AN ABSTRACT OF THE THESIS OF

Donald W. Wolf for the degree of Master of Science in Rangeland Resources presented on May 20, 1993.

Title: Land Use and Nonpoint Source Phosphorus Pollution in the Dairy-McKay Hydrologic Unit Area of the Tualatin River Basin, Oregon

Abstract approved: ______________________________
John C. Buckhouse

Human activities may contribute to the eutrophication of surface waters by providing nutrients to aquatic ecosystems. Phosphorus is frequently identified as a nutrient that is limiting to most aquatic ecosystems under natural conditions. Sources of phosphorus contributing to eutrophic conditions often include nonpoint sources that are dispersed across the landscape. In the Tualatin Basin of Oregon, nonpoint sources have been identified as contributing to phosphorus levels in the Tualatin River that exceed limits established in water quality regulations.

The first section of this paper provides a review of relevant literature to explore connections between land use and the sources and transport of nonpoint source phosphorus into the Tualatin Basin. Additionally, where these connections exist, methods to alter existing land use practices to reduce phosphorus contributions are identified.

The second section of this paper reviews and analyzes existing data gathered by agencies in the Tualatin Basin to look for evidence of connections between land use and the sources and transport of nonpoint source phosphorus.

As one of the most obvious and influential connections, sediment-carried particulate phosphorus is examined both for its influence to the total phosphorus content of streams, and for evidence that it may become more influential as it is transported downstream. Data sets are also examined for seasonal effects and for interactions between phosphorus and other sampled water quality parameters.

The third section is an examination and discussion of relevant social issues connected to nonpoint source phosphorus issues in the realization that any solution must be not only technically achievable, but also acceptable to society. Two surveys that attempt to describe the concerns of citizens, one for the general public and one for landowners, are reported.

In addition, the problems of establishing regulatory control for a problem whose limits are still undefined is discussed. A philosophy of management—adaptive management—is discussed, and a program for controlling nonpoint source phosphorus in the Tualatin Basin that incorporate adaptive management principles is proposed. Finally, the issues surrounding which segments of society are responsible for paying for control are discussed.

Land Use and Nonpoint Source Phosphorus Pollution
in the Dairy-McKay Hydrologic Unit Area of
the Tualatin River Basin, Oregon

by

Donald W. Wolf

A THESIS

submitted to

Oregon State University

in partial fulfillment of
the requirements for the
degree of

Master of Science

Completed May 20, 1993

Commencement June 1993

APPROVED:

Professor of Rangeland Resources in charge of major

Head of Department of Rangeland Resources

Dean of Graduate School

Date thesis is presented

ACKNOWLEDGEMENTS

As with any endeavor, this one certainly was not accomplished alone. While I would like to thank everyone who provided assistance, the complete list is too long for this venue. But there are a few who deserve special mention.

Perhaps graduate degrees should be conferred under joint ownership. Certainly my wife, Anne, who among other things played the role of editor in chief and comma corrector, is a major contributor to this work. She is also foolish enough to unconditionally believe in my abilities.

Funding for this project was provided by USDA Hydrologic Unit Plan Area: Tualatin River Basin, Dairy-Mckay Creeks, Washington County, Oregon, FIPS code #067, USGS Hydrologic Unit codes 17090010-030 and 17090010-040. I certainly could not have completed this project without this support.

Although the analysis and interpretation are my own, much of the data used in the technical section of this document was graciously provided by Jan Miller of the Unified Sewerage Agency of Hillsboro. Neil Rambo, Washington County watershed extension agent provided the data for the portion of the social section reporting the results of the Extension Service landowner survey.

My major professor, John Buckhouse of Rangeland Resources at OSU, and my other graduate committee members; Larry Larson from Rangeland Resources at EOSC, Doug Johnson from Rangeland Resources at OSU; Ron Miner from Bioresource Engineeringat OSU; and Tim Cross from Agricultural and Resource Economics at OSU, offered a variety of assistance for which I am grateful. I do owe a special debt to Dr. Buckhouse for accepting a "nontraditional" student, and offering a research assistantship, the chance to determine my own direction, and friendship. The best payment I can think of is to do the same for someone else in the future.

Thank you to the Benno Warkentin and the OSU Water Resources Research Institute for publishing my literature review and including me in discussions of the larger issues in the Tualatin Basin.

Faculty members and fellow graduate students in the Department of Rangeland Resources also deserve a share of credit or their roles as friends, resources, sounding boards, and fellow travelers on this road.

To all of you, mentioned and unmentioned, thank you.

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INTRODUCTION

BACKGROUND

Water quality is of increasing concern to society. Supplies of water are for all practical purposes static while the demand for high quality water for industry, agriculture, population and recreation steadily increases. Currently, Oregon's Tualatin River is the center of a controversy relating to this concern for water that is clean and useable for a variety of purposes.

The Tualatin River originates in the Oregon Coast Range and runs east to join the Willamette River 40 miles away. Along its way it meanders through roughly 86 miles of channel and drains 711 square miles of land with varied topography and use (Carter, 1975). For most of its last 40 miles, the channel has little drop in elevation, giving it a slow moving, almost lakelike, character during the summer low flow period. During the summer this stretch may experience periods of eutrophication when, to put it simply, the river "stinks" (Castle, 1991).

Although the quality of water in the Tualatin River has been of concern to some for a long time, concern was focused in 1986 when the Northwest Environmental Defense Center filed suit against the Environmental Protection Agency (EPA) (Castle, 1991; Cleland, 1991). The suit sought to force the adoption and enforcement of pollutant limits for Oregon streams in general and the Tualatin specifically. It was decided that these limits, called total maximum daily load or TMDL, should have more local input than the federal government could provide, so the task was passed to the Oregon Department of Environmental Quality (DEQ) (Castle, 1991).

In 1987 DEQ conducted a statewide assessment of nonpoint source (NPS) pollution problems. As a result of this assessment, the Tualatin River Basin became the DEQ's priority surface water concern. The Tualatin was defined as "water quality limited," a designation that has specific meaning in relation to practices required to reduce pollutants (Cleland, 1991; Soil Conservation Service, 1990). For the Tualatin, studies showed that both ammonia and phosphorus (P) were factors limiting water quality, but P was considered to be the key limiting factor and a stringent TMDL, 0.07 mg/l (70 ug/l) of total P, was set for the Tualatin River Basin. It is estimated that of the total P contributed to the Tualatin on a yearly basis, 85 percent is from point sources such as sewage treatment plants and 15 percent is from nonpoint sources (Castle, 1991). As a water quality limited basin, all sources that contribute to the problem are responsible for bringing the problem under control.

Of the subbasins comprising the Tualatin drainage, the Dairy-McKay subbasin (or hydrologic unit) was identified as a major contributor to the water quality problems of the Tualatin River. Termed a hydrologic unit area (HUA) by USDA, this subbasin (Figure 1) contains only about one-third of the total area (256 square miles) of the Tualatin Basin, but about half of the forested land and half of the agricultural land. These land uses contribute sediments and sediment-related nutrients to surface waters, with about 60 percent of agricultural lands eroding at three times the rate considered acceptable by the Soil Conservation Service (Soil Conservation Service, 1990). On Dairy and McKay creeks the TMDL for P is frequently exceeded upstream of any known point sources, indicating that a portion of the problem is from nonpoint sources (Soil Conservation Service, 1990). This has focused attention on all land management activities in the basin.

OBJECTIVES

This paper has four purposes:

1. A review of relevant literature to explore possible connections between land use and the sources and transport of NPS phosphorus in the Tualatin Basin.
2. If these connections exist, identify in the literature how these practices might be modified to reduce contributions of NPS phosphorus to the problem.
3. A review of existing technical data to look for evidence of of these connections.
4. An examination of relevant social issues in the realization that any solutions must be not only technically achievable but also acceptable to society.

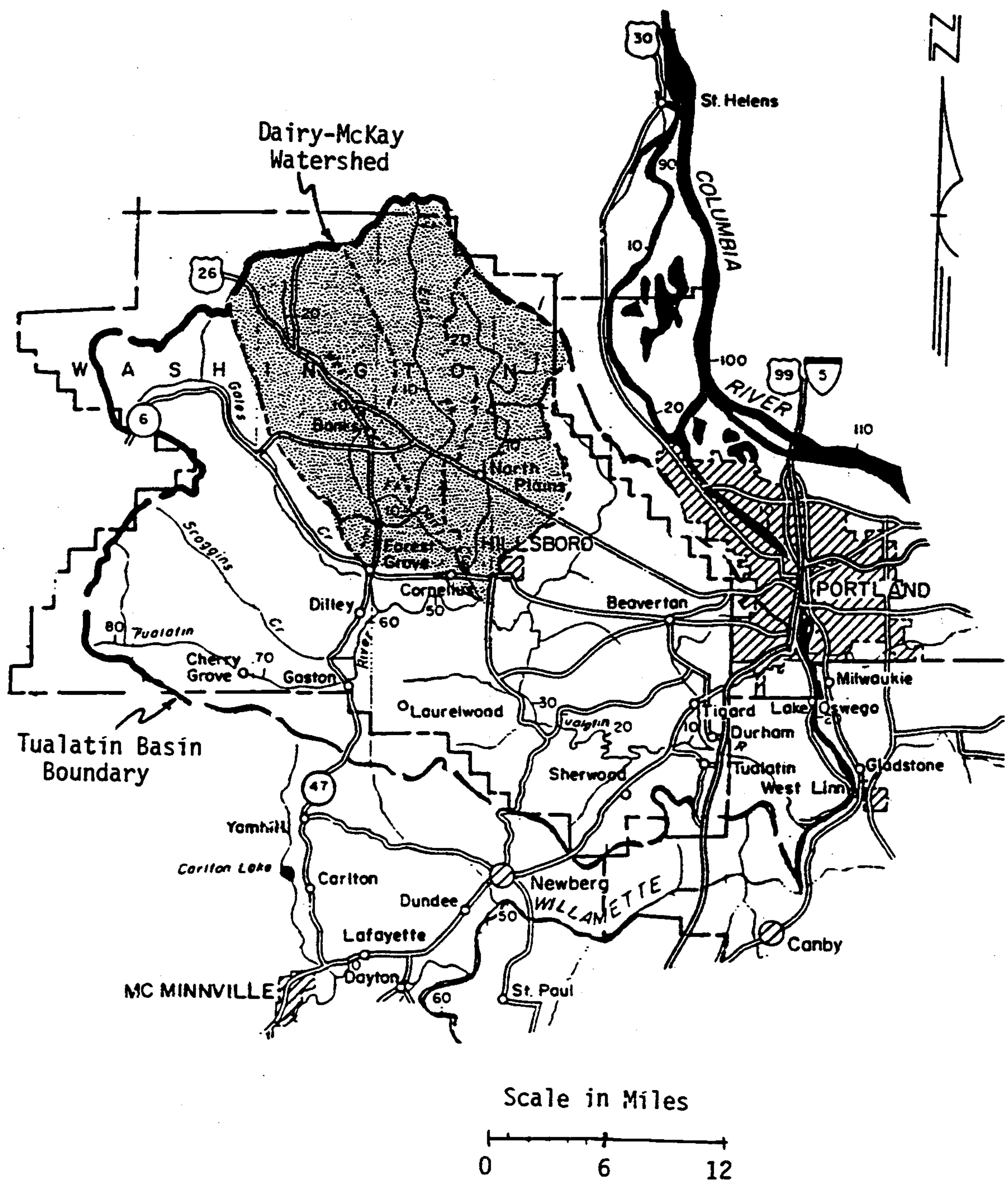


Figure 1. The Dairy-McKay Hydrologic Unit Area
(from Soil Conservation Service, 1990)

LITERATURE REVIEW

THE NATURE OF NONPOINT SOURCE POLLUTION

Point source pollutants are those contaminants that enter the environment from an identifiable source (Chesters and Schierow, 1985). Point sources are often responsible for pollutants that are concentrated at the point of entry but disperse as they move farther away from the source.

Nonpoint source (NPS) pollutants are those contaminants that enter the environment from diffuse sources (Chesters and Schierow, 1985). In contrast to point source pollutants, which lessen in concentration after they enter the environment, NPS pollutants may not be recognized as a problem until they become more concentrated by wind or water patterns.

While these definitions may seem concise, in practice the boundaries between point and nonpoint pollution are not always clear. The smokestack of a factory is an identifiable point source pollutant of air. Yet as pollutants from the smoke disperse, settle to the ground, and are carried into watercourses, they become NPS pollutants of water. The identification of pollutants as point or nonpoint source includes not only the source, but the way pollutants are delivered to the affected resource.

The nature of NPS pollutants makes them difficult to identify and control. These pollutants may be from airborne or land-based sources (Chesters and Schierow, 1985; Loehr, 1974). Airborne pollutants may originate from point sources, such as the exhaust pipe of a vehicle, but are spread and deposited over wide areas (Chesters and Schierow, 1985).

Land-based pollutants are generally from sources that are diffuse. The assortment of sediments, nutrients, and chemicals carried with urban runoff; sediments from agriculture, silviculture, construction, or mining; toxic metals from mining; nutrients from croplands or silviculture; and animal wastes from livestock are examples of diffuse land-based pollutants (Chesters and Schierow, 1985; Loehr, 1974; Myers et al., 1985).

The majority of NPS pollutants come from either agricultural, mining, urban, construction, or silvicultural sources (Myers et al., 1985). These nonpoint sources are estimated to be responsible for half or more of all nitrogen, coliform bacteria, iron, phosphorus, oil, zinc, lead, chromium, and copper contributed to surface waters of the United States annually (Chesters and Schierow, 1985). Sediments from nonpoint sources are responsible for an estimated $6 billion in damage per year (Clark, 1985). NPS phosphorus contributions are large compared with other sources. Agriculture alone is responsible for five times as much P that enters surface waters as is contributed by all point sources (Duda and Johnson, 1985). Although NPS phosphorus is contributed by many sources including construction, urban runoff, and silviculture, an estimated 60 percent of the total annual contribution is from agriculture (Chesters and Schierow, 1985).

PHOSPHORUS AND AQUATIC ENVIRONMENTS

Much of the literature on phosphorus from agricultural, soil science, and geological sources is concerned with the scarcity of P and the problems of delivering it in the amounts necessary for vigorous plant growth rather than with P as a pollutant. Generally, terrestrial concentrations are low, and where abundant it is a benefit not a detriment. Aquatic researchers generally considered concentrations to be too insignificant to be of interest until the early 1960s (Griffith, 1973).

Much as a weed is a plant in the wrong place, P as a pollutant is a nutrient in the wrong place. Phosphorus is an element essential for life that occurs naturally in all living cells and every ecosystem (Griffith, 1973; Hooper, 1973; Kilmer and Taylor, 1980; McKelvey, 1973).

The problems P poses are not from its presence, but from the relative amounts in which it is present (Kilmer and Taylor, 1980; Sharpley and Menzel, 1987). Phosphorus and nitrogen are the two elements that are the most critical to the growth of plants (Brady, 1974). Although limiting to plants in general, P is the single most limiting factor for aquatic plant growth (Nelson and Logan, 1983; Sharpley and Menzel, 1987; Syers et al., 1973). Large inputs of other nutrients have relatively little effect on algal growth unless P is available (Nelson and Logan, 1983). Amounts lost from soils through erosion or leaching that are insignificant to the total soil content, or to terrestrial plants, may cause eutrophication when added to aquatic systems because of the low P levels those systems evolved with (Kilmer and Taylor, 1980; Sharpley and Menzel, 1987).

While increased plant growth might seem a desirable goal, in aquatic environments the effects of that growth can be far from desirable. Although slightly increased water fertility can have beneficial effects on fisheries, most aquatic ecosystems evolved with low nutrient levels (Smith, 1959; Verduin, 1970). A shift to higher nutrient levels, especially P, affects primary productivity and causes aquatic plants, in general, and algae in particular, to reproduce and grow at high rates (Forster et al., 1985; Nelson and Logan, 1983; MacKenthun, 1973a; Odum, 1975; Sawyer, 1973; Syers et al., 1973; Thomas, 1973; Verduin, 1970). These rapid growth conditions can have extensive effects on aquatic systems. An increase of surface plants reduces light penetration, which in turn reduces or eliminates plant growth at greater depths. This, combined with competition for other essential needs and the relatively short lifespan of many of the individual plants, produces a large amount of dead organic material that increases the biochemical oxygen demand (BOD) for decay processes (MacKenthun, 1973a; Odum, 1975; Sawyer, 1973; Verduin, 1970).

This demand for oxygen, along with the rotting vegetation, can result in bad tastes in drinking water, even after passing through water purification systems, and foul smells in water used for recreation or drinking (Odum, 1975; Verduin, 1970). During periods of high photosynthetic production, the withdrawal of CO_2 for plant respiration may cause the water to become more alkaline (Boers, 1991; MacKenthun, 1973a). The change in pH and oxygen depletion from increased BOD may result in the death of other aquatic organisms or a change in the species composition of the aquatic community (O'Kelley, 1973; Sawyer, 1973; Verduin, 1970).

This process, known as eutrophication, may affect the potential uses of water. Eutrophic waters may be unsuitable for boating, fishing, swimming, drinking, irrigation, or other uses (Armstrong and Rohlich, 1973; MacKenthun and Ingram, 1967; Odum, 1975). Although other nutrients may play a role in eutrophication, it is P that is considered to be the nutrient most amenable to control, because it is generally the most limiting nutrient and because measures to control P are more likely to succeed than for other nutrients (Cahill et al., 1974; Syers et al., 1973; Thomas, 1973). In general, lakes and streams that are relatively undisturbed by human activities have relatively low levels of P that will not support the rapid algal growth characteristic of eutrophication (Thomas, 1973; Verduin, 1970).

The other element that is commonly limiting to aquatic systems, nitrogen, may be delivered to aquatic systems in large quantities by rainwater or by the ability of bacteria and blue-green algae to fix atmospheric nitrogen (Thomas, 1973). In contrast to nitrogen, P does not have a gaseous phase in its biogeochemical cycle and once present in an aquatic system will tend to be stored in the system unless physically removed (Keup, 1969; Thomas, 1973).

In surface waters the majority of P is held in a variety of organic storage pools (Hooper, 1973; MacKenthun, 1973a). These storage pools include the living aquatic community of plants and animals that are either free-swimming or associated with the bottom, organic particulate material, dissolved organic compounds, and the P contained in bottom sediments (Hooper, 1973; MacKenthun, 1973a; MacKenthun and Ingram, 1967). In relatively undisturbed lakes the portion contained in organic particulate material, living and dead, may be greater than 60 percent of all P in the surface water ecosystem (Hooper, 1973). The amount contained in each of these storage pools changes rapidly in response to alterations in physical conditions or nutrient inputs (Hooper, 1973). This rapid cycling between storage pools gives P in aquatic systems a transient character, with availability varying in response to the interactions of biological, chemical, and physical factors (Hooper, 1973; MacKenthun, 1973a). Uptake or release of P from one storage pool may greatly affect the availability of P to others, such as the estimate that on a daily basis the waste products and dead cells of lake zooplankton may provide 40 percent to 70 percent of the P needed by phytoplankton in a noneutrophic lake (Golterman, 1973).

As the rapid growth conditions that accompany eutrophication begin to change the patterns of P cycling, changes in species composition take place (O'Kelley, 1973; Sawyer, 1973; Verduin, 1970). Some species of algae and bacteria have a greater positive response to increased P availability and their growth is greatly favored by these conditions (O'Kelley, 1973). When P is present in quantities greater than that needed for the immediate growth needs, many algae and bacteria may take up more than is needed for current growth (luxury uptake), excreting that above their storage capacity in a highly bioavailable form, or holding it until supplies are deficient or death releases it to another storage pool (Boberg and Persson, 1988; Hooper, 1973; O'Kelley, 1973; Sawyer, 1973).

In addition to the large amounts of P, relative to phytoplanton needs, that may be released by the decay of algae produced during a "bloom," the withdrawal of CO_2 for plant respiration may cause the pH of the water to rise to values of 10 or more (Boers, 1991; MacKenthun, 1973a). The availability of P from sediments is significantly increased for pH values above 9.5 indicating that eutrophic conditions may increase the availability of P for further plant growth (Boers, 1991).

The harmful effects of P are only those indirect effects associated with increased water fertility. Phosphorus as a nutrient is not toxic in any way (Griffith, 1973; Kilmer and Taylor, 1980; Sharpley and Menzel, 1987).

SOURCES OF PHOSPHORUS

The quantity of P in streams and lakes is a product of complex relationships involving geologic processes, atmospheric inputs, biological and chemical processes, hydrology, topography, vegetation, land use, and management (Ellis, 1989; Keup, 1969; Loehr, 1974). A discussion of those sources most responsible follows.

Geological Sources

Phosphorus is the 11th most abundant element in the earth's crust (Holtan et al., 1988; McKelvey, 1973). It is widely distributed, being a constituent of most rocks, but is classified as a trace element since it comprises only about 0.1 percent of the rocks of the earth's crust (McKelvey, 1973). It occurs naturally in more than 200 phosphate compounds, although most, perhaps 95 percent, occurs as fluorapatite (Boberg and Persson, 1988; Fisher, 1973; Holtan et al., 1988; McKelvey, 1973).

Igneous rocks have highly differing phosphate contents, even when considered in terms of major groups (McKelvey, 1973). The content of apatite in igneous and metamorphic rocks can be as high as 18 percent, but is generally less than 12 percent (Boberg and Persson, 1988; Holtan et al., 1988). Sedimentary rocks are derived from the weathering products of igneous rocks, and because of the diversity of combinations of elements, including the remnants of biological processes, have even more diverse P contents (McKelvey, 1973). The phosphate content of rocks may be high in a local area, but generally the content is relatively low, less than 0.2 percent (McKelvey, 1973).

The local availability of P from geologic sources is largely influenced by three factors. First, availability is affected by the phosphate content of the rocks in the local area. Rocks with a content much higher than average may occur over large areas and still be a negligible part of the total content of the earth's crust (McKelvey, 1973). This is especially significant to basaltic volcanic rocks (McKelvey, 1973). Secondly, the forms of phosphate found in rocks vary widely in their availability to plants (Dillon and Kirchner, 1975; McKelvey, 1973). Lastly, the environment of the local area—its climate, background pH, and the presence of other minerals that may tend to fix or liberate P—will affect the availability of P from geologic sources (Golterman et al., 1983; McKelvey, 1973).

In any case, in contrast to many other nutrient cycles, the lack of a gaseous component in the interactions in the phosphorus cycle provides P with a one-way trip from rocks, through waterways to the sea (Holtan et al., 1988; Keup, 1969; McKelvey, 1973). It will be millions of years before geologic processes expose the deposits of P currently contained in ocean sediments to the weathering processes that can begin the cycle again (Holtan et al., 1988).

Soils

As a product of geologic parent material, soils naturally contain phosphorus compounds although the amounts vary widely (Brady, 1974). Those soils formed from igneous rock generally have the highest P content (Bailey, 1968). Generally soils that are well-drained also have higher P levels (Bailey, 1968). However, a large portion of this phosphorus total, especially in soils high in clays, calcium, aluminum, or iron, is chemically bound (adsorbed) to soil particles and unavailable, at least in the short-term, to terrestrial plants (Brady, 1974; Holtan et al., 1988; Kilmer and Taylor, 1980; Nelson and Logan, 1983; Sharpley and Menzel, 1987).

The capacity of soils to adsorb P also varies widely (Table 1) (Barrow, 1980; Brady, 1974; McAllister and Logan, 1978; Oloya and Logan, 1980). Those with high capacities tend to become P-enriched over time as phosphorus is made available for adsorption to the soil particles from weathering, organic materials, or fertilizers (Table 2). As an example of this high adsorption capacity and enrichment, a study cited by Kao and Blanchar (1973) of an Indiana soil after 82 years of phosphate fertilization showed the P content of the soil had nearly doubled while leaving the adsorption capacity nearly unchanged.

Table 1. Phosphorus Content, Availability, and Adsorption Capacity for Soils and Sediments in the Maumee River Basin, Ohio (from McAllister and Logan, 1978)

	Total P (ug/g)	Available P (ug/g)	Adsorption maximum (ug/g)
Soils			
Roselms I	1,018	26.8	287
Broughton	568	2.7	209
Roselms II	554	15.8	249
Lenawee	976	46.4	216
Blount	450	13.7	244
Paulding	780	8.6	199
Hoytville	816	21.7	258
Bottom sediments			
Independence (12/1/1975)	476	36.7	222
Auglaize (12/1/1975)	1,260	28.6	4,870
Tiffin (12/1/1975)	753	24.2	1,930
Independence (3/24/1976)	949	19.0	3,580
Auglaize (3/24/1976)	1,150	13.9	4,550

The generally high adsorption capacity of soils prevents little P from escaping the soil profile, although small amounts are present in subsurface runoff (water traveling through soil below the surface) (Ellis et al., 1989; Freeze, 1972; Nelson and Logan, 1983). However, the largest amounts of P carried in runoff are not leachates from water percolating through the soil profile, but P carried with sediments detached from the soil surface (Ahl, 1988; Cahill, 1977; Maas et al., 1987; Reddy et al., 1978; Sharpley and Syers, 1979).

Table 2. Total Phosphorus Content of Soils: Examples from Four States (from Brady, 1974; Reddy et al., 1978)

Soils	Total P (ug/g)	Organic Fraction (%)	Reference
Western Oregon soils			Bertramson and Stephenson, 1942
Hill soils	357	65.9	
Old valley-filling soils	1,479	29.4	
Recent valley soils	848	25.6	
Iowa soils			Pearson and Simonson, 1939
Prairie soils	613	41.6	
Gray-brown podzolic soils	574	37.3	
Planosols	495	52.7	
Arizona soils			Fuller and McGeorge, 1951
Surface soils	703	36.0	
Subsurface soils	125	34.0	
Ohio soils			Reddy et al., 1978
Silty clay	715	44.9	
Silt loam	679	49.3	
Sandy loam	398	43.2	

When soil particles are moved to watercourses by erosional processes the adsorbed P is carried with them. In aquatic systems, any phosphorus compound may be transformed to a bioavailable form given the right conditions and enough time (Van Wazer, 1973). Waterborne sediments with adsorbed P are surrounded by water and all surfaces are subject to the enzymatic processes of algae. These processes can transform phosphorus compounds to bioavailable forms at rates tens of thousands of times more rapidly than chemical hydrolysis reactions at normal temperatures (Van Wazer, 1973). Eroded sediments are a rich source of P for aquatic systems.

Atmospheric Inputs

The phosphorus cycle does not have a gaseous component, but significant atmospheric contributions can be made by windborne particles. These contributions may include dust carried by wind or rain and windborne seeds and pollen (Ahl, 1988; Holtan et al., 1988; Sober and Bates, 1979). Pollen is very rich in P, making it a potentially rich source for streams with a dense canopy of vegetation (Griffith, 1973).

The P content of precipitation is highly variable both regionally and temporally (Holtan et al., 1988; Loehr, 1974; Sober and Bates, 1979). While rain-carried dust may come from many sources, activities that increase the amount of dust, and activities, such as fertilization, which enrich the dust at its source, increase its contribution (Ahl, 1988). Generally atmospheric contributions are highest during summer and near industrial or agricultural areas and lowest near remote areas and during the season of highest precipitation (Holtan et al., 1988).

Phosphorus from atmospheric sources can be a significant nonpoint source (Table 3), but the relative contribution varies widely, from 1.2 percent to 80 percent, and is generally greatest where other sources are limited (Barica and Armstrong, 1971; Loehr, 1974; Sober and Bates, 1979).

Anthropogenic Inputs

Point sources may contribute P directly to water in readily available forms from industrial discharges, sewage effluent (often enriched by P from detergents), and

Table 3. Atmospheric Phosphorus Loading (from Ahl, 1988; Barica and Armstrong, 1971; Holtan et al., 1988; Loehr, 1974; Sober, 1979)

Location	P Load (kg/yr/ha)	Reference
United Kingdom		
Upland	0.27	Owens, 1970
Northern	0.2–1.0	Owens, 1970
Scotland	0.45–0.7	Crisp, 1966
Finland	0.14	Happala, 1977
Denmark	0.10–0.40	Harremoes, 1977
Sweden	0.20	Ahl and Oden, 1975
Norway	0.34	Berge et al., 1979
USSR	0.11–0.15	Evdokimova et al., 1976
United States		
Cincinnati, Ohio	0.6	Weibel, 1969
Northern Mississippi	0.41	Duffy et al., 1978
Lake Mendota, Wisc.	1.02	Sonzogni and Lee, 1974
Ithaca, New York	0.05	Likens, 1972
Hubbard Brook, New Hampshire	0.10	Hobbie and Likens, 1973
Lake Carl Blackwell, Oklahoma	0.605	Sober and Bates, 1979
Canada		
Northern	0.046	Schindler et al., 1974
Central	0.24–0.53	Schindler et al., 1976
Eastern	0.30	Schindler and Nighswander 1970
Ontario	0.77	Dillon, 1975
New Zealand	0.41	Bargh, 1977

concentrated animal waste from confined livestock operations (Ellis et al., 1989; Holtan et al., 1970; Maas et al., 1987). Similarly septic tank drainfields, dispersed animal wastes, crop fertilizers, irrigation return, tile drainage, and nutrients contained in urban runoff may be significant sources of nonpoint source enrichment if improperly managed (Holtan et al., 1988; Loehr, 1974; Maas et al., 1987; Miller et al., 1978).

Groundwater

For P-enriched surface water to recharge groundwater aquifers it must first percolate through the overlying layers of soil and other materials (Nelson and Logan, 1983). The concentration of P in groundwater is determined by the P adsorption characteristics of those materials (Nelson and Logan, 1983).

Generally, the concentrations of P in groundwater are low, due to the high P adsorption capacity of most soils, although extremely porous or cracked soils may not allow sufficient time for complete adsorption to take place (Bailey, 1968; Keup, 1969; Maas et al., 1987; Nelson and Logan, 1983). In a review of studies in Wisconsin and Maine, Keup (1969) found more than 80 percent of groundwater had concentrations less than 0.02 mg/l (20 ug/l). The highest concentration was a single spring in Wisconsin with a concentration of 0.192 mg/l (192 ug/l). Concentrations of P have rarely been of concern as an impairment of groundwater (Maas et al., 1987).

