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Summary of a Discussion

The Relationship between Land Use and Surface Water Phosphorus Concentrations

OREGON STATE UNIVERSITY EXTENSION SERVICE

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Summary of a Discussion

The Relationship between Land Use and Surface Water Phosphorus Concentrations

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Foreword

This report is a concise summary of information, ideas, and questions presented at a symposium on phosphorus held at Oregon State University, November 12, 1996. The primary purpose of the symposium was to deal with issues of water quality as they relate to livestock management in the upper Klamath Basin.

Different disciplines within the university were represented, as were various state and federal agencies. All of the participants had experiences, ideas, and/or data relating to recent issues on land use and water quality. There were some disparate conclusions and viewpoints relating to critical questions, inputs, research directions, and decision making processes with respect to livestock, phosphorus, and water quality. There also were many areas of commonality. The differences in opinion and concerns underscore the need for closer communication and more sharing of information and ideas among scientific disciplines, agencies, special interest groups, and elected officials.

The goals of this publication are: (1) to summarize the information and thoughts presented by those attending the symposium, and (2) to provide background, ideas, and direction for landowners and state and federal agencies facing similar issues and problems within comparable landscapes and climatic regimes.

The emphasis in this publication is on trends, or relative values, of P. Actual numbers seldom are used due to the lack of information on analytical techniques, detection limits, sampling and storage methods, and the laboratories that performed the analyses. Without this information, the comparison of numbers becomes at the very least deceptive, and probably meaningless. Analytical values can vary widely among different labs even when identical techniques and methodologies are used, and it often is difficult to reproduce results.

Introduction

> "One of the ongoing water-quality issues for which we do not have an answer relates to the potential increase in phosphorus concentration of downstream waters when cattle graze irrigated pastures. This question has been the subject of considerable public concern in the Klamath Basin. In those areas in which phosphorus is the limiting nutrient for algae growth, this question becomes highly important and frequently arouses strong emotion, whatever the view of the speaker."
>
> —*Ron Miner and Ron Hathaway*

Although some conclude that the management of surface water quality by controlling phosphorus alone is unrealistic, phosphorus long has been considered the most critical and limiting nutrient to freshwater plant growth, including algae. Therefore, it is of prime importance in developing management strategies for controlling eutrophication.

Ron Hathaway, OSU Extension Service staff chair for Klamath County, states that the United States Environmental Protection Agency (EPA) examined studies on the effects of grazing livestock on surface water and found different results and conclusions among the studies. A compilation of six studies revealed that three of them found an impact on surface water quality from livestock grazing, while three did not (EPA, 1993).

Clearly, additional research, with well-designed sampling regimes and analytical methodologies, is needed to answer critical questions for the system(s) of interest. However, it is critical to recognize that, even with well-designed experiments, the complexity of P pathways and system variability make it impractical to compare studies and results from different areas.

The area of interest

The Klamath Basin is a large, almost completely closed basin in southern Klamath County in south-central Oregon. One of the most prominent features and important resources is Upper Klamath Lake, a 90,000-acre lake that is highly eutrophied. Significant algal blooms occur on the northern part of the lake. The basin is bordered on two or more sides by steep mountain ridges. Elevation ranges from 4,000 feet on the basin floor to more than 7,000 feet on the ridges and mountains.

Average annual precipitation ranges from 10–15 inches within the valleys. Inputs into the lake include:

- Precipitation and snow melt via several small creeks flowing from the central and southern Oregon Cascades
- The Klamath Marsh via the Williamson River to the northeast
- Agency Lake, which is connected to the Klamath by a short, narrow waterway (Agency Lake lies to the north of Klamath Lake and receives precipitation and snow melt from the Crater Lake National Park area via the Wood River and Annie Creek systems.)

Klamath Lake averages 8 feet in depth with a 6-foot control variation. It is drained by the Link River, which connects to the Klamath River, which flows into northern California.

Snowfall accounts for 30 percent of the moisture in the valleys (15–45 inches) and up to 50 percent in the foothills (60–125 inches) and mountains (>160 inches).

