



## **WATER RESOURCES RESEARCH GRANT PROPOSAL**

**Title:** Phosphorus Source/Sink Dynamics in a Flood-Irrigated Agricultural System in Central Idaho

**Focus Categories:** AG, HYDGEO, HYDROL, IG, NU, NPP, ST and WQL

**Keywords:** Agriculture, Contaminant Transport, Irrigation Management, Land Use, Phosphorus, Pollutants, Runoff, Unsaturated Flow, Soil Chemistry, Soil Erosion, Suspended Sediments, Water Quality Management, Water Quality Monitoring

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**FY 2000 Federal Funds:** \$14,962

**FY 2000 Non-Federal Funds:** \$29,925

### **Principal Investigators:**

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### **Cooperator:**

Mr. D. Davidson, Idaho Soil Conservation Commission

**Congressional District:** First

### **Statement of Critical Regional or State Water Problems**

Water quality protection through restoration and management of watersheds is receiving tremendous attention in the United States at all levels of government and in local communities. Since contributions of most point sources (e.g., sewage treatment plants and industrial sites) have been reduced to acceptable levels, the main emphasis presently is on the control of non-point sources originating from urban, forest, agricultural, and recreational lands. Non-point sources are covered by sections 208, 303(d) and 319 of the Clean Water Act. Approximately 1000 water bodies are currently classified as impaired or use-limited in each state in the western U.S. Many water bodies are classified as P-limited due to their high nitrogen:phosphorus ratios ( $N:P \gg 10$ ) (Sharpley et al., 1994; Chapra, 1997). Consequently, water pollution abatement strategies frequently focus on reductions in P loading. State and local agencies throughout the U.S. are in the process of setting permissible load allocations, expressed as Total Maximum Daily Load (TMDL), and developing water quality management plans for all use-limited water bodies. The greatest challenge in developing these management plans is meaningful and realistic allocation of load reductions for all land uses within a watershed. Unfortunately, because

these agencies operate with very limited financial resources and have an extremely challenging time line (e.g., eight years in Idaho), load reduction goals are based on minimally comprehensive, and potentially misleading, water quality monitoring data and on a limited understanding of fate and transport of pollutants. Some perceive the process as subjective and empirical in nature. The development of the water quality management plan for the Cascade Reservoir in Idaho exemplifies the problems described above. Water quality data have been collected at different levels of comprehensiveness for forest, urban and agricultural land uses. Partitioning the total P load into the various land uses is difficult given the lack of comprehensive data. In particular, P loading from agriculture, mainly irrigated pasture and hay land, has not been accurately determined due to extremely limited monitoring data and the lack of representative model parameters. The agricultural P load is currently estimated to be ~15,800 kg P/yr or 44% of the annual P load to the reservoir (D. Davidson, Idaho Soil Conservation Commission, personal communication). This value is determined from the area-weighted difference between the estimated total nonpoint load (~35,700 kg P/yr) and estimates for natural (~11,000 kg P/yr), forest (~5,900 kg P/yr) and urban sources (~3,000 kg P/yr). Indirect assessment of agricultural P loading is subject to over-estimation and, therefore, is potentially unfair to agricultural land owners. During Phase II of TMDL development, agriculture as a whole would need to reduce its P loading by 30%. Major problems could arise if landowners commit to expensive Best Management Practices (BMPs) only to find out years later that their efforts did not achieve specific water quality goals. Furthermore, several studies show that loading from non-point P sources is seasonally dependent, a fact not addressed in the current Cascade Reservoir load allocations. Given the inherent uncertainties associated with estimating non-point P sources, it seems critical to pursue an improved assessment of the agricultural contribution.

The research literature contains insufficient information for estimation of P loading from irrigated agriculture. It is clear, therefore, that a comprehensive study is needed to document relationships between P loading and watershed parameters that would 1) provide a more accurate value for agricultural P loading in the Cascade Watershed and 2) provide information that would be readily transferable to other agricultural regions in the western United States. Such relationships should be developed from direct measurement of flow volumes and soil-water P concentrations monitored throughout the year to accurately determine seasonal P dynamics.

### **Statement of Results or Benefits**

The proposed study will provide an in-depth analysis of the seasonal P contribution from irrigated pasture and hay land to the Cascade Reservoir. We hypothesize that P cycling is seasonally dependent. Hence, we will determine P loading by evaluating source/sink relationships during *i*) spring snowmelt and rain-on-snow events, and *ii*) the growing season which is characterized by subsurface irrigation. Phosphorus will be determined as total (TP), dissolved (DP) and particulate (PP). These P fractions are important in selection of BMPs to reduce P loading (e.g., total runoff reduction when DP loading is high versus erosion control when PP loading is high).

Results will include (1) a continuous, three-year record of DP and PP loading from two 18 ha, irrigated pasture/hay fields, (2) semi-empirical quantification of surface and sub-surface contributions to P transport using enrichment ratios and P desorption, (3) an improved understanding of *in-situ* P sorption-desorption as a function of seasonal soil saturation and temperature, and (4) the dynamics of P transport beyond pasture fields in irrigation ditches. Findings from Year 1 are given in Section 17. In Year 2, we will continue data collection as planned and further develop the source/sink relationships. After Year 2, we will have more robust export coefficients and more events to evaluate the relationships shown below. The combined results of fields and ditches will also be extrapolated to estimate P sinks and sources at the watershed scale. The immediate study area in Idaho affects Cascade Reservoir which is designated on the 1994 303(d) list as a high priority water body. Results of this study are directly applicable to the 20,000 ha of sub-irrigated pasture and alfalfa hay lands, affecting almost all water bodies within the Cascade Reservoir watershed. Collectively these water bodies are limited for cold water biota, contact recreation, domestic and agricultural water supply and salmonid spawning. Currently, the Agricultural Source Plan refers to this study to clarify questions related to TMDL implementation in Cascade Reservoir Watersheds. Results will also be relevant to improved watershed management of thousands of hectares of irrigated pasture and alfalfa hay in the Intermountain Region of the western United States.

