If the differences between soils are large enough and they can be divided into two or more identifiable groups, this information could be incorporated into a P index or used to refine the current manure application guidelines. If the differences are of no practical significance, a regression equation using data from all 13 soils could be developed to describe the general relationship between STP and Runoff P for all South Dakota soils. To this end it is recommended that discussions should be held with state regulators and state and federal natural resource agencies to determine how the data should be used.
All of the 13 soils studied exhibited TDP concentrations below current identified critical P concentrations (1 ppm TDP) (Sharpley et. al. 1996) at an STP concentration <100 ppm (Olsen-P). As discussed earlier, the current manure application guidelines should provide protection against water resource contamination for much of South Dakota.

However, the current standard may not provide adequate protection to South Dakota's lake resources. Eutrophication may become a problem if the STP in significant portions of watersheds draining to phosphorus limited lakes are allowed to rise to the limits defined by the current manure management guidelines. It is therefore recommended that water quality profesisnals in South Dakota evaluate whether the current manure management guidelines protect the most sensitive resources. They should also discuss ways to protect sensitive water bodies without over-regulating the livestock industry in the least-sensitive areas of South Dakota.

OVERALL GOALS MET

The project goal was met. The information gained was incorporated into the current manure management requirements for CAFOs in South Dakota.

The two project objectives were reachec or exceeded.

1. Establish laboratory correlations among STP and runoff P for the Aberdeen, Clarno, Egan, Highmore, Houdek, Millboro, Pierre, and Williams soil series collected from across South Dakota that range in STP levels from low to high.

2. Provide manure management education to extension educators and livestock producers.

Final evaluation of project success will be determined by how the findings are incorporated into manure management guidelines and how well accepted they are by livestock producers.

Table 5. Expenditures Table for Manure Management BMPs Based on Soil Phosphorus: Evaluating Additional Soil/Runoff P Relationships.

Original and Actual Expenditures

Manure Management BMPs Based on Soil Phosphorus: Evaluating Additional Soil/Runoff P Relationships

	EPA 319			Local Match				
	Original	Actual	Original Proposed Match (SDSU and WRI)	SD Corn Utilization Council	East Dakota Water Devlpmnt District	SD Soybean Council	SD Farm Bureau	SD Beef Council
Salary	$ 57,097.00	$57,501.85	$34,738.00					
Benefits	13,013.00	$11,052.35	$ 7,435.00					
Tuition Remission								
Travel	$ 3,970.00	$ 4,153.01						
Contractual	$ 1,630.00	$ 130.00	$21,453.00	$10,000.00	$2,500.00	$10,000.00	$7,500.00	
Supplies	$ 1,300.00	$ 4,172.80						
Printing								*$5,000.00
Capital Assets								
Indirect Costs	$ 20,023.00	$20,023.00	$20,518.00					
	$97,033.00	**$97,033.00**	**$84,144.00**	**$10,000.00**	**$2,500.00**	**$10,000.00**	**$7,500.00**	***$5,000.00**

*Some of the expenses incurred for printing and publication of results may not occur until after the project closes on September 30, 2007 and therefore may not be available to be included in the match for this project.

EPA Section 319 Education Training and Demonstration

The original project budget contained a total of $97,033 in 319 grant funds. The largest expenditure was salary and benefits for two Principal Investigators. Funds were also included for travel to collect soils, supplies for the rain simulator, and printing costs for reports and brochures. The budget also included indirect costs to SDSU. Actual expenditures of EPA 319 funds closely followed the project budget (Table 5) although the amount budgeted for salary for the principal investigator were used to support the successor, other staff, and students who were assigned to complete project tasks. Less than planned was expended for salaries and benefits but more was expended for travel and supplies. A lesser amount than planned was needed for lab analysis (Table 3) because nine rather than the planned ten plots were analyzed for three soil series.

Producer Groups

Local Match:

In the original project budget, match for the EPA 319 was to be provided by SDSU from salary and benefits for two PIs paid by state funds. Several grants from producer-groups were to be used mostly for analytical services. Local match in the actual budget closely followed the original plan. The $5,000 committed to the project by the Beef Industry Council for local match has not been entirely committed. Some of the expenses incurred for printing and publication of results may not occur until after the project closes on September 30, 2007 and therefore may not be available to be included in the match for this project.

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Figure 10. Relationship between total dissolved P (TDP) concentration in surface runoff and Olsen-P (mg kg^{-1}) for the Houdek soil series at the 0-5 cm soil depth. Evaluation derived via indoor rainfall simulation.