Timber, cattle ranching, and irrigated agriculture are the main regional industries. The warmer parts of the valleys experience a growing season of approximately 90–120 days. Temperatures within the valley average 90°F or above 15 days per year. The Wood River system has only a 50-day growing season and is suitable only for irrigated pasture.

The Wood River and Annie Creek areas have been used for livestock grazing for the past 60–80 years. Currently, approximately 1.5 animal units/acre graze 40,000–60,000 acres of nonfertilized, irrigated pasture containing bluegrass, rushes, sedges, clovers, and native forbs. During presettlement times, the pasture in this area was riparian meadows and marshes.

Irrigation water is reused in the lower fields. These areas are flood irrigated three to four times between April and late-September/early-October. The water table is at the surface in the spring, and irrigation is said to keep it near the surface through the summer.

The soils in this area are mapped as associations described as: (1) very deep, poorly drained, neutral to slightly acid soils that have formed in alluvium derived from pumiceous cinders and ash; (2) ponded, very deep, very poorly drained, slightly acid mucks that have formed in organic material; and are (3) bordered by deep to very deep, well-drained to excessively well-drained soils that formed in ash and cinder (Klamath County Soil Survey).

Initial thoughts and questions of interest

The prime question, and motivation for this symposium, was phrased by Ron Hathaway as: "What contributions do grazing livestock have on surface water quality?" In relation to this point, several additional, related questions were raised. These questions fell into four broad groups:

(1) Those related to cattle

- How much P is in manure?
- Is P in manure in different forms than the P in plants?
- If so, how does the P in manure relate to mobility and biological availability? (How do cattle affect the distribution of P within the soil?)
- Does the manure itself move and, if so, what are its vectors and spheres of influence?
- At what cattle population densities do impacts on water quality begin to appear?

(2) Those related to the system

- What are the important P pathways within this system?
- What are the "natural" or background levels of P in this system?
- What roles do the soils play in P dynamics (i.e., sorption isotherms and buffering)? Are they sources, sinks, or both at various times?
- What is the tendency for runoff versus infiltration?
- Is the problem an erosion problem as opposed to the physical act of the cow?
- What are the geochemical contributions to P in the system?
- What are the biogeochemical and redox influences on P in the system?
- What is the role of vegetation within the system?
- What is the effect of the extensive marsh areas to the northwest and northeast of Klamath Lake?
- What is the P budget within this basin?

(3) Those related to sampling and analyses

- What do we sample and why (soil, soil solution, sediments, stream water, etc.)?
- What parameters do we analyze and why (total P, soluble P, ortho-P, organic P, "readily available" extractable P, soil biota, redox environment, organic C, soluble Fe)?
- Where do we sample and how?
- What analytical methods should be used?
- What are the organic C effects on P solubility?
- How do we interpret and compare numbers generated from these analyses?

(4) Those related to landowners and management practices

- What are the best management practices (BMPs) that will reduce P loading to streams and subsequent impacts on water quality?
- Do we focus on erosion control? Water control? Animal control?
- How do we avoid situations driven by litigation?
- How do we advise voluntary groups to address these situations?

- How do we market voluntary water-quality, landowner-driven compliance?
- How do we measure progress?

And, possibly, the single most important question generated from the overwhelming assortment above is:

- Which questions would (1) maximize the amount of the most critically important information, and (2) be adequately answerable within given time and budget constraints?

Although some of these questions have current answers, many can be addressed only by future field research and analysis of the volumes of literature related to these subjects.

Input from the literature and the laboratory

Waste and nutrients

Important to the solution of any problem is to adequately define the problem and assess what already is known about it. Dan Sullivan, soil scientist at OSU, provided insight by sharing existing data on N and P dynamics under dairy land use.

Over 90 percent of the dairies surveyed in western Washington in 1991 had high to very high soil test P (Bray 1). Soil P accumulation was noted even for dairies that were doing a good job of managing N (as indicated by low residual soil nitrate-N concentrations).

Western Washington dairies differ considerably from Klamath grazing operations in two ways:

- Large quantities of P are imported in feeds on the western Washington dairies.
- There are more animals per acre on the Washington dairies than in the Klamath Basin.