### **Nature, Scope, and Objectives of the Research**

Estimates of phosphorus (P) loading from agricultural land use in western states are needed for remediation of water quality problems as well as for long-term sustainable watershed management. Although P loading has received considerable attention in the research literature in the past two to three decades, annual estimates of P loading from subsurface/flood or sprinkler irrigated pasture land have not been reported. Many reports available on non-irrigated pastures are mostly applicable to soils in the eastern and midwestern portions of the United States (e.g., Edwards et al. 1996; Austin et al. 1996; Beaulac and Reckhow, 1982; Loehr, 1974; Harms et al., 1974). Miller et al. (1984) reported net loss of P from flood irrigated grass and alfalfa hay land in Nevada, but measurements only covered the irrigation season, ignoring P loading during spring snowmelt.

The principal investigators have one completed and one ongoing research project in the study watershed. McGeehan (1996) conducted a study on P sorption and desorption in seasonally saturated soils from the Cascade area documenting the potential for changes in P sorption and desorption that occur in response to changing soil redox conditions. Both PI's are involved in a mass balance study of two fully instrumented field sites in the watershed in collaboration with the Valley County Soil and Water Conservation District (VSWCD). This project received funding from the Idaho Department of Water Resources to evaluate P export from agriculture in irrigated pasture/hay fields for water quality improvement with emphasis on sprinkler irrigation as a BMP and includes mass balance measurements, cost-benefit analyses and other socio-economic aspects.

Since an isolated field experiment falls short of documenting the temporal and spatial variable P loading at the watershed scale, we will expand the ongoing project to include P transport from the pasture fields to irrigation ditches connecting the fields to Willow Creek. Important questions we attempt to answer are: "What are the relative magnitudes of P sources from agriculture in the Cascade Reservoir watershed ?", "What time of year do these sources release the greatest P loading?" and finally, "When is the impact of an individual source noticeable in downstream aquatic ecosystems?"

The overall objective of this proposal, therefore, is to develop seasonal P source/sink relationships for irrigated pastures. We hypothesize that P cycling is dynamic and seasonally dependent, and requires evaluation at a scale larger than the field scale. Hence, we will compare P source/sink relationships during *i*) spring snowmelt and rain-on-snow events, and *ii*) the growing season that is characterized by subsurface irrigation. Source/sink relationships will be determined by measuring enrichment ratios and P desorption in soil/sediment samples and dissolved (DP), particulate (PP), and total (TP) for water samples. Detailed field data will be collected for three years from two fields and associated ditches in a subwatershed of the Cascade Reservoir watershed in central Idaho. After Year 2, we expect to have a relatively complete data set for preliminary extrapolation to the watershed scale.

Specific research objectives are:

**Objective 1.** To determine surface and sub-surface P inputs and outputs on a seasonal basis for two subsurface irrigated pasture/hay fields.

**Objective 2.** To develop seasonal P transport relationships for dissolved and particulate P and predict annual P loading.

**Objective 3.** To determine the dynamics of P transport beyond pasture fields in irrigation ditches.

Note: Objective 2 in the previous version of this proposal was eliminated because Dr. McGeehan no longer holds a research position in the Soils Department. Laboratory P sorption experiments performed by McGeehan (1996) and P desorption experiments performed during Year 1 will replace the soil chemical characteristics to be linked with transport relationships.

## **Methods, Procedures, and Facilities**

### **The mass balance: predictive equations and parameter selection**

We will determine source/sink relationships of P loading for two forms: PP and DP (see Table 1). Predictive equations have been reported in the literature and briefly will be reviewed here to show which parameters need to be estimated and which water quality constituents will be measured in our study. These equations serve as a starting point for the proposed study.

*PP in runoff sediments:* As soil erosion is a selective process with respect to particle size, selectivity has been observed for P loss in runoff sediments, with the result that eroded soil is usually richer in P than the surface soil from which the eroded soil comes (Sharpley, 1980). Particulate P transport, therefore, is predicted from an equation of the form (Edwards et al., 1996):

$$PP = TSS_y \times \text{Soil TP} \times ER \quad (1)$$

where PP is the (event) particulate P transport (kg/ha), TSS<sub>y</sub> is the event total suspended sediment yield (kg/ha), Soil TP is the TP content of the surface soil (kg/kg), and ER is the enrichment ratio (= PSED/Soil TP where PSED is the TP content of eroded soil). We assume that the use of TSS<sub>y</sub> for total sediment yield is reasonable for pasture land (Edwards et al., 1996). Sharpley (1980) developed a relationship between ln(ER) and ln(TSS<sub>y</sub>) as:

$$\ln(ER) = a_0 + a_1 \times \ln(TSS_y) \quad (2)$$

where coefficients a<sub>0</sub> and a<sub>1</sub> appear to vary with soil and land use with approximate values of 2.2 for a<sub>0</sub> and -0.24 for a<sub>1</sub> representing a variety of soil and cover conditions. *DP in runoff water:* A general, predictive equation for DP in runoff water is as follows (Edwards et al., 1996):

$$DP = 0.01 \times D \times \text{Soil TP} \times XC \quad (3)$$

where DP is (event) soluble P transport (kg/ha), D is event runoff (mm), Soil TP is in mg/kg, and XC is an extraction coefficient considered to represent the mixing of soil and runoff as well as the P desorption properties of the soil. The factor 0.01 assures consistent units. High runoff interaction and easily desorbed soil P would be reflected in an increase in XC.

To be able to develop and test above relationships for subsurface irrigated pastures, we need to determine all parameters in Eqns. 1- 3 either by direct measurement or derived from measured parameters. Exceptions are a<sub>0</sub>, a<sub>1</sub>, and XC, which will be determined by regression analysis. In addition, because Eqns. 1 - 3 were derived for rainfall-runoff events on soils in eastern and midwestern states, we will also focus on P desorption kinetics, subsurface P contributions, and manure input and plant uptake for development of different relationships for irrigated agriculture in western states. For example, the relationship between the average DP concentration in runoff for an individual event and the kinetics of soil P desorption tested by Sharpley and Smith (1989) may be of interest for irrigated pastures as a replacement for Eqn. 3. Application of event-based relationships to subsurface irrigation also will be addressed during data analysis.

Table 1 summarizes the parameters measured and derived, and includes abbreviations used throughout this section of the proposal. For spring snowmelt runoff waters, we expect to determine all constituents from monitoring stations at the outlet points of each field. For subsurface irrigation, we need to determine net losses as the difference between

incoming irrigation water and return flows. Measurements in the ditches will not likely conform to Eqns. 1 – 3.