TRANSPORT OF PHOSPHORUS

While nonpoint source P is in transport from one site to another, it is capable of undergoing a number of transformations. Unfortunately, the chemistry of the interactions of P as it is carried by soil, sediment, and water are extremely complex and not completely understood (Bostrom et al., 1988b; Nelson and Logan, 1983). Because the chemical forms P takes during transport vary widely and rapidly, its transport may be better understood by considering the physical forms of transport, particulate and soluble (or dissolved).

Soluble Phosphorus

Background levels of P are difficult to determine because phosphorus transport is very sensitive to man's activities, and virtually no basins are completely undisturbed (Ahl, 1988). However, soluble P levels of 0.007 mg/l (7 ug/l) have been commonly reported for forest streams and lakes without sources of urban or agricultural runoff and is considered to be a common value for background levels of soluble P in many surface waters (Verduin, 1970). This does not mean that all systems have similar background levels. A summary of eight studies from relatively undisturbed forested watersheds by Loehr (1974) found values as high as 0.008 mg/l (8 ug/l) soluble P for the Tieton River and 0.009 mg/l (9 ug/l) soluble P for the Yakima River. Waterways that drain organic soils, such as muck soils, may have background concentrations that are higher by 10 times or more (Table 4) (Duxbury and Peverly, 1978). Despite exceptions, it is assumed that most aquatic ecosystems developed with concentrations close to the 0.007 mg/l (7 ug/l) level of dissolved P, but by the early 1970s all major streams in the United States had levels five to 30 times greater (Verduin, 1970).

Table 4. Phosphorus Concentration in Drainage Water from Mucklands (Histosols) (from Duxbury and Peverly, 1978)

Location	Soluble P Concentration (ug/l)	Reference
New York		
Shallow soils	3,850	Duxbury and Peverly, 1978
Deep soils	9,100	Duxbury and Peverly, 1978
Florida	30,000	Hortenstine and Forbes, 1972

By definition, soluble P is a form that will easily dissolve in water and is readily available for plant growth (Bostrom et al., 1988a; Nelson and Logan, 1983; Sharpley and Menzel, 1987; Syers et al., 1973). It is this dissolved form of P, rather than total P (including adsorbed forms), that is primarily responsible for eutrophication and other water quality problems (Nelson and Logan, 1983; Sharpley and Menzel, 1987; Syers et al., 1973). Unfortunately, the separation of dissolved P in field samples is an arbitrary process, being defined as the portion that will pass through a 0.45 micron filter, which may include some fine colloidal materials with adsorbed P (Nelson and Logan, 1983). It may be difficult to differentiate between materials that are truly dissolved and those associated with fine clays and silts (Walling, 1977).

Concentrations of soluble P are the product of a variety of watershed processes and generally independent of stream discharge rates (Cahill, 1977; Nelson and Logan, 1983; Prairie and Kalff, 1988a). No modeling equations have been found that adequately predict the complexities of soluble P equilibrium reactions under varying conditions (Nelson and Logan, 1983).

Soluble P may be contributed directly or indirectly to a watercourse in groundwater and by fertilizers or animal wastes (Armstrong and Rohlich, 1973; Boreham et al., 1987; Brady, 1974; Collin, 1975; Duda and Johnson, 1985; Hall, 1986; Kilmer and Taylor, 1980; Nelson and Logan, 1983; Nielsen, 1987; OECD, 1986; Phillips, 1986; Phillips, 1987; Sharpley and Menzel, 1987; Sommers and Sutton, 1980; Thornley and Bos, 1985; Unwin, 1987; Verduin, 1970; Young et al., 1985). Soluble P may also be a product of P equilibrium reactions that take place during rainfall and runoff events.

One such reaction occurs when water drops from rainfall or sprinkler irrigation leach small amounts of P from the leaves of plants as they pass over the leaf surface (Sharpley, 1981; Sharpley et al., 1981b; Sharpley and Menzel, 1987). A similar reaction takes place when water running over the surface of the soil causes the desorption of P from the thin surface layer of soil with which it is in contact (Sharpley et al., 1981a; Sharpley et al., 1981b; Sharpley and Menzel, 1987). The losses from the plant canopy, soil surface, and leaching from dead plant material are the primary sources of soluble P added to overland runoff (Sharpley, 1981; Sharpley et al., 1981b; Sharpley and Menzel, 1987).

Particulate Phosphorus

Particulate P includes organic materials and minerals containing P and soil particles with P bound to them (adsorbed P) (Boberg and Persson, 1988). Particulate P in streams includes P bound to sediments from surface and streambank erosion, and contained in the remains of living and dead aquatic organisms (Boberg and Persson, 1988; Hooper, 1973; Sharpley and Syers, 1979; Walling, 1977).

The major portion of P carried in runoff is generally sediment bound (Sharpley and Syers, 1979). As long as this P is bound to the particles it is not available for plant growth (Kilmer and Taylor, 1980; Nelson and Logan, 1983; Sharpley and Menzel, 1987). The amount of particulate P transformed to the dissolved form and available to plants as these materials break down varies, but can be significant, especially from organic material (Nelson and Logan, 1983; Oloya and Logan, 1980; Sharpley and Menzel, 1987; Sharpley and Syers, 1979). Although it is known that the transformation from particulate to dissolved form takes place, the combinations of conditions that cause this are not fully understood (Bostrom et al., 1988b).

Fine-textured soils, such as clays and silts, have the greatest affinity for P (Day et al., 1987; McAllister and Logan, 1978; Miller, 1977; Nelson and Logan, 1983; Sharpley and Menzel, 1987). Soil erosion processes from overland flow are selective, with fine sediments being more likely to be carried in runoff (Kilmer and Taylor, 1980; Miller, 1977; Sharpley and Menzel, 1987). This preference increases the nutrient concentration of sediments by selecting those particles most likely to be carrying adsorbed P (Miller, 1977; Nelson and Logan, 1983; Sharpley and Menzel, 1987). The ratio between the P concentration in runoff sediment and the P concentration of the soil it was derived from is termed the enrichment ratio (Nelson and Logan, 1983; Sharpley and Menzel, 1987). Enrichment ratios of 1:2 to 1:6 are not uncommon for large watersheds and are one of the elements of predicting total sediment P loads (Nelson and Logan, 1983). Total sediment P loads are considered to be a product of soil loss, the P content of surface soil, sediment enrichment ratio, and sediment delivery rate (Nelson and Logan, 1983). Sediment enrichment ratios have an inverse relationship with soil loss. As the sediment delivery ratio decreases, it is the finest, most enriched particles that will continue to be carried (Nelson and Logan, 1983).

Most of the soil eroded from the land surface in any given year is moved during large storm events (Knox, 1977; Sullivan, 1985). The movement of soil as sediment depends on the detachment and transport of soil particles by such forces as flowing water or the impact of raindrops (Brady, 1974). Vegetative cover lessens both the force of raindrop impact for detachment and the velocity of the overland flow for transport (Brady, 1974). Vegetation can also decrease the amounts of sediment delivered to a stream by reducing the velocity of overland flow, decreasing its capacity to carry sediments (Cooper et al., 1987; Lowrance, 1990; Lowrance et al., 1984; Lowrance et al., 1985; Omernik et al., 1981; Schlosser and Karr, 1981).

One of the transformations between particulate P and soluble P takes place as soil particles suspended in overland flow interact with rainwater in sorption-desorption reactions during detachment and transport (Nelson and Logan, 1983). The extent and direction of these exchanges depends on the P equilibria of the soil carried and the soluble P concentration of the rainwater (Nelson and Logan, 1983).

Other transformations from particulate to soluble form take place after sediments are delivered to the watercourse. Suspended sediments act as a buffering agent for P in streams, adsorbing P when soluble concentrations are high, and desorbing P when soluble concentrations are low (Black, 1970; Golterman, 1973; Hill, 1982). As particles settle, in slack water areas or lakes, the buffering is reduced in both speed and capacity (Hill, 1982; Sharpley and Menzel, 1978). This is moderated in part by the tendency of the smallest particles, which have a greater capacity for sorption-desorption reactions, to stay suspended for the greatest time (Hesse, 1973; Oloya and Logan, 1980).

In turbulent streams or rivers there is generally enough energy to resuspend or keep suspended both large, heavy particles and lighter, finer particles. As velocity decreases, such as during periods of low flow, the heavier particles will settle out, leaving the clays and silts in suspension (Boberg and Persson, 1988). This selectivity for particle size is similar to that of overland erosion and has similar effects. During low flow periods, the total suspended material will decrease, but the total P in the water column will stay proportionally higher.

The pH of water surrounding particles also has an effect on transformations. In soils, P is most available for plants in a range near neutral pH. At lower pH levels it tends to form less soluble compounds with readily available iron, aluminum or manganese and at higher pH levels, with calcium (Brady, 1974). In water, these elements are not as available, and P from sediments is increasingly released into solution at pH levels below 5.0 or above 9.5 (Boers, 1991; DeLaune et al., 1981).

The P bound to sediments is not all immediately available to plants, but is available as transformations take place over time (Nelson and Logan, 1983; Sharpley and Menzel, 1987; Van Wazer, 1973). Sediments rich in iron or aluminum may have more immediate effects on algal growth since P bound to these elements is most readily available to algae (Dorich et al., 1980). As algae reduce the soluble P concentration in water below that of the equilibrium P concentration of the sediment, sediment-bound P will be desorbed and become available for plant growth (Golterman, 1973; McAllister and Logan, 1978). Rooted aquatic plants are able to extract P from sediments that have been deposited which are less available to sorption-desorption reactions (MacKenthun, 1973a). Material from dead aquatic plants, rooted or free-floating, is a ready source of P for other aquatic plants (MacKenthun, 1968; Nelson and Logan, 1983; Sharpley and

Menzel, 1987). In this organic mass, large quantities of P can be moved gradually downstream in a form that is not routinely analyzed (Keup, 1969). These aquatic plants have been found to make up a substantial portion of particulate matter in streams (Rigler, 1979). Individual P atoms are taken up by plants, released in organic compounds, perhaps settle to the bottom as sediment for a time, are taken up again by plants, and continue moving downstream in this spiral fashion (Meyer et al., 1988; Mulholland et al., 1983; Newbold et al., 1983). The rate and distance P moves with each spiral varies with seasonal changes in light, temperature, and other environmental factors (Mulholland et al., 1983). When conditions are favorable, biological cycling can be very rapid, especially in shallow waters in which the entire water column is exposed to light, such as is common in streams without a closed overhead canopy (Holtan et al., 1988). At any one time, much of the total P of the system may be tied up in one of these temporary storage pools. An accurate analysis of the total P in the system and predictions of its movement and transformations, even if fully understood, would be exceedingly complex.

In addition to sediment from the land surface, another major source of sediment is streambank erosion (Sharpley and Syers, 1979; Walling, 1977). Increased flow and velocity, which may resuspend instream sediments, also affect the amount of sediment removed from streambanks (Sharpley and Syers, 1979; Walling, 1977). Although the subsoils from streambanks tend to be less P-enriched than field topsoils, streambanks may contribute as much as 75 percent of all sediments for some streams (Kilmer and Taylor, 1980; Sharpley and Menzel, 1987; Sharpley and Syers, 1979). Streambank erosion is most severe for wet, unprotected banks that are subjected to rising flows with their accompanying increased velocities (Walling, 1977).

Sediments in flowing water systems move on a seasonal scale. Small particles and organic material will tend to stay suspended for longer periods and during lower flows than larger soil particles (Boberg and Persson, 1988; Keup, 1969; Walling, 1977). During high flows, sediments deposited during periods of low flow will be resuspended and moved downstream (Boberg and Persson, 1988; Cahill, 1977; Cahill et al., 1974; Hill, 1982; Keup, 1969; Meyer et al., 1988; Rigler, 1979). The total P stored in stream or river sediments can be very large (Hill, 1982; Keup, 1969; Rigler, 1979). Most of this sediment is moved on the rising limb of the storm hydrograph, especially during high flow events early in the runoff season (Paustian and Beschta, 1979; Meyer et al., 1988; Rigler, 1979; Sullivan, 1985). The concentrations of sediment during stormflow can change rapidly, and sediment loads are often underestimated by calculations based on averages (Cahill, 1977; Paustian and Beschta, 1979; Rigler, 1979). Particulate P concentrations in streamflow are generally closely correlated to suspended sediments in stream discharge (Cahill, 1977; Golterman, 1983; Meyer et al., 1988). Consequently, estimates of annual loading of sediments and particulate P, which generally is the majority of total P in streams, is often severely underestimated (Cahill, 1977; Rigler, 1979).

Generally, a stream system has three broadly defined sections. The steeper section, or reach, near the headwaters is often the site of streambed erosion, or degradation. The middle reach is a transitional zone of lower gradient, often temporarily storing materials moved from upper reaches that will be resuspended and moved at higher flows. Lower stream reaches have the least gradient and are the deposition, or aggradation, site for materials transported from the upper reaches (Statzner and Higler, 1985). In lakes or river reaches with aggrading channels, sediments may have long residence times. Coarse or dense materials, which have low P equilibria and therefore contribute less P from desorption, settle more rapidly and may exclude previously deposited sediments from many reactions by burying them (MacKenthun, 1973a; Oloya and Logan, 1980). Under such conditions sediments may act as a P sink, storing large quantities for extended periods (Syers et al., 1973). Portions of this stored P may become available through the exchange of water held in between sediment particles, through the action of rooted plants if the surface of the sediments is in the photic zone, or if the sediments are resuspended by turbulent mixing, changing flow conditions, or other factors (Cahill, 1977; MacKenthun, 1973a; Syers et al., 1973).

Surface sediments are generally the finest in texture, having been the last to settle out, and are much more susceptible to sorption-desorption reactions due to their size, proximity to changing P concentrations in water, and availability to algae and rooted plants (Golterman, 1973; Hesse, 1973; MacKenthun, 1973a; McAllister and Logan, 1978; Oloya and Logan, 1980; Syers et al., 1973). Distinct biotic communities often develop to take advantage of this deposited material (Vannote et al., 1980). Organic sediments, generally light in weight and found on the surface, readily release P as they decay (Syers et al., 1973). Surface sediments may react to lowered P equilibria very rapidly, releasing P through desorption in a matter of minutes (Oloya and Logan, 1980). Through a variety of chemical and biochemical processes, deposited sediments, especially those with a high organic content, may contribute bioavailable forms of P for years without additional inputs (Duxbury and Peverly, 1978; Sharpley and Menzel, 1987).

Total Phosphorus

Total P is the sum of soluble and particulate P concentrations or loads. Although soluble P is the form that is immediately available for plant growth, the many transformations that P can undergo in an aquatic system make total P the most stable measure of P (MacKenthun, 1968). It has been recommended that when it is necessary to set limits on P, total P should be used as form around which guidelines are established (MacKenthun, 1968).

In the summary from relatively undisturbed forested watersheds by Loehr (1974) cited above, values as high as 0.115 mg/l (115 ug/l) total P for the Tieton River and 0.07 mg/l (70 ug/l) total P for the Yakima River were found. Average total P concentrations for rivers in Britain have been reported as 0.07 mg/l (70 ug/l), showing some similarity even over geographic boundaries (Klein, 1962).

The concentrations of P required for nuisance plant growth varies between systems, depending on complex interactions between the availability of other nutrients, temperature, and light (MacKenthun, 1968; MacKenthun, 1973b; Sylvester, 1961). Generally concentrations that produce eutrophic conditions are lower for standing waters, such as lakes and reservoirs, than for streams (MacKenthun, 1968; MacKenthun, 1973b). In some systems total P levels as low as 0.02 mg/l (20 ug/l) can be considered as a threshold for eutrophication, being the point at which the periphyton (algae and other organisms that form a living film on the stream bottom) composition of communities begins to change (Clausen and Meals, 1989; Verduin, 1970). In Seattle's Green Lake, nuisance algal blooms have occurred when soluble P concentrations were 0.01 mg/l (10 ug/l) (Sylvester, 1962). Levels recommended to prevent nuisance plant growths by MacKenthun (1968) are concentrations of not more than 0.10 mg/l (100 ug/l) of total P in flowing waters, and not more than 0.05 mg/l (50 ug/l) of total P where streams enter standing waters.

Seasonal Variations

Both load and concentration of P vary over time. Loads are highly affected by the seasonal variation in suspended sediment load discussed above. Concentrations also vary seasonally, but the influences are not as clear. Three explanations—runoff effect, dilution effect, and temperature effect—have been offered, and the answer probably lies in combinations of these effects.

The runoff effect describes an increase in concentration with an increase in streamflow (Cahill et al., 1974). This may be explained by suspended sediment loads, both those entering the stream from the land surface and those reentering the water column from the bottom as increasing flow increases turbulence (Cahill, 1974). The magnitude of this effect will be influenced by the P content of the sediments.

The effect of dilution may be used to describe two related conditions. One is a rise in P concentrations as streamflow decreases, and the other is a drop in P concentrations as flow increases (Cahill et al., 1974). In streams with a groundwater baseflow that is relatively enriched, summer low flows are not diluted by low concentration stormwater and concentrations will be high (Cahill et al., 1974; Prairie and Kalff, 1988a). As water from a storm enters such a stream, concentrations may drop as baseflow is diluted. However, if the storm event is a large one and flow rises rapidly, then the runoff effect may be the predominant influence.

Streamflow also affects how long water, sediments, and the nutrients they carry remain in the stream channel. Referred to as detention time, decreasing flow during the summer period of little precipitation increases the residence time of nutrients, making them more available for algal growth (Rickert and Hines, 1978). Management activities can shorten residence time through flow augmentation or increase it through water withdrawals (Rickert and Hines, 1978).

Temperature may directly affect P concentration dynamics. In soil, high temperatures will yield solutions with high P concentrations (Barrow, 1974; Barrow and Shaw, 1975; Stuanes, 1982). For water similar relationships have been shown. When water temperatures rise above 15°C (60°F) the rate at which P is released from suspended solids and sediments is substantially increased (Karr and Schlosser, 1978).

Temperature may also affect P concentrations indirectly. Warmer temperatures may promote the growth of aquatic plants, which in turn may remove P from the water for growth. Over time, as the plants die, this P will then reenter the stream and be recycled in the spiral fashion previously described.

Other seasonal events that may affect P concentration and load include the addition of nutrient-rich leaves in autumn and increased aquatic plant growth with increased light (Mulholland et al., 1985; Waller and Hart, 1986). In many heavily shaded streams maximum plant growth may occur in late fall after streamside plants have shed their leaves and the canopy has opened (Mulholland et al., 1985).

Management Implications for the Tualatin Basin

No matter the form, virtually all P that makes its way into surface waters is carried there by water, primarily overland flow (Figure 2). Particulate P contributed to a stream is primarily carried in runoff sediments (Ellis, 1989; Kilmer and Taylor, 1980; Nelson and Logan, 1983; Sharpley and Menzel, 1987). Dissolved P that infiltrates the soil surface will very likely be adsorbed, and losses from subsurface drainage are slight, although amounts are higher for very rapid subsurface runoff because the time available for adsorption is reduced (Sharpley and Menzel, 1987; Sharpley and Syers, 1979). Simply stated, to control NPS phosphorus, prevent overland flow and soil erosion by keeping soil and water on site.

The TMDL placed on the Tualatin Basin is based on concentrations of total P, particulate and dissolved loads combined, rather than the more bioavailable dissolved form. As with any other sediments, particulate P may settle out of the water column and be incorporated into bottom deposits (Hill, 1982; Keup, 1968; Leopold et al., 1964; Meyer and Likens, 1979). Sediment P deposited in the photic zone may be available to rooted plants (Meyer and Likens, 1979). Organic materials from these plants, a source of bioavailable P, may then reenter the water column for transport downstream (Nelson and

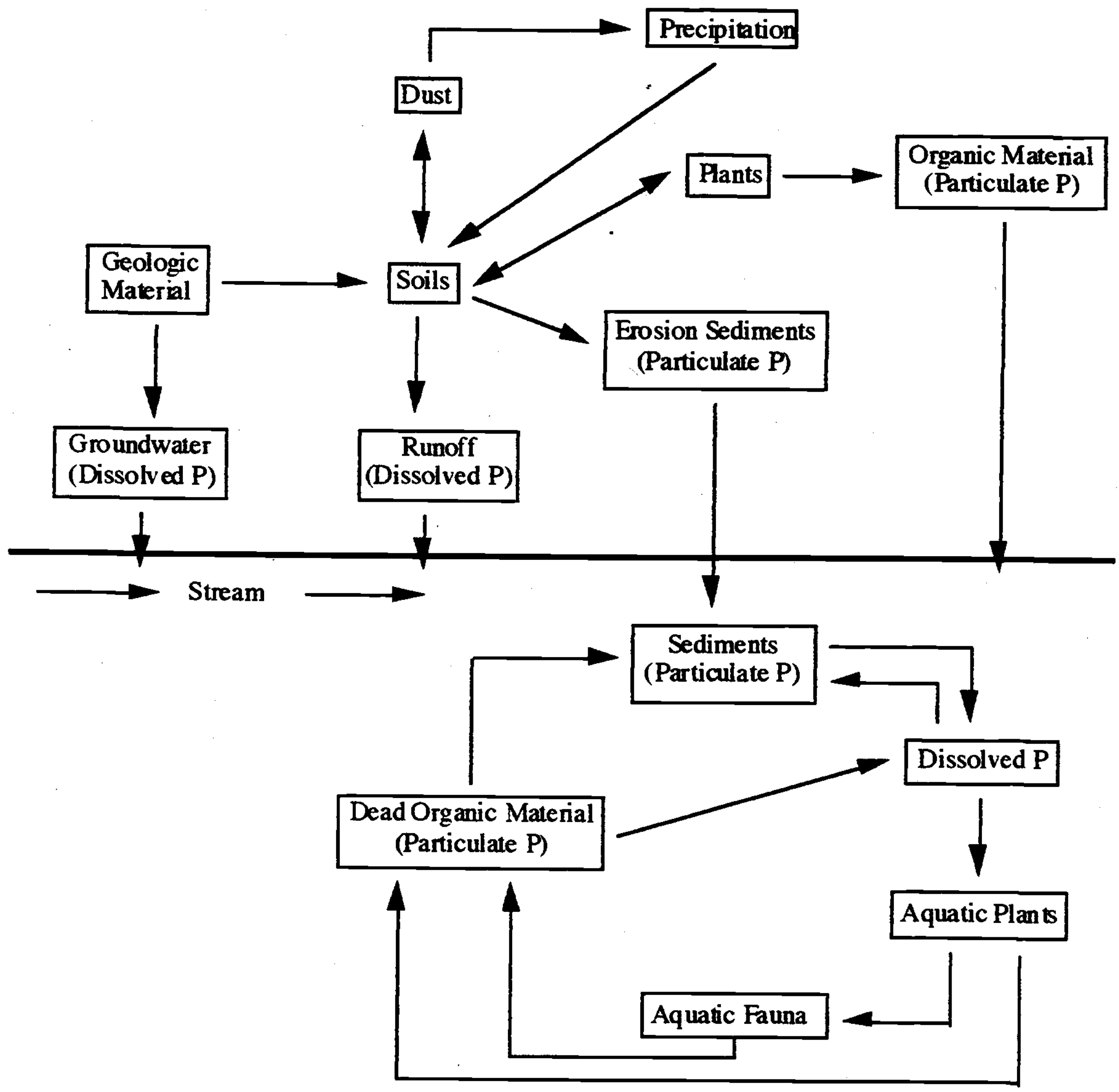


Figure 2. Movement of P in a Landscape

Logan, 1983; Oloya and Logan, 1980; Sharpley and Menzel, 1987). Sediment deposits, including organic material, may be resuspended and moved downstream when flows increase, especially by the moderate frequency and magnitude flows responsible for most sediment transport (Keup, 1968; Leopold et al., 1964).

Eventually these P-enriched sediments may be deposited in the mainstem of the Tualatin. The portion where eutrophication generally occurs, the part that has the lowest gradient and water velocity, is the most likely place for these sediments to be deposited (Leopold et al., 1964). It is likely that P in sediments in this portion of the river act similarly to sediment P in lakes. Research on P in lakes has shown that portions of this total sediment load can be desorbed over time (Armstrong et al., 1987; Bostrom et al., 1988b; Oloya and Logan, 1980; Syers et al., 1973). The retention time of P in sediments may be very short (minutes) or very long (centuries) and varies with the form of P, the process required for desorption, and the contact of the sediments with moving water (Armstrong et al., 1987; Duxbury and Peverly, 1978; Golterman, 1973; McAllister and Logan, 1978; MacKenthun, 1973; Oloya and Logan, 1980; Nordin, 1977; Syers et al., 1973; Van Wazer, 1973). If the lower Tualatin does function as a lake, detaining sediments during low flow periods, then this TMDL reflects a tenable view of P interactions in the Tualatin system. Control of eutrophication requires consideration of the bioavailability of the P available over the long term from particulate P and the control of particulate P contributions (Sharpley and Menzel, 1987).

Given that regulations for the Tualatin Basin are based on total P, then both dissolved and particulate P are of NPS concern. If dissolved P were the primary concern, then land uses that produce or use P that readily enters solution, such as livestock operators and users of chemical P fertilizers for agriculture and silviculture, would be of concern. But since all P forms are included, any land use that may produce sediment is also of concern. Nationally, agriculture is responsible for about 70 percent of the NPS phosphorus, primarily from sediments, fertilizers and animal wastes (Chesters and Schierow, 1985). In the Dairy-McKay watershed, nearly two-thirds of cropland, which has higher sediment production and delivery rates than many other agricultural uses, is within one-quarter mile of a stream (Soil Conservation Service, 1990). Due to the amount of land disturbance in proximity to streams, the relative amount of P contributed to the Tualatin system by agriculture may be similar to the national averages.

PHOSPHORUS AND LAND USE

Forestry

Effects of Forest Practices on Dissolved Phosphorus

Generally P has been of interest because it is in short supply (Fredriksen, 1971). Phosphorus is a relatively recent pollutant of concern, especially viewed as total P. Many studies of nutrients in forest ecosystems have not reported results for P (Corbett et al., 1978; Likens et al., 1970; Fowler et al., 1988). Studies that have examined P in forest ecosystems have generally examined concentrations of dissolved P and found little effect from forest harvest (Brown et al., 1973; Harr and Fredriksen, 1988; Fredriksen, 1971; Schreiber et al., 1976; Tiedemann et al., 1988).

Effects of Forest Practices on Particulate Phosphorus

Particulate P includes both soil particles and organic matter moved as sediments. The total sediment found in a stream is the sum of sediment from surface erosion, soil mass movement, and channel erosion (Currier et al., 1979). Although both soils and vegetation may act a sink for P, most of the P in any terrestrial system is found in the soil. For example, in a Douglas-fir ecosystem 97.5 percent of P was stored in soils, the remainder being in vegetation and litter (Cole et al., 1967). Amounts of P lost from soils through erosion or leaching may be insignificant to the total soil content, or to terrestrial plants, but still cause eutrophication when added to aquatic ecosystems (Kilmer and Taylor, 1980; Sawyer, 1973; Sharpley and Menzel, 1987). The litter component of forest ecosystems probably has little effect on P transport (Sawyer, 1973). Even directing small streams through buried slash piles had no significant effect on concentrations of total P (Larson and Wooldridge, 1980).

Phosphorus in water flowing over the soil surface tends to be rapidly adsorbed by soil particles near the surface when infiltration occurs. Because of this adsorption, sediments from topsoils tend to be enriched with P, while those from subsoils, such as from streambank erosion, tend to be much lower in concentration (Kilmer and Taylor, 1980; Sharpley, 1980; Sharpley and Menzel, 1987). Fine textured soils, such as clays, have the greatest affinity for P (McAllister and Logan, 1978; Nelson and Logan, 1983; Sharpley and Menzel, 1987). These soils are also the most erodible, giving sediments much higher P concentrations than the soils they came from (Nelson and Logan, 1983; Ongley, 1976; Sharpley, 1980; Sharpley and Menzel, 1987). As overland flow passes over vegetation or litter on its way to a stream, reduced velocity may cause larger sediment particles to be deposited. Since P has a great affinity for the smallest particles, such as colloidal clays, the sediments that reach the stream are more likely to be P-enriched (Omernik et al., 1981).

For most sites tree removal in itself generally has little or no effect on sediment concentrations in streams (Brown and Krygier, 1971). The activities associated with forest harvest, such as road building, skidding, and slash burning can increase sediment production for relatively short periods (a couple of years) (Beschta, 1978; Brown and Krygier, 1971; Environmental Protection Agency, 1973; Packer, 1967; Swanston, 1967). Some of these sediments may be retained in the stream system for many years, making the offsite effects cumulative (Anderson, 1967; Coats and Miller, 1981).

As an example, it is estimated that typical erosion rates for the approximately 1,650 forested acres harvested annually in the Dairy-McKay watershed are 50 tons/acre the first postharvest year (Soil Conservation Service, 1990). The average erosion for reestablishment period of five years is 15 tons/acre, or 137,000 tons annual erosion associated with harvest activities (Soil Conservation Service, 1990).

Forest harvest can increase water yield that may affect systems differently (Rothacher, 1967). This will generally not affect land-based sediments, but it may increase instream erosion in systems without sufficient streamside vegetation to hold soil in banks and protect the soil surface from the scouring of high water (Packer, 1967). In other systems, the water yield response may be too small to significantly increase downstream erosion and sediment transport (Harr and McCorison, 1979).