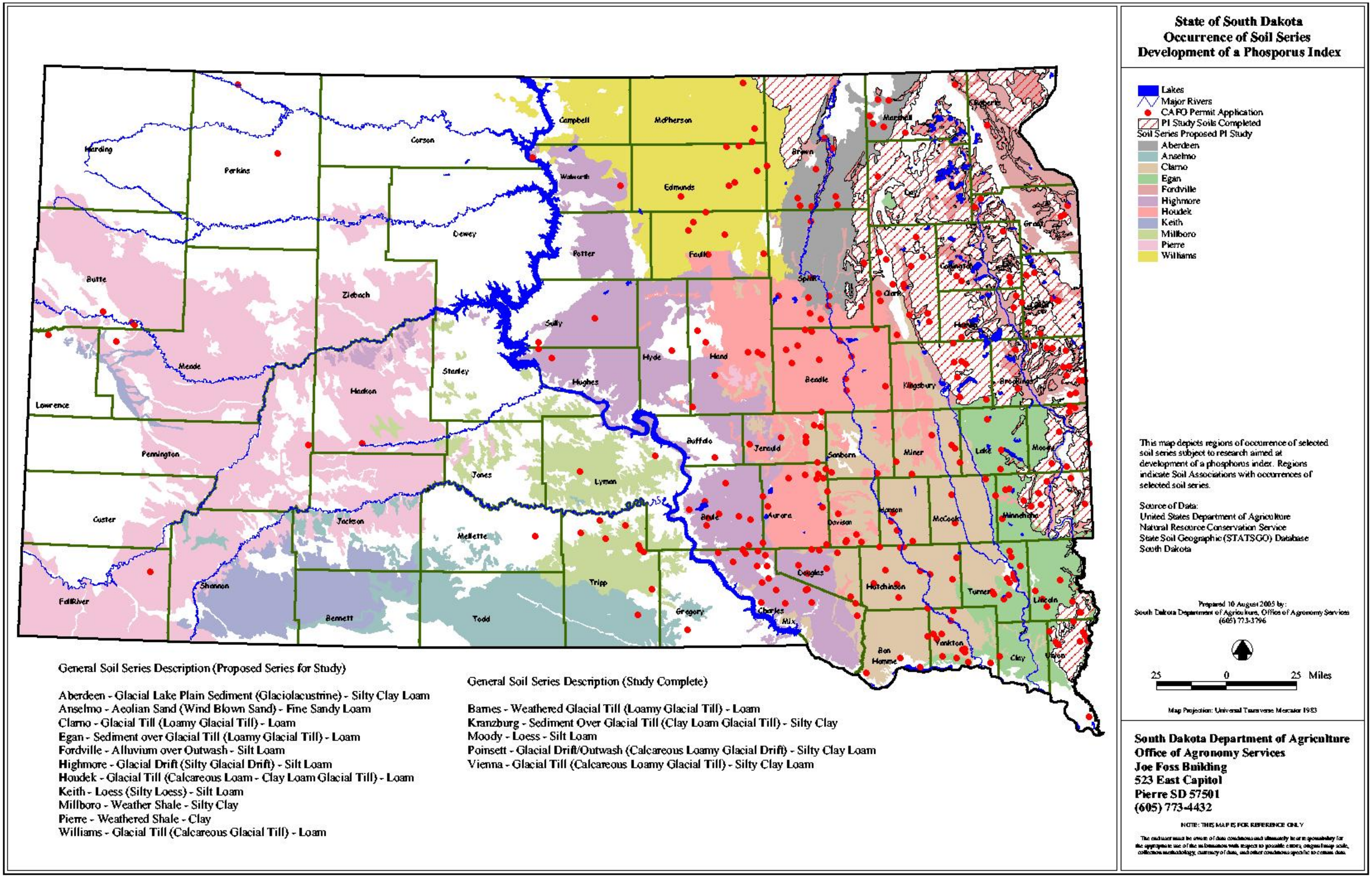
Figure 11. Relationship between total dissolved P (TDP) concentration in surface runoff and Olsen-P (mg kg^{-1}) for the Millboro soil series at the 0-5 cm soil depth. Evaluation derived via indoor rainfall simulation.

Figure 12. Relationship between total dissolved P (TDP)] concentration in surface runoff and Olsen-P (mg kg^{-1}) for the Pierre soil series at the 0-5 cm soil depth. Evaluation derived via indoor rainfall simulation.

Figure 13. Relationship between total dissolved P (TDP) concentration in surface runoff and Olsen-P (mg kg^{-1}) for the Williams soil series at the 0-5 cm soil depth. Evaluation derived via indoor rainfall simulation.

Figure 14. SAS output showing the predicted relationship between total dissolved P (TDP) concentration in surface runoff and Olsen-P (mg kg^{-1}) for the studied soil series at the 0-5 cm soil depth. Evaluation derived via indoor rainfall simulation.

APPENDIX 1: State of South Dakota Occurrence of Soil Series and Development of a Phosphorus Index map.



APPENDIX 2: National Research Project for Simulated Rainfall - Surface Runoff Studies.