Table 1. Measured and calculated parameters in the proposed study and abbreviations used.

Parameter	Abbreviation	Measured/Derived	Origin
Runoff depth	D	Derived	measured discharge (Q)
Total P	TP	Measured	runoff water
Dissolved P <sup>1</sup>	DP	Measured	runoff&subsurface water
Particulate P	PP	Derived	runoff water: TP - DP
Total suspended solids	TSS <sub>y or 1</sub>	Measured	runoff water
Total P in soil	Soil TP	Measured	surface soil in field
Total P in sediment	PSED	Measured	surface soil in gullies
Enrichment ratio	ER	Derived	runoff water & soil: TP <sub>eroded</sub> soil/soil TP
a <sub>0</sub> & a <sub>1</sub>	-	Derived	Eqn. 2 (regression)
Extraction coefficient	XC	Derived	Eqn. 3 (regression)

<sup>1</sup> dissolved P is assumed to consist mostly of ortho-phosphate (Sharpley et al., 1994).

### Description of fields in Idaho

Our research area is located within Boulder/Willow Creek watershed (Fig. 3) a subwatershed of Cascade Reservoir, which itself is located in the western portion of the central mountains of Idaho, situated within Long Valley, and surrounding the towns of Cascade, Donnelly, and McCall. The total watershed area to Cascade Reservoir embodies seven primary subwatersheds with an approximate area of 124,600 ha. The majority of these subwatersheds are forested (66.6%) with irrigated pasture being the second primary land use (14.4%). Elevations range from approximately 2700 m. at mountain peaks to 1463 m. at the reservoir level. Precipitation occurs primarily as snow or rain on snow. Snow generally begins accumulating in early November, reaches maximum depth of up to one meter in February, and starts to melt by mid-April. Approximately 150 mm of precipitation is received during the growing season in the valleys. Soils are mostly loam but vary from clay loam to sandy loam textures.

The privately owned pasture lands are located at lower elevations with a slope of 1 to 4% and range in size from 18 to 27 ha. Cattle grazing occurs from late spring to early fall. Pasture lands are primarily irrigated by sub-irrigation which consists of a set of contoured ditches crossing the land to carry water continuously during snow-melt (April through June) and irrigation (June through October) seasons. Seepage from contoured ditches maintains the water table at high levels so that adequate moisture is available in the root zone at all times. Sub-irrigation sometimes is complemented by flood irrigation during high evapotranspiration periods to ensure adequate root zone moisture.

## Description of ongoing study in research watershed

Our ongoing study objective is to determine seasonal P export coefficients through a water and P mass balance on two fields. These field sites were selected in the Boulder/Willow Creek watershed. Each field measures approximately 18 ha. Currently, both fields are used as cattle pastures and are irrigated using subsurface irrigation practices with one main inlet ditch and one main outlet ditch (see Fig. 1). Average temperature at this site is 5°C, average precipitation is 584 mm, with an average of 72 frost free days.

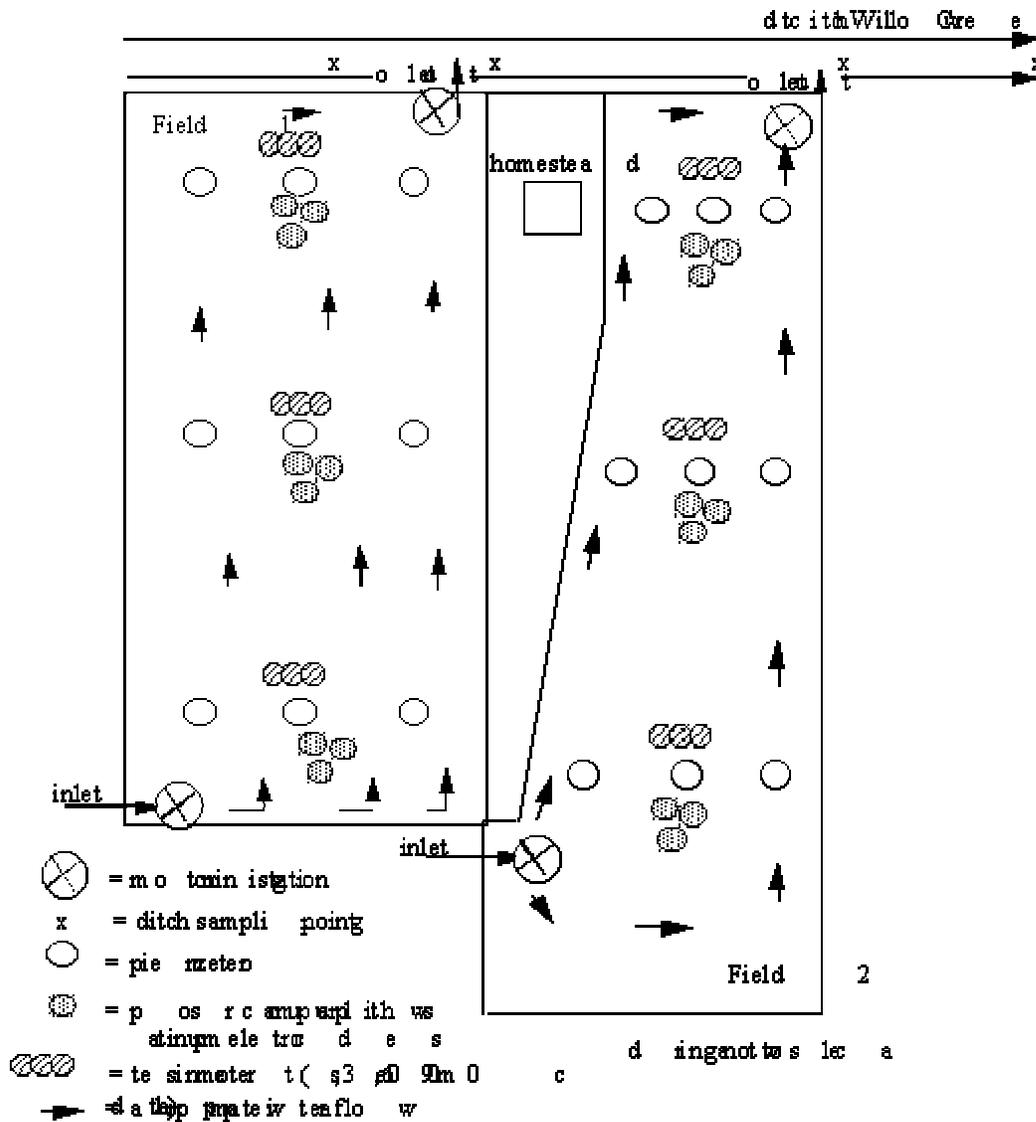


Figure 1. Schematic of subsurface irrigated fields in ongoing study.