The Washington survey does, however, illustrate:

- The possibility of soil P buildup due to manure P inputs
- The need for soil P test data (Bray 1 or Na bicarbonate P tests) for sites of interest in the Klamath Basin

Sullivan also provided data that showed that the greatest additions and subsequent runoff values of P came from cattle manures and poultry litters.

Sullivan provided a paper by Withers and Sharpley (1995) that showed data on the P and N contents of various manures (Table 1).

The authors state that the P content and composition of fresh livestock manures vary, and depend on "the type and age of the animal, the type of bedding material used, and the composition and digestibility of the diet, particularly where mineral supplements are used." They also state that mineralization of the organic P fraction by microorganisms increases the inorganic P component in the manures (Gerritse and Vriesma, 1974; Goss and Stewart, 1979). The manure-P is considered to become completely available in the long term (Smith and van Dijk, 1988).

Among the many points raised by the authors that are relevant to the issues facing the Klamath Basin are:

- Soil compaction reduces the uptake of P by diminishing pore space and availability of oxygen and water.
- Plant P uptake is more "efficient" than that of animals.
- Animals can play a large role in the recycling of P and the "magnitude of P surpluses or potential soil P accumulations."

Sullivan also stressed the need for a P assessment tool and presented a table from Lemunyon and Gilbert (1993) indexing the vulnerability of P loss with respect to a variety of site characteristics. Knowledge of the P budget within the basin with respect to cattle and feed also was felt to be critically important information. A thorough review of the literature, coupled with the current numbers of animals and practices within the Klamath Basin, could answer some of the questions posed at this symposium.

Table 1.—Average P and N contents of animal manures on a dry weight basis (g kg^{-1}).

	Nitrogen	Phosphorus
Beef	32.5	9.6
Dairy	39.6	6.7
Sheep	44.4	10.3

Data from table in Withers and Sharpley (1995).

Chemistry

John Baham, an environmental soil geochemist at OSU, took a different emphasis. He focused on accumulations of P within soils, important biogeochemical mechanisms for its availability, and redox (anaerobic versus aerobic) soil environments.

Baham first provided evidence of long-term accumulation of P in soils. Increasing P concentrations were discovered by analyzing data from soil-P tests performed on several Willamette Valley soils during the past 50 years. These data demonstrated that up to 50 percent of the soils in the Willamette Valley are "overfertilized" with respect to P.

Baham also pointed out that relatively simple techniques, such as sorption isotherms, would provide important information on the capacity, or "buffering" ability, of soils for P. An important concept related to the buffering ability of sediments and soils is the equilibrium P concentration (EPC), which is derived from the isotherm data. Some investigators have found positive correlation between the EPC of sediments and soil particulates and soluble P in solution (Klotz, 1985; Meyer, 1979; Wes Jarrell, personal communication). These data provide insight into whether the soils/sediments are serving as sources or sinks for P.

Baham also provided data from his lab and field work on anaerobic (reducing) systems and their effect on the critical relationship between soluble Fe and P (Figure 1).

As the soil environment becomes more reducing, Fe and P become soluble. Baham found that in some soils, up to 10 percent of the Fe oxide fraction can become soluble, with P following a similar pattern.

In the Willamette Valley, the highest soluble Fe and P levels occur in the spring and early summer, when adequate moisture and increased temperatures facilitate microbial reductive dissolution. This process is driven by organic C, which is the source of the electrons that reduce the redox-sensitive metals in the absence of O_2. Baham's work suggests that the extensive marsh areas around Klamath and Agency Lakes may play an important role in P dynamics. This possibility also was suggested by John Buckhouse (OSU Department of Rangeland Resources).

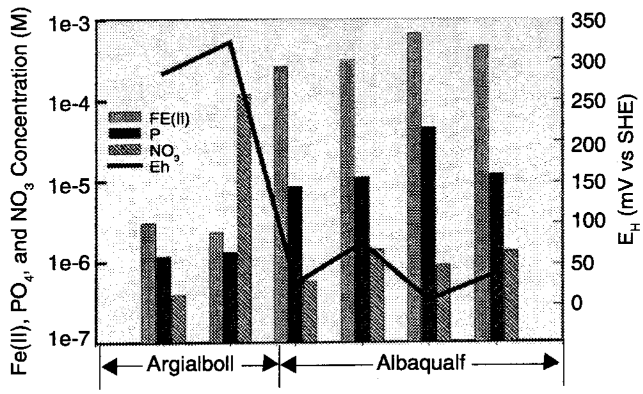

Figure 1.—Increasing concentrations of Fe and P with declining redox potentials in a transect moving from well-drained soils (Argialbolls) to poorly drained, wetter soils (Albaqualfs).