Management Implications: Controlling NPS Phosphorus From Forest Land

Identifying effective methods of controlling NPS phosphorus from forests depends on the type of P targeted. If dissolved P is the pollutant of concern, then fertilization of forest stands and the use of slash burning are the primary activities that need careful consideration (see Figure 3). However, if total P is identified as the concern, then any activity that increases the likelihood of sediment reaching a watercourse is also of concern (see Figure 4). In the past, investigation has been done to identify which forest practices are primarily responsible for increased sediment production. These practices are the logical starting places for reducing total P inputs from forest practices

Roadbuilding. The effect of roads on sediment production has been widely studied. They have been found to contribute as much as 90 percent of all sediments from forested lands (Brooks et al., 1991). Summaries by Swanston (1971) and Brown (1980) of various studies illustrate the general trend of roadbuilding causing increased sediment production. Generally, poor planning and maintenance cause even greater problems (Brown, 1980). Surface erosion associated with roads and skid trails is proportional to road and skid trail density (Brown, 1980). In addition, roads along streams have the greatest effect on sediment production (Anderson, 1974). In basins that are P sensitive, road construction should be planned to minimize the length of roads necessary, continued maintenance should be performed, and, in both planning and maintenance, every technique available to reduce sediment production should be used. Roads, skid trails, and log landing sites, should also be placed some distance from streams to decrease the likelihood of sediments reaching stream channels (Anderson, 1974; Lynch and Corbett, 1990). Alternative yarding methods that reduce soil disturbance associated

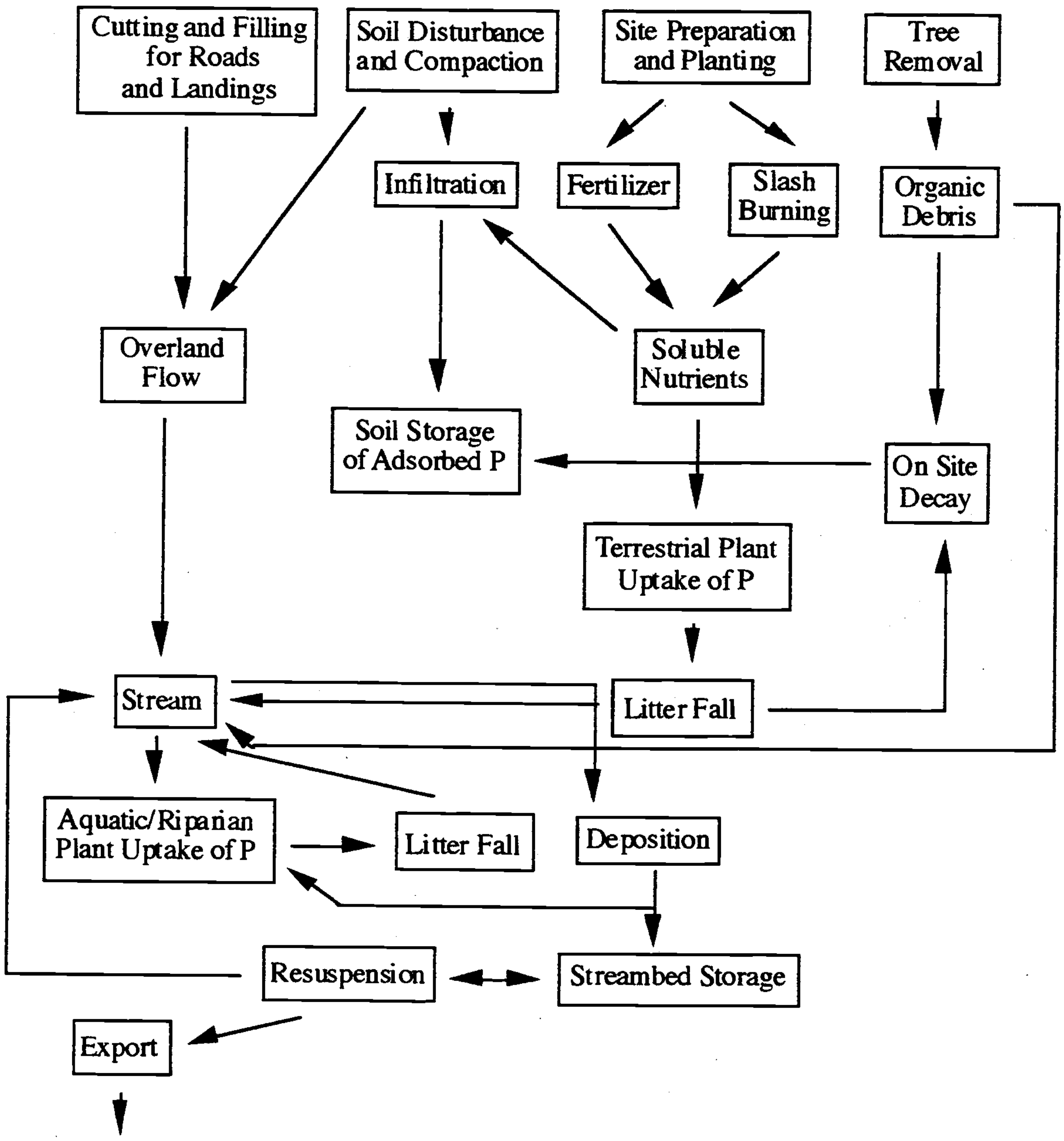


Figure 3. Influences of Forest Practices on the Transport of Dissolved P

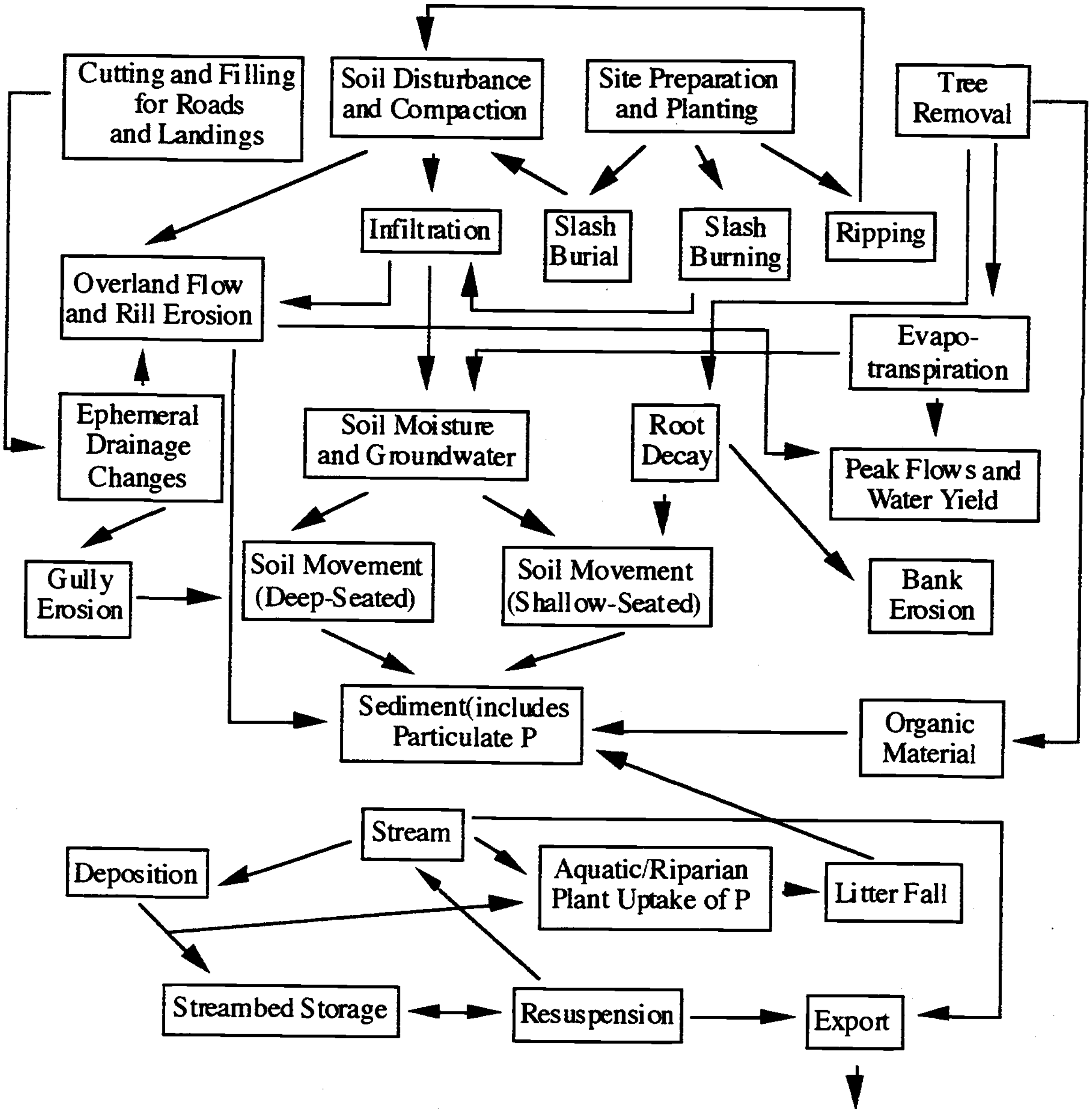


Figure 4. Influences of Forest Practices on the Transport of Particulate P

with contact between the log and the ground and that have a reduced reliance on roads, such as helicopter or balloon logging, should also be seriously considered in P sensitive basins.

Logging. Generally, tree removal by itself has little effect on sediment production. An exception would be especially steep sites or those with unstable soils, where the removal of forest vegetation may cause increased sediment production by removing the stabilizing influence of root systems (Brooks et al., 1991; Coats and Miller, 1981; Nikolayenko, 1974; Swanston, 1967). In P sensitive basins these areas must be managed thoughtfully. Harvest of these areas should be avoided or performed selectively to avoid destabilizing large areas in a short time period.

Site Preparation. Studies of the effects of slash burning on nutrients have somewhat variable results. Fredriksen (1971) reported a doubling of dissolved P after slash burning in the western Cascades of Oregon, while a study in the Oregon Coast Range by Brown and others (1973) and another by Harr and Fredriksen (1988) in the western Cascades of Oregon found concentrations of dissolved P to be relatively unchanged after slash burning. Although none of the studies reported total P or particulate P concentrations, all reported large increases of sediment following slash burning, which would be consistent with large losses of particulate P. In the study reported by Harr and Fredriksen (1988), suspended sediment levels remained elevated for nine years following slash burning. Slash burning would not be a recommended management practice in P sensitive basins.

Slash burial, although more expensive, has been considered as an alternative means of slash disposal (Larson and Wooldridge, 1980). Studies of nutrients in water flowing through buried slash piles indicate that buried slash may not be a significant source of nutrients (Larson and Wooldridge, 1980). Generally, the P found in organic materials becomes bioavailable as materials decay, but is readily adsorbed by soil particles if transported in subsurface flow. The disposal of slash by burial would be preferable to burning, but careful consideration would need to be given to the amount of soil disturbance necessary for burial.

Another suggested alternative has been leaving slash on the soil surface to naturally decompose. The study by Harr and Fredriksen (1988) showed that this method worked well to reduce sediment production following harvest. Suspended sediment levels from this unit showed a brief increase associated with road construction and then returned to background levels. This method is not without costs however. Growth of the replanted tree stand was approximately half of that in the burned area, possibly from increased shrub competition.

Streamside Management. Riparian areas have been identified as sites that influence many aspects of water quality in streams, including sediments (Brooks et al., 1991; Brown, 1980; Karr and Dudley, 1981; Karr and Schlosser, 1978; Lowrance et al., 1984; Lowrance et al., 1985; Lynch and Corbett, 1990; Nikolayenko, 1974; Omernik et al., 1981; Schlosser and Karr, 1981). Riparian vegetation helps reduce the velocity of any overland flow, increasing the opportunity for sediments to deposit before reaching watercourses, and promotes infiltration (Gregory et al., 1991; Karr and Schlosser, 1978; Li and Shen, 1973). Plant uptake will also help detain P before it reaches the stream (Karr and Dudley, 1981; Lowrance et al., 1984; Lowrance et al., 1985; Omernik et al., 1981; Schlosser and Karr, 1981). Phosphorus that infiltrates is likely to be adsorbed onto soil particles and unlikely to move farther except as particulate P, associated with either sediment or organic materials (Lowrance et al., 1984; Lowrance et al., 1985; Omernik et al., 1981; Sharpley and Menzel, 1987). Over time these riparian nutrient sinks need to be managed with selective forest harvest and minimal soil disturbance to move the P retained in them offsite rather than into streams as organic material (Lowrance et al., 1984; Lowrance et al., 1985; Lowrance, 1990). Opinions on the required width of this riparian buffer zone necessary to control sediments varies, but generally these strips are wider than those only concerned with vegetation for stream shading and woody debris contributions (Brown, 1980; Lynch and Corbett, 1990; Lowrance, 1990). The costs of this practice are primarily those of removing land from production (Karr and Dudley, 1981).

Summary and Conclusions

The land disturbance of silviculture at any one time is on a relatively small scale compared with agricultural land uses. But the effect on the site and affected local area, although short-lived, is high in both impact and pollutant loading (McElroy, 1977).

Where NPS phosphorus is a water quality concern, the effects of forest activities will depend on whether total P or dissolved P is used as the basis for regulation. If dissolved P is the pollutant of concern, then forest activities (with the possible exception of slash burning) have relatively little effect. However, if total P is of concern, then any forest activity that disturbs the soil surface and has the potential of producing sediment is of concern. As an example of the potential effects of forest practices on P, in some areas average particulate P concentrations can be predicted from the extent of forest cover (Prairie and Kalff, 1988b).

In areas regulated by total P concentrations, methods that are most effective in preventing or reducing sediment production need to be identified and implemented. If effective control is not achieved, then any method that reduces soil erosion, including the reduction or elimination of forest harvest may need to be considered to meet NPS pollutant goals. This should prove a strong incentive for research and change.

Agriculture

Because of the large areas of land used for agricultural purposes in the United States, agriculture's share of land-based NPS pollution is large. The diffuse nature of these pollutants makes direct measurement difficult, but estimates indicate that for the nearly two-thirds of the nation's nonfederal land that is cultivated or used for grazing, agriculture contributes nearly 70 percent (3 million tons annually) of the total load of P, primarily from sediments, fertilizers and animal wastes (Chesters and Schierow, 1985; Myers, 1986).

Without doubt agriculture has had great effect on the appearance, structure, and function of the land. These changes have created many benefits, but also some unanticipated problems.

The development of farmland alters the quantity of nutrients and sediments exported from it and the quality and flow of water that drains from it (Smith, 1959). The ratio of change from background load to current load of sediment and nutrients is generally proportional to the extent that land has been changed from its natural state to a disturbed state, generally agriculture (McElroy, 1977; Prairie and Kalff, 1988b). Even the conversion of land from forest to pasture, which is a relatively stable use, has doubled the amount of P exported from the watershed in some areas (Dickinson and Wall, 1977; Dillon and Kirchner, 1975).

Effects of Agricultural Practices on Dissolved Phosphorus

Agriculture may contribute soluble P to a stream in a variety of ways (see Figure 5). There is a basic dilemma in attempting to supply the P necessary for plant growth. In order for P to be available it must be supplied in quantities greater than can be immediately adsorbed by soil and in forms that are readily soluble (Brady, 1974). This also increases quantities of soluble P at the soil surface where it is most likely to be carried off-site with overland flow (Armstong and Rohlich, 1973; Kilmer and Taylor, 1980; Nelson and Logan, 1983; Sharpley and Menzel, 1987; Verduin, 1970).

Dissolved P may also be contributed to surface waters in significant amounts when animal wastes are carried in runoff (Boreham et al., 1987; Brady, 1974; Collin, 1975; Duda and Johnson, 1985; Hall, 1986; Nielsen, 1987; OECD, 1986; Phillips, 1986; Phillips, 1987; Sommers and Sutton, 1980; Thornley and Bos, 1985; Unwin, 1987; Young et al., 1985).

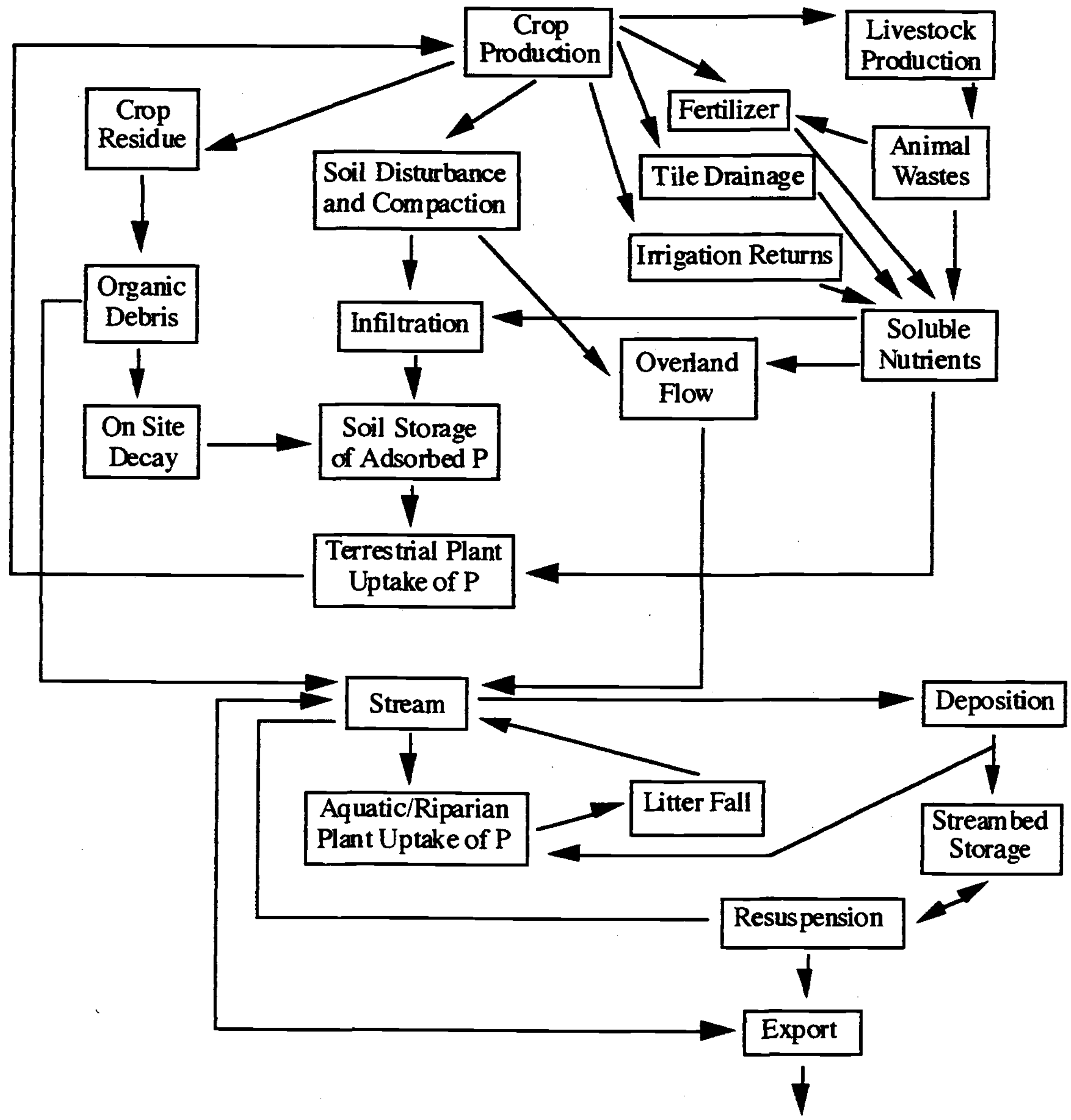


Figure 5. Influences of Agriculture on the Transport of Dissolved P

Effects of Agricultural Practices on Particulate Phosphorus

Activities that disturb the land surface may contribute particulate P to streams (see Figure 6). Most of the P lost from agricultural lands is moved in particulate form as sediment in stormflow runoff (Cahill, 1977; Reddy et al., 1978). The volume of runoff and amount of sediment lost are related to the amount of rainfall, erodibility of soils, the length and steepness of slopes, and extent and nature of vegetation on the land surface

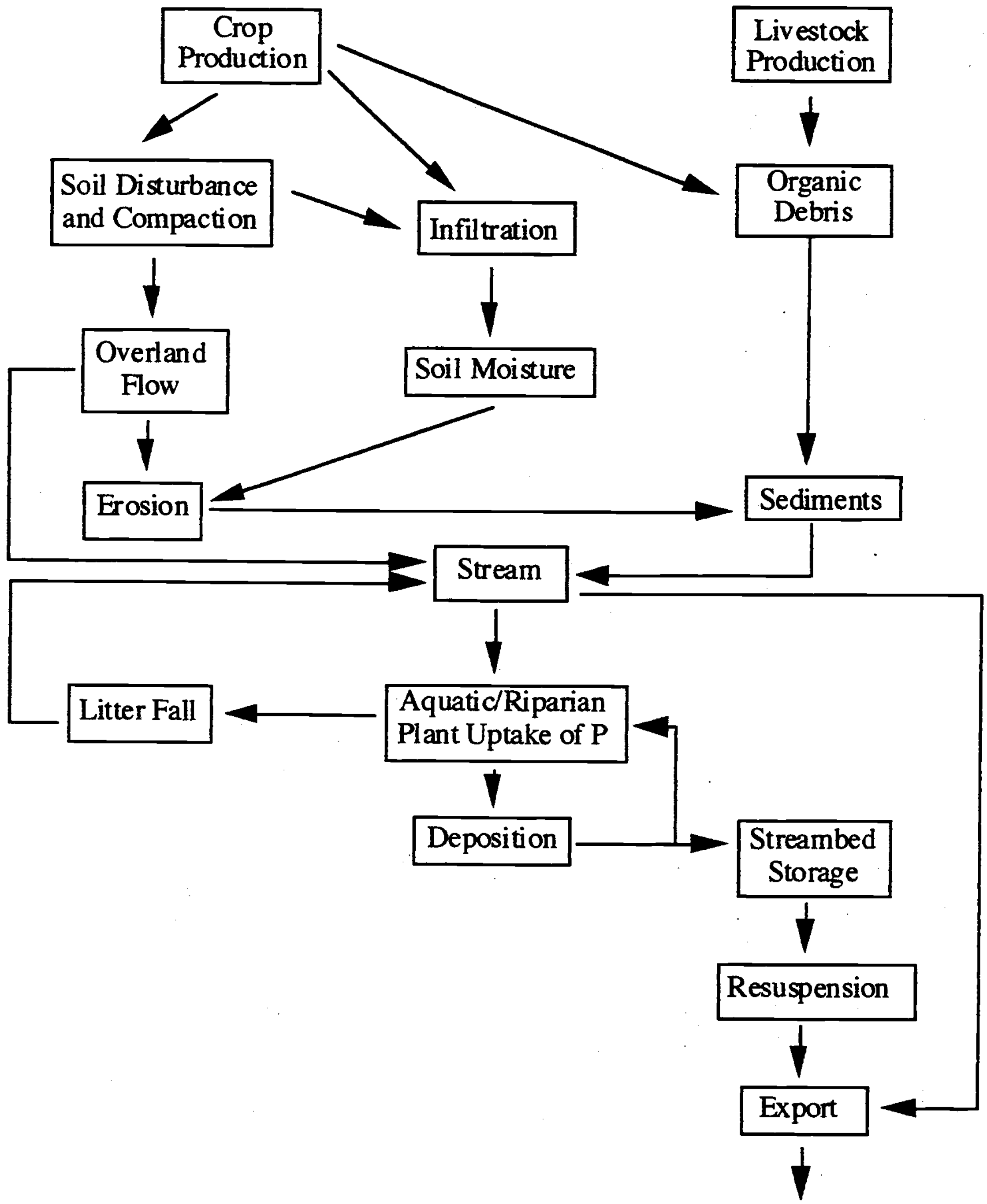


Figure 6. Influences of Agriculture on the Transport of Particulate P

(Brady, 1974; Brooks et al., 1991; Schlosser and Karr, 1981). The amount of sediment delivered to a stream depends on the factors listed above and the distance to the watercourse (Maas et al., 1987; Schlosser and Karr, 1981). Of the factors that affect both the amount of sediment lost from a site and the amount of sediment delivered to a watercourse, the one most readily managed by human activity is vegetation.

Without vegetative cover, exposed soils are likely to have surface particles loosened by rainfall impact (Brady, 1974; Brooks et al., 1991). Loosened particles may be carried into the surface pores and reduce the infiltration rate, which in turn increases the volume of runoff (Brady, 1974; Brooks et al., 1991; Mueller et al., 1981). As volume of flow increases so does the capacity of the runoff to loosen and transport sediments (Brady, 1974; Brooks et al., 1991). Vegetative cover can decrease sediment delivery rates and volume of overland flow by reducing the impact of raindrops and providing stems and organic material to reduce runoff velocity, increase surface storage sites, and retain sediments (Brady, 1974; Brooks et al., 1991; Cooper et al., 1987; Lowrance, 1990; Lowrance et al., 1984; Lowrance et al., 1985; Mueller et al., 1981; Omernik et al., 1981; Schlosser and Karr, 1981).

Management Implications: Controlling NPS Phosphorus from Agricultural Lands

The method for controlling NPS phosphorus pollution from agricultural land is a prescription that applies to nearly all NPS pollutants. Simply stated: Keep soil and water on the site. If all water infiltrates through soils and all soils stay on site, losses of P will be very low, similar to the background level of undisturbed sites. While the solution may be simply stated, it is not a simply applied solution.

The variability of climate and conditions on a site make total elimination of runoff and erosion unlikely. Even undisturbed natural systems at steady state have slight erosion (Jenny, 1984). Currently the U.S. Department of Agriculture considers, on average, five tons per acre to be an acceptable rate of erosion (Jenny, 1984; Worster, 1984). In watersheds with extensive cultivation and P-enriched topsoils, five tons per acre, while not having a negative effect on crop production, could have great detrimental effects on the receiving waters.

Agriculture has identified best management practices (BMPs) that describe practices effective for retaining soil and water on site under different conditions. The adoption of appropriate BMPs would be a great step toward reducing overland flow and the sediments it carries (Agricultural Research Service, 1975). Although studies on Vermont watersheds summarized by Clausen and Meals (1989) indicate that although effective at reducing pollutant loads, BMPs were often unable to provide the level of control needed to meet water quality goals. Others have shown that the effectiveness of BMPs are greatly enhanced when they are used in combination rather than singly (Maas et al., 1987). Effective control of NPS phosphorus in the Tualatin Basin will not come from a single strategy, but from a variety of strategies applied in combinations that fit individual site conditions. The following is a summary of some BMPs and other management techniques that may be applicable to the Tualatin Basin.

Conservation Tillage. A variety of methods use little or no tillage to retain crop residues on the soil surface and increase the organic content of the surface layer (Agricultural Research Service, 1975; Baker, 1985; Chesters and Schierow, 1985; Crosson and Ostov, 1990; Mueller et al., 1981). The tillage systems most effective in reducing sediment production are those with minimum soil disturbance and maximum organic material left on site (Razavian, 1990).

While valuable for reducing sediment loss and the particulate P associated with it, this practice may increase the loss of dissolved P through the leaching of the organic material remaining on the site (Alberts and Spomer, 1985; Forster et al., 1985; Langdale et al., 1975; Maas et al., 1987; Mueller et al., 1981; Razavian, 1990). Effectiveness at reducing total P loads would probably be site specific, depending on the relative P concentrations carried in sediments and leachate.

Winter Cover Crops. Much soil is lost during the portion of the year when soils are saturated, infiltration is slow, and water flowing over unprotected soils easily moves sediment. Vegetation aids in binding the soil and slowing overland flow (Agricultural Research Service, 1975). The effectiveness of this practice depends on the cover crop planted and the growth stage the crop achieves before the nongrowing season (Maas et al., 1987). A detriment of this system is that the cover crop delays the spring warming and drying of soil, potentially delaying plowing and planting (Maas et al., 1987).

Contour Farming. Contour plowing and the alternating of row crops with grass or hay strips can reduce soil loss by up to 50 percent on moderate slopes (Agricultural Research Service, 1975; Chesters and Schierow, 1985; Maas et al., 1987). This method rapidly decreases in effectiveness on steep slopes and is always proportionally more effective at reducing sediments than nutrients (Maas et al., 1987).

Terracing. This method alters the shape of the land surface to reduce the effective slope length. Reducing slope length decreases runoff velocity and the capacity of runoff to carry sediments (Agricultural Research Service, 1975; Chesters and Schierow, 1985). Terracing may reduce soil loss by 50 percent to 98 percent, although nutrient loss reductions are not as high (Maas et al., 1987).

Grassed Waterways and Diversions. Vegetated waterways reduce instream erosion, reduce the velocity of flows, and allow deposition of sediments on site (Agricultural Research Service, 1975). High runoff volumes or sediment loads greatly reduce the effectiveness of this practice (Maas et al., 1987). Its effectiveness can be enhanced by using it in conjunction with other methods, such as conservation tillage, strip farming, or terracing (Maas, et al., 1987).

Riparian Filter Strips. Strips of riparian forest or forest and grass along streams provide many water quality benefits, including shading and maintaining instream temperatures, providing habitat and food for aquatic organisms, and acting as sediment deposition sites and nutrient sinks (Brooks et al., 1991; Brown, 1980; Cooper et al., 1987; Cooper and Gilliam, 1987; Gregory et al., 1991; Karr and Dudley, 1981; Karr and Schlosser, 1978; Li and Shen, 1973; Lowrance et al., 1984; Lowrance et al., 1985; Lynch and Corbett, 1990; Maas et al., 1987; Meyer and Likens, 1979; Nikolayenko, 1974; Omernik et al., 1981; Schlosser and Karr, 1981). Riparian vegetation may reduce sediment delivery to a stream by more than 90 percent, although the sediment that reaches the stream will be the portion most highly P-enriched (Cooper et al., 1987; Karr and Schlosser, 1978; Nikolayenko, 1974; Omernik et al., 1981). Used as a nutrient management tool with dairy wastes, Dickey and Vanderholm (1981) found nutrients reduced 80 percent by concentration and 90 percent by weight. Although it is likely that dissolved P in water that infiltrates the soil will be adsorbed and stay on site, research has been inconclusive as to the effectiveness for reducing soluble P loads to streams (Cooper and Gilliam, 1987; Green and Kauffman, 1989; Lowrance et al., 1984; Lowrance et al., 1985; Meyer and Likens, 1979; Omernik et al., 1981; Sharpley and Menzel, 1987). The instream alteration of light and temperature conditions associated with these areas may also change the rate of nutrient processing in the stream (Cummins, 1974).