Two soil types cover the total field area: the Roseberry coarse sandy loam and the Donnel sandy loam. The Roseberry soil is a deep, poorly drained, level to gently sloping soil formed in alluvium and glacial outwash from granitic sources. Permeability in the upper layers is moderately rapid. Runoff is slow. The Donnel soil is a deep, well drained soil on

2 to 4% slope. Permeability is moderately rapid in the surface layers and rapid below. Roots in both soils extend to more than 150 cm.

Each inlet and outlet ditch in both fields is instrumented with flumes, automatic water samplers, and dataloggers. Flow and water sampling are event-based throughout the year. Each field also is equipped with nine groundwater wells from which groundwater levels are measured and water samples are taken monthly. Soil sampling is done before and after the irrigation season. Mr. Davidson from the Soil Conservation Commission has assisted the PI's in instrument installation, field sampling, and maintenance. He will continue his assistance throughout the duration of this project. The landowners have agreed to the use of their land for the duration of the study (see support letters in Collaborative Agreements). Preliminary findings and specific results from FY1999 are provided in Section 17.

### **Research procedures**

We first list analytical methods common to all objectives and provide detail on Quality Assurance protocols. Then we will explain how each objective will be achieved. *Analytical methods.* Water samples and soil extract solutions from P desorption procedures will be divided into two bottles. Phosphorus fractionation will be accomplished using methods from Sharpley (1993). TP will be determined on unfiltered samples following four-acid digestion (EPA Method 3050). All other aqueous samples will be filtered (0.45  $\mu\text{m}$ ) prior to chemical analysis. DP will be determined on filtered samples by the ascorbic acid method of Watanabe and Olsen (1965). PP will be calculated as the difference between TP and DP. Each P fraction will be determined by colorimetrically using a spectrophotometer. Soil and ditch sediment samples will be air dried and ground to pass a 2 mm-sieve. Large pieces of organic debris ( $> \sim 0.3$  cm) will be removed prior to grinding. Phosphorus analysis will be performed on the dried, ground sediment samples. Analysis of water and soil samples will be performed in the laboratory of Dr. Boll with the help of graduate and undergraduate students trained through this project. Four-point sorption isotherms will be determined using standard batch sorption methodology (Nair et al. 1984) and initial P concentrations ranging from 0 to 100 mg P L<sup>-1</sup>. P desorption profiles will be determined using a 10-cycle sequential technique described by Oloya and Logan (1980). Cumulative desorbed P will be calculated from the total P released from each sample through 10 desorption cycles. Soil TP and plant analyses will be conducted by the University of Idaho Analytical Sciences Laboratory.

*Quality Assurance.* Standard Quality Assurance procedures will be followed as outlined in the Standard Methods for the Examination of Water and Waste Water (American Public Health Association, 1995) and Standard Methods of Soil Analysis (Klestra and Bartz, 1996). All stages of the project will be supervised by experienced UI and Idaho Soil Conservation Commission investigators to ensure reliability of results. All sampling and analytical procedures will follow written Standard Operating Procedures. Glassware and plastic bottles used for this study will be acid washed before (re-)use. Adequate samples will be collected utilizing appropriate equipment to ensure reliable P loading estimates. Water samples, except those for TP analysis, will be filtered on site prior to

transport. To address field soil variability, a series of subsamples will be collected and thoroughly mixed to form a composite sample. Water, soil and plant samples will be stored on wet ice (at 4 °C) following collection and immediately transported to the laboratories for analyses. Shipment procedures are to place the cooler with samples on the bus from Cascade to Moscow, ID, collect them at the bus stop and analyze them the same or next day. On occasion, personnel traveling from the site in Idaho will carry samples directly to the laboratory. Determination of DP in water samples and soil extract solutions will take place within 48 hours of collection and filtration in the field. TP and dissolved metal samples will be preserved at pH<2 using H<sub>2</sub>SO<sub>4</sub> and analyzed within 7 days. Our quality assurance procedures have worked extremely well during FY 1999. Several contaminated samples were detected using these procedures.

Chemical analysis of the samples will follow Good Laboratory Practices regarding sample storage, timeliness of analysis, analytical precision and accuracy, data collection and record keeping. All chemical analyses will be performed using certified standards. Standard curves used for quantification will be subjected to statistical evaluation in order to determine an estimate of precision. Standard EPA methodology will be used whenever possible. Methods that are not EPA protocols are fully described in the experimental section of this proposal. Approximately 5% additional samples will be analyzed for Quality Assurance and Quality Control (QA/QC). These samples will include duplicates collected from the field and internal references (including blanks) developed in the laboratory.

All water, plant, and soil data will be replicated and subjected to statistical analyses. Means will be compared using conventional mean separation procedures at a significance level of 5%.

**Objective 1.** To determine seasonal surface and sub-surface P inputs and outputs on a seasonal basis for two subsurface irrigated pasture/hay fields.

To achieve this objective, activities include measurement of input and output in surface waters, measurement of subsurface contributions, determination of soil TP, PSED, manure inputs to the fields, and plant uptake. The graduate student and Dr. Boll will cooperate closely with Mr. Davidson of the Idaho Soil Conservation Commission in execution of this objective. Mr. Davidson will be responsible for timely sample collection, filtration, preservation and shipment of samples. Mr. Brooks, and graduate and undergraduate students will assist Mr. Davidson during periods of more frequent sampling and when soil sampling is scheduled.

Installation of measurement equipment in this objective was completed prior to September 1, 1998, as part of the Irrigation Practices Evaluation Project (Fig. 1). A description was provided above.