National Research Project for Simulated Rainfall
Surface Runoff Studies

PROTOCOL

The field objectives of the National Phosphorus project are to characterize soil test P (STP) - runoff P relationships for a representative cross-section of important agricultural soils across all Major Land Resource Areas in the U.S. Soils subject to past manure additions from the range of major animal production systems (i.e. dairy cattle, beef cattle, hogs, poultry, etc.), will be covered. These soils will be located in watersheds contributing to the range of different types of waterbodies and different climatic regions. The initial goal of the National Phosphorus Research Project is to relate soil test P and surface runoff P, with other confounding factors such as fertilizer or manure application minimized. However, while the plots are in place and after the they have been rained on several times, it is the perfect time to apply fertilizer or manure as per location guidelines and expand the research program.

Plot establishment

- Select area for plot establishment on slopes typical of the benchmark soil, but with sufficient slope (>2) to generate runoff; avoiding sites with significant depression storage areas; select cropping system with typical percent cover; and either identify sites with a preexisting range of STP levels or adjust STP levels (see below).
- Construct runoff plots at each site with dimensions of 2 m long and width of 0.75 to 2 m. The long axis should be oriented down the slope. Under situations of intrasite variability, plots should be 1.5- to 2-m wide by 2-m long. Preliminary studies have shown a minimum of 10 paired sites are needed to accurately describe the soil - runoff P relationship.
- Install metal borders (0.08 inch thick and six inches wide) 5 cm above the ground to isolate surface runoff.
- Install runoff collection gutter at the downslope edge of each plot to divert runoff to a collection point. See Figure 1.
- If plots are established in pastures, mow the plots to a uniform height of approximately 10 cm, one week before the rain simulation and remove the grass clippings.

Adjustment of soil P levels

- Identify sites that provide a range of STP levels on the same soil due to previous manure and fertilizer applications by the landowner, with no P applied in the previous nine months.
- Adjust STP levels of individual plots to obtain a STP range from “low” to “very high” by additions of manure. Levels that qualify as “low” and “very high” may depend on the location and extractant used. In pasture situations, adjustment of STP levels may require several applications of manure to the same plot with follow-up soil testing to ensure attainment of the desired levels, and adjustments may take up to a year or longer to accomplish. In tillage situations, STP adjustments could be done more quickly because more manure could be applied and incorporated at each application.

Soil sampling

- The simplest method is to collect and bulk in the field, 10 cores for each sampling depth (0-5 and 0-15 cm) from within each plot, after raining.
- A more rigorous approach is to air dry the 10 cores and mix equal weights of each core thoroughly to form a composite sample. Run analyses on composite sample, and, if necessary, determine variation in properties from individual samples.

  If collection of individual cores and bulking after air drying is impractical, participants should note that variability in single sample volumes may result in significant, unpredictable sampling error. This error can *affect associations between STP and runoff P, resulting in poor correlation of these variables. We feel that at a minimum, a consistent sampling and bulking method must be used throughout your study.*

- If the plots are to be used in subsequent manure management studies, then soil samples should be taken outside but adjacent to the plots. If soil cores are taken inside the plot, the insitu hydrologic properties of the plots will be destroyed.

Soil analyses

- Air dry soil samples and sieve (2-mm) to remove larger rock particles and most of the grass thatch material.
- Analyze the samples using one or more of the extractants appropriate for your area, e.g., Texas A&M, Mehlich III (Mehlich, 1984), Bray-Kurtz P1 (Bray and Kurtz, 1945), Olsen (Olsen et al., 1954), Fe oxide-impregnated paper strip (Sharpley, 1993), distilled water (Pote et al., 1996), and ammonium oxalate (Sheldrick, 1984; Pote et al., 1996).
- Archive remaining soil sample for further analysis.

Source-water testing

- Collect sample of the source water to be used for the rain simulations.
- Perform as complete analysis of the source water as possible to gain a perspective of the general quality of the source water. Conductivity, pH, and ICAP (inductively coupled argon plasma spectrometer) analysis will provide a perspective of the overall quality and concentrations of potential cations (Al, Fe, Ca) that could interact with the phosphate ion.
- Test source water (outlined below) to determine if dispersion of soil particles is greater than would be produced by rain water.
    1. In a test tube, mix a sample of the surface soil receiving simulated rainfall into a water sample from the water source to be used. Use a ratio of 1 g of soil for each 8 mL of source water (e.g., 5 g of soil in 40 mL of water). Conduct duplicates.
    2. Repeat above step but substitute deionized water for the source water.
    3. Cap the test tubes and shake for about 30 min on a reciprocating shaker.
    4. Place the test tubes in a rack and let stand motionless for three hours.
    5. Observe any visual difference between the clarity of the suspension between the two treatments (deionized water vs source water).

       Assume the deionized water represents low buffered rainwater, serves as the control, and produces little soil dispersion. Most of the solids should settle out in the 3-h period. If the dispersion properties of the source water are similar to the control, then the source water will not affect the dispersion properties of the soil and can be used as source water for simulated rainfall. If, however, dispersion still exists after 3 h (as evidenced by turbidity in the treatment test tubes), the source water can influence dispersion and an alternative source water should be found.