Uptake by plants will also help detain P before it reaches the stream (Karr and Dudley, 1981; Lowrance et al., 1984; Lowrance et al., 1985; Omernik et al., 1981; Schlosser and Karr, 1981). The effectiveness of these riparian nutrient sinks can be improved by crop removal or selective forest harvest and minimal soil disturbance to transport assimilated P offsite rather than into streams as organic material or leachate (Iskandar and Syers, 1980; Lowrance et al., 1984; Lowrance et al., 1985; Lowrance, 1990).

More research is needed to identify the parameters required for effective control in different areas. Effectiveness is controlled by the width of the filter strip, type of vegetation, slope, rate at which runoff is applied, uniformity of runoff application along the length of the filter, concentration and load of pollutant, and management of the filter strip (Maas et al., 1987). Opinions on the width necessary for effective sediment control vary, but are generally wider than those only concerned with shading to regulate stream temperatures (Brown, 1980; Lynch and Corbett, 1990; Lowrance, 1990). The costs of this practice are primarily those of removing land from production (Karr and Dudley, 1981).

Nursery Management. Rainfall runoff and irrigation return flows from containerized nurseries can contain not only nutrients, but other pollutants that may affect water quality (Wayland, 1992). Effective control involves both practices and structures, but specific management techniques suggested for new nurseries vary somewhat from those recommended for established operations (Wayland, 1992).

Proper planning is one of the most effective management tools for a new nursery. It is recommended that where economical water pollution prevention is desired, nurseries should not be located within one-quarter mile of surface waters (Wayland, 1992). In addition, all structures in new operations should be designed with drainage systems that will allow testing of drainage water before it leaves the site (Wayland, 1992).

Redesigning or retrofitting established nurseries with drainage systems for pollution control can cost thousands of dollars (Wayland, 1992). To avoid these costs, other methods, both structural and managerial, that reduce runoff and nutrient export can be used.

Structural methods include not only drainage systems, but also vegetation management and altering the physiognomy of the land surface. Locating varieties that need the most irrigation and fertilization as far away from surface waters as possible is one useful method. Runoff from sloped sites can be reduced with vegetated soil berms on the uphill side of the operation to redirect overland flow around the nursery (Wayland, 1992). This effectively makes management and control of runoff from the nursery more possible by reducing the quantity of water from the nursery. On the downhill side of the operation, nutrient control can also be aided by planting vegetative filter strips with permanent grass cover and rapidly growing trees to take up nutrients and slow the velocity of flow, making infiltration more likely (Wayland, 1992). Poplars work well for this application, having the highest nutrient uptake rates (Wayland, 1992).

Fertilizer management is an important way established nurseries can reduce the loads of nutrients that can be transported to streams. This includes using the least environmentally mobile forms of nutrients, such as slow-release formulas; precise application methods, such as hand application; and tissue testing as a component of setting fertilization schedules to obtain optimum but not excessive application (Wayland, 1992).

Low-Input Sustainable Agriculture (LISA) Systems. Traditional agriculture systems relied on the recycling of nutrients present onsite and the maintenance of soil health, while modern agricultural methods have shifted the emphasis from fertility to production (Sawyer, 1973). LISA is based on the idea that agriculture has the ability to renew its own resources and develop economically, culturally, and environmentally sustainable systems with a reduced reliance on purchased inputs (Ikerd, 1990; Rodale, 1990; Schaller, 1990). By emphasizing soil health, erosion reduction, active management of nutrients, and the reduction of synthetic additions such as fertilizers and pesticides, low-input systems have the potential for improving water quality (Crosson and Ostrov, 1990; Flach, 1990; Weinberg, 1990).

Nutrient Management. Fertilizers should be applied at rates consistent with plant needs. This principle applies to both chemical fertilizers and animal wastes used as fertilizers (Agricultural Research Service, 1975; Armstrong and Rohlich, 1973; Brady, 1974; Collin, 1975; Hall, 1986; Hergert et al., 1981a; Kilmer and Taylor, 1980; Maas et al., 1987; Nielsen, 1987; OECD, 1986; Phillips, 1986; Phillips, 1987; Reddy et al., 1980; Sharpley and Menzel, 1987; Sommers and Sutton, 1980; Thornley and Bos, 1985; Unwin, 1987; Verduin, 1970; Young et al., 1985). For animal wastes this may require the testing of the nutrient content of manures to ensure application at the proper rate. Excessive loading can overload the P adsorption capacities of the soil, increasing the amounts of soluble P available to move offsite (Iskandar and Syers, 1980; Reddy et al., 1980).

Nutrient applications must be at the proper times. Applying any nutrients (chemical or animal waste) when soils are saturated increases the probability that nutrients will be lost to overland flows or drainage (Agricultural Research Service, 1975; Clausen and Meals, 1989; Hergert et al., 1981b; Iskandar and Syers, 1980; Kilmer and Taylor, 1980; Maas et al., 1987; OECD, 1986). For manures, adequate storage allows greater flexibility in timing of applications (Maas et al., 1987; OECD, 1986; Phillips, 1986).

Surface applications should be incorporated into the soil surface. Distributing fertilizers—chemical, animal waste, or plant residues (cover crop or crop residue)—widely and mixing them into soils helps reduce nutrient leaching and aids in water infiltration (Agricultural Research Service, 1975; Clausen and Meals, 1989; Hall, 1986; Maas et al., 1987; OECD, 1986; Phillips, 1986; Phillips, 1987; Reddy et al., 1980; Verduin, 1970).

Management of Grazing Livestock. For livestock management on grazed pastures, controlling where, when, and for how long animals graze is an important factor in controlling particulate P. An illustration of this principle is shown in a study of nutrient movement on hill pastures by McColl and Gibson (1979). In this study, P loss from two pastures, one grazed recently with relatively little vegetation remaining and one with long grass, were compared. In the first two rain events following fertilization with superphosphate, the recently grazed pasture lost 170 times as much P and eight times as much water as the pasture with long grass. This difference was attributed to the longer grass increasing opportunities for infiltration and reducing the amount of water and sediment transported off of the site.

The amounts of P lost from areas of concentrated animal use such as barnyards and feedlots can be reduced by diverting runoff to flow around these sites (Maas et al., 1987). For pastures, especially those with high intensity grazing, it is possible for fecal pats to be carried by overland flow (Ryden et al., 1973). Methods for controlling this form of particulate P are limited to reducing runoff by improving infiltration and restricting how close to streams livestock are allowed to graze or congregate (Ryden et al., 1973). Restricting animal access to streams can also reduce direct contributions of feces and urine to streams (Maas et al., 1987).

The locations of water, minerals, shade, fences, and other physical factors that affect animal distribution can also affect the distribution of excrement. Patterns that effectively encourage distribution serve several valuable functions. Even distribution decreases the likelihood of surface water contamination and encourages plant growth by increasing the evenness of nutrient availability for plants and the evenness of forage use (Wilkinson and Lowery, 1973).

Grazing management practices such as high-intensity, short-duration grazing designed to promote rapid and even forage use also promote rapid turnover and even distribution of nutrients (Wilkinson and Lowery, 1973). In contrast, season-long grazing generally results in uneven distribution of use and excrement (Wilkinson and Lowery, 1973).

Animal Waste Management. To control the quality of water flowing through an area with livestock, restricting animal access to streams and diverting runoff to flow around barnyard or feedlot sites with concentrated wastes are effective practices (Maas et al., 1987).

Animal wastes may also be treated by aerobic or anaerobic digestion to concentrate the slurries and reduce the total volume of effluent to be spread on the land (Brady, 1974; OECD, 1986; Phillips, 1986). Vegetative filter strips have also been used to effectively treat nutrient-enriched runoff from feedlots (Dickey and Vanderholm, 1981). One innovative recycling proposal suggests growing duckweed, to be used as feed for dairy cattle, in lagoons containing wastes from dairy cattle (Hillman and Culley, 1978).

Urban/Residential

Urban areas contribute a great diversity of NPS pollutants from the many different activities that take place in urban environments. The runoff from urban storm drains may carry large loads of pollutants—antifreeze, oil, various particulates, pesticides, fertilizers—that were originally deposited on city streets, parking lots, lawns, golf courses, and parks (Chesters and Schierow, 1985; Myers et al., 1985).

Urban areas may also contribute significant amounts of P (Figure 7 and Figure 8). Contributions per unit area can approach one-third of a dairy or be nearly equal to intensively farmed agricultural areas (Kilmer and Taylor, 1980; Sawyer, 1973). Weibel and others (1964), using data from Seattle, report stormwater runoff concentrations of P 200 times the accepted background level for streams. Phosphorus carried in runoff from urban areas primarily travels over impervious surfaces and has little opportunity to infiltrate and be adsorbed by soils. Often this runoff is carried directly into watercourses.

Atmospheric sources, lawn and garden fertilizers, animal wastes, and P carried with sediments all contribute to the total P load from urban and residential areas, but the single largest source is P from the leaching of organic trash and debris (Waller and Hart,

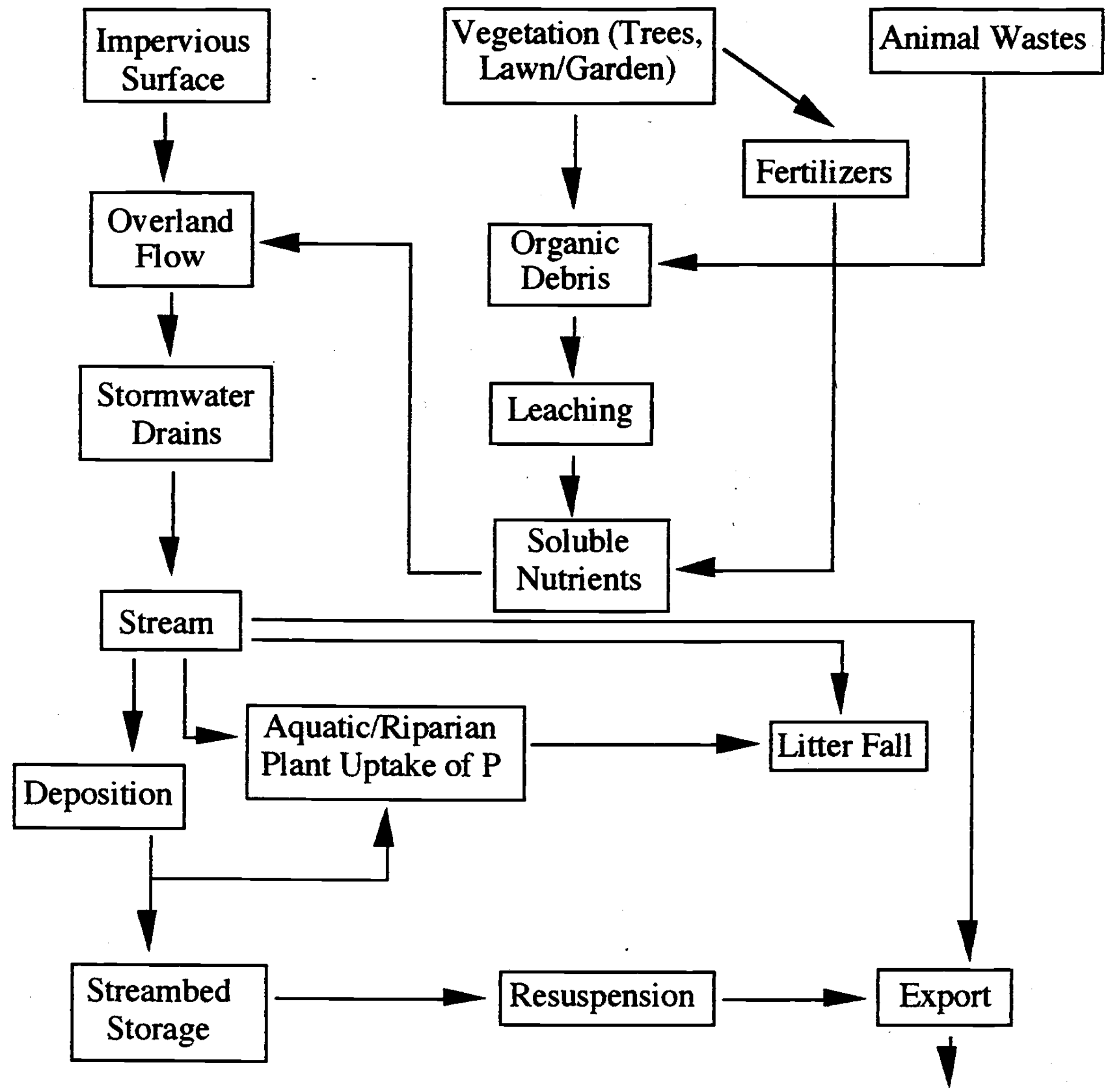


Figure 7. Influences of Urban/Residential Areas on the Transport of Dissolved P

1986). For example, leaf litter may lose as much as 30 percent of its dry weight through leaching within 24 hours of wetting (Cummins et al., 1972; Petersen and Cummins, 1974).

Construction sediments may also be a significant source of P. Disturbed soils on construction sites are not shielded by vegetation from the impact of raindrops, increasing the likelihood of the detachment and transport of soil particles as sediments. Sediments from construction are not retained by vegetation and their sediment delivery ratios may be very high. Depending on the characteristics of rainfall, soils, and topography in a basin the increase in sediment loads with development will vary. Increases associated with development have been reported from Japan by Kinosita and Yamazaki (1974) as 148 percent of predevelopment levels, from Quebec by Warnock and Lagoke (1974) as 300 percent to 500 percent, from Britain by Walling (1974) as 500 percent to 1,000

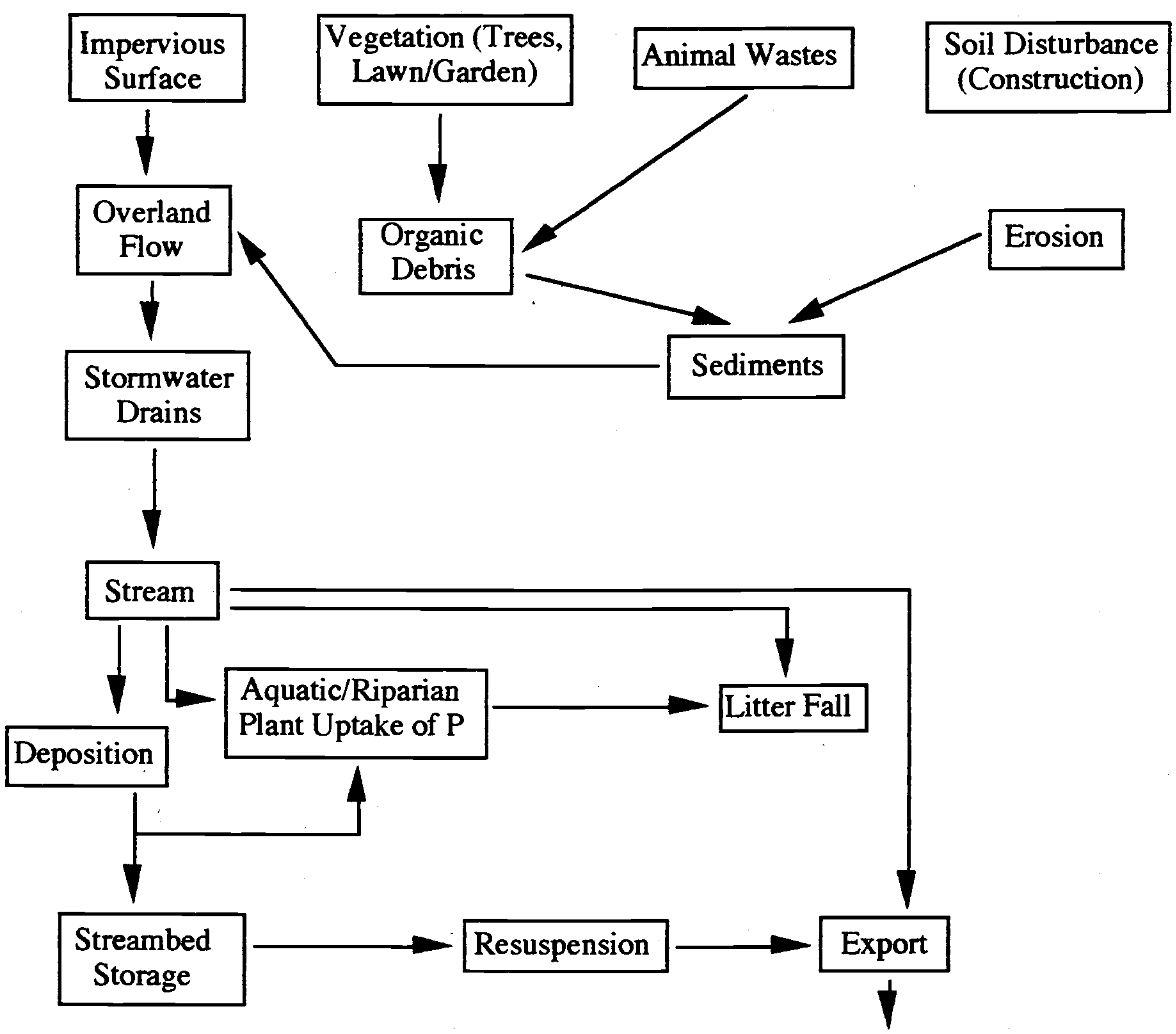


Figure 8. Influences of Urban/Residential Areas on the Transport of Particulate P

percent, and from the Baltimore and Washington D.C. area of the United States by Chen (1974) as averaging 6,000 percent for sites without erosion control. An estimated 600 million tons of sediment are lost annually from development sites in the United States (Lake, 1991).

Management Implications: Controlling NPS Phosphorus From Urban/Residential Areas

The wide variety of NPS pollutants from urban areas makes simple, effective prescriptions for nonpoint source control impossible. Control of nonpoint source P depends on combinations of methods that limit sources and retain runoff water through a variety of means.

Leaf Collection. Collection of leaves and organic material greatly reduce the amount of leached soluble P and organic particulate P delivered to receiving waters (Waller and Hart, 1986).

Sediment Control Measures. Sediment fences and traps used on construction sites will partially control sediment-bound P. Because smaller particles—those most P-enriched will be more likely to escape—this control measure is a first step, not a method for complete control (Maas et al., 1987).

The construction of sediment retention basins that allow the settling of sediments and P-enriched materials is a second step in the treatment of P-laden runoff (Ellis, 1985; Field, 1985; Lake, 1991; Maas et al., 1987; Waller and Hart, 1986). Because most P-bearing materials in urban areas are light and easily moved, retaining the first half-inch of runoff has been shown to be effective for P control (Maas et al., 1987).

Runoff Reduction. Impervious surfaces in urban environments prevent water from infiltrating through the soil and being adsorbed to soil particles. One opportunity for increasing infiltration is altering the physiognomy of grassed areas, providing swales for the collection of runoff (Maas et al., 1987). Another opportunity developed within the last decade is a system of porous asphalt-concrete pavement underlain by a gravel base, which has been shown to be effective in increasing infiltration and reducing stormflow volume (Ellis, 1985; Field, 1985).

Summary and Conclusions

Phosphorus is an element that is not toxic but which, when present in amounts greater than historic levels, may cause aquatic plants to grow at increased levels. Under these conditions the water quality for many uses declines.

Although the sources of P are diverse, amounts present in most systems have been relatively constant and most aquatic systems have developed in concert with these natural levels. Of concern are elevated levels caused by human activities. On a basin scale these include any land or water use that may introduce additional amounts of P or disturb the land surface allowing increased amounts to be transported to streams.

Control of eutrophication in systems where P is a limiting factor requires the control of P entering streams. Point source control is relatively simple, but may be insufficient to reduce P to desired levels. In this case the control of nonpoint sources also becomes necessary. For all land—agricultural, forested and urban—this requires controlling runoff and the materials it carries.

The dynamics of P are complex and it is an element that easily crosses boundaries, between both land uses and traditional disciplines. To come to a workable understanding of its interactions, investigations will also need to cross those boundaries. Phosphorus management requires a more integrated view, not only of its interactions in soil, or water, or plants, or stream biota, but of its interactions between these elements and across the landscape.

NONPOINT SOURCE PHOSPHORUS POLLUTION: THE TECHNICAL CONTEXT

INTRODUCTION

Many of the current problems related to natural resources that face society are not simple, but an amalgam of complex interrelationships that must be considered when searching for solutions. Not only do we need to discover adequate scientific information to make an informed and reasonable choice based on solutions that are technically achievable, but also decisions that are socially, economically, and politically feasible. In many cases we may have enough scientific information to design reasoned plans that will mitigate the immediate problem, but the social and economic costs for some of these solutions may be higher than society is willing to accept. The first step in finding an acceptable solution is to accumulate the scientific understanding to allow us to generate possible solutions. These may then be judged for their social, economic and political acceptability. Some of the issues that bear on the scientific aspects of nonpoint source P pollution are discussed in this section.

When waterborne nutrients, such as P, cause eutrophication the sources and loads of the nutrients must be identified before control measures can be taken. Identifying sources that make the greatest contributions helps focus efforts to achieve effective and efficient control.

For the Tualatin Basin large point sources, such as sewage treatment facilities, have been identified and control is under way, but the work of identifying nonpoint sources and their relative contributions is still in progress. As of yet, research has not offered any certainties, but a number of different sources have been suggested as the most influential, including livestock waste and human septic tank effluent, dissolved P in runoff from soils naturally high in phosphorus, P from fertilization that provides more P than soils can adsorb or crops can use, groundwater with high P concentrations, the release of P from deposited river sediments, sediments from streambank erosion, and sediments from upland erosion. With the exception of groundwater concentrations, all are related at some point in their interactions to particulate P and to the movement of water and sediments in overland flow. Because land use affects infiltration and erosion, it may be expected that various land uses will affect downstream P concentrations differently.

Current river characteristics can be seen as not only affected by current land use practices, but as the cumulative effects of changes in the land that have occcured since EuroAmerican settlement. Today, most agricultural crops provide an incomplete soil cover, and urban and residential uses provide areas where rain falls on rooftops and streets rather than on layers of leaves. While the total volume of water which falls on the basin during a year may be similar, the timing of flows in the streams may be greatly altered.

In the past, when a greater proportion of the land surface was covered with vegetation throughout the year, it is likely that precipitation which infiltrated the soil surface was held for longer periods before being released to stream channels. With less infiltration, streamflow may take on a somewhat "flashy" regime, with winter precipitation draining from the basin in a shorter period and summer flows being reduced through less groundwater recharge.

METHODS

For this study water quality data was analyzed from several sites in the Dairy-McKay HUA. Analyses examined various water quality parameters, including P concentrations, at a site over time for patterns related to temporal changes and between sites for patterns related to land uses. Some sites have only been sampled for a single summer season, others for several seasons.

The methods used reflect a scientific step-wise search for pieces in a water-quality puzzle. Currently the dynamics of NPS phosphorus in the Dairy-McKay subbasin and the Tualatin River Basin are not understood well enough to guarantee immediate and effective control, but as more pieces are added to the puzzle the total picture should become clear. The purpose of this study is to turn over a few pieces, and point to others that may help view of the total picture.

Data

Data used in the following analyses are from two sources, the Unified Sewerage Agency (USA) and the Oregon Department of Forestry (ODF). Samples gathered by USA were processed in their own water quality laboratory using standard water quality laboratory techniques. Samples gathered by ODF were analyzed at Oregon State University using standard methods.

Statistical Analysis

Statistical analysis of water quality data can be problematic because basic assumptions required for statistical validity are often violated. Statistics, both parametric and nonparametric, require that observations are independent and random. Unfortunately, the nature of watercourses can cause violations of independence since an upstream and downstream sample are not independent of each other. If samples are repeatedly collected at the same site and on a regular schedule, as is common with grab samples, then randomness may also be violated (Brooks et al., 1991). Fortunately, violations do not necessarily invalidate statistics based on the data, but require consideration of whether or not these violations affect the validity of the results (Ponce, 1980; Brooks et al., 1991). Most water quality data analysis uses parametric statistical methods (Ponce, 1980).

Comparisons between watersheds must also be made cautiously. For comparisons to be useful, basins should be similar in size, geology, shape, past and current land use, climate, and location (Brooks et al., 1991). If comparisons between watersheds are planned to evaluate the effectiveness of management changes, adequate baseline data to predict the hydrologic behavior of the treated watershed from the behavior of the untreated watershed is required (Brooks et al., 1991).

Unfortunately, for those of us interested in nonpoint source P, the sampling design used by the agencies involved to date was not intended to provide definitive information on P. The data available will not support extensive or intensive analysis with great reliability. For this analysis I have depended primarily on simple descriptive statistics, although some other techniques, such as multiple regression, are used as potential indicators of trends.

Site Descriptions

The Dairy-McKay HUA is a subbasin of the Tualatin River. The Dairy-McKay HUA is approximately one-third forested, one-third agricultural, and one-third urban/residential. Although land use patterns are mixed, generally the highest elevation lands are forested, the middle elevation lands farmed, and the lowest elevation lands nearest the river relegated to residential and urban use.

The HUA contains three major streams of notable size, West Fork of Dairy Creek, East Fork of Dairy Creek and McKay Creek. All arise in the forested lands in the northern part of Washington County, although small portions of the watersheds they drain are included in the boundaries of Columbia and Multnomah counties. The two forks of Dairy Creek flow into the relatively level bottomlands before joining between the hamlets of Roy and Verboort. Downstream Dairy Creek is first joined by a smaller tributary, Council Creek, and then McKay Creek, after it is joined by Waible Creek a short distance upstream. As a single stream Dairy Creek flows on to join the Tualatin River within a short distance.

These three streams, draining relatively large areas of land, include a variety of soil types. The relatively level flood plains and bottom lands of all, especially in the corridor near the Tualatin River, have a concentration of residential and urban uses with agriculture mixed in and becoming more common away from the river. The soil common to this area is the Wapato-Verboort-Cove association, composed of very deep but poorly drained silty clays and loams. Being poorly drained, which increases the potential for overland flow, and a clay, which provides particles that easily adsorb P, makes this soil association one that is likely to yield sediments with a high P content.

Moving from the bottomlands toward the headwaters of McKay Creek, the soils change on the mainly agricultural midslopes to Woodburn-Quatama-Willamette associations, which are very deep and moderately well-drained to well-drained silt loams and loams. The forested uplands generally west of the headwaters are primarily in the Cascade-Cornelius association, which is very deep and poorly drained to moderately well drained silt loams. The forested uplands generally east of the headwaters are primarily Cascade soils, moderately deep, somewhat poorly drained, silt loams (Soil Conservation Service, 1982).

Following Dairy Creek upstream from the bottomlands to the agricultural midslopes, both forks pass through Woodburn-Quatama-Willamette associations, which are very deep and moderately well-drained to well-drained silt loams and loams; and Aloha-Amity-Dayton associations, which are very deep, generally poorly drained silt loams. Rising higher into the hills, the East Fork first enters the Cascade-Cornelius association, which is composed of very deep and poorly drained to moderately well drained silt loams, and then in the steeper forested hills, the Olyic-Melby association, composed of deep, well-drained, silt loams. By contrast, the West Fork passes through an area of Laurelwood association, very deep well-drained silt loams before entering the Olyic-Melby association in the steeper uplands surrounding the headwaters (Soil Conservation Service, 1982).

The locations of the various sampling sites are shown on the map of the Dairy-McKay HUA in Figure 9. Summary statistics and profiles showing the total P concentration—split into soluble and particulate portions—for each sample site are shown in Appendix A.