*Activity A:* Measurement of input and output in runoff water

During the non-irrigation season, little flow enters the fields through inlet ditches since they are closed. Water quality sampling at the outlet ditches will be event-based, collecting samples at higher frequencies during peak flow than during low flows. Automatic samplers will be programmed to extract water samples once every 96 hours, 24 hours, and four hours for low flow, moderate flow and high flow, respectively. We do not expect many snowmelt events, for, generally, the majority of snowmelt occurs in the months of May and June. After the first snow fall, snow depth and density will be measured weekly by Mr. Davidson of the Idaho Soil Conservation Commission until fully melted.

During the irrigation seasons, water quality samples will be taken at regular time intervals of one sample every other day or three samples per week. Water quality samples will be analyzed for TSS, TP, and DP. Under subsurface/flood irrigation, stations at both inflow and outlet ditches will monitor the parameters as listed for the non-irrigation season.

*Activity B:* Measurement of subsurface flow contributions.

Piezometers in combination with in-situ saturated hydraulic conductivity measurements (Johnson et al., 1952) serve to quantify lateral flow. Tensiometer readings will determine vertical water movement. Both groundwater levels and tensiometer readings will be taken bi-weekly during the irrigation season, monthly during the non-irrigation season and weekly during main snowmelt periods. If vertical water movement is apparent from tensiometer readings, we will take ground water samples to quantify vertical P transport. This activity will be initiated in Year 2.

*Activity C:* Soil/eroded sediment P determination, manure loading, and plant uptake.

Total P in soil and eroded sediment in each field will be determined before and after each irrigation season. One soil sample per two acres will be removed from the 0 to 5 cm depth. Eroded sediment samples will be taken in the channels leaving each field.

Inputs of fertilizer and manure from grazing animals will be estimated through consultation with the land owner. Literature values will be used to convert numbers of animals to manure output and subsequent P contribution. P uptake by vegetation will be determined from clippings taken across the fields before and after the irrigation season.

Note: during Year 1, we experienced unusual weather conditions which made data collection during part of the Spring snowmelt period difficult. In order to assure meaningful results in this project, we have initiated a laboratory flume study to simulate special flow conditions observed in the field. Three flumes are 1 m long, 0.3 m wide, and 0.2 m deep. Soils from field 1 and 2 were taken and will be packed in the flumes to the same bulk density as in the field sites. Subsurface flow, surface flow and rainfall will be simulated followed by event-based sample collection. This study will overcome the potential pitfalls experienced in Year 1 for this and subsequent objectives.

**Objective 2.** To develop seasonal P transport relationships for dissolved and particulate P and predict annual P loading.

Each set of data pertaining to the non-irrigation season and subsurface irrigation seasons will be analyzed separately. For the irrigation season, net loss of TSS, TP, DP, and PP will be calculated for this objective. Data will be evaluated on a year by year basis. The graduate student and Dr. Boll will be responsible for this task with Dr. McGeehan in an advisory role.

*Activity A:* Determination of a water balance.

A water balance calculation will be performed from measured discharges, precipitation (rain and snowmelt), subsurface water flux, and estimated evaporation from the weather station at McCall's golf course, and one in Cascade. The water balance data will provide the relative importance of different hydrologic processes in the transport of P. In addition, this balance will serve as a check on measurement accuracy and describe any site-specific characteristics of our study fields.

*Activity B:* Determination of relationship for PP in runoff sediments (Eqns. 1 and 2).

PP will be determined as the difference between TP and DP. ER will be calculated as the ratio of PP in eroded soil to TP in soil samples. The parameters  $a_0$  and  $a_1$  in Eqn. 2 then will be determined applying simple linear regression to TSS and ER. Values of ER,  $a_0$  and  $a_1$  will be compared to literature values. Similarly, regression will determine how well Eqn. 1 holds for conditions in this study.

*Activity C:* Determination of relationship for DP in runoff water (Eqn. 3).

Values for XC in Eqn. 3 will be determined from measured data of D, Soil TP and DP in runoff water and will be correlated to P desorption estimates from Objective 2. Agreement between these values and literature values will be evaluated, and new relationships will be developed accordingly.

*Activity D:* Determination of P loading as a function of P desorption and subsurface water.

Regression analysis will be applied to parameters measured and derived for runoff and subsurface waters including P desorption estimates (as a function of temperature, mineral dissolution, and saturation) from Objective 2. This activity will develop new relationships specific to subsurface/flood and sprinkler irrigation, and will be very unique when P relationships in Eqns. 1 - 3 do not describe P transport very well.

*Activity E:* Determination of annual P source/sink relationships from data from the two fields.

Annual TP loading ( $\text{mg P ha}^{-1} \text{ yr}^{-1}$ ) will be estimated using measured TP in runoff water and using relationships developed in Activities B - D by summation of DP and PP estimates for each season. In addition, estimates of annual DP and PP will be compared to annual TP loading estimates. These values will be compared to indirect methods employed currently by state and local agencies in Cascade Reservoir watershed. A negative or positive loading value will indicate whether the field acted as a source or sink, respectively.

**Objective 3.** To determine the dynamics of P transport beyond pasture fields in irrigation ditches.

*Activity A:* Data collection in irrigation ditches leaving the fields.

Four locations have been selected for ditch sampling. These are before and after discharge of field 1 and 2 into the irrigation ditch. This ditch connects to Willow Creek approximately 1000 m. after leaving field 2. Measurements are associated with determination of flow rate and P concentrations for nine flow events at these four sampling locations. The nine events will be partitioned into three events during the irrigation season, three during the fall rain/snow, and three during spring snow melt and rain-on-snow events. Concentration measurements are divided in ditch runoff water, ditch sediments, and ditch vegetation. We discuss methods of field measurement of flow and concentrations. Both PI's and graduate and undergraduate students will be involved in this objective. Dr. Boll, Mr. Brooks and the graduate student and undergraduate students will be responsible for the physical aspects such flow measurements and sampling, and for soil/water chemistry related tasks. Mr. Davidson also will assist in field activities, and Dr. McGeehan will fill an advisory role in these activities.