    6. Each soil receiving simulated rainfall should be tested for dispersion effects.
    7. Source water effects on soil P release can be determined by extraction of soil with various source waters (e.g., distilled, tap, ground water, well water, and carbon filtered) at a soil to solution ratio of 1 to 10 for 30 min. The soil to solution ratio and short time approximate suspended sediment concentration of the simulated rainfall-runoff event.

- Transport water to the site (if necessary), preferably not more than 24 h before simulations (Figure 2). Hose reels (Figure 3) can greatly simplify the mechanics of conducting the simulations.

Antecedent moisture

- Determine the antecedent moisture conditions at the site using a soil moisture probe (similar to DELTA-T DEVICES *ThetaProbe*, type ML2). To identify θ_v corresponding to field capacity, conduct the following analyses:

1. Position the open end of a plastic bucket (open on each end) in the soil to a depth of about 5 cm to form a watertight seal. Run duplicates.

2. Gradually add water to the bucket to form a head (~15 cm) and allow to drain.
3. Repeat the above process several times to ensure saturation and then cover the site with an evaporation barrier (plastic) and wait 48 h. After 48 h, take readings with the *ThetaProbe* and take soil samples (5 cm) for determination of θ_v.
4. Allow the system to continue to dry, taking *ThetaProbe* measurements and soil samples for θ_v determinations. Depending on conditions, this could be one- to two-day intervals.
5. From this data, you will know the θ_v that represents field moisture content and also be able to construct a graph of the *ThetaProbe* output vs. θ_v and perform a soil-specific calibration as outlined in the manual.

Rain simulators

- Rain simulators based on design of Miller (1987).
- Each simulator has one TeeJet™ ½HH-SS50WSQ nozzle placed in the center of the simulator and 305 cm (10 ft) above the soil surface. The nozzles and associated water piping, pressure gauge, and electrical wiring are mounted on an aluminum frame. The frame is fitted with tarps to provide a windscreen.
- A pressure regulator is used to establish a water flow rate of 210 mL/sec at each nozzle. The regulator must be placed adjacent (on the same level) to the nozzle on top of the simulator (see Fig. 1). Obtaining the correct flow rate out of the nozzle is the first step to ensuring proper amount and distribution of kinetic energy.
- Measure flow rate by sticking tube (we use a 10 foot length of 2 inch pvc pipe) around nozzle and collecting effluent from tube. The #50 nozzle should have a flow rate of 210 mL/sec. If a #30 nozzle is used, this should have a flow rate of 125 mL/sec.
- Given the proper flow rate, measure rainfall intensity by pan method, NOT by the cup method. In short, collect rain with a tray that covers the entire area of the runoff plots. Using cups results in an overestimation of rainfall intensity.
- Before each simulation run, center the nozzle over the plot. By knowing the dimensions of your simulator and the position of the nozzle, you can tape (duct-tape) markers on the bars of the simulator so once the simulator is aligned correctly (downslope and across slope) the simulator will be centered.

Cautionary notes on simulator

- The temperature of the water makes a difference. The Arkansas crew did intensity runs with water out of the cold water tap (around 70 F) and got the desired 6.97 cm/h and then changed to the hot water tap. We wanted to know what effect this has because sometime we may fill the tank on Friday for a run on Monday. During that time the water will warm up, relative to the cold water tap. Anyway, you get the picture if you are doing runs in Erath County, TX, with the temperature a chilly 104 degrees! With the hot water, we reduced our intensity to 6.2 cm/h. So, we would recommend collecting the water on the day of the runs rather than several days in advance.
- The ½ HH SS 50WSQ is an industrial nozzle, with a spray angle of 104 degrees plus or minus 5%. The nozzles wear with time, affecting both intensity and uniformity. With use this should be checked and the nozzles changed at least each season.
- The pressure regulator, which is used to set the flow rate and intensity for each simulation, **must** be at the same level as the nozzle.
- The simulator should be entirely enclosed with tarps to minimize wind disturbance of rainfall intensity.

Rain simulation

- If the plots are established in pasture or conservation tillage (residue management) systems, measure the percent cover using the string method (Laflen et al., 1981).
- Evaluate the moisture conditions at the test site as outlined above (**Antecedent Moisture**).
- Conduct the simulation run at an intensity of approximately 70 mm/h. Alternatively, conduct the simulation at an intensity corresponding to a ten-year storm for the location. The 70 mm/h intensity is intended to permit comparisons between sites, whereas the intensity of the ten-year storm is intended to approximate local conditions.
- Three rainfall simulations to be conducted at one-day intervals. The first rainfall is conducted at site soil moisture conditions and time to initiation of surface runoff noted for later evaluation of site hydrologic response. The sites will be at approximately field capacity for the second and third rainfalls.
- Collect runoff *in toto* for 30 min, weigh to determine runoff volume, and take a subsample of the collected runoff. A runoff sample at the end of the 30-minute event should also be collected for analysis to reflect an equilibrium P

value. Note: Collection of runoff *in toto* is impractical if plots are much larger than 1 x 2 m, since the runoff volumes produced are large. Alternatively, collect runoff samples of approximately 1 L at 5-min intervals during the runoff event beginning 2.5 min after the start of continuous runoff (six discrete samples/plot/rain), giving a total runoff time of 30 minutes. Record sample volumes and the times required to collect them to calculate the mean runoff flow rates and total runoff volumes and to construct a composite sample from the six discrete samples. The discrete samples can be analyzed individually, but analysis of the flow-weighted composite is less expensive.