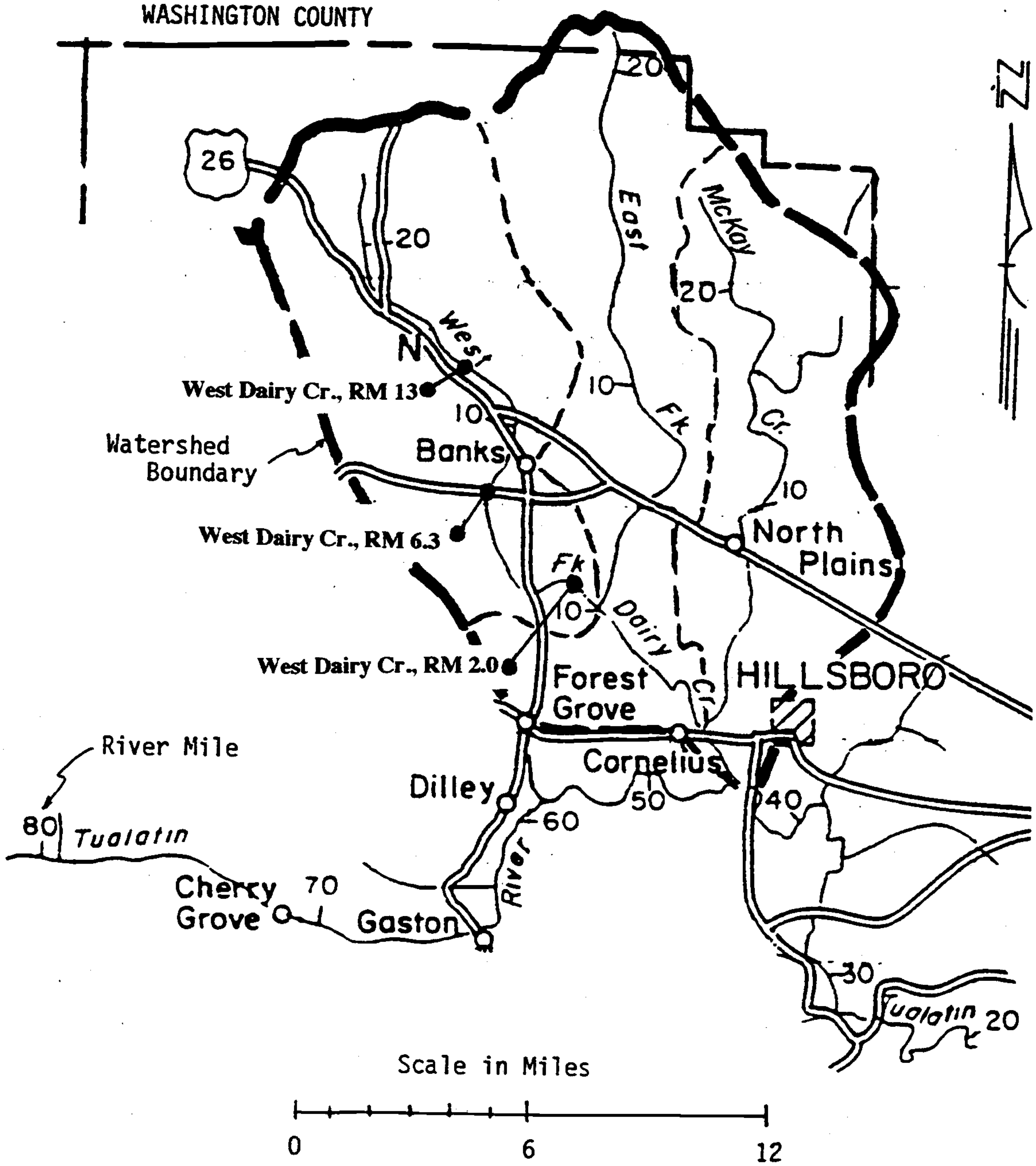


Figure 9a. Sample Site Locations: West Fork of Dairy Creek
(from Soil Conservation Service, 1990)

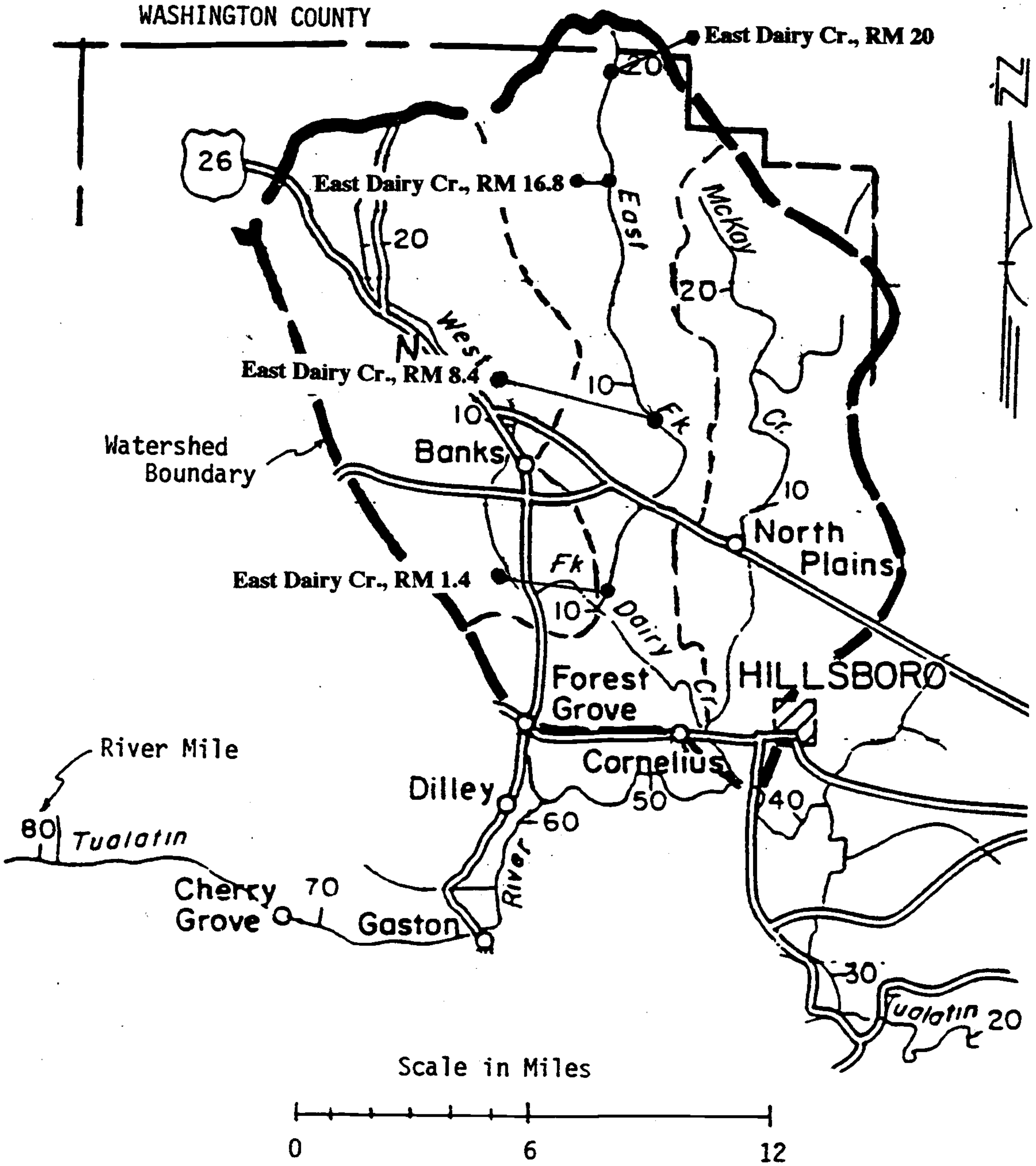


Figure 9b. Sample Site Locations: East Fork of Dairy Creek
(from Soil Conservation Service, 1990)

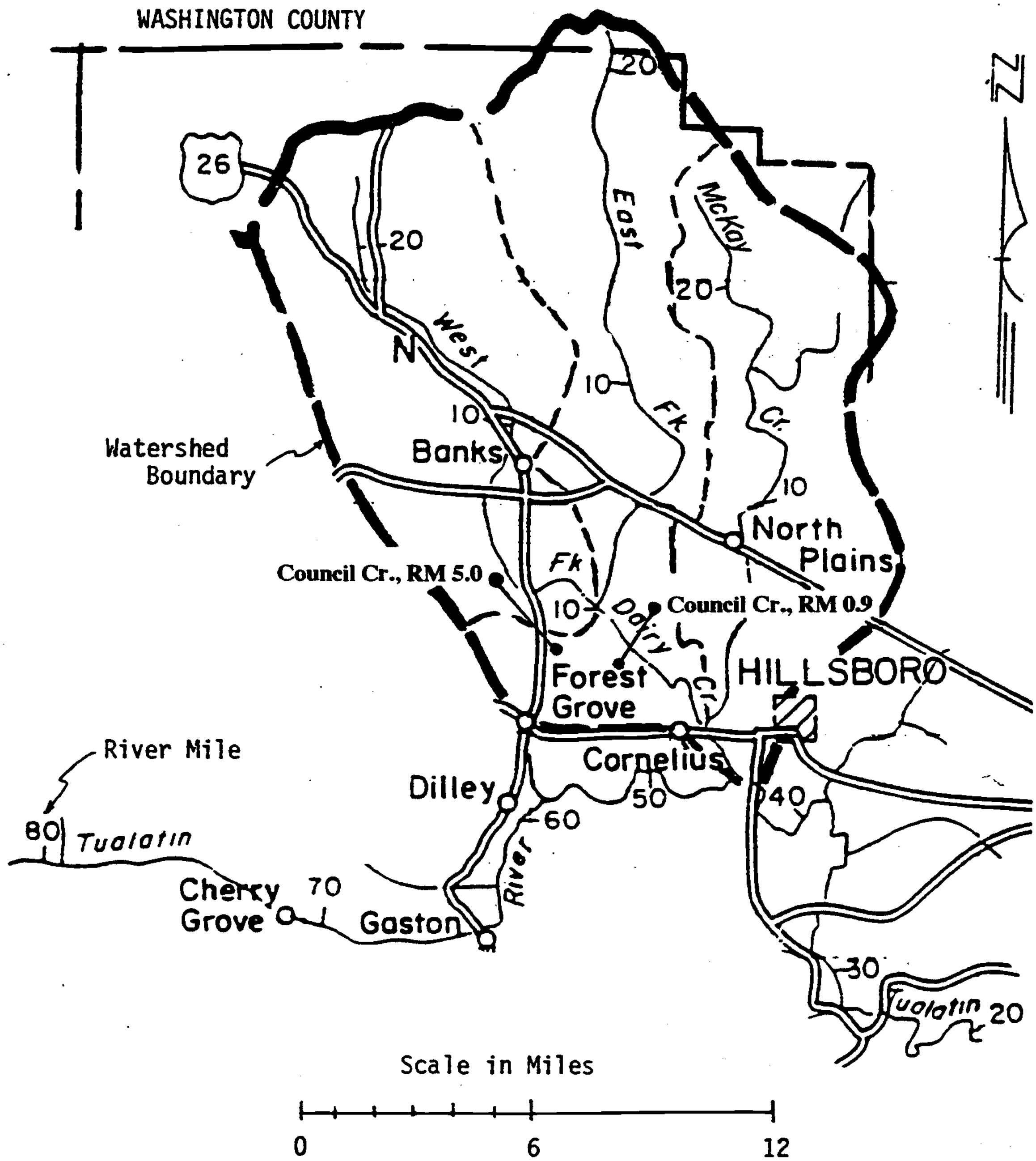


Figure 9c. Sample Site Locations: Council Creek
(from Soil Conservation Service, 1990)

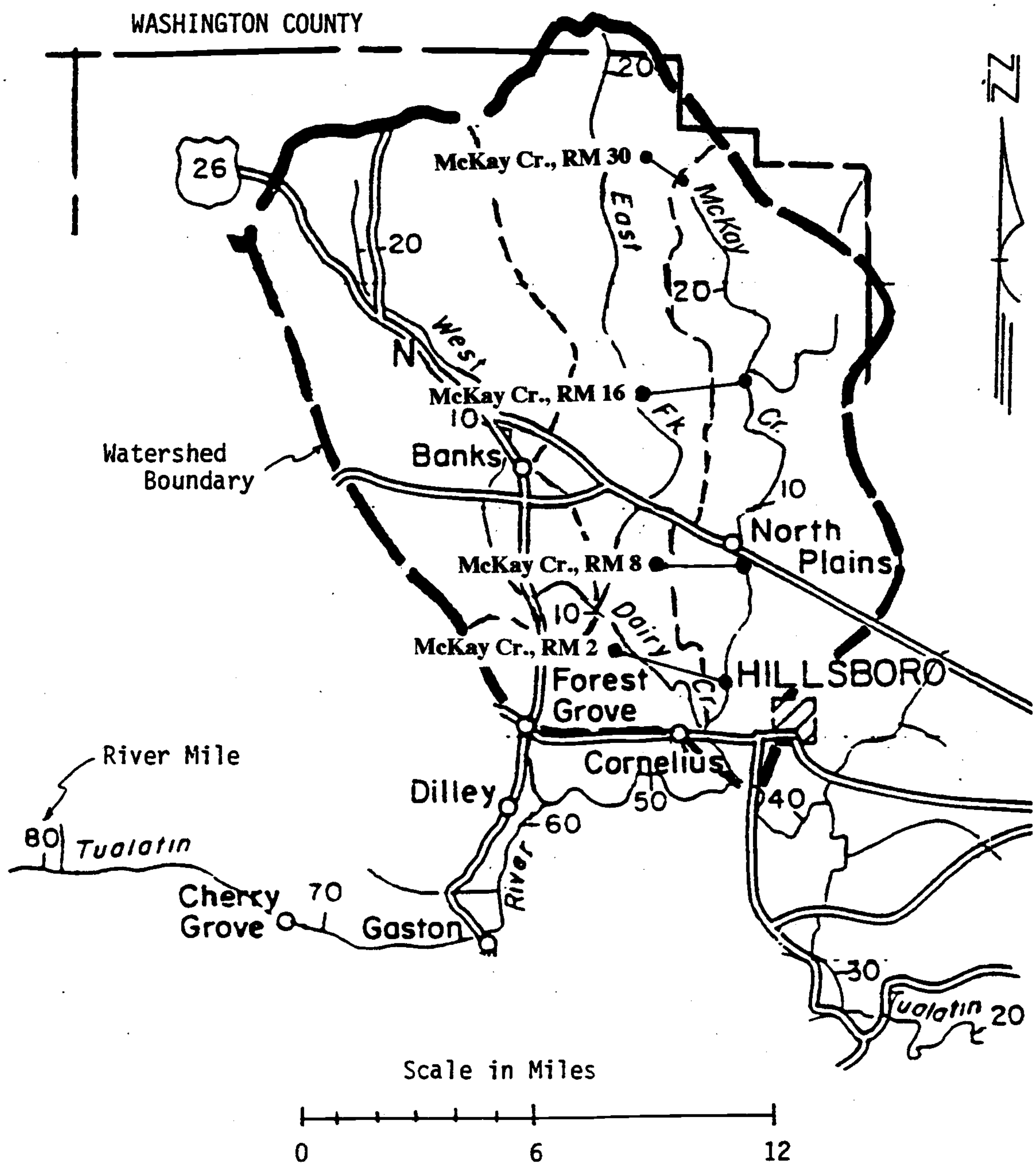


Figure 9d. Sample Site Locations: McKay Creek
(from Soil Conservation Service, 1990)

RESULTS AND DISCUSSION

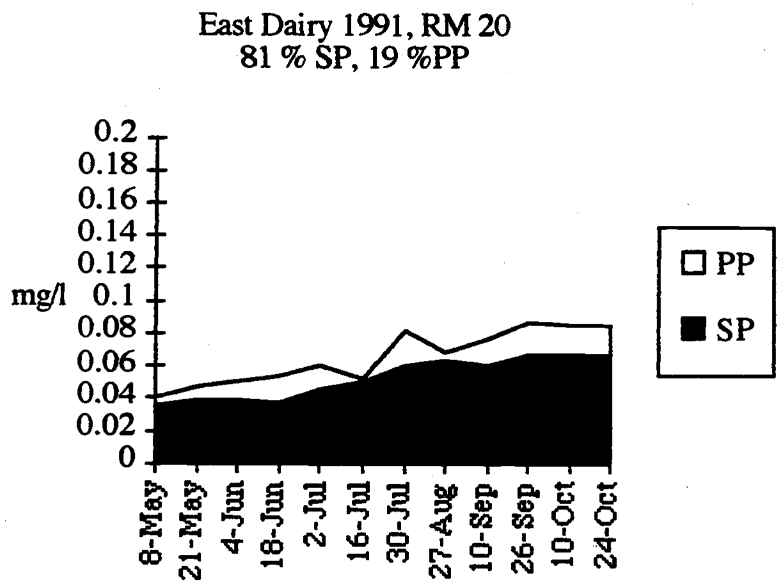
Particulate Phosphorus

Suspended Sediments

Research in a number of basins has shown a relationship between concentrations of suspended sediment and the total P concentration and, even more closely, between suspended sediments and the particulate P concentrations (Cahill, 1977; Golterman, 1983). Particulate P is defined as total P minus the soluble P fraction (Golterman, 1973).

As a stream flows from headwaters to mouth the amount and type of sediments it carries changes. Near the headwaters, where gradients are relatively steep and velocities faster, it may carry large particles that have a relatively low P content. Approaching the mouth, where gradients are lower and velocities slower, the stream may carry less of a total load of sediments, but those sediments are those most likely to have adsorbed P attached to them. Not only does the stream at this point carry sediments from its headwaters, but also sediments from other tributaries that have joined it along the way. In this way, particulate P increases as a proportion to the total P content as the stream nears the mouth. If this were the only factor influencing the P characteristics of sediments, then an examination of the proportions of P carried should show this effect. The East Fork of Dairy Creek during the 1991 sample season (Figure 10) shows how this influence might appear.

In reality, few streams are this simple. Stream reaches of slow-moving water may allow fine sediments to settle out, temporarily storing them until later high flow events resuspend them. Streams with this pattern may show less of an influence from particulates from headwaters to mouth, or the particulate proportion of total P may rise and then fall showing changes in the proportions during downstream transport. For the sites included in this study, the proportions are shown in Table 5.



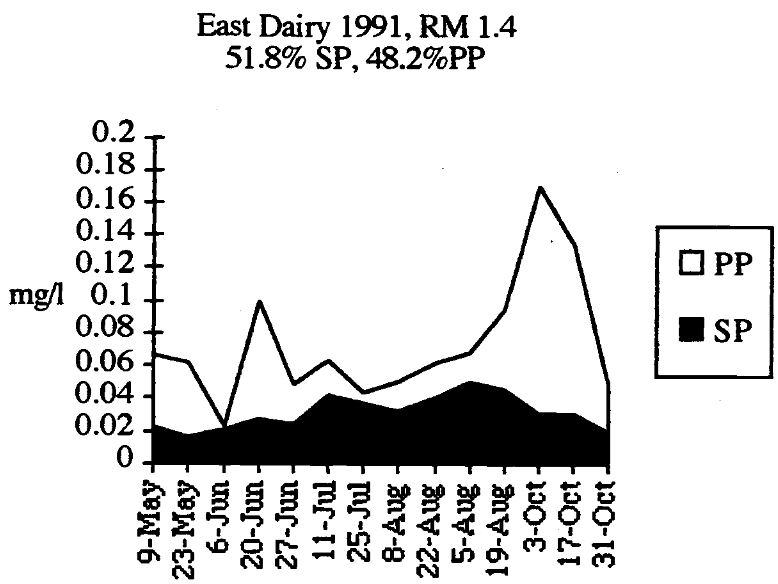


Figure 10. Relative Proportions of Phosphorus Forms in the East Fork of Dairy Creek, 1991.

Table 5. Mean Percentage Particulate P for Dairy-McKay HUA

Site	1990, %PP	1991, %PP
West Fork of Dairy Creek		
RM 13	Not sampled	24
RM 6.3	69	55
RM 2	70	62
East Fork of Dairy Creek		
RM 20	Not sampled	19
RM 16.8	54	23
RM 8.4	Not sampled	53
RM 1.4	68	48
Council Creek		
RM 5	62	Not sampled
RM 0.9	83	Not sampled
McKay Creek		
RM 30	Not sampled	44
RM 16	Not sampled	16
RM 8	76	Not sampled
RM 2	52	49

Sediment Enrichment Ratios

Generally, a greater portion of the total P load carried by a stream is in particulate form; therefore a change in suspended sediments carrying particulate P will cause a change in total P (Reddy et al., 1978). This relationship is partly determined by the enrichment ratio of the sediments (Nelson and Logan, 1983; Sharpley and Menzel, 1987). A system with rapid erosion that efficiently carries large sediments will have a smaller ratio of particulate P to suspended sediment than another system with similar physical characteristics, but with the retention of more sediments on the land. In this second system, the small particles most likely to be carried to the stream are also the particles most likely to be greatly P-enriched. Therefore, the ratio of the percentage of total P carried as particulate P to the amount of suspended sediments will be larger.

The percent particulate P to suspended sediment ratio may offer insight into relative contributions and transport. For long-term monitoring of the effectiveness of nonpoint source control, an increase in this enrichment ratio could indicate that management practices are being somewhat effective in reducing the total sediment contributed to the watercourse. The mean percent particulate P to suspended sediment ratios for sites in the Dairy-McKay HUA are shown in Table 6.

Table 6. Mean Enrichment Ratios for Dairy-McKay HUA

Site	1990	1991
West Fork of Dairy Creek		
RM 13	Not sampled	3.9
RM 6.3	8.1	14.4
RM 2	4.4	6.9
East Fork of Dairy Creek		
RM 16.8	11.3	Not sampled
RM 8.4	Not sampled	8.6
RM 1.4	12.5	217
Council Creek		
RM 5	11.4	Not sampled
RM 0.9	11.6	Not sampled
McKay Creek		
RM 30	Not sampled	12.3
RM 16	Not sampled	23.4
RM 8	15.3	Not sampled
RM 2	9.6	19.1

The streams shown in Table 6 have different loading patterns. Although most show a general increase in the enrichment ratio with downstream transport, the enrichment ratios for both the West Fork of Dairy Creek and McKay Creek increase near the midpoint and then drop to their lowest levels near the mouth. This could be from a number of causes, including enriched irrigation runoff carrying a high concentration of fine, highly enriched sediments, a change in flow increasing the suspension of fine sediments, or an increase in enriched organic matter such as diatoms or algae. Only further examination would be able to determine the cause with certainty.

Comparing enrichment ratios of upstream and downstream sites indicates that some form of enrichment, such as the settling of larger, less-enriched particles, is taking place as the streams flow from headwaters to mouth. Another factor that may affect enrichment ratios, and which could be a confounding influence, is the change in soil type from the silty loams and loams of the uplands to the silty clays and clays of the bottomlands, because sediments from soils with high clay content are more likely to be P-enriched.

Seasonal Effects

Some general patterns emerge fairly clearly. As described by other researchers, P concentrations generally rise throughout the dry months, in this case summer and early fall, receding after wet season rains, in this case late fall, begin in earnest. The description by Cahill and others (1974) in which P concentrations rise with decreasing streamflow (influenced by evaporation) is one explanation for this pattern. Under this regime P concentrations should decrease following any storm event large enough to have runoff. However, if sediments and particulates play a large part in the P dynamics of the system, the effects will be less clear, since concentrations of total P may rise as a summer's worth of airborne dust is washed from exposed surfaces and stream sediments are disturbed by rising flows.

Both Cahill and others (1974) and Prairie and Kalff (1988a) describe another possible explanation. P concentrations would rise throughout the low-flow period in a stream in which groundwater baseflow is P-enriched. A stream operating under this regime would see P concentrations in summer flows rise unless diluted by stormwater. For the Dairy-McKay HUA, definitive studies of P concentrations in groundwater have not been done, although P concentrations in headwaters, such as the West Fork of Dairy Creek at Strassel Road, indicate that, at least in the uplands, P concentrations are relatively low.

Seasonal increases in water temperature during the low flow period may also play a part in rising P concentrations, directly or indirectly. Temperatures above 15°C (60°F) will substantially increase the rate at which P is released from sediments and suspended solids (Karr and Schlosser, 1978). Warm temperatures may also increase the growth of aquatic plants, intensifying their influence in P dynamics.

For those sites with enough observations to be useful, splitting samples into two groups, one with water temperatures at or above 15°C and one with temperatures below 15°C helps illustrate the possible validity of this idea. Table 7 summarizes the differences in soluble P measured at some sites when water temperatures were equal to or greater than 15°C and when below 15°C.

Table 7. Possible Effects of Temperature on Soluble P (SP)

Site	Year	Mean SP Conc. <15°C	Mean SP Conc. ≥15°C	Percent Change	Direction of Change
West Fk. Dairy Cr. RM 6.3	1991	0.029 mg/l (n=5, s=0.011)	0.058 mg/l (n=6, s=0.0117)	100	Increase
West Fk. Dairy Cr. RM 2	1991	0.036 mg/l (n=8, s=0.012)	0.053 mg/l (n=6, s=0.011)	47	Increase
East Fk. Dairy Cr. RM 8.4	1991	0.023 mg/l (n=6, s=0.005)	0.034 mg/l (n=6, s=0.007)	48	Increase
East Fk. Dairy Cr. Rm 1.4	1991	0.026 mg/l (n=9, s=0.008)	0.042 mg/l (n=5, s=0.010)	62	Increase
East Fk. Dairy Cr. RM 1.4	1990	0.023 mg/l (n=4, s=0.008)	0.032 mg/l (n=7, s=0.10)	39	Increase
McKay Cr. RM 2	1991	0.042 mg/l (n=8, s=0.019)	0.074 mg/l (n=6, s=0.027)	76	Increase
McKay Cr. RM 2	1990	0.041 mg/l (n=11, s=0.022)	0.075 mg/l (n=14, s=0.022)	83	Increase

The assumptions for statistical validity are not met due to small sample sizes and large standard deviations, but the anecdotal picture appears strong. When temperatures are above 15°C soluble P concentrations are higher than when temperatures fall below that level. Unfortunately, the large number of other interacting factors makes the conclusion that this is a simple and direct temperature effect untenable. Temperature could directly affect the P adsorption-desorption dynamics, or indirectly this could be related to other temperature influenced processes such as dissolved oxygen or an indicator of algal activity, as an excretion from P available in excess of luxury uptake or from the decay of dead algal cells (Boberg and Persson, 1988; Hooper, 1973; O'Kelley, 1973; Sawyer, 1973).

An alternate explanation could be that P concentrations are highly flow-dependent and that temperature is an indirect indicator of flow, since the period when temperatures are the highest is also the period of lowest flows when the temperature of a water column is highly affected by its volume and exposure to surrounding air. If flow data was available for these sites it might be possible to come to some conclusions, but it is not available.

Relationships Between P Concentrations and Other Water Quality Parameters

Multiple Regression Analysis

In an attempt to illuminate some of the relationships between components, data sets from USA with relatively complete sets of parameters were analyzed more fully. For each set, multiple regression analysis (MRA) was performed using soluble phosphorus (SP) and particulate phosphorus (PP) individually as dependent variables. The assumptions required for reliable predictive statistics are not strictly met (i.e., sample size, random sample), but the results may be considered indicative of some relationships between components of the data set.

In this application, MRA constructs a model from independent variable values to predict the values of the dependent variable. The R-squared value generated indicates how well the model predicts dependent values. If an independent variable is added, and the R-squared value does not increase significantly, that variable is not important to the model's explanation of the data. Conversely, if a variable is removed, and the R-squared value decreases greatly, that variable is important to the model's explanation of the data. For each of the data sets, the independent variables listed are those that had a significant effect on the R-squared value of the solution.

Table 8. Particulate Phosphorus Multiple Regression Analysis

Sites	**SP**	**TSS**	**TDS**	**Tmp**	**pH**	**DO**	**chl-A-CR**	**chl-A-UCR**	**phpt-A**	**Q**	R^2
Tualatin 1984 (71.5)	0.02	0.00	0.11	0.21	0.22	0.26	0.02			0.01	0.85
Tualatin 1985 (71.5)	0.01	0.11	0.07	0.32	0.01	0.01	.00			.00	0.52
Gales 1990 (1.5)	0.04	0.12	0.03	0.00	0.10		0.06			0.05	0.39
Gales 1991 (1.5)	0.32	0.17	0.03	0.00	0.02	0.03	0.04	0.04	0.01	0.04	0.54
East Dairy 1990 (1.4)	0.14	0.75	0.02	0.01	0.00					0.05	0.92
East Dairy 1991 (1.4)	0.02	0.01	0.03	0.18	0.10					0.35	0.69

Values indicate the variance in the model explained by each component.
Tualatin '84 (71.5) = Tualatin River at Cherry Grove (RM 71.5), 1984, 12 samples taken monthly between Jan. 4 and Dec. 5
Tualatin '85 (71.5) = Tualatin River at Cherry Grove (RM 71.5), 1985, 12 samples taken monthly between Jan. 2 and Dec. 4
Gales '90 (1.5) = Gales Creek at New Highway 47 (RM 1.5), 1990, 24 samples taken at weekly intervals between May 7 and Oct. 29
Gales '91 (1.5) = Gales Creek at New Highway 47 (RM 1.5), 1991, 20 samples taken at weekly intervals between May 6 and Oct. 28
East Dairy '90 (1.4) = East Fork of Dairy Creek at Roy Road Bridge (RM 1.4),10 samples taken at two week intervals between June 6 and Oct. 24
East Dairy '91 (1.4) = East Fork of Dairy Creek at Roy Road Bridge (RM 1.4),13 samples taken at two week intervals between May 23 and Oct. 31
SP = soluble phosphorus; **TSS** = total suspended solids; **TDS** = total dissolved solids; **Tmp** = water temperature; **pH** = a measure of acidic or basic conditions; **DO** = dissolved oxygen; **Chl-A-CR** = chlorophyll A: corrected, a measure of algal activity; **Chl-A-UCR** = chlorophyll A: uncorrected, a measure of algal activity; **Phpt-A** = phaeophytin-A, a measure of algal activity; and **Q** = streamflow

The results recorded in Table 8 show the results of MRA using particulate P as the dependent variable for three different sites, each one sampled for two seasons. One of the most striking points illustrated is the lack of consistency between years. The results from theTualatin River are a good example of this. Even though the same set of parameters were sampled and used for analysis, the R-squared values are markedly dissimilar. The same point can be made for the Gales Creek and East Fork of Dairy Creek sites.

Another interesting point can be made by examining values for components between years for the East Fork of Dairy Creek shown in Table 8. In the 1990 data set, which has an R-squared of 0.92, TSS (total suspended solids) alone account for 0.75 of that total. Yet for the 1991 data, all parameters combined account for less of the variance than TSS did the prior year.

The results recorded in Table 9 compare the results of MRA using soluble P as the dependent variable for three different sites, each one sampled for two seasons. In contrast to the particulate P analysis discussed above, there is a greater consistency in the results, although the R-squared values make these analysis interesting, but inconclusive.

For all sample sets temperature and,when available, some measure of algal activity are influential in the solution. The influence of streamflow, which varies from the most influential component for the 1984 data set for the Tualatin River, to no influence in the 1991 data set for Gales Creek, is much less clear. Similarly, the role of TSS varies, not only between sites, but between years at the same site as shown by the data sets for 1990 and 1991 for the East Fork of Dairy Creek.