#### Flow rate determination

Flow rates in irrigation ditches leaving the pasture fields will be determined as the product of cross-sectional area ( $\text{m}^2$ ) and velocity ( $\text{m/s}$ ). We will determine cross-sectional area (A) and wetted perimeter (P) as a function of ditch depth once at each sampling location prior to a flow event. Also prior to each flow event, we will measure the water depth and flow velocity (v) with Marsh McBirney portable current meters using the Velocity-Area method. From the first velocity measurement we then solve for Manning's n for each sampling location from the following equation:

$$v = \left(\frac{1.49}{n}\right) R^{2/3} S^{1/2}$$

where R = hydraulic radius (m) (= A/P), and S = channel bottom slope (m/m). Channel bottom slope (S) will be measured once during the study. Subsequent velocity measurements during a flow event will use above equation with just one measurement of ditch depth.

## P concentration determination

*Ditch Water:* Samples for P determination in ditches during flow events will be collected using depth-integrated sampling procedures outlined in Edwards and Glysson (1988). For waters of sufficient depth, we will use the US-DH48 depth integrated sampler. For shallow waters, grab samples will be taken at different locations in the cross-section. In either case, one composite sample will be generated at each sampling location representative of the average concentration at a particular time during the flow event. During each flow event, five to ten 500-mL composite samples will be collected. Time intervals between samples depend on the flow event. They will be chosen so that our samples represent some baseflow, and the rising limb and falling limb of the hydrograph. Our experience is that most flow events, especially those during the irrigation season and following snowmelt, are on the order of more than 10 hours to several days.

*Ditch Sediments:* Sediment samples will be collected following the methodology of Sallade and Sims (1997). Samples will be collected from the center of the ditch using Wildco handheld sediment samplers. Prior to sampling, any undercomposed organic debris on the surface of sediments (leaves or plant residue) will be removed. Sallade and Sims, (1997) showed that the greatest concentration of available P is found in the surface sediments. For this reason, sediment cores (5 cm diam.) will be taken from 0 to 5 cm depth at each sample point.

*Vegetation:* Vegetation samples will be collected at the edge of the forest, in the pasture fields, and in and along streams and ditches twice during the growing season. A representative selection of plant matter will be collected and composited into one sample for each location.

*Activity B:* Data analysis and interpretation.

Phosphorus concentrations will be multiplied by flow rates to obtain loading estimates of DP and TP in surface waters leaving fields 1 and 2. For purposes of this study we assume that subsurface contributions to the ditches are negligible during flow events. Two comparisons will be made using these data. First, we will examine the data from the four locations to find source/sink relationships within the ditches by season. Second, we will correlate these seasonal source/sink relationships to those developed for P transport in field 1 and 2. The combined effect of field and ditch source/sink relationships will provide basic trends in P transport in Cascade Reservoir's subwatersheds. These relationships will direct the development of Best Management Practices for P transport reduction.

## **Equipment and facilities**

A study site has been confirmed with a landowner in the Willow Creek watershed in Idaho. Automated water samplers, streamflow gauging equipment, data loggers, flumes and piezometers have been purchased through the grant from the Idaho Department of Water Resources (see Budget). Installation of this equipment was completed prior to the

start of this study with help from local and state agencies (Idaho Department of Agriculture, Natural Resource Conservation Service, Valley Soil and Water Conservation District). Dr. Boll's laboratory also has available one Marsh McBirney Model 201 flow meter, two US DH-48 depth integrated samplers, and a WildCo Handsampler for ditch sediment sampling. Computer facilities at the Department of Biological and Agricultural Engineering at the University of Idaho include a Pentium-166 Gateway 2000 PC, 64 MB RAM, a Pentium-233 128 MB RAM and a Pentium-60 16 MB RAM. These computers have sufficient capability and disk space to store the data and perform regression analyses and other data analyses.

The majority of water quality samples will be analyzed in Dr. Boll's laboratory and soil samples prepared for analysis in the Analytical Sciences Laboratory where Dr. McGeehan now is Chief Chemist. Dr. Boll's laboratory consists of two locations: a water quality laboratory in Buchanan Engineering Laboratory and a newly renovated Environmental Engineering Laboratory in the Gauss-Johnson Laboratory. Equipment specific for the analysis tasks include: a spectrophotometer for colorimetric analysis, hotplates for digestion, several filtration apparatus, a drying oven, a fume hood, automatic pipettes, and the necessary glasswares.

### **Related Research**

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### **Phosphorus terminology**

Phosphorus (P) occurs naturally in soil from weathering of primary P-bearing minerals in the parent materials (e.g., apatite). Additions of plant residues, fertilizers, and animal wastes enhances the P content of the surface soil layer (McElroy et al., 1976). Phosphorus is an important nutrient to aquatic ecosystems where, in excess, it can cause accelerated eutrophication.

Phosphorus in soils occurs either as organic or inorganic P. The relative proportion of these two categories varies widely. Organic P generally is high in surface soils where organic matter tends to accumulate. Sorption of inorganic P is controlled by soil pH and the contents of silicate clays, and metal hydrous oxides (Enfield and Bledsoe, 1975; Ryden and Pratt, 1979; Berkheiser et al., 1980). Although P sorption occurs over a wide range in pH, maximum sorption is observed below pH 6 with sorption decreasing substantially above pH 7 (Berkheiser et al., 1980). Oxides and hydroxides of Al, Fe, and Mn control P sorption in acidic soils while Ca and Mg minerals predominate in alkaline and calcareous soils. Concentrations of solid-phase P in eroded soil (sediment) are determined largely by the nutrient content of the in situ soil. A dynamic equilibrium

exists between dissolved and sorbed P in soil-water and in surface runoff, which is well described by the adsorption Langmuir isotherm (Novotny and Olem, 1994).