- It is recommended that discrete samples be taken during an event for the first few simulations to define the P chemograph. Subsequent simulations only require a single sample of the total flow. This dramatically reduces field and analytical labor and in most cases, a flow-weighted event P concentration will be used.
- Filter (0.45-µm pore diameter) subsample of each composite sample to remove particulate matter.
- Keep the filtered and unfiltered runoff samples at 4^oC until analyzed. Alternatively, acidify the filtered and unfiltered runoff samples with concentrated HCl. **NOTE:** acidification for sample storage will not allow the subsequent determination of algal-available P by either strip or resin membrane methods. Add 1 drop of concentrated HCl to each 10 mL of runoff sample to lower pH to approximately 2.
- Analyze soil and water samples as soon as possible or store soil and runoff samples in the dark at 4EC until analyzed.

Runoff Sample Analyses

- Analyze samples following procedures in APHA (1992; Pierzynski, 2000): Dissolved molybdate reactive/soluble P, total dissolved P, total P, bioavailable P, suspended sediment, pH.

Data analyses

- Analyze relationship between STP levels and runoff P concentrations by regression analysis. Develop regressions and correlation coefficients for each soil series. Determine (a) if a significant relationship exists between STP and runoff P levels for each of the soils and (b) if the relationship between STP and runoff P is the same between soils.

Indoor Soil Box - Rainfall Simulation Protocol

The indoor soil box protocol has been established for specific conditions and objectives. Firstly, when a site is extensively tilled to achieve plot uniformity, it is suggested that similar relationships between soil P and surface runoff P will be obtained with indoor runoff boxes as with field plots. However, it cannot be emphasized strongly enough that indoor boxes are not intended to replace field plots and are to be used in conjunction with field plots. The second scenario under which the indoor boxes may be used is to broaden the selection of soils evaluated. Clearly, the number of field plot sites that can be evaluated over the next two to four years will be limited. The indoor boxes will help strengthen the data base relating soil P and surface runoff P as a function of soil type.

Soil Collection

- Soil from the surface 7.5 cm of selected benchmark soils should be collected in a relatively dry condition with as little residue as possible. The sampled soil depth equates to the depth of soil used in the runoff boxes.
- Physical, chemical, and mineralogical properties are determined on each soil as per National P field protocol.
- Soils are air-dried in the laboratory, then sifted through a 19-mm sieve, and thoroughly mixed. Pretreatment of soil is minimal and a coarse sieve used to retain as much as possible.

Runoff Box Construction

- We propose 1-m long, 20-cm wide, and 7.5-cm deep soil boxes, with side and back walls 2.5 cm higher than the soil surface (Figure 4a). The height of side wall is similar to the height of the field plot boundaries and should not result in any rain shadowing effect in boxes not in the center of the rainfall simulator.
- The boxes are constructed with stainless steel, galvanized sheet metal or plywood. The former are more expensive but will be sturdier, easier to clean, and last longer. If made from wood, the side walls, ends and bottom should be screwed and glued together and then caulked from the inside to seal them. The caulking may need to be touched up occasionally. As long as damp soil is not left in the box for a long time after an experiment has been completed, the wooden boxes can last for several years. However, the general consensus of the group is that metal boxes will be easier to maintain and their additional cost is small compared to other project expenditures.

- Drainage holes (5-mm diameter) are located on the base of the box, at upper, mid, and lower locations (Figure 4b). Although this will not replicate field drainage, several group members thought some drainage was necessary and would improve reproducibility. Surface runoff is collected at the downslope end by a V-shaped aluminum trough. The shaped metal is screwed and caulked to the outside lip of the box (see Figure 5). A cover is attached to the end of the side-wall to protect the runoff collector trough from direct input of rainfall.

Packing the Box with Soil

- The box is packed with a predetermined weight of soil, so that the final weight of soil in the box is known and the approximate bulk density of field soil can be achieved. Cheesecloth is placed on the bottom of box, followed by the addition of 5 cm of soil. Soil is usually added several times to achieve the appropriate bulk density. We use a wooden tamper to pack the soil during filling (Figure 4c).
- Soil is added until it is level with the lower lip of the runoff box. After the desired bulk density is achieved by soil addition and tamping, the box is then placed at the required distance below the simulator nozzle (3.05 m or 10 feet). To a certain extent, packing is somewhat subjective depending on the "packer". However, a personal or individual protocol is developed after a couple of boxes are packed. Soils will be evaluated in triplicate, so that each soil should be packed into three different boxes for the runoff study.