Table 9. Soluble Phosphorus Multiple Regression Analysis

Sites	**PP**	**TSS**	**TDS**	**Tmp**	**pH**	**DO**	**chl-A-CR**	**chl-A-UCR**	**phpt-A**	**Q**	**R^2**
Tualatin '84 (71.5)	0.02	0.11	0.00	0.22	0.00	0.03	0.17			0.34	0.89
Tualatin '85 (71.5)	0.01	0.01	0.01	0.02	0.08		0.44			0.12	0.68
Gales '90 (1.5)	0.04	0.01	0.09	0.41	0.00		0.01			0.19	0.75
Gales '91 (1.5)	0.32	0.02	0.18	0.01	0.00	0.00	0.01	0.27	0.04	0.00	0.86
East Dairy '90 (1.4)	0.14	0.30	0.00	0.27	0.00					0.02	0.81
East Dairy '91 (1.4)	0.02	0.00	0.00	0.58	0.00					0.27	0.87

Values indicate the variance in the model explained by each component.
Tualatin '84 (71.5) = Tualatin River at Cherry Grove (RM 71.5), 1984, 12 samples taken monthly between Jan. 4 and Dec. 5
Tualatin '85 (71.5) = Tualatin River at Cherry Grove (RM 71.5), 1985, 12 samples taken monthly between Jan. 2 and Dec. 4
Gales '90 (1.5) = Gales Creek at New Highway 47 (RM 1.5), 1990, 24 samples taken at weekly intervals between May 7 and Oct. 29
Gales '91 (1.5) = Gales Creek at New Highway 47 (RM 1.5), 1991, 20 samples taken at weekly intervals between May 6 and Oct. 28
East Dairy '90 (1.4) = East Fork of Dairy Creek at Roy Road Bridge (RM 1.4),10 samples taken at two week intervals between June 6 and Oct. 24
East Dairy '91 (1.4) = East Fork of Dairy Creek at Roy Road Bridge (RM 1.4),13 samples taken at two week intervals between May 23 and Oct. 31
PP = particulate phosphorus; **TSS** = total suspended solids; **TDS** = total dissolved solids; **Tmp** = water temperature; **pH** = a measure of acidic or basic conditions; **DO** = dissolved oxygen; **Chl-A-CR** = chlorophyll A: corrected, a measure of algal activity; **Chl-A-UCR** = chlorophyll A: uncorrected, a measure of algal activity; **Phpt-A** = phaeophytin-A, a measure of algal activity; and **Q** = streamflow

Little of certainty can be stated from this use of modeling except, and it is an important point, P dynamics are not simple. Concentrations of P, whether viewed as soluble P, particulate P or total P, are the result of complex interactions between a variety of factors. Although a particular variable may be very influential for a particular data set, it should be noted that does not mean it is necessarily that influential in reality. The model reflects only those factors used to construct it and some of those factors may be influenced by a variety of other factors. As an example, dissolved oxygen had some influence in several data sets, but it is in turn influenced by elevation, water temperature, flow turbulence, the activity of photosynthetic plants, and the decay of organic material.

Each of these is in turn affected by another set of complex factors. In the study of P, saying that *A* is caused by *B* is nearly always erroneous. *A* is influenced by *B*, but also by *C* through *Z*.

Predictive Analysis

The values from MRA were also used to perform linear forecasting for the East Fork of Dairy Creek at Roy Road Bridge 1990 data set. This data set had the highest R-squared values for both dependent variables and, therefore, assumedly the best description of relationships between dependent and independent variables. Linear forecasting uses the values generated by the MRA model to predict values for the dependent variable when independent values are altered. It should be noted that due to the complexity of interactions possible for P, any model of this type will be inadequate to fully predict its transformations. This model is offered not as a means of predicting values for P, but rather as an exploration of some of its interrelationships.

Soluble P. For this data set, 31.9 percent of total P was in soluble form. The linear forecast values show a negative correlation between total dissolved solids and soluble P, with soluble P decreasing as total dissolved solids increases. Information from other studies would suggest that this could be the result of P being removed from the soluble P pool by adsorption onto the fine particles such as the colloidal clays that would be included in the total dissolved solids sample (Black, 1970; Golterman, 1973; Hill, 1982).

The forecast also showed a positive correlation between temperature and soluble P. According to the values derived from MRA, a decrease in average temperature by 1°C during the sample season could reduce soluble P by nearly 24 percent. Although the predicted values may be questionable, if the trend is accurate, increased shading from vegetation management of streamside areas to maintain lower water temperatures has potential for controlling concentrations of soluble P at much lower levels.

Particulate P. In the MRA data set for the East Fork of Dairy Creek at Roy Road Bridge from 1990, 68.1 percent of total P is carried in particulate form, making the management of particulate P critical to the overall control of P. Particulate P showed a strong positive correlation to total suspended solids. It certainly is not unexpected that the particulate portion of P would be tied to suspended solids. However, the influence of sediments in the total picture of P at this site is indicated by the values. According to the MRA values, a 10 percent decrease in total suspended sediments would reduce particulate P nearly 44 percent. Although this seems unlikely, since further decreases soon make particulate P a negative value, it indicates that controlling the particulate P portion of the total P problem through active erosion prevention, especially near streams, and other measures, such as the management of riparian vegetation corridors as sediment filters, has potential for reducing the P content of streams.

SUMMARY AND CONCLUSIONS: TECHNICAL CONTEXT

The levels of P in a stream are influenced by a variety of influences that occur across the landscape (Figure 11). The data presented on the influence of particulate P to the total P concentrations in the Dairy-McKay HUA supports the contention that a land use is one major factor determining the P content of streams. It is apparent, and not unexpected, that the influence of particulate P on total P is much greater at downstream sites than at upstream sites. If the mouth of a stream is considered as the mouth of a funnel, collecting and concentrating materials gathered from upstream, it is logical that the downstream reaches would have much greater levels of particulates. The materials from all such streams enter the river and become the contributions to a much larger

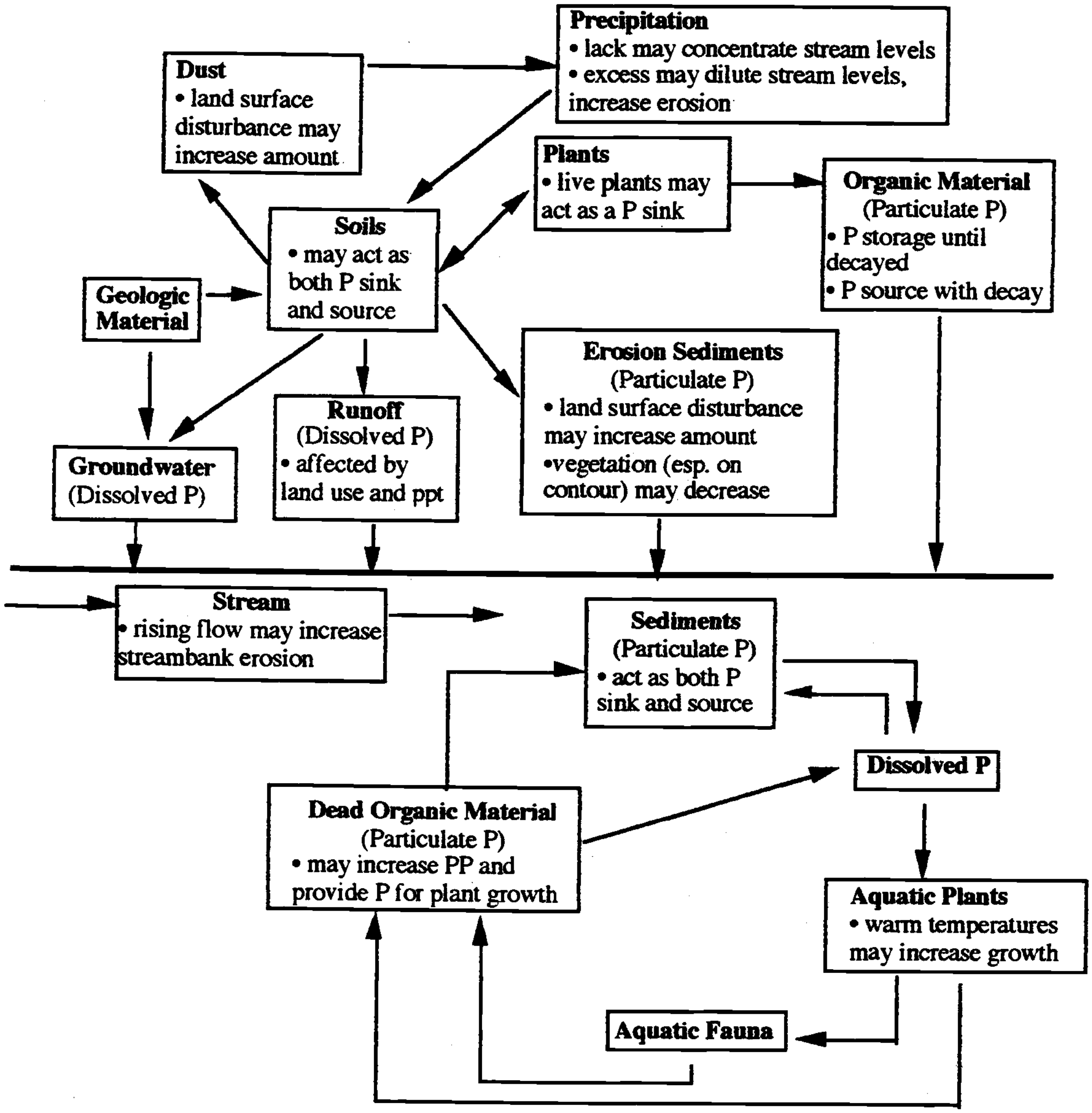


Figure 11. Landscape Level P Interactions

funnel. In this way whatever land uses take place near the upstream reaches of Dairy Creek eventually influence the P concentrations at Lake Oswego, the mouth of the Tualatin River, the Willamette River, and eventually the Columbia River.

Considering a number of indicators—the soils of the bottomlands, the greater likelihood of sediments being transported from areas adjacent to streams, and the trends from linear forecasting indicating that both temperature and sediments are very influential in determining P concentrations—it is apparent that the management of areas near streams is likely to have the greatest effect on the P content of streams. The establishment of riparian buffers for both sediment filtering and to provide shade to help maintain cooler streamwater temperatures would appear to be one practice with particular merit.

The transport and movement of P is a complex process involving a variety of interactions. No single factor or theory satisfactorily accounts for and predicts its movements. Managing a watershed containing a waterway of concern in a manner that reduces nonpoint source P inputs, especially particulate forms, will be more assured of success than management with an instream focus.

Suggestions for Future Research

Sampling

Water quality samples that include sediments and sediment-related nutrients such as P may best be sampled at stratified depths, throughout the year, and.more frequently than is possible with grab samples.

Particulate P concentrations in streamflow are generally closely correlated to suspended sediments in stream discharge (Cahill, 1977; Golterman, 1983; Meyer et al., 1988). Concentrations of sediment during stormflow can change rapidly, and sediment loads are often underestimated by calculations based on averages (Cahill, 1977; Paustian and Beschta, 1979; Rigler, 1979). The use of a pumping sampler is one way to sample on a temporal scale that will more accurately reflect the sediment load carried throughout the year. With infrequent samples, such as grab samples, the mean of the data may not represent the mean of the actual values (Ongley, 1976).

Changing flow conditions also affect the placement of the fine particles that are most likely to carry P. These particles will be found at different depths under different flow conditions making stratified sampling a method more likely to yield accurate load estimates (Ongley, 1976).

To date most sampling in this region has been done during the summer low flow period. During low flow, nutrients and sediments have a longer residence time, allowing them to be more involved in a variety of interactions (Hill, 1982). During the summer low flow period it is likely that a greater proportion of P is tied up in organic materials. The inadvertent inclusion of organic materials, such as diatoms or algae, in water quality samples may lead to inaccurate conclusions about both loading and transport of P.

Flow data

Movement of sediments is flow dependent. Low flows may overestimate P load as concentrations increase and fine particles stay suspended. Conversely, data from low flows also have the potential for underestimating loads since most of the sediment load, including much of the particulate P load, may move with high flow events, and then only during a portion of the event (MacKenthun, 1973; Ongley, 1976).

Questions

There are many unresolved questions about nonpoint source P that, if answered, would greatly aid in the management of basins with water quality problems. Among these are:

1. How long are sediments stored in the Tualatin and its tributaries? How much P is released from these sediments over time? If the period is long and release is high, then higher-than-acceptable P concentrations may persist even after effective control is gained in the uplands. This question will have to be answered before the effectiveness of land management practices can be accurately evaluated.

2 How much P is contributed to the Tualatin system by groundwater? Although it is not common, it is also not unknown for groundwater to carry high concentrations of P. If this is the case for parts of the Tualatin Basin, then the methods for management will be different than for sediments.

3 What is the P content of the various soils in the Tualatin Basin? For different land uses, what are the erosion rates and P delivery rates to streams for these soils? This information would establish the P loads contributed by land uses and point to those areas where control efforts would have the greatest effect.

4 What are the forms of P in the sediments carried from the land? Knowledge of the relative amounts of P in different forms will help determine the time frame for availability of those forms.

5 What P loads and in what forms are carried by various streams from throughout the year? Studies from headwaters to mouth would aid in understanding loading and transport mechanisms, which in turn would greatly assist in designing effective management practices.

6 What are there relationships between discharge and load for the Tualatin and its tributaries? Constant flow and water quality data would delineate relationships between flow and transport if they exist. If these relationships do exist, then other management methods, such as flow augmentation during summer months to reduce sediment residence time, might be feasible.

NONPOINT SOURCE PHOSPHORUS POLLUTION: THE SOCIAL CONTEXT

INTRODUCTION

Water, as one of the necessities of life, often acts as a catalyst for development and change in human societies. The earliest concepts of land ownership were those applied to wells and springs (Satterlund, 1972). The ability of groups to cooperate and specialize for a long-term social goal were demonstrated more than 5,000 years ago with the construction of dams in Egypt and water supply and drainage systems in the Indus Valley (Frank, 1955). In Moslem societies, laws and traditions developed around water that address the ideas of community property and community responsibility (Frank, 1955). In North America, the Hohokam people living near present day Phoenix, Arizona, brought more than 100,000 acres under irrigation by building more than 135 miles of superbly designed canals between 300 B.C. and 1400 A.D. (Dunbar, 1983; Reisner, 1986). Across the centuries and around the world, as one of the few absolute necessities of life, water is very influential.

In our own society water continues to serve as a catalyst for change, often as the focus of conflicts that force us to reexamine traditional values. Today, issues concerning both the quantity and quality of water force the continuing reexamination of rights, responsibilities, and equity as they apply to individuals, society, and the environment.

As populations increase, the demand for resources also increases, inevitably creating conflicts over those shared resources. These conflicts are not new; many wars have been fought over land and other resources. It's not surprising, when you consider current rates of population growth and technological development, that this type of conflict appears to be becoming more common. Current examples include demand for water by urban users versus agricultural users in much of the arid and semi-arid West, lumber interests versus environmental interests in the Pacific Northwest's old-growth timber controversy, concerns over the conversion of agricultural land to residential uses throughout much of the nation, and fishery interests versus hydropower, irrigation, recreation, and water-based transportation interests in the controversy over salmon stocks on the West Coast.

In the Tualatin Valley of Oregon another, quieter, controversy, has developed.

In many areas, such as western Oregon, it is water quality that is of increasing concern. The quantity of water is sufficient for current needs, but the quantity of high quality water is not. Demand steadily increases for industry, agriculture, population, and recreation, but the supply of high quality water decreases as it is affected by the uses of an expanding culture. The current controversy on the Tualatin River is an example of a water-related conflict that pushes society toward readjusting old values and developing new values.

COMMUNITY VALUES IN THE TUALATIN BASIN

By its very nature, identifying the sources and the relative contributions of those sources to NPS pollution can be difficult. It is difficult to assign portions of responsibility for NPS pollution to any group since the relative portions of the problem are unknown. Similarly, attributing values positions to groups can be somewhat difficult because of the differences in perception of the nature and extent of the problem. This contributes to a diversity of positions within groups and the formation of a multitude of subgroups.

Although there may be little disagreement that NPS pollution is a problem, there is considerable disparity over a definition of what it is. An example of these differences is shown by the following set of definitions of NPS pollution ascribed to different groups.

Developers and builders — sediment from construction.

Farmers and ranchers—sediment, fertilizers, pesticides and animal wastes carried from the land by rain.

Urban dwellers — assorted objects and substances washed from streets and parking lots by rain.

Public health officers — leachate from landfills or wastewater or sewage sludge disposed of on the land surface.

Recreationists — fouling of lakes and streams.

Fish and wildlife biologists — the impact on habitats of urban and agricultural activities (Howe, 1985).

Each group has a different definition, based on how NPS water pollution and its control may affect them.

Another proposed way of looking at groups involved with NPS issues splits the interested public into four categories:

1. Those who cause NPS pollution (e.g., farmers, developers, urban dwellers)
2. People whose living depends on those who cause NPS pollution (e.g., those who sell to or buy from farmers).
3. Individuals or groups affected by NPS pollution. A subset of this group would be those who are not directly affected, but have a commitment to environmental quality. Recreational users would be in the first set; a member of the Audubon Society who does not use the Tualatin Basin or who resides in another region, is an example of the second.
4. Those whose job it is to care about NPS pollution (e.g., agencies in some way responsible for water quality) (Libby, 1985).

It may be helpful to remember that often NPS pollution issues revolve around a single pollutant (e.g., phosphorus) or source (e.g., livestock) rather than the general label of NPS pollution. In the four categories listed above, membership may change depending on which pollutant is of concern. For example, if P is carried by sediments from agricultural land, a farmer would fit into the first category. If the issue is heavy metal contamination from the spreading of sewage sludge, the same farmer may move to the third category.

For myself, I think broad categories of groups may be defined by what they value:

1. Maximum water quality— Those who value ideal environmental conditions and view economic effects as secondary issues.
2. Acceptable water quality— Those willing to accept a minimal level of environmental degradation for the sake of economics.
3. Acceptable economic quality— This group is willing to accept a minimal level of economic degradation for the sake of the environment.
4. Maximum economic quality— Those who value ideal economic conditions and view environmental effects as secondary concerns.

Combining the two sets of categories helps establish positions for groups in the Tualatin Basin (Table 10). The actual positions are based on conversations with individuals from the area (farmers, dairy operators, containerized nursery operators, teachers, and retirees) and representatives of agencies concerned in some way with NPS pollution in the basin (Oregon Department of Environmental Quality (DEQ), Oregon Department of Forestry (ODF), Oregon Department of Agriculture (ODA), Unified Sewage Agency (USA), Soil Conservation Service (SCS), OSU Cooperative Extension Service (CES), and Washington County Soil and Water Conservation Service (WCSWCD)).

At least anecdotally, the group that seems to be the most intransigent toward NPS pollutant controls are some of those who supply agricultural producers. It may be that they perceive fewer acceptable options than producers. A farmer can change practices or land uses, but the supplier for the discarded ways may not be as flexible. Its analogous to Studebaker making the change from wagons to autos, but the owner of a warehouse full of buggywhips had fewer options. Currently, some suppliers are still denying that there is an agricultural connection to the problem.

Table 10. Nonpoint Source Water Pollution Values for Groups in the Tualatin Basin

	Maximum Water Quality	**Acceptable Water Quality**	**Acceptable Economic Quality**	**Maximum Economic Quality**
1. Those who cause NPS pollution	• Homeowners	• Homeowners	• Homeowners • Ag producers • Forest producers • Developers	
2. People whose living depends on those who cause NPS pollution			• Ag suppliers • Forest products suppliers and manufacturers • Building materials suppliers	• Ag suppliers
3a. Those who are directly affected by NPS pollution	• Recreationists • Homeowners	• Recreationists • Homeowners		
3b. Those who are indirectly affected, but committed to environmental quality	• Citizens • Citizen environmental groups	• Citizens • Citizen environmental groups		
4. Those whose job it is to care about NPS pollution	• DEQ • EPA	• USA • SCS • CES • ODA • ODF	• WCSWCD • Chambers of Commerce	

Public Perceptions: The Tualatin Conference

On May 9, 1992, a conference concerning the Tualatin River titled "The Once and Future Tualatin" was held in Hillsboro, Oregon. This conference was organized by the Oregon Rivers Council and drew 75 participants, including representatives from more than 20 groups including citizen, business, government and public utility interests. A portion of the conference was devoted to participant interaction to identify primary problems, values, and strategies that could be used in managing the Tualatin Basin (Oregon Rivers Council, 1992). It should be noted that the participants were citizens who are in some way stakeholders in Tualatin issues rather than a random sampling and, therefore, conclusions should be evaluated in this light.

As a group, the three primary problems identified were:

1. inadequate public access to the river,
2. inadequate protection for riparian wildlife habitat and wetlands, and
3. increased demand for water caused by urban growth (Oregon Rivers Council, 1992).

The three primary values identified by the group, ranked by importance, were:

1. water quality,
2. wildlife habitat, and
3. recreation and esthetic values (Oregon Rivers Council, 1992).

Preferred strategies to solve problems and protect values identified by the group were:

1. public watershed and natural resource education,
2. coordinated management and planning of the basin at a watershed/ecosystem level, and
3. better monitoring and enforcement of land-use regulations.

Other suggestions of note included improving the scientific understanding of the Tualatin Basin and creating buffer strips between riparian areas and development (Oregon Rivers Council, 1992).

Although water quality concerns, especially eutrophication and related P loads, are driving the regulatory and legal issues surrounding the Tualatin, it is interesting to note that none of the primary problems identified by this group were directly related to water quality. Water quality concerns appear be only one symptom of much broader concerns over the quality of life in the basin.

Water quality was identified as one of the primary values of this group, but other values identified show a larger concern for quality of life issues.

The solutions proposed do not revolve around increased regulation, but rather around education, cooperation, and using those regulations that already exist. I think this group as a whole could be described as valuing "acceptable water quality", willing to accept some economic effects for maximum water quality.

Public Perceptions: OSU Extension Landowner Survey

During April of 1992 a survey of 298 landowners engaged in either farm and/or forestry operations in the Dairy-McKay HUA of the Tualatin Basin was performed by OSU Extension Service. OSU Extension Service is charged with an information and education function for NPS pollution issues related to farm and forest use in the HUA. This survey was undertaken to assess landowner knowledge of NPS issues and better define the information needs of the landowners. Although most questions were targeted at land use practices, two questions have application to perceptions and values held by landowners concerning water quality in the Dairy-McKay HUA.

The first question asked how serious water quality problems were in their immediate area. Of those who identified themselves as primarily involved in farming, and willing to express an opinion (n=178), 61 percent felt there was no serious problem and only 39 percent considered the problem to be somewhat to very serious. Of those who felt there was a problem (n=62), the most frequently given reasons concerned agricultural and livestock runoff and forest spraying (cited by 42 percent of respondents), pollution in general, often with references to water that was of poor quality, particularly in smell (cited by 25 percent of respondents), fewer fish (cited by 13 percent of respondents), overcutting by forest operations, logging waste and erosion from logging operations (cited by 13 percent of respondents), and overpopulation, overuse and low water levels (cited by 13 percent of respondents) (Oregon State University Extension Service, 1992).

Those involved with forest operations answered the same question and showed similar perceptions and values. Of those expressing an opinion (n=120), 65 percent felt there was no serious problem with water quality, and only 29 percent considered the problem to be somewhat to very serious. Of those who felt there was a problem (n=39), the most frequently given reasons concerned agricultural and livestock runoff and forest spraying (cited by 24 percent of respondents), pollution in general, often with references to water that was of poor quality, particularly in smell (cited by 24 percent of respondents), excessive cutting by forest operations, logging waste and erosion from logging operations (cited by 20 percent of respondents), overpopulation, overuse and low water levels (cited by 12 percent of respondents), and sewage dumping or trash in streams (cited by 12 percent of respondents) (Oregon State University Extension Service, 1992). Considering that nutrient levels in water samples from the streams in this area frequently exceed the maximums allowed for the Tualatin River, it is apparent that an educational effort is needed to better inform landowners about the issues and concerns in the Tualatin Basin as a whole.

The second question was an open-ended inquiry asking for any comments respondents might have about water quality in the streams and rivers of Washington County. Of the landowners involved with farming, 64 percent (114 respondents) offered additional comments. Most of the comments of those who expressed an opinion can be divided as addressing three major issues.

The first issue is simply whether or not a problem exists. Comments on this point were nearly equally divided with 14 percent commenting that water quality was a mess or that pollution was increasing, and 13 percent commenting that there is no problem with water quality (Oregon State University Extension Service, 1992).

The second issue relates to the source of the problem. Agricultural chemicals were identified in 13 percent of the comments. Of this total, 7 percent were about agricultural chemicals in general (including fertilizers), but the remainder, 6 percent, specifically targeted chemicals used in nursery operations. Human waste, primarily from sewer and septic tank sources, and logging debris were each identified as major sources of the problem by 7 percent of the respondents. Population increases were seen as a major problem by 5. percent of those commenting (Oregon State University Extension Service, 1992).

The third issue concerns solutions to the problem. A need for greater education and awareness was called for by 7 percent of participants; better management and monitoring was included in 7 percent of comments. Who pays for the cleanup of water quality problems was identified by 5 percent, with an equal group of 5 percent holding that it is problem shared by everyone (Oregon State University Extension Service, 1992).

Of those landowners involved with forestry, 70 percent (84 respondents) had additional comments. The comments of those who expressed an opinion can again be broken into three major issues.

Forest landowner comments showed a different focus on the first issue of whether or not a problem exists. While farm landowners were nearly equally divided in their comments, of those forest landowners who expressed an opinion, 28 percent commented that the streams and rivers were a mess or that pollution was increasing, with a much smaller group, 8. percent, commenting that there is no problem with water quality (Oregon State University Extension Service, 1992).

For the second issue, sources of the problem, while farm owners most frequently identified farm activities as a source of the problem, forest landowners split the problem between forestry and agriculture, with agricultural chemicals and logging debris each identified in 10 percent of the comments. Population increases and development (industrial and commercial) were each identified as major sources of the problem in 8. percent of the comments. Human waste, primarily from sewer and septic tank sources, was identified in 5 percent of the comments (Oregon State University Extension Service, 1992).

The third issue concerns solutions to the problem. A need for better management and monitoring was included in 8 percent of comments, and greater education and awareness was called for by 7 percent of participants. An additional 7 percent felt that the issue was too political and should be left alone. Who pays for the cleanup of water quality problems was identified by 11 percent, with 7 percent holding that it is a problem shared by all (Oregon State University Extension Service, 1992).

These responses indicate that while some landowners have already made an effort to become informed on the issues, many others have a need for greater information on the nature and extent of the problem. This will help rural producers understand the needs and concerns of the urban/residential areas that surround them. These areas are growing in population and political influence, making understanding and cooperation on both sides critical to the survival of agriculture, private forestry and the portion of the economy they support.

SYSTEMS: INTERACTION BETWEEN GROUPS AND ENVIRONMENT

Although defining exact group membership can be difficult, the functional interactions between groups is somewhat more straightforward. The legal and regulatory driving force behind the system is the water quality in the Tualatin River, especially those times when the water "stinks." Phosphorus loading is considered the indicator of those conditions, so P is the element that is measured as an indicator of overall quality. It is probable that if the periods of eutrophication disappeared, much of the immediate concern over NPS pollutants in the Tualatin Basin would dissipate, even if P levels had not reached the TMDL target. However, concerns about the quality of life—expressed as concerns over wildlife habitat, ecosystems, and recreation—would probably persist even if NPS control levels are reached.

As long as P loads remain elevated, the pressure on those responsible for NPS pollutants will remain high. In turn, their actions and concerns affect the actions and concerns of others in the system (Figure 11). The implementation of P management should reduce loads (Figure 12) and, therefore, concern over this specific aspect of water quality. However, other water quality related concerns such as discussed in the results of the Tualatin Conference below may not be affected by reduced P loads.

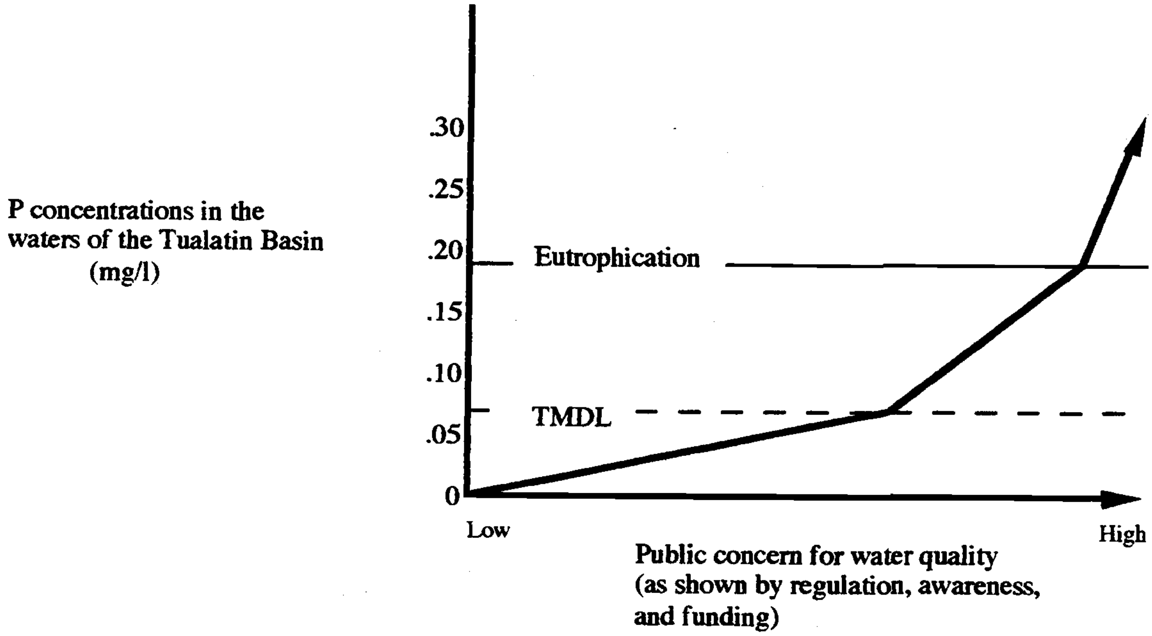


Figure 12. Effect of P on Concern for Water Quality

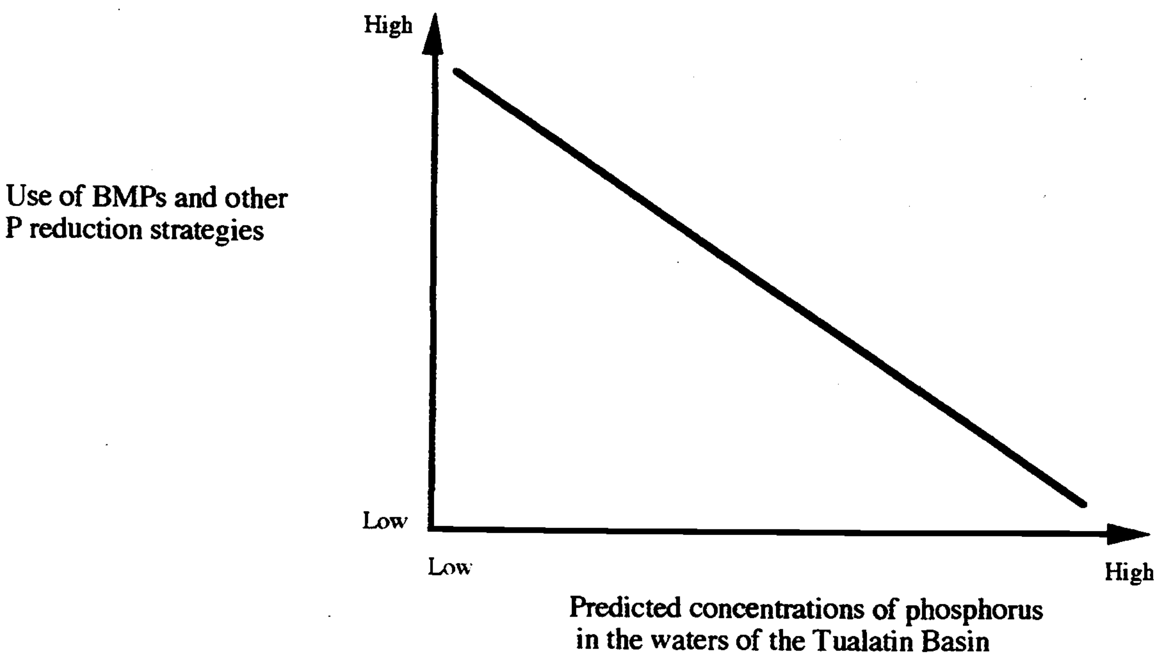


Figure 13. Expected Effects of BMPs on P Concentrations

Ultimately, NPS pollution control affects everyone. On one level, controlling NPS pollution may directly affect landowners by restricting their freedom to determine the uses and management of land. On another level, resources used for pollution abatement and control are resources that cannot be used elsewhere. It indirectly affects tax rates, social and educational programs, agricultural and industrial productivity, dietary choices, career choices, recreational choices, and all other facets of society. Uncontrolled pollution has similar far-reaching effects by impairing a shared resource.