Once P is lost to a stream, the nature of P existing in sediments or in solution becomes significant in the nutrition of aquatic microorganisms. Bioavailable P is more meaningful than total P because the first is in a form readily available for uptake by these aquatic organisms (Sharpley and Smith, 1993; Sharpley et al., 1992). It has been estimated that 67 - 87% of DP can be considered bioavailable P (Sharpley and Smith, 1993). Brown et al. (1983) found that on average 80% of the DP and 25% of the PP became bioavailable in the Cannonsville Reservoir in the Catskills Region of New York State. Sharpley (1993) developed an approach using iron-oxide impregnated paper to determine BAP

Phosphorus transport from a given site to a stream can occur either by association with sediment, dissolved in surface runoff waters, by interflow or in leaching waters. Concentrations of dissolved and particulate P may change with season and type of precipitation/snowmelt/irrigation-runoff event. In runoff from no till or pasture, the sediment load is generally so low that dissolved P can exceed that of runoff from fields with higher erosion (Sharpley et al., 1994). The soil solution generally contains low P concentrations (< 0.1 mg P/L) resulting in low P loads in leaching waters. However, many soils in the United States exhibit high P soil tests. For example, Parker et al. (1946) showed the highest levels of P content in soils in the Pacific Northwest. More recent data show that 60% of soil samples taken in Idaho and Utah contain high P levels (Sharpley et al., 1994), ranking these states as the highest in the United States. These studies show that evaluation of soil TP and DP on a site-specific basis is necessary to accurately predict P transport.

Quantitative relationships describing P cycling in ditches or small streams are not readily available in the literature. In particular, the seasonal exchange between P in sediments and P in the overlying flowing or standing water has only been speculated upon (Sallade and Sims, 1997a). The dynamics of P cycling in ditches and streams integrates three processes which determine the concentration of different phosphorus components at any given time. These processes include mass flow by surface water, mass flow by subsurface water, and a diffusion process involving sorption-desorption. A fourth process often considered is precipitation- dissolution, but sorption-desorption reactions usually give a better description of the uptake and release of P by soils (Frossard et al., 1995). Flow of particulate matter occurs only in surface flows. Flow of dissolved portions can occur both in surface and subsurface flows. Most aquatic ecosystems will be affected by both types of flow and thus, any study trying to understand P cycling through different ecosystems needs to include them.

For irrigated pastures, the levels of particulate P usually greatly exceed the annual inputs from animal manure or fertilizer. Effects of cattle grazing on nutrient losses in the Pacific Northwest were studied by Jawson et al. (1982). They concluded that although grazing appeared to cause an increase in TN, TP, total organic carbon, chemical oxygen demand, and chloride losses in runoff, the quantities would not seem to be a significant threat to downstream water. Klahr (1988), who sampled irrigated pasture fields in the Cascade

Reservoir watershed did not show any correlation between concentration of nutrients in irrigation return flows and the presence or absence of grazing animals. Hence, it is reasonable to assume that particulate P concentrations are functions only of soil type. Soil sampling is the best way to determine these concentrations (Haith and Tubbs, 1981).

### **Previous water quality studies on irrigated and non-irrigated pastures**

Phosphorus export from cropland or dry land pastures has been studied more extensively than irrigated pastures. McElroy (1976) states that P losses from well managed pastures and forested soils are usually low (e.g., 0.03 kg/ha from unfertilized pasture during 6 months, and 0.04 kg/ha after addition of 45 kg of P/ha). Other sources confirm the findings by McElroy (Loehr, 1974; Beaulac and Reckhow, 1982).

Klahr (1988), who collected the only agriculturally specific water quality in Cascade Reservoir watershed, showed increased concentrations of P due to irrigated pasture land use. During the irrigation season, however, concentrations in surface return flows are higher than inflows, but these are offset by very low return flow volumes. Hence, although not specifically emphasized by Klahr (1988), her data clearly show that the non-irrigation season contributed higher loading of sediment and P than the irrigated season by one order of magnitude.

Miller et al. (1984) measured flood irrigation and surface return flow volumes at four sites in Nevada during three irrigation seasons. They reported the surface loading per individual irrigation event and cumulative loading throughout the irrigation season. Total P and dissolved P were found to have a net P loss (in kg/ha) from the fields via surface return flow every season from one site and only one season from another site. Losses of dissolved P were associated with fertilizer applications to alfalfa. Interestingly, levels of constituent contributions to surface runoff appeared to be more related to site characteristics, water management practice and hydrologic variation than to the presence or absence of grazing animals.

Austin et al. (1996) studied the relationship between four rates of superphosphate applications (250 - 1000 kg/ha) and runoff P concentration for flood irrigated perennial pastures in Australia. They reported that the primary loss mechanism for P following single fertilizer application was through dissolution rather than sediment transport. Edwards et al. (1996) measured runoff, sediment yield, soluble P transport, and particulate P transport data from four manure laden pasture fields in northwestern Arkansas. An inverse linear relationship between the natural logarithms of enrichment ratio and sediment yield (Eqn. 2) was found for all fields, but the slopes were lower than values reported earlier for general use.

### **Modeling approaches**

A variety of modeling approaches are available. Two of the three modeling approaches to assess P loading to surface waters will be discussed in more detail here. Details on the

third approach, the semi-empirical approach of runoff P transport, are provided in the Methods, Procedures, and Facilities section.

*Theoretically based P transport models:* Some of the more comprehensive, theoretical P transport models have been developed and reported by Novotny et al. (1978) and Storm et al. (1988). Simplified versions of these approaches have been incorporated into larger simulation models such as ANSWERS, EPIC, HSPF, and MIKE (Donigian et al., 1995; Havno et al., 1995; Williams, 1995). Each of these models partition P transport into a solution and sediment phase similar to the approach taken in the proposed study. Processes included for calculating the concentration of dissolved P are: release of inorganic P, adsorption of dissolved P, and P uptake by vegetation. For the concentration of inorganic particulate P, processes include deposition, resuspension and release and adsorption of dissolved P. The latter usually is modeled using either first-order kinetics or a Freundlich isotherm. In addition, P mineralization, P immobilization and mineral P cycling are accounted for in great detail.

*Empirical correlations:* A practical, yet empirical, modeling approach is termed export coefficient modeling. This method calculates total nutrient load delivered to a water body as the sum of the individual loads exported from each nutrient source in its catchment. Terms for biological fixation of P in the soils of the watershed, or in streams are not included. Development of export coefficients initially requires a detailed plot or field scale study. The export coefficient modeling approach permits scaling up from plot or field-scale experiments to the catchment scale, allowing application of findings from field experimental studies at a suitable scale for catchment scale management (Johnes, 1996; Mattikalli and Richards, 1996). In general, seasonal hydrological variations cannot be reliably accounted for using the traditional export coefficient modeling approach (Haith and Tubbs, 1981; Delwiche and Haith, 1983) allowing, at best, for annual averaging. As a result, a range of values is reported in the literature (McElroy, 1976) and the selection process essentially becomes arbitrary (Haith and Tubbs, 1981).