Simulating Rainfall and Chemical Analyses

- This portion of the protocol closely follows the field protocol discussed previously. Soils are pre-wet to control for antecedent moisture. A furnace filter is placed on the soil surface to protect the soil from raindrop impact, simulating crop cover. The soil is saturated using the rainfall simulator and the furnace filter removed. Saturated soils are left to drain for 24-36 hrs (covered with plastic) until field capacity is achieved. Volumetric soil moisture content is determined by theta probe. Depending on user capabilities and amount of soil, it is recommended that for each soil, a "prewetted" and "air-dried" condition (no prewetting) be evaluated.
- Runoff boxes can be set at two slopes, a field slope and a "common" slope (about 4 to 5%), with the field slope offering comparison with field data, and the common slope enabling comparison across the National P Project. At a minimum, soils should be evaluated under the common slope.
- Rainfall simulations are conducted three times, at one-day intervals between rainfall events to allow the soil to return to field capacity. Rainfall is applied at 7.0 cm hr^{-1} until 30 minutes of runoff has been collected (same protocol as for the National P field plots). A single bulk runoff sample (typically 5 to 7 L) is collected for the 30-min event. As per field protocol, discrete samples can be collected during the first few storms to define the P chemograph.
- Runoff volume, sediment yield, and P are measured as defined under the field protocol. Dissolved, algal-available, and total P forms should be measured. Soil samples for chemical analysis should be collected from the material during packing. If samples are needed after a rainfall, a sample can be taken from the up-slope end of the box and replaced with a small amount of the original soil. As the boxes are prepacked, limited sampling at the upper end of the box will not effect flow pathways as in the field plots.

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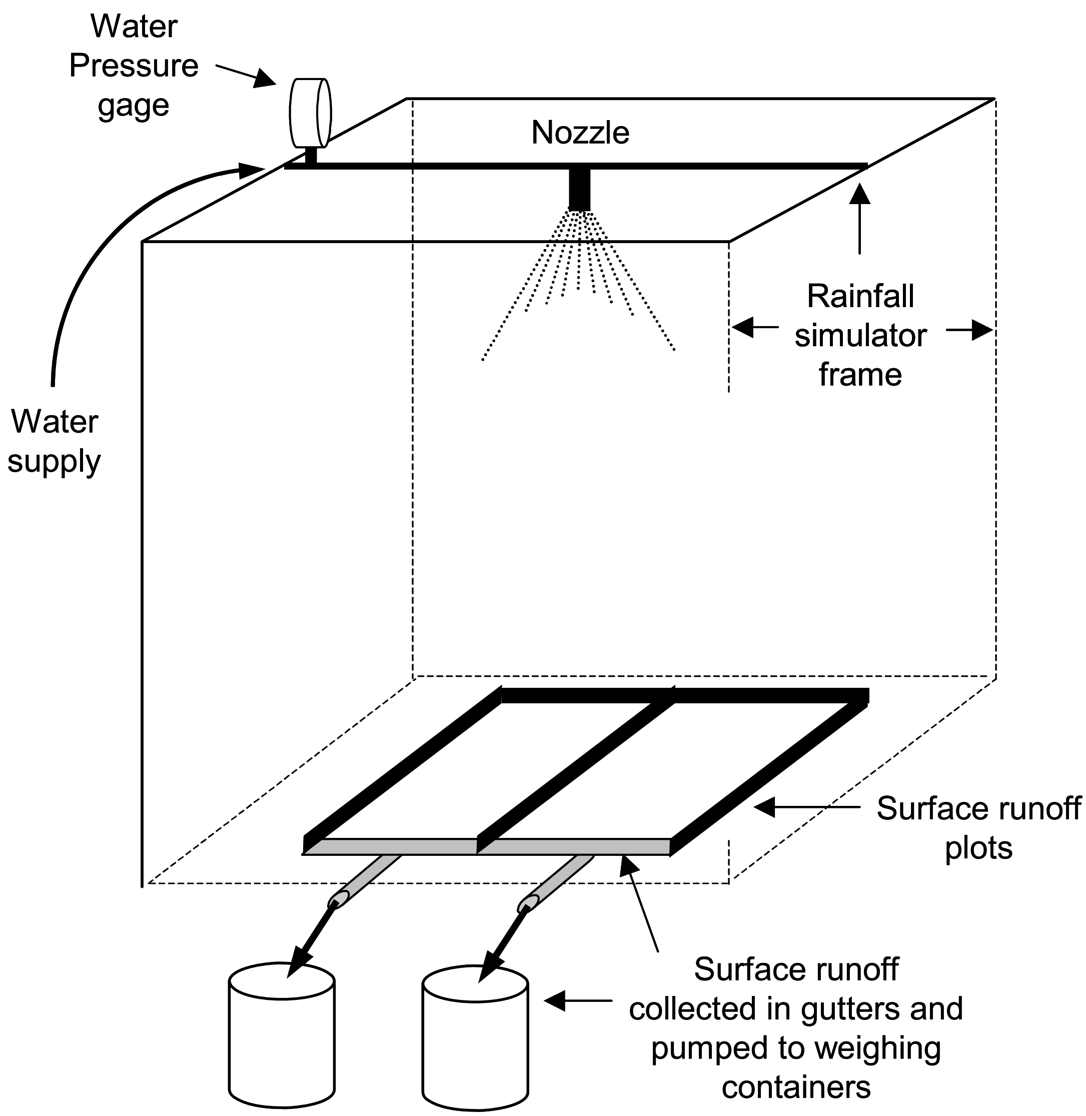