Pathways, analyses, and numbers

John Baham, Benno Warkentin (OSU soil scientist), John Buckhouse, and John Jackson of the Unified Sewerage Agency (USA) all stressed the need for detailed knowledge of P pathways. Any management or regulatory practices based on the concept of P as the limiting water-quality nutrient must consider the following two factors: (1) the "preferred" pathways the molecule will take on its journey through the system, and (2) in what form(s) the molecule will leave the system.

Warkentin also reiterated the importance of organic C on P solubility and the need for meaningful data on such important parameters. He also stressed what may be the most important fundamental issues of any study:

- How you sample
- What you sample
- What you analyze
- The realization that interpretation of the sampling values ("the numbers") requires careful thought, consideration, and knowledge of the methodologies employed. Baham, who has detailed knowledge and experience in analytical technique, also expressed concern over baseline values, or "background noise," between standards and samples. In addition to known interferences from molecules such as silica and arsenate, there are concerns that dissolved organic C and organic matter may play unexpected roles in the current colorimetric analyses of P.

Dean Hanson, analytical chemist for the plant analysis lab at OSU, found silica to begin to have a positive interference in P values at concentrations as low as 3 ppm Si.

Input from field observations

Several participants brought data and observations from field experiences throughout the state. These experiences provided knowledge and insight into many issues of concern, and helped to identify remaining questions and areas of incomplete knowledge.

The Klamath Basin

Ron Hathaway and the Klamath County office of the OSU Extension Service received a grant from the Oregon Water Resources Research Institute (OWRRI) at OSU to address the issue of P contribution to surface water from cattle grazing on irrigated pasture. Annie Creek was monitored for P and N over three summers. Although land use in this part of the basin includes recreation, national forest, timber harvest, and livestock grazing, the uses do not comingle and can be adequately separated. There are roughly 1.5 animal units (AU) per acre in the grazed area.

Annie Creek is said to have stable banks and riparian areas in good condition. It has a summer flow of 300 cfs. Sampling occurred below the irrigated pasture just above Agency Lake.

Samples also were taken from below Crater Lake National Park to determine "natural," or background levels, from a pristine environment. The OWRRI report stated that through 3 years of monitoring, no differences in P concentrations were found as one moved downstream. Hathaway stated that background levels were considered high and ranged from 25–85 ppb, with snow melt yielding flushes of P.

The Yamhill Basin

Scott Stewart, a graduate student in soil science at OSU, did a detailed watershed study in response to concerns expressed by the Yamhill County Soil and Water Conservation District over P loading and surface water quality. The Baker Creek watershed, west of McMinnville, was selected due to its excellent delineation between types of land use.

Baker Creek, a tributary of the Yamhill River, was intensively sampled and monitored over a 2-year period. Using Geographical Information Systems (GIS), the area affecting each sampling point was delineated, as were the soils, their associated parent materials (geology), and land use classes within those delineations. Samples occasionally were split between OSU, Oregon Graduate Institute (OGI), and Oregon Department of Environmental Quality (DEQ) labs to coordinate analytical methods for meaningful comparisons of the generated values. Splitting samples also allowed researchers to determine the reproducibility of these values, as well as the variability between different labs using identical methodology and technique.

Through 2 years of monitoring, the patterns remained the same; during the period of low flow, the highest average in-stream concentrations of soluble and total P occurred below steep irrigated pasture that had been managed for livestock and sheep for 50 years. During the period of high flow, the greatest P concentrations were found in two first-order streams, one draining a small dairy operation and the other a housing development.