ONE POSSIBLE SOLUTION: ADAPTIVE MANAGEMENT

Decisions based on our best knowledge are often seen to be flawed in hindsight. The state of our knowledge and understanding of natural systems changes rapidly as new information is discovered and integrated. Management strategies based on today's knowledge will always be deemed inadequate in the future because they are based on old information. Adaptive management is a strategy that has been developed to incorporate uncertainty into management. Developed at the University of British Columbia during the 1970s as a way to manage large-scale ecosystems, and currently used by the Northwest Power Planning Council's Columbia River Basin Fish and Wildlife Program, in essence it views management as a large experiment, managing according to our best information, evaluating the results, and modifying management as knowledge is gained (Mahar, 1990). By focusing on learning by doing, it is more flexible than traditional management approaches that have used a fixed policy.

Adaptive management strategies incorporate four basic principles. First, management problems must be specifically defined or "bounded." This includes specifying relevant objectives and limitations. Second, current information on all factors and of interactions between factors is assembled. This includes modeling interactions to detect egregious errors in underlying assumptions of how the system works. Thirdly, recognizing that uncertainty exists in natural systems, alternative explanations that fit current knowledge are identified. Fourth, policies conservative enough to allow for error are designed to meet objectives while searching for a better understanding of how the total system works (Walters, 1986).

In practice, adaptive management is a set of experiments and research projects using extensive monitoring and evaluation to compare results against expectations. Management is modified to try to bring the results closer to the specified objectives in the next round of experiments. By trying various management strategies and limiting the application of any one management policy until its effects are better known, adaptive management also has the advantages of being reversible and reducing the consequences of being wrong (Fickeisen, 1992).

The control of NPS pollutants is an uncertain science. The pathways pollutants follow after reaching watercourses is relatively simple, but the source and transport of the pollutants to that point can be impossible to define with certainty. Effective control of NPS phosphorus in the Tualatin Basin will not come from a single strategy, but from a variety of strategies applied in combinations that fit individual site conditions. Only experience and experimentation can determine which practices and combinations of practices will have the greatest benefit. It seems a situation designed for adaptive management.

Currently one of the biggest stumbling blocks to action on the NPS problems in the Tualatin Basin is a lack of definitive knowledge. Phosphorus sources, transport mechanisms, transformation conditions, and levels necessary for eutrophication are not fully understood. To date this has resulted in relative inaction from a reticence to accept the political consequences of being wrong. To wait for full knowledge and understanding is to allow the problem to perpetuate—knowledge is never adequate.

Delay due to "scientific uncertainty" shows an incomplete understanding of science — science is rarely "certain" (Fickeisen, 1992). We do, however, have the ability to make changes in resource management and monitor the effects of those changes. The following is a description of one course of action that I believe could lead to NPS phosphorus control in the Tualatin Basin.

Phase I: Point Source Control

Point sources are easier to identify and control than nonpoint sources and a logical starting point for rapid change. Point source contributors should be responsible for removing P prior to releasing effluents into surface waters. USA has already begun P removal at their tertiary treatment plants. This and a ban on phosphorus detergents in the basin has already begun to reduce total loads for the river.

Phase II: Oregon's Rural Land Practices Act

In Oregon, water quality from forested lands is controlled in part by the requirements of the Forest Practices Act. Currently, there is not an analogous document for nonforested lands, but I believe it is necessary. As a society we have established guidelines for operating a motor vehicle intended to protect society as a whole. Would a set of established guidelines to protect the soil and water resources on which we all depend be fundamentally different?

Although an Agricultural Practices Act has been discussed and proposed, it may be inadequate for the needs of an area such as the Dairy-McKay HUA. Increasingly, in areas such as this, which are adjacent to urban areas, farmlands are being broken into smaller parcels in which the primary use is residential, with a small block of land in what has often been referred to as a "hobby farm." These parcels would not be included if legislation was aimed at ~~lands~~ for agricultural production, but in many areas these are an increasing proportion of the land base and often the site of intensive and occasionally abusive land management practices. Legislation to protect soil and water conservation values should include all lands outside of incorporated communities.

Such legislation, a "Rural Land Practices Act", should establish minimum required standards for soil and water conservation practices on all rural lands, commercial and noncommercial. As standards, it would be possible to emphasize not just blanket prescriptive regulations, the traditional regulatory approach, but the desired outcomes of the standards. It should also provide an information/education program, including technical assistance, to increase public awareness and help participants achieve compliance. By allowing establishment of appropriate practices at the local level within the framework of standards, a base of practices appropriate to the specific locale could be established.

Both agriculture and silviculture have identified best management practices (BMPs) that describe practices effective for retaining soil and water on site under different conditions. The adoption of appropriate BMPs would be a great step toward reducing overland flow and the sediments it carries (U.S. Dept. of Agriculture, Agricultural Research Service, 1975). Identification of reasonable and effective BMPs could be done in cooperation with the Soil and Water Conservation Districts that already exist. The operators within these districts could provide input to help avoid the problems inherent when blanket rules are applied to a variable world.

The requirements of such an act would not need to be exceptionally rigorous, but rather a few commonsense BMPs to help keep soil, water, and nutrients onsite, including vegetation and nutrient management. For example, to protect sites from surface erosion bare soil should not be left exposed during the winter high precipitation period. Tree (orchard and Christmas), vine (berries and grapes), row, and nursery crops should maintain grass strips between rows. Wherever it is consistent with the culture of the crop (it often is not for grapes), both rows and grassed strips should be established on contour. Winter cover crops should also be used where practical. Using crops that are legumes may further reduce the need for adding fertilizers to cropland. Sites with winter cover tend to be moist later in the spring, delaying plowing, so this method would not be appropriate for all crop systems or sites.

Nutrient management should include testing soil nutrient levels, applying fertilizer in amounts consistent with plant needs and, where possible, incorporating the fertilizer into the soil surface. For farm operations which use manure as a fertilizer this would also include manure nutrient testing, application at appropriate rates, and applying manure when soils are not saturated.

Information/education programs have been shown to be a vital part in successful NPS pollution control programs (Sorenson, 1985). Extension programs have traditionally provided the type of information and assistance required to make this part of the program work. Specific programs for identified audiences would help each individual see both their part in the problem and their part in the solution. In addition this program would offer advice in implementing those solutions.

Phase III: Tualatin Basin Monitoring District

A network of water quality monitoring stations should be established throughout the basin to evaluate nonpoint source contributions. Currently some water quality testing is being done, but the number of sites and type of information being gathered is inadequate for effective management.

As an example, nearly all testing of P concentrations is done during the portion of the year when precipitation and streamflow are lowest. As discussed in the literature review, it is likely that particulate P contributions are moved from upstream areas during winter flows, deposited in downstream areas, and affect mainstem Tualatin P concentrations during the summer. To monitor and assess such contributions, in fact, to evaluate if their influence is even significant, testing throughout the year would be required.

Each major tributary should have a series of stations established to monitor changes in nutrient concentrations and transport factors, such as sediments and discharge, from headwater to mouth. Smaller streams that contribute to these tributaries should have stations established near both headwaters and confluence. This system would allow monitoring of the contributions of different land uses and source areas. Large scale experiments could then be established within subbasins and monitored. For example, establishing riparian filter strips in a small subbasin would help establish their effectiveness without committing large areas of land or resources to a single untested solution. Unfortunately, from the standpoint of implementing an adaptive management plan, the establishment of this monitoring system is the most crucial and, in terms of front end cost, the most expensive.

Phase IV: Control Through Innovation

While the adoption and consistent use of BMPs on areas adjacent to watercourses would be a great step forward, one of the implications of the definition "water quality limited" is that current BMPs are not enough. Areas with more extensive problems need solutions that go beyond the minimal standards set by the proposed Rural Land Practices Act. These areas, such as the Tualatin Basin, require the application and testing of innovative methods that have promise, but are of unknown effectiveness for the area. Two such ideas are discussed below; others are limited only by imagination.

Along both ephemeral and perennial channels, riparian forest buffer strips should be established. Although the effectiveness of these strips in the Tualatin is unknown, in other areas these have provided direct benefits to the reduction of NPS contributions by reducing the amount of surface runoff and sediment reaching streams. These strips, which are a combination of grass, shrubs, and trees, slow overland flow, giving water a greater opportunity to infiltrate and trap sediments (Lowrance et al., 1984; Lowrance et al., 1985). Healthy riparian vegetation may also help reduce streambank erosion, another concern in the Dairy-McKay HUA, by anchoring and protecting soil on streambanks. Unfortunately, the record of riparian filter strips is mixed. While they have reduced sediment and nutrients at some sites, they have increased the nutrient concentration of sediments reaching the stream or added nutrients by adding organic materials in others (Omernik et al., 1981). To explore its effectiveness, this idea should be tried in varying width and management combinations in separate subbasins, monitored, and evaluated.

In Washington County, which contains most of the Dairy-McKay HUA, containerized nursery crops are the single largest agricultural product. Many of these nurseries fertilize their crops by adding nutrients to the irrigation water, potentially adding not only sediments but dissolved nutrients to streams. Wetlands have been created for removing nutrients from sewage treatment effluent with fairly good results. Would a created wetland be able to bring water from a containerized nursery to the stringent level acceptable in the Tualatin Basin? This is another idea that should be explored, monitored and evaluated.

PAYING FOR CONTROL: THE *REAL* PROBLEM

It's the basic problem of NPS pollution control programs: Who pays? Should it be the individual landowner who is relatively unaffected by the problem and receives few of the benefits from control? For example, allotting land for filter strips or created wetlands would mean a reduction of land used for agricultural and silvicultural production (Karr and Dudley, 1981). The amount required would be small relative to the whole, but may be large, perhaps economically devastating, to an individual landowner. Or should downstream users and the public in general, who have not directly created the problem but receive the benefits, pay for control (Maas et al., 1987)? Who is responsible? Whose problem is it? Who pays? What is fair?

To date most NPS control programs have offered public funds to private landowners to help implement programs, generally on a cost-share basis. The rationale for this practice is that those who receive the benefits should pay or, at least, share the costs required to produce those benefits. From a practical viewpoint, these programs are also useful because economic constraints are one of the factors preventing farmers from adopting conservation practices (Napier et al., 1984). This approach has been shown to be an effective one for getting operators to participate in nonpoint pollution control programs (Kerns and Kramer, 1985). Many programs also offer information, education, and technical assistance to help landowners put controls in effect. Regulation, cooperation with the private sector (e.g., a creamery establishing price penalties for failing to meet minimum dairy waste controls), and tax incentives have also been used in some areas (Maas et al., 1987).

The concept of cost-sharing is not a new one. In traditional Moslem societies, where water is a limited resource, laws and traditions have developed to address the ownership, use and protection of water. Under this system, which has persisted for hundreds of years, the responsibility for water resources is shared by the community. All who share rights to a watercourse are responsible for caring for it, with the responsibility and cost proportional to right (Frank, 1955).

Similarly, water development in traditional Hispanic communities in the arid American Southwest developed with a strong cooperative element including shared responsibility. The ditch system which supplied water for both irrigation and domestic use was controlled by an acequeia, an association composed of community members.

Maintenance and repair were the responsibilities of those who benefitted from the development, and the water rights were held as a trust for the community (Wilkinson, 1992).

Some economists have suggested another approach, market forces, to decide who pays for NPS pollutant control. Market approaches, often suggested as emissions trading for point sources or air pollution, use the approach that once regulations are established, those who more than meet the regulated limits can, for economic considerations, trade their success against the failure of others to meet the regulated limit (Netusil, 1993). As an example for nonpoint source issues, if sediment discharges from cropland were regulated at no more than 5 tons/acre/year, then an operation of 100 acres that averaged 4 tons/acre/year, would be able to sell a credit for 100 tons/year to another operator who was not in compliance.

Using this approach the only direct cost to the public is the cost of administration and enforcement. Although this does have some advantages, it also presents problems of equity. The agricultural operator bears the costs of controlling pollution, but the public at large reaps the benefits of NPS pollution control. Asking producers to bear all direct costs while the public gains benefits may also harm the competitiveness of these producers.

There are other fundamental differences from many of the point sources suggested for emissions trading. Specific NPS pollution issues tend to affect relatively small areas, concentrating costs and reducing competitiveness within a locality. Those industries suggested for emissions trading affect much larger regions, both with the form of pollution and their market. In addition, while, for example, reducing the carbon emissions of all steel plants affects an entire market, and therefore the price of goods produced from an entire market, NPS pollution problems are not so evenly distributed, and farmers are notoriously unable to affect the market prices of the goods they produce.

I think it is entirely appropriate for the public to pay for NPS control in the Tualatin Basin. After establishment, the standards set by the proposed Rural Land Practices Act should be considered as expected standards, but for initial implementation, technical assistance and tax incentives or cost-sharing should be offered to make adoption quicker and more palatable. For more innovative control methods, public funding is an appropriate way of sharing risk. Consistent with the Moslem method mentioned above, the share of costs for control should be proportional to right. A portion of the cost should be paid for by the federal and state governments, since both water and the river are shared resources and the land uses of the basin economically benefit the public as a whole. Residents of the Tualatin Basin should be responsible for the remaining portion of the costs. This part of the cost could be shared through county income and property taxes. By also taxing water uses, such as sewage and irrigation rates, the share paid by an individual will rise proportionally to their use.

SUMMARY AND CONCLUSIONS: SOCIAL CONTEXT

Knowledge of all of the applicable interactions of water and NPS phosphorus in the Tualatin is incomplete, and waiting for all the answers would be similar to waiting for Godot. Many of the questions will only be answered by trial and error, and that may not give us complete knowledge, but instead give us only what works—this time, in this specific place, with these conditions.

Often management or regulation is set for a single point in time, without acknowledging that conditions change; but management must follow changing conditions to remain effective. An adaptive management approach that both monitors P concentrations in streams throughout the basin and actively tests, evaluates, and implements control methods has the best chance to gain control of P loads and maintain the reduction over time.

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APPENDICES

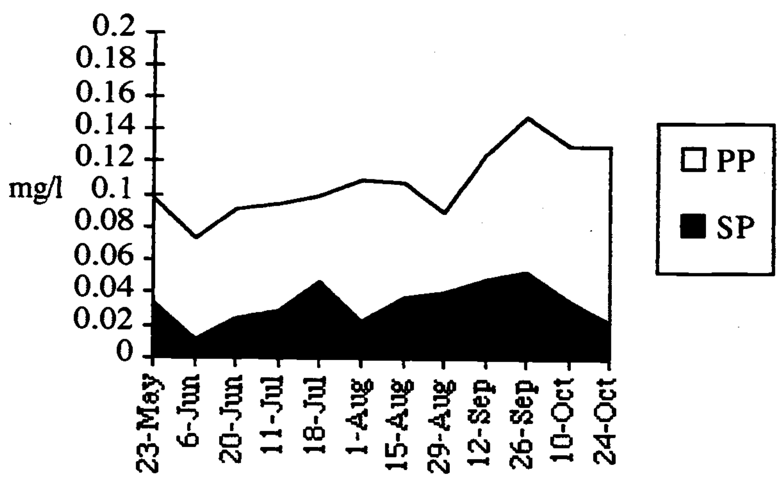
APPENDIX A:

SAMPLE SITE SUMMARIES

West Fork of Dairy Creek Site Descriptions for 1990 (from upstream to downstream)

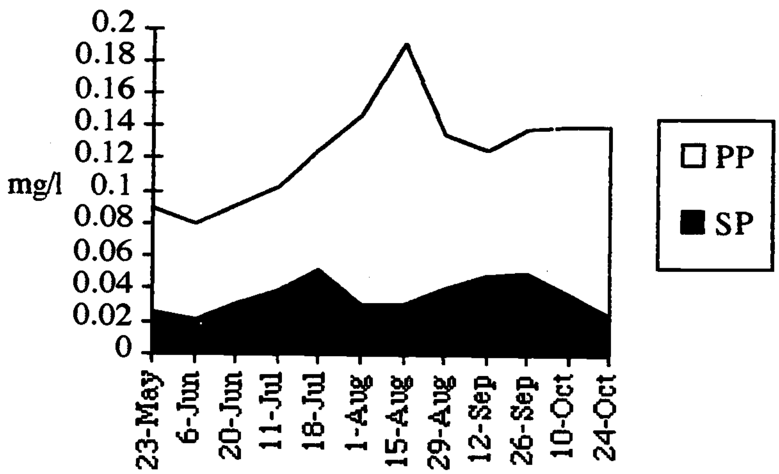
West Fork of Dairy Creek at Highway 6 (RM 6.3)
Data source: USA
Sampling season: 05/23-10/24
Frequency: 2 weeks
Number of samples: 11

	Mean	**Min**	**Max**
Total P (mg/l)	0.108	0.073	0.148
Soluble P (mg/l)	0.034	0.011	0.054
Particulate P (mg/l)	0.074	0.049	0.108
% of TP as SP	31.1	15.1	47
% of TP as PP	68.9	53	84.9
Enrichment Ratio	8.1	4.1	13.5



West Fork of Dairy Creek at Evers Rd. (RM 2.0)
Data source: USA
Sampling season: 05/23-10/24
Frequency: 2 weeks
Number of samples: 11

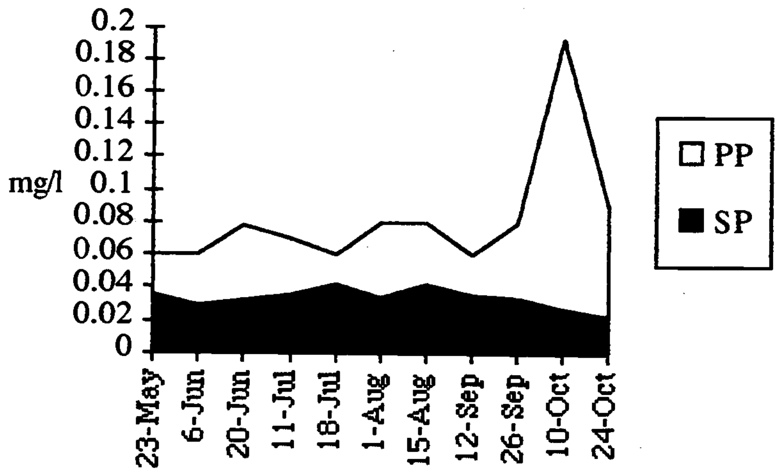
	Mean	Min	Max
Total P (mg/l)	0.126	0.08	0.191
Soluble P (mg/l)	0.036	0.021	0.052
Particulate P (mg/l)	0.09	0.059	0.16
% of TP as SP	29.6	16.2	41.6
% of TP as PP	70.4	58.4	83.8
Enrichment Ratio	4.4	2.2	8.1



East Fork of Dairy Creek Site Descriptions for 1990 (from upstream to downstream)

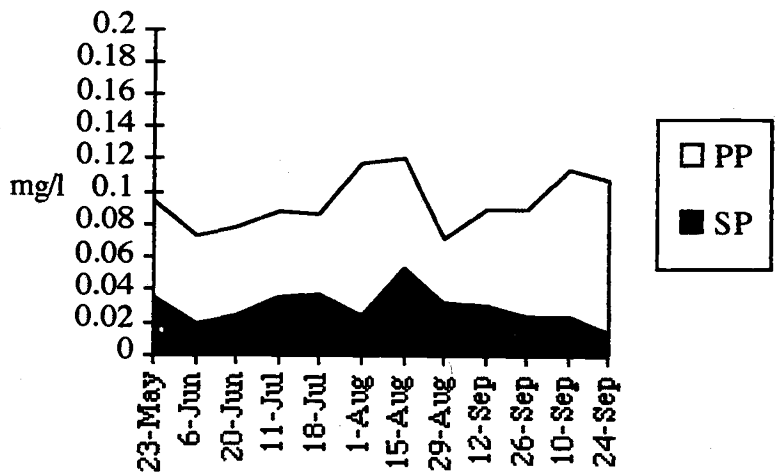
East Fork of Dairy Creek at Fern Flat (RM 16.8)
Data source: USA
Soil association: Olyic-Melby silt loam
Sampling season: 05/23-10/24
Frequency: 2 weeks
Number of samples: 11

	Mean	**Min**	**Max**
Total P (mg/l)	0.08	0.052	0.192
Soluble P (mg/l)	0.036	0.023	0.057
Particulate P (mg/l)	0.049	0.018	0.164
% of TP as SP	46.2	14.6	70.5
% of TP as PP	53.8	29.5	85.4
Enrichment Ratio	11.3	0.0	38.6



East Fork of Dairy Creek at Roy Bridge (RM 1.4)
Data source: USA
Soil association: Wapato-Verboort-Cove silty clay loams and clays
Sampling season: 05/23-10/24
Frequency: 2 weeks
Number of samples: 11

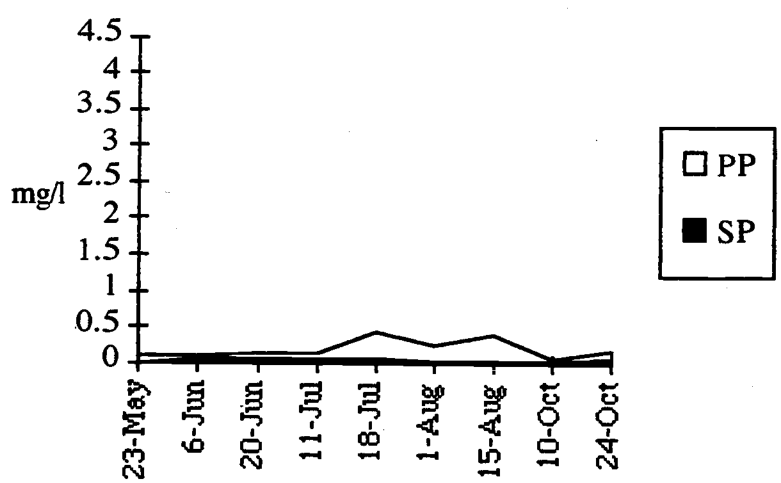
	Mean	**Min**	**Max**
Total P (mg/l)	0.094	0.072	0.12
Soluble P (mg/l)	0.03	0.014	0.053
Particulate P (mg/l)	0.065	0.04	0.094
% of TP as SP	31.9	13	44.4
% of TP as PP	68.1	55.6	87
Enrichment Ratio	12.5	3.4	35.1



Council Creek Site Descriptions for 1990 (from upstream to downstream)

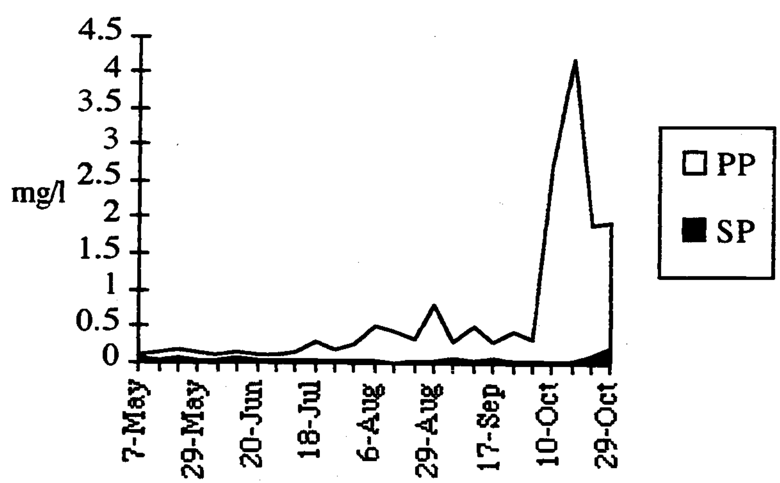
Council Creek at Beal Rd. (RM 5.0)
Data source: USA
Soil association: Wapato-Verboort-Cove silty clay loams and clays
Sampling season: 05/23-10/24
Frequency: 2 weeks
Number of samples: 7

	Mean	Min	Max
Total P (mg/l)	0.205	0.065	0.45
Soluble P (mg/l)	0.05	0.011	0.079
Particulate P (mg/l)	0.155	0.044	0.393
% of TP as SP	31	9.6	63.3
% of TP as PP	74.4	36.7	90.4
Enrichment Ratio	11.4	2.1	26.6



Council Creek at Hobbs Street (RM 0.9)
Data source: USA
Soil association: Woodburn-Quatama-Willamette silt loams and loams
Sampling season: 05/07-10/29
Frequency: weekly
Number of samples: 24

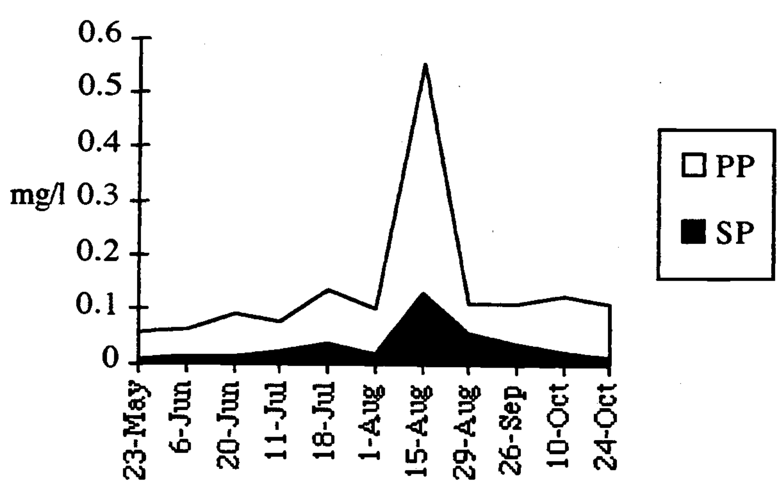
	Mean	**Min**	**Max**
Total P (mg/l)	0.66	0.104	4.2
Soluble P (mg/l)	0.044	0.009	0.202
Particulate P (mg/l)	0.616	0.055	4.17
% of TP as SP	16.7	0.7	50
% of TP as PP	83.3	50	99.3
Enrichment Ratio	11.6	0.7	68



McKay Creek Site Descriptions for 1990 (from upstream to downstream)

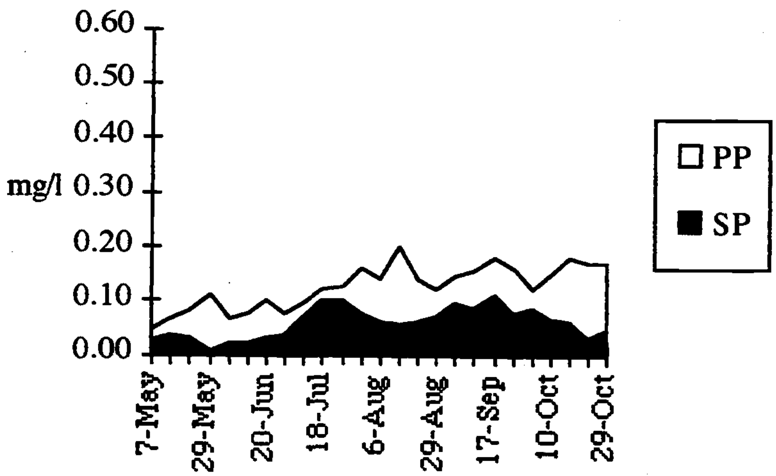
McKay Creek at Sunset Hwy (RM 8)
Data source: USA
Soil association: Wapato-Verboort-Cove silty clay loams and clays
Sampling season: 05/23-10/24
Frequency: 2 weeks
Number of samples: 11

	Mean	Min	Max
Total P (mg/l)	0.141	0.06	0.552
Soluble P (mg/l)	0.034	0.011	0.13
Particulate P (mg/l)	0.098	0.0	0.422
% of TP as SP	24.2	11.4	51.8
% of TP as PP	75.8	48.2	88.6
Enrichment Ratio	15.3	6.0	35.2