Figure 1. Plan of the rainfall simulators, surface runoff plots, and water collectors.

Arkansas prototype

Pennsylvania prototype

Figure 2. Goose-neck trailer with 1600-gal. capacity water tank. (Chem-tainer Industries, Inc. 361 Neptune Ave. West Babylon, NY 11704, 516-661-8300).

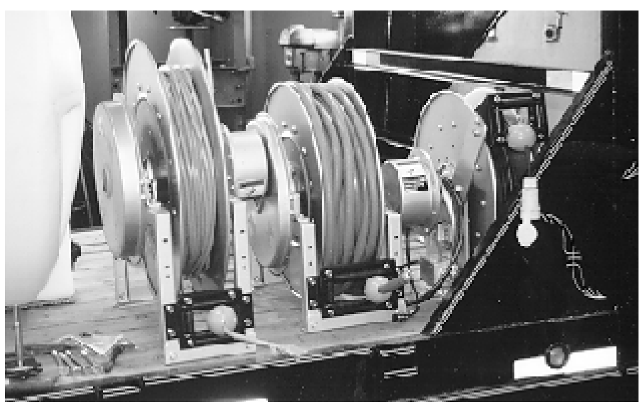


Figure 3. Hose reels for power cords, “brain stem,” and water lines. (Hannay Reels, 553 State Route 143, PO Box 159, Westerlo, New York 12193-0159, 518-797-3791,