In addition to above approaches there are the budget models (Chapra, 1997) which focus on a mass balance approach to simulate steady-state and long-term temporal trends of lakes.

### **Sorption/desorption dynamics**

The mobility and bioavailability of P is significantly influenced by changes in soil redox status, which, in turn, is influenced by duration of saturation (McGeehan, 1996). It also is apparent that soil temperature and organic matter play an important role in P sorption. Although P is not redox active and, therefore, is not directly affected by soil flooding, a decrease in redox potential indirectly influences P availability through its affect on Fe hydrous oxide solubility.

*Previous work by principle investigator:* There are conflicting reports regarding the effect of variable soil redox potential on Fe transformations and P retention. Resolving these conflicting bodies of evidence necessitates a study of the P dynamics under conditions

existing in field soils. A previous laboratory study conducted by McGeehan (1996) on P sorption and desorption in seasonally saturated soils from the Cascade area clearly documented the potential for changes in P sorption and desorption that occur in response to changing soil redox conditions. The P sorption capacity increased in all flooded-dried soils, relative to the control (0 days flooding) (Fig. 2). The increased sorption capacity observed in the flooded-dried soils did not lead to increased P desorption (Fig. 3). To fully understand the implications of seasonally changes in climate and soil properties on P desorption and the potential for transport, field data must be collected throughout the year on a site specific basis.

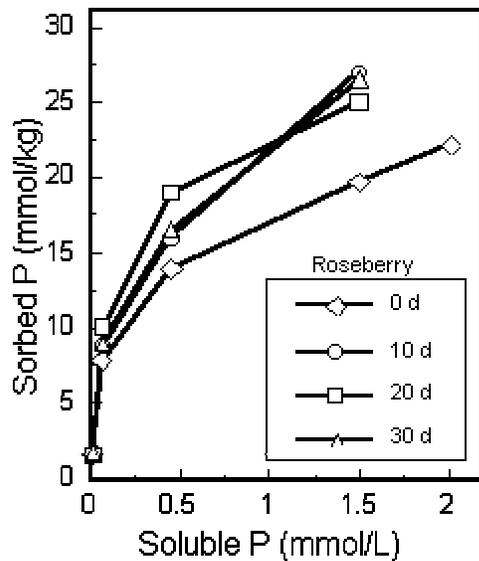


Figure 2. P sorption in a soil subjected to flooding periods of 0, 10, 20, and 30 d., followed by a 20 d. drying period.

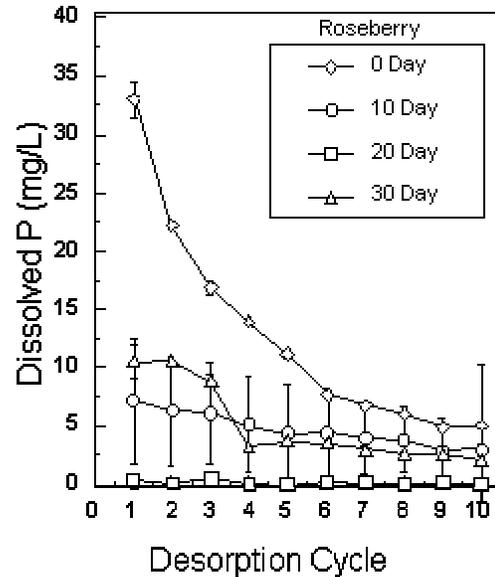


Figure 3. P desorption in a soil to flooding periods of 0, 10, 20, and 30 d., followed by a 20 d. drying period.

*General background:* The biogeochemical processes responsible for P immobilization in soils are well understood for aerobic systems relative to anaerobic systems. Soil saturation, due to irrigation practice or seasonally high water tables, can convert a soil from an aerobic system to one that is dominated primarily by anaerobic (low redox) processes. Anaerobiosis activates a host of biological and chemical processes which can change the physical and chemical soil properties responsible for P retention. The aqueous-phase chemistry of flooded soils has been studied extensively and changes in pH, redox potential, and dissolved metal concentrations are well characterized (Ponnamperuma, 1972; Gambrell and Patrick, 1978; Lindsay, 1979). Several studies show phosphates adsorbed or coprecipitated with Fe(III) hydrous oxides are released as a result of soil anaerobiosis (Mortimer, 1971; Patrick and Khalid, 1974; Gambrell and Patrick, 1978; Ponnamperuma, 1972). Hill and Sawhney (1981) report that the conversion of a soil from an aerobic to an anaerobic state decreases P sorption and may

facilitate desorption of stored P. In contrast, some studies suggest an increase in P sorption may occur as a result of soil flooding (Patrick and Khalid, 1974; Khalid et al., 1977). Increased P sorption is attributed to the reduction of semi-crystalline ferric hydroxide to amorphous ferrous hydroxides, which have greater surface areas and more sorption sites.

Soil flooding followed by drainage increased P sorption in 5 of 10 soils studied by Sah and Mikkelsen (1989a) and in each of the ten soils studied by McGeehan (1996). The increase in P sorption was attributed in part to conversion of Fe oxides to amorphous forms (Sah and Mikkelsen (1989b; McGeehan, 1996). The importance of soil flooding-drainage cycles in P sorption has long been recognized by engineers designing systems for land treatment municipal wastewater. Most system design protocols apply wastewater continuously until the sorption capacity is reached, then application is discontinued allowing the soil to 'rest' for several months, after which the soil is capable of further P sorption (Overcash and Pal, 1979; USEPA, 1981). Although the exact mechanisms are not stated, Sawhney and Hill (1978) conclude that soil wetting and drying brings Al, Fe, or Ca and fresh mineral surfaces in equilibrium with the soil solution, creating new sites for P sorption.

Soil temperature is another important variable controlling P sorption-desorption. The majority of research on wetland and riparian systems has been conducted in the southern and eastern U.S. where soil temperatures in excess of 35 °C are common in late summer. The impact of soil flooding and drainage on P retention at soil temperatures representative of the Cascade Watershed is unknown.