Interestingly, the highest P values within the basin were found in potable water from a deep artesian spring source. Stewart also observed that when samples taken on the same date were compared, water within the forestry land use class remained of high quality and free of algal blooms, although soluble and total P concentrations were the same as those found in other stream segments experiencing blooms and degradation. These observations, coupled with the high quality of the spring water, reflect the importance of additional variables on surface water quality, such as light, temperature, kinetic energy (flow velocity), and healthy riparian areas.

This study also referenced work by Reddy, et al. (1980), who found greater movement of P (in the form of organic P) in Ultisols used for the disposal of animal wastes. These are the same types of soils that comprise much of the irrigated pasture on Baker Creek, below which the highest stream P values were found.

The Tualatin Basin

The Tualatin River is an 83-mile-long river that originates in the Oregon Coast Range and drains into the Willamette River. Bob Baumgardner (DEQ) has stated that the Tualatin may be "the most studied basin in the world" (OWRRI, 1994). Experiences and data from the Tualatin are extensive and provide valuable lessons and sources of information. Several participants provided data and input from this region.

Mike Wolf, of the Oregon Department of Agriculture, spoke about the Tualatin Total Maximum Daily Load (TMDL) requirements and how these reductions were met.

Burris and Christensen Creeks, within the Tualatin Basin, were identified as P sources. These creeks have approximately 4,500 acres of watershed area with mixed land use and very high stream P levels.

Wolf stated that there are 50 livestock operations within this basin, and when the focus was placed on those within the tributaries, the Tualatin improved. Emphasis on improved handling and applying of manures, and the relocation of one of the receiving ponds, resulted in "great progress" in Burris and Christensen Creeks. Phosphorus concentrations declined, while dissolved oxygen levels were elevated, indicating that livestock was indeed the appropriate focus.

Wolf also reiterated the importance of understanding the P budget of a basin, mentioning the potential for accumulation when P is imported with feed as opposed to being harvested from the basin. He stressed that although there is a need to focus on nutrients, other parameters besides P are crucial to surface water quality.

John Jackson, Director of Planning for the Unified Sewerage Agency (USA), spoke about total waste control within the Tualatin Basin. In 1989, treatment plants at Rock Creek and Durham released a total of 400 lb of P per day. In 1994, the value was 14.6 lb of P per day, a 96 percent reduction in SP levels. Jackson also had data from Jackson Bottom, a wetland area near Hillsboro, showing very high P levels in deep groundwater, where conditions are highly reducing. This supports Stewart's and Kling's (unpublished data) findings in deep groundwater samples from Polk County, and illustrates the importance of Baham's work on redox environments and reducing systems.

Forestry

George Ice, a forest hydrologist for the National Council of the Pulp and Paper Industry for Air and Stream Improvement, addressed the issue of forestry contributions of P to surface water quality. It was mentioned that while simple models identify forest practices as sources of P, three studies from Oregon showed no changes in dissolved P after forest harvest. Furthermore, P levels did not respond to management.

Studies on the Middle Santiam River showed no differences in mean summer total P, and studies from the Tualatin showed no relationship between forest practices and P concentrations. These studies are supported by Stewart's findings regarding forestry land use on the Baker Creek watershed.

A study on Mica Creek, a 37.7 mi^2 watershed in Idaho that has not been managed since the 1930s, found low background levels and little seasonal pattern. A management comparison on Nomini Creek, a roadless area, incorporated an 8-hectare control plot, a 9-hectare BMP plot, and 10 hectares of "logger's choice" (lack of BMP) practices. The control and BMP plots found no increase in P, but the "logger's choice" methods resulted in a 296 percent increase in total P and a 560 percent increase in "sediment-bound" P. These findings illustrate that BMPs can play a major role in the control of P inputs into streams.

Ice felt that some of the more pertinent information needs are greater knowledge and understanding of:

- Background loads
- In-stream processes and delivery systems
- P storage and cycling
- Biologically significant forms
- Management of riparian areas
- Improved models, especially those that address the quality of management

Some studies show increased water yields after harvesting. Increased water yields have been correlated to algal production, but production is inversely proportional to the increase in water.

Table 2.—EPIC model predictions for sediment and soluble P under different land use.