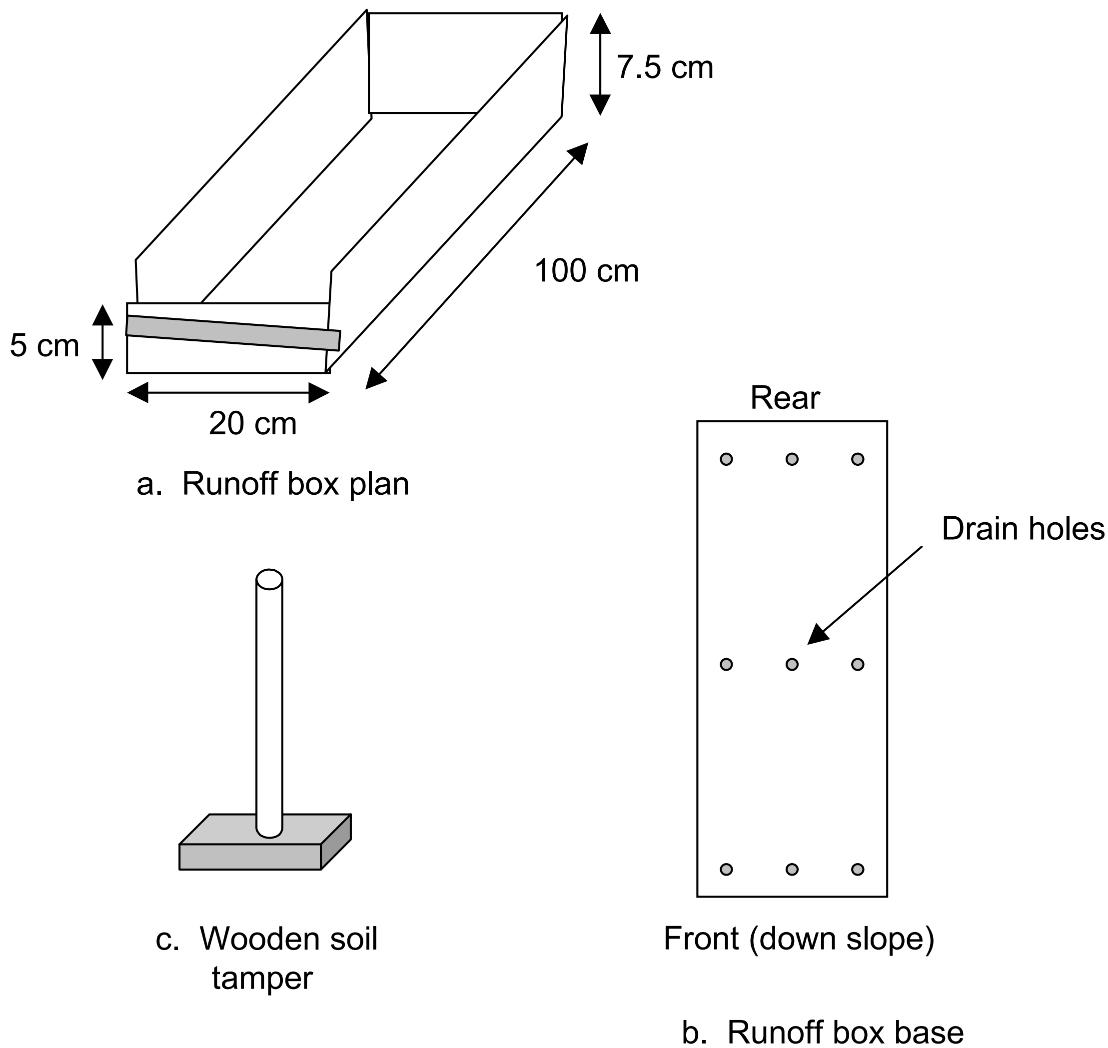
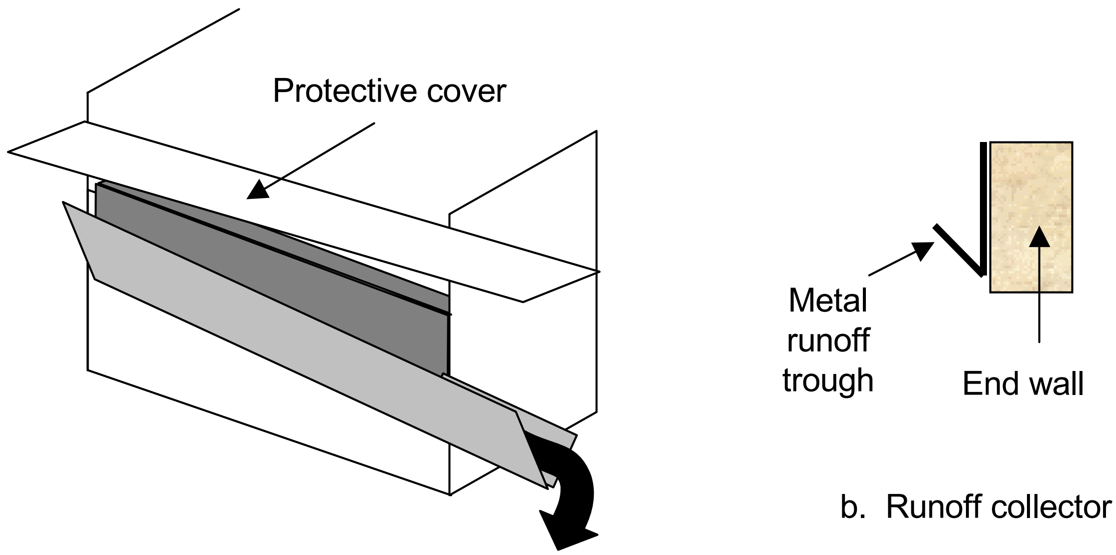


Figure 4. Runoff box plan.



a. Front plan with runoff collector

b. Runoff collector

Figure 5. Runoff collection.

APPENDIX 3: Agenda for the Professional Soil Scientists Association of South Dakota Meeting.

Professional Soil Scientists Association of South Dakota
Annual Meeting
Friday, March 9, 2007
Room 300
Federal Building, Huron, South Dakota

8:30-8:50	Registration	
8:50-9:00	Welcome	Roger Assmus
9:00-9:30	Detailed Elevation Maps for Soil Survey Updates	Jim Millar
9:30-10:00	SunGrant Update	Jim Doolittle
10:00-10:30	Soil Carbon and Productivity Issues – A Literature Review	Anthony Bly
10:30-11:00	Reconstructing Pre-Agricultural Prairie Wetland Bathymetry using Sediment Markers	Craig Novotny
11:00-11:30	Phosphorus Runoff at a Watershed Scale	Dave German
11:30-12:00	Clay Minerals and the Origin of Life	Roger Assmus
12:00-1:00	Lunch – on your own	
1:00-1:45	Hunting Nutrients and Trapping Carbon	Kris Nichols
1:45-2:15	Soil Quality: Melting Pot or Mosaic	Tom Schumacher
2:15-2:35	The New SDSU Agronomy Farm Soils	Bruce Kunze
2:35-2:45	Break	
2:45-3:30	Business Meeting	
Posters	Tillage Erosion Coefficient Development for the Chisel Plow	Joe Schumacher
	Smithsonian Soil Exhibit	Bruce Kunze
	Tillage management and previous crop effects on soil physical properties	Walt Riedell