Land use	Sediment P (lb/a/yr)	Soluble P (lb/a/yr)	Average Concentration Soluble P (ppm)
Hay	0.07	0.04	0.6
1 AU/acre	0.05	0.10	0.5
2 AU/acre	0.19	1.00	2.0

Modeling

Dean Moberg, of the Natural Resources Conservation Service (NRCS), presented his work in modeling contributions of P from agriculture with crops and animal units. Moberg worked with a model called EPIC, which has been used for long-term erosion predictions and now is used for yield and P runoff predictions. Model assumptions include:

- Woodburn soil series
- Hydrologic group B
- 200 ft length @ 3 percent slope
- 141 ppm Bray 1 soil test value
- 10 years of Portland weather
- N fertilization as needed
- No P fertilization
- 10 lb/acre dry dairy manure
- The model partitions P into "sediment" and soluble P

Moberg found the values from this model to be similar to values given by Sullivan and Stewart (Table 2). He stated that some of the problems with this model include:

- Some of the assumptions, especially curve numbers
- Yields that are too low for pasture
- Lack of calibration of the EPIC model
- No "double-checking" of the numbers

Final thoughts and ideas

In synthesizing the important points that arose during the presentations and discussion, it is clear that some areas of commonality were reached. Among the most important points relating to what we currently know are:

- Phosphorus pathways within the soil are complex and not completely understood.
- Phosphorus moves in these systems and is not immobilized by the soils and/or sediments.
- Phosphorus values measured during summer flow are a function of subsurface seepage and not overland flow or erosion processes.
- Redox chemistry has a major impact on the mobilization of Fe and P.
- The elimination of any point sources will yield improvements.
- The inputs of P in the Klamath Basin are from diffuse, non-point sources.

Ron Miner also calculated a direct in-stream contribution of 0.002 mg P/l/cow assuming:

- ~ 1.5 AU/acre
- 100 lb P_2O_5 excreted in manure/cow/year
- 10 percent of the manure goes directly into the stream
- 1 cfs flow for the stream

Based on this calculation, Miner concluded that while fencing a stream may be a solution to bacterial input, it would not solve the P problem.

Logical next steps

Among those areas identified as most important for future research were:

- Forms and pathways of P between manures, grasses, and within the soil
- The overall P budget within the Klamath Basin
- Soil-water equilibrium values during aerobic/anaerobic "seasons"
- BMPs that provide positive control of animals and reduce erosion
- The density of populations that threaten vegetation within the riparian areas
- Hydrologic processes within the basin
- Soil P values and buffering capacity

- How to sample (design and frequency of sampling to adequately address the questions of interest)

Many participants felt the synthesis, publication, and distribution of the information presented at this symposium, as well as continued discussion among groups with diverse knowledge and experience, are important steps toward defining the relevant directions for substantiating whether grazing cattle increase P concentrations and load within the Klamath Basin.

Additional sources of data on P measurement within the Klamath Basin

United States Geological Survey, Portland office

Ron Hathaway, OSU Extension Service, Klamath County chair

Klamath Tribes—Fish and Wildlife, Jake Kann, biologist

John Hart, OSU Extension soil scientist (soil test results on cultivated fields)

Symposium participants

Baham, John, *Oregon State University, Crop and Soil Science*

Buckhouse, John, *Oregon State University, Rangeland Resources*

Hathaway, Ron, *Oregon State University Extension Service, Klamath County*

Ice, George, *National Pulp and Paper Institute for Air and Stream Improvement*

Jackson, John, *Unified Sewerage Agency*

Ko, Lee, *United States Department of Agriculture, Natural Resources Conservation Service, Hillsboro, Oregon*

Marxer, Larry, *Department of Environmental Quality, Laboratory Section, Surface Water Monitoring*

Miner, Ron, *Oregon State University, Bioresource Engineering*

Moberg, Dean, *United States Department of Agriculture, Natural Resources*

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Sullivan, Dan, *Oregon State University, Crop and Soil Science*

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Warkentin, Benno, *Oregon State University, Crop and Soil Science*

Wiltsey, Mike, *Department of Environmental Quality, Northwest Region Water Quality Section, TMDL Review*

Wolf, Mike, *Oregon Department of Agriculture, Salem, Oregon*

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