McKay Creek at Hornecker Rd. (RM 2)
Data source: USA
Soil association: Wapato-Verboort-Cove silty clay loams and clays
Sampling season: 05/07-10/29
Frequency: weekly
Number of samples: 24

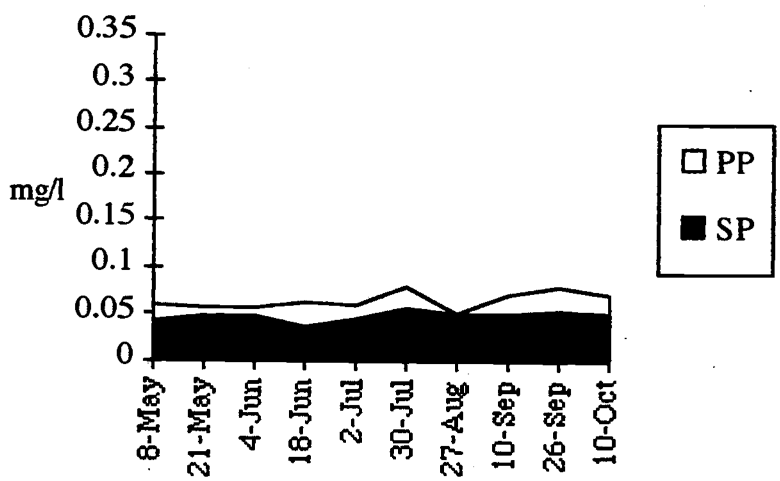
	Mean	**Min**	**Max**
Total P (mg/l)	0.128	0.05	0.202
Soluble P (mg/l)	0.06	0.009	0.11
Particulate P (mg/l)	0.068	0.2	0.142
% of TP as SP	47.6	8.2	83.3
% of TP as PP	52.4	16.7	91.8
Enrichment Ratio	9.6	2.3	22.9



West Fork of Dairy Creek Site Descriptions for 1991 (from upstream to downstream)

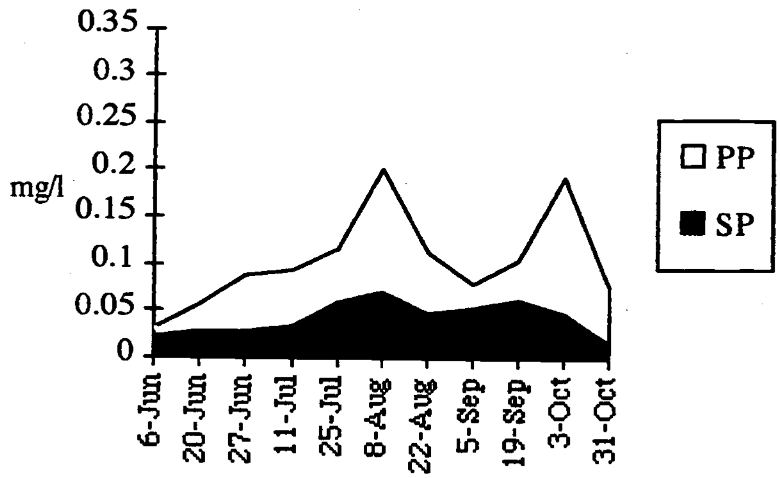
Tributary of West Fork of Dairy Creek near Strassel Road
(Tributary enters at approx. RM 13)
Data source: ODF
Soil association: Olyic-Melby silt loam
Sampling season: 05/08-10/24
Frequency: 2 weeks
Number of samples: 13

	Mean	**Min**	**Max**
Total P (mg/l)	0.06	0.035	0.08
Soluble P (mg/l)	0.053	0.038	0.098
Particulate P (mg/l)	0.016	0.001	0.025
% of TP as SP	76.2	61.3	98.1
% of TP as PP	23.8	1.9	38.7
Enrichment Ratio	3.9	0.4	9.3



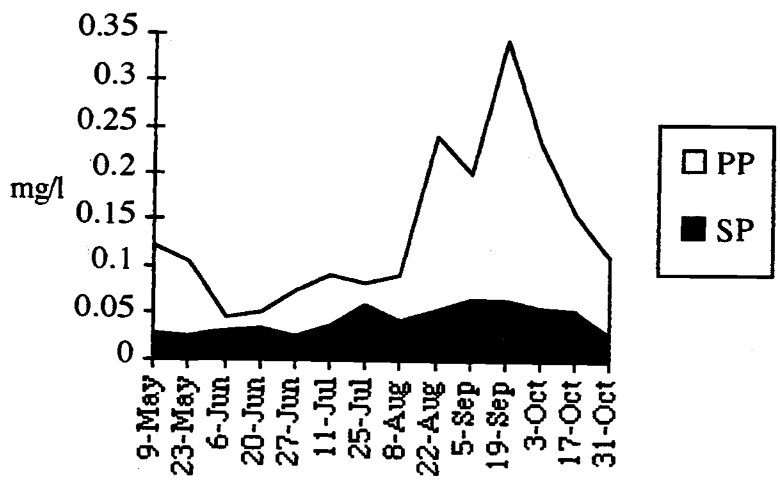
West Fork of Dairy Creek at Highway 6 (RM 6.3)
Data source: USA
Soil association: Olyic-Melby silt loam
Sampling season: 06/06-10/31
Frequency: 2 weeks
Number of samples: 11

	Mean	Min	Max
Total P (mg/l)	0.11	0.03	0.2
Soluble P (mg/l)	0.086	0.017	0.56
Particulate P (mg/l)	0.062	0.008	0.144
% of TP as SP	44.9	22.1	73.3
% of TP as PP	55.1	26.7	77.9
Enrichment Ratio	14.4	4.2	54.1



West Fork of Dairy Creek at Evers Rd. (RM 2.0)
Data source: USA
Soil association: Wapato-Verboort-Cove silty clay loams and clays
Sampling season: 05/09-10/31
Frequency: 2 weeks
Number of samples: 14

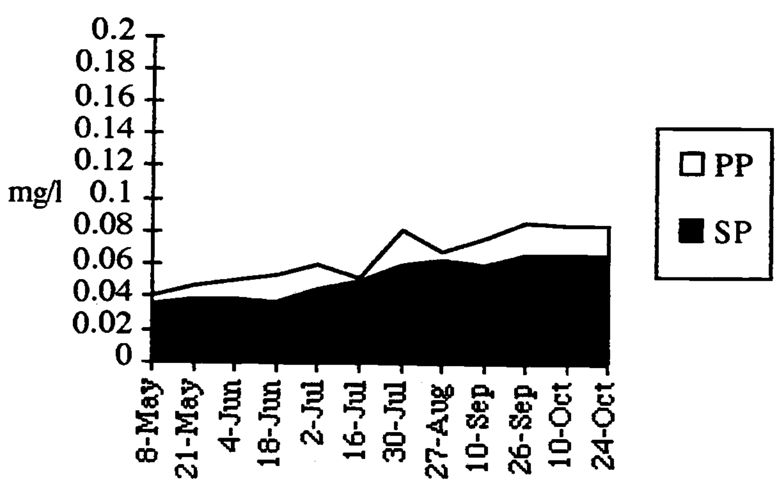
	Mean	Min	Max
Total P (mg/l)	0.139	0.46	0.342
Soluble P (mg/l)	0.043	0.025	0.065
Particulate P (mg/l)	0.095	0.016	0.278
% of TP as SP	37.9	18.7	71.1
% of TP as PP	66.1	28.9	81.3
Enrichment Ratio	6.9	1.0	35.6



East Fork of Dairy Creek Site Descriptions for 1991 (from upstream to downstream)

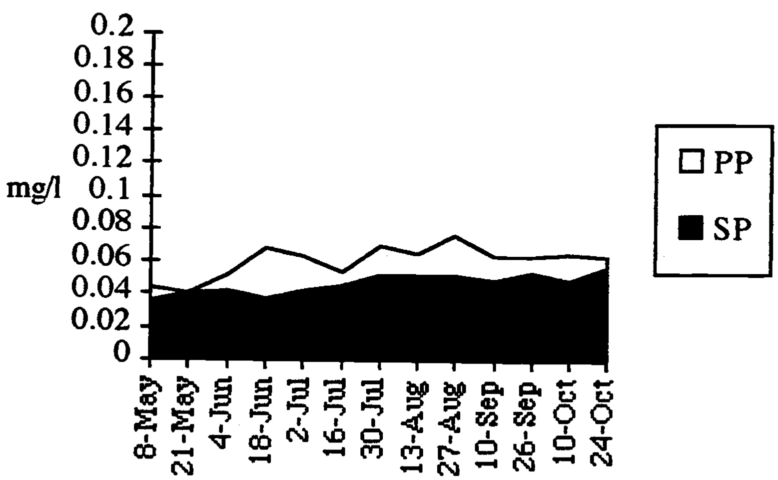
East Fork of Dairy near confluence with Campbell Creek (RM 20)
Data source: ODF
Soil association: Olyic-Melby silt loam
Sampling season: 05/08-10/24
Frequency: 2 weeks
Number of samples: 13

	Mean	**Min**	**Max**
Total P (mg/l)	0.064	0.04	0.087
Soluble P (mg/l)	0.053	0.035	0.067
Particulate P (mg/l)	0.013	0.002	0.02
% of TP as SP	81	71.7	96.2
% of TP as PP	19	3.8	28.3
Enrichment Ratio	6.13	0.0	11.9



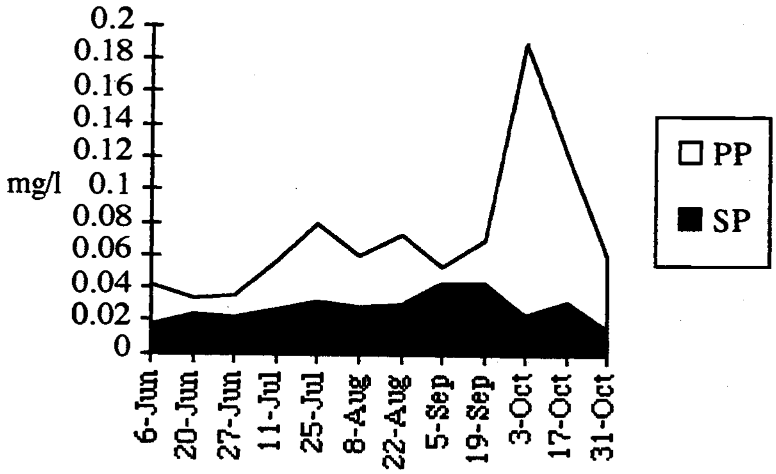
East Fork of Dairy Creek at Fern Flat (RM 16.8)
Data source: ODF
Soil association: Olyic-Melby silt loam
Sampling season: 05/08-10/24
Frequency: 2 weeks
Number of samples: 10

	Mean	Min	Max
Total P (mg/l)	0.062	0.044	0.076
Soluble P (mg/l)	0.047	0.036	0.057
Particulate P (mg/l)	0.015	0.007	0.03
% of TP as SP	76.6	55.9	89.1
% of TP as PP	23.4	11	44.1
Enrichment Ratio	9.6	0.0	30.8



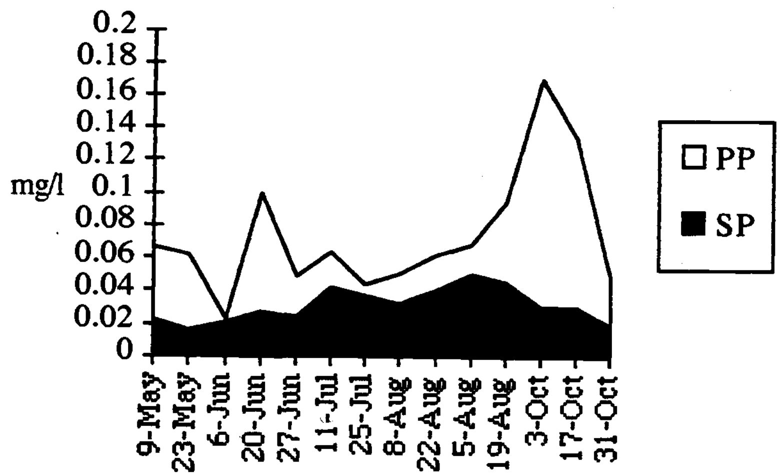
East Fork of Dairy Creek at Dairy Creek Rd. (RM 8.4)
Data source: USA
Soil association: Wapato-Verboort-Cove silty clay loams and clays
Sampling season: 06/06-10/31
Frequency: 2 weeks
Number of samples: 12

	Mean	**Min**	**Max**
Total P (mg/l)	0.073	0.034	0.189
Soluble P (mg/l)	0.028	0.016	0.044
Particulate P (mg/l)	0.044	0.01	0.165
% of TP as SP	46.9	12.7	79.6
% of TP as PP	53.1	20.4	87.3
Enrichment Ratio	8.6	1.4	43.5



East Fork of Dairy Creek at Roy Bridge (RM 1.4)
Data source: USA
Soil association: Wapato-Verboort-Cove silty clay loams and clays
Sampling season: 05/09-10/31
Frequency: 2 weeks
Number of samples: 14

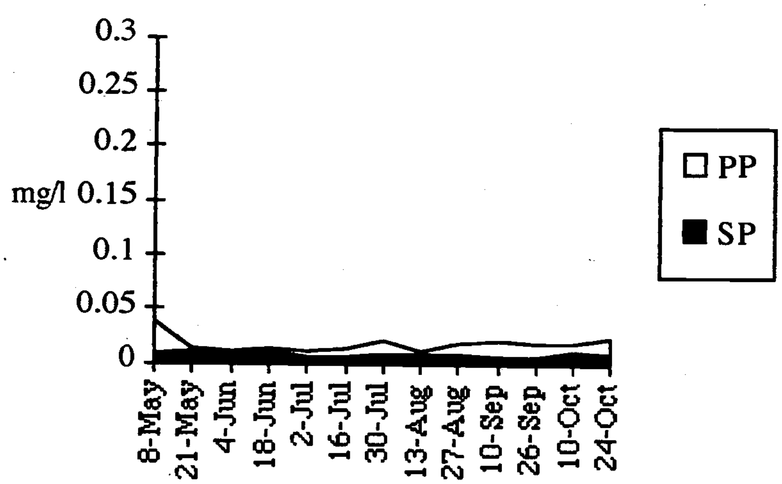
	Mean	Min	Max
Total P (mg/l)	0.074	0.022	0.17
Soluble P (mg/l)	0.032	0.016	0.05
Particulate P (mg/l)	0.042	0.001	0.14
% of TP as SP	51.8	17.7	95.4
% of TP as PP	48.2	4.5	82.4
Enrichment Ratio	217	1.7	2916.7



McKay Creek Site Descriptions for 1991 (from upstream to downstream)

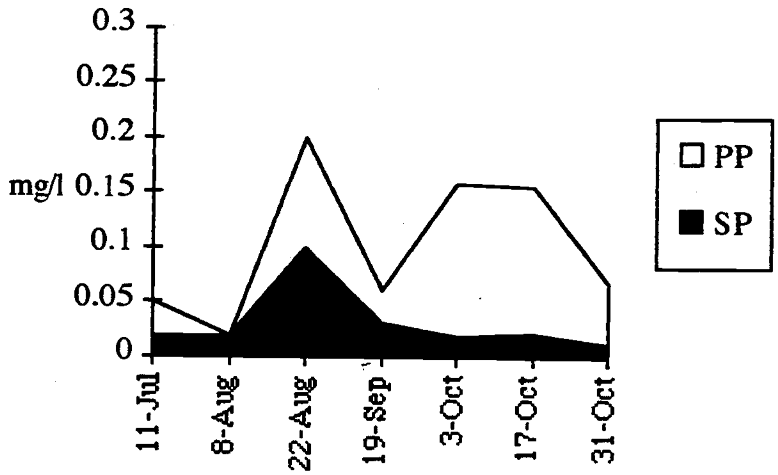
McKay Creek (RM 30)
Data source: ODF
Soil association: Cascade silt loam
Sampling season: 05/08-10/24
Frequency: 2 weeks
Number of samples: 13

	Mean	**Min**	**Max**
Total P (mg/l)	0.019	0.013	0.038
Soluble P (mg/l)	0.01	0.007	0.013
Particulate P (mg/l)	0.009	0.002	0.029
% of TP as SP	55.9	23.7	86.7
% of TP as PP	44.1	13.3	76.3
Enrichment Ratio	12.3	2.1	41.7



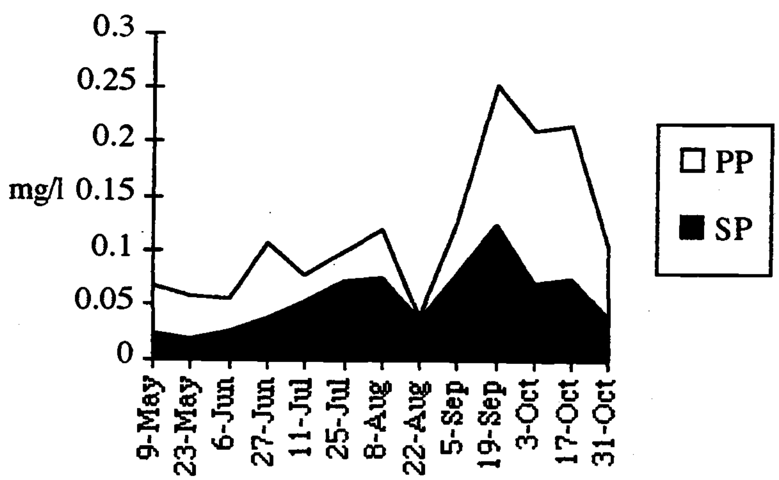
McKay Creek at Northrup Rd. (RM 16.0)
Data source: USA
Soil association: Woodburn-Quatama-Willamette silt loams and loams
Sampling season: 7/11-10/31
Frequency: 2 weeks
Number of samples: 7

	Mean	**Min**	**Max**
Total P (mg/l)	0.083	0.013	0.2
Soluble P (mg/l)	0.031	0.011	0.099
Particulate P (mg/l)	0.07	0.0	0.139
% of TP as SP	40.3	11.5	100
% of TP as PP	59.7	0.0	88.5
Enrichment Ratio	23.4	0.0	100



McKay Creek at Hornecker Rd. (RM 2)
Data source: USA
Soil association: Wapato-Verboort-Cove silty clay loams and clays
Sampling season: 05/09-10/31
Frequency: 2 weeks
Number of samples: 14

	Mean	Min	Max
Total P (mg/l)	0.112	0.034	0.253
Soluble P (mg/l)	0.056	0.02	0.125
Particulate P (mg/l)	0.062	0.003	0.141
% of TP as SP	51.1	33.2	92.5
% of TP as PP	48.9	7.5	66.8
Enrichment Ratio	19.1	0.0	59.4



APPENDIX B:

DATA SETS

Data-West Fk. Dairy '90

Site	Source	Date	Temp-C	pH	TP	SP	PP	TS	TDS	TSS
RM 6.3	USA	05/23/90	12.00	7.50	0.098	0.034	0.064	96.00	88.40	7.60
RM 6.3	USA	06/06/90	14.00	7.20	0.073	0.011	0.062	96.00	87.00	9.00
RM 6.3	USA	06/20/90	16.00	7.50	0.091	0.024	0.067	114.00	105.00	8.66
RM 6.3	USA	07/11/90		7.60	0.094	0.029	0.065	110.00	93.00	17.00
RM 6.3	USA	07/18/90	16.00	7.90	0.100	0.047	0.053	108.00	102.00	5.76
RM 6.3	USA	08/01/90	18.00	7.60	0.110	0.022	0.088	136.00	119.00	17.10
RM 6.3	USA	08/15/90	17.00	7.80	0.107	0.038	0.069	120.00	110.00	10.20
RM 6.3	USA	08/29/90	17.00	7.70	0.089	0.040	0.049	96.00	88.60	7.40
RM 6.3	USA	09/12/90	15.00	7.60	0.125	0.048	0.077	114.00	108.00	5.76
RM 6.3	USA	09/26/90	15.00	7.10	0.148	0.054	0.094	138.00	125.00	13.10
RM 6.3	USA	10/10/90	10.00	7.30	0.130	0.035	0.095	120.00	115.00	5.40
RM 6.3	USA	10/24/90	8.00	7.30	0.130	0.022	0.108	130.00	122.00	8.44
MEAN			14.36	7.51	0.108	0.034	0.074	114.83	105.25	9.62
MIN			8.00	7.10	0.073	0.011	0.049	96.00	87.00	5.40
MAX			18.00	7.90	0.148	0.054	0.108	138.00	125.00	17.10
STDEV			2.99	0.23	0.021	0.012	0.017	14.15	13.04	3.90
COUNT			11.00	12.00	12.000	12.000	12.000	12.00	12.00	12.00

Data-West Fk. Dairy '90

Site	Source	Date	Temp-C	pH	TP	SP	PP	TS	TDS	TSS
RM 2	USA	05/23/90	13.00	7.50	0.090	0.026	0.064	96.00	84.50	11.50
RM 2	USA	06/06/90	15.00	7.30	0.080	0.021	0.059	104.00	93.00	10.80
RM 2	USA	06/20/90	15.00	7.50	0.092	0.030	0.062	124.00	109.00	15.26
RM 2	USA	07/11/90		7.40	0.102	0.039	0.063	130.00	102.00	27.80
RM 2	USA	07/18/90	17.00	7.70	0.125	0.052	0.073	134.00	114.00	20.30
RM 2	USA	08/01/90	18.00	7.40	0.147	0.031	0.116	140.00	121.00	18.90
RM 2	USA	08/15/90	18.00	7.50	0.191	0.031	0.160	154.00	126.00	27.80
RM 2	USA	08/29/90	17.00	7.60	0.135	0.040	0.095	128.00	103.00	25.20
RM 2	USA	09/12/90	16.00	7.60	0.125	0.048	0.077	142.00	129.00	12.60
RM 2	USA	09/26/90	15.00	7.20	0.139	0.051	0.088	134.00	120.00	13.80
RM 2	USA	10/10/90	10.00	7.30	0.140	0.038	0.102	138.00	107.00	31.00
RM 2	USA	10/24/90	9.00	7.40	0.140	0.025	0.115	130.00	120.00	10.20
MEAN			14.82	7.45	0.126	0.036	0.090	129.50	110.71	18.76
MIN			9.00	7.20	0.080	0.021	0.059	96.00	84.50	10.20
MAX			18.00	7.70	0.191	0.052	0.160	154.00	129.00	31.00
STDEV			2.89	0.14	0.030	0.010	0.029	15.23	12.94	7.20
COUNT			11.00	12.00	12.000	12.000	12.000	12.00	12.00	12.00

Data-West Fk. Dairy '91

Site	Source	Date	Temp-C	pH	TP	SP	PP	TS	TDS	TSS
RM 13	ODF	05/08/91	9.70	7.53	0.060	0.042	0.018			7.20
RM 13	ODF	05/21/91	9.70		0.056	0.048	0.008			6.40
RM 13	ODF	06/04/91	8.90	7.30	0.058	0.049	0.009			7.00
RM 13	ODF	06/18/91	10.20	6.79	0.062	0.038	0.024			6.60
RM 13	ODF	07/02/91	13.70	6.64	0.060	0.046	0.014			8.60
RM 13	ODF	07/16/91	13.00	6.58	0.035	0.047				6.20
RM 13	ODF	07/30/91	14.40		0.079	0.056	0.023			7.40
RM 13	ODF	08/13/91	13.60	7.79	0.044	0.054				7.80
RM 13	ODF	08/27/91	12.80		0.052	0.051	0.001			4.60
RM 13	ODF	09/10/91	12.00	6.93	0.072	0.052	0.020			3.00
RM 13	ODF	09/26/91	11.70		0.080	0.055	0.025			6.20
RM 13	ODF	10/10/91	11.10		0.070	0.052	0.018			9.00
RM 13	ODF	10/24/91	9.40		0.055	0.098				45.70
MEAN			11.55	7.08	0.060	0.053	0.016			9.67
MIN			8.90	6.58	0.035	0.038	0.001			3.00
MAX			14.40	7.79	0.080	0.098	0.025			45.70
STDEV			1.78	0.43	0.012	0.014	0.007			10.51
COUNT			13.00	7.00	13.000	13.000	10.000			13.00

Data-West Fk. Dairy '91

Site	Source	Date	Temp-C	pH	TP	SP	PP	TS	TDS	TSS
RM 6.3	USA	06/06/91	12.00	7.40	0.030	0.022	0.008	100.00	94.00	6.36
RM 6.3	USA	06/20/91	12.00	7.30	0.055	0.029	0.026	98.00	90.00	8.48
RM 6.3	USA	06/27/91	11.00	7.10	0.087	0.027	0.060	88.00	83.00	5.08
RM 6.3	USA	07/11/91	16.00	7.10	0.093	0.034	0.059	104.00	101.00	2.76
RM 6.3	USA	07/25/91	17.00	7.40	0.117	0.059	0.058	86.00	82.00	3.52
RM 6.3	USA	08/08/91	17.00	7.00	0.200	0.070	0.130	112.00	98.00	14.50
RM 6.3	USA	08/22/91	19.00	7.40	0.112	0.047	0.065	150.00	143.00	6.72
RM 6.3	USA	09/05/91	17.00	7.40	0.080	0.052	0.028	102.00	97.00	5.28
RM 6.3	USA	09/19/91	16.00	7.40	0.105	0.063	0.042	94.00	86.00	7.84
RM 6.3	USA	10/03/91	12.00	7.00	0.193	0.049	0.144	104.00	100.00	3.92
RM 6.3	USA	10/17/91		7.20	0.176	0.560		138.00	131.00	7.28
RM 6.3	USA	10/31/91	4.00	7.20	0.077	0.017	0.060	104.00	103.00	1.44
MEAN			13.91	7.24	0.110	0.086	0.062	106.67	100.67	6.10
MIN			4.00	7.00	0.030	0.017	0.008	86.00	82.00	1.44
MAX			19.00	7.40	0.200	0.560	0.144	150.00	143.00	14.50
STDEV			4.06	0.16	0.051	0.144	0.039	18.23	17.73	3.25
COUNT			11.00	12.00	12.000	12.000	11.000	12.00	12.00	12.00

Data-West Fk. Dairy '91

Site	Source	Date	Temp-C	pH	TP	SP	PP	TS	TDS	TSS
RM 2	USA	05/09/91	8.00	7.10	0.122	0.029	0.093	106.00	90.80	15.20
RM 2	USA	05/23/91	11.00	7.10	0.105	0.026	0.079	98.00	83.50	14.50
RM 2	USA	06/06/91	12.00	7.30	0.046	0.030	0.016	114.00	111.00	3.04
RM 2	USA	06/20/91	10.00	7.20	0.050	0.033	0.017	114.00	101.00	13.30
RM 2	USA	06/27/91	12.00	7.20	0.073	0.025	0.048	100.00	89.00	10.90
RM 2	USA	07/11/91	15.00	7.20	0.090	0.036	0.054	104.00	92.00	12.00
RM 2	USA	07/25/91	17.00	7.30	0.083	0.059	0.024	104.00	91.00	12.70
RM 2	USA	08/08/91	17.00	7.50	0.090	0.042	0.048	96.00	90.00	6.24
RM 2	USA	08/22/91	19.00	7.30	0.241	0.054	0.187	216.00	182.00	34.40
RM 2	USA	09/05/91	16.00	7.20	0.200	0.065	0.135	140.00	114.00	26.40
RM 2	USA	09/19/91	16.00	7.60	0.342	0.064	0.278	150.00	72.00	77.70
RM 2	USA	10/03/91	11.00	7.20	0.230	0.058	0.172	114.00	100.00	14.30
RM 2	USA	10/17/91	9.00	7.60	0.157	0.055	0.102	140.00	132.00	8.12
RM 2	USA	10/31/91	5.00	7.20	0.110	0.028	0.082	100.00	98.00	2.36
MEAN			12.71	7.29	0.139	0.043	0.095	121.14	103.31	17.94
MIN			5.00	7.10	0.046	0.025	0.016	96.00	72.00	2.36
MAX			19.00	7.60	0.342	0.065	0.278	216.00	182.00	77.70
STDEV			3.90	0.16	0.082	0.015	0.072	31.14	25.94	18.47
COUNT			14.00	14.00	14.000	14.000	14.000	14.00	14.00	14.00

Data-East Fk. Dairy '90

Site	Source	Date	Temp-C	pH	TP	SP	PP	TS	TDS	TSS
RM 16.8	USA	O5/23/90	10.00	7.80	0.060	0.036	0.024	70.00	67.90	2.10
RM 16.8	USA	6/6/90	11.00	7.70	0.061	0.029	0.032	82.00	71.90	10.10
RM 16.8	USA	6/20/90	12.00	7.80	0.078	0.032	0.046	118.00	99.00	5.08
RM 16.8	USA	7/11/90		7.60	0.070	0.036	0.034	82.00	76.00	5.66
RM 16.8	USA	7/18/90	11.00	7.90	0.061	0.043	0.018	78.00	74.30	3.66
RM 16.8	USA	8/1/90	13.00	7.80	0.080	0.034	0.046	92.00	88.00	4.04
RM 16.8	USA	8/15/90	12.00	7.80	0.080	0.043	0.037	82.00	78.30	3.68
RM 16.8	USA	8/29/90	13.00	7.80	0.052	0.057		70.00	66.40	3.56
RM 16.8	USA	9/12/90	12.00	7.80	0.060	0.035	0.025	76.00	75.00	1.08
RM 16.8	USA	9/26/90	12.00	7.50	0.080	0.034	0.046	104.00	71.00	32.70
RM 16.8	USA	10/10/90	8.00	7.60	0.192	0.028	0.164	196.00	80.00	116.00
RM 16.8	USA	10/24/90	6.00	7.60	0.090	0.023	0.067	110.00	105.00	4.96
MEAN			10.91	7.73	0.080	0.036	0.049	96.67	79.40	16.05
MIN			6.00	7.50	0.052	0.023	0.018	70.00	66.40	1.08
MAX			13.00	7.90	0.192	0.057	0.164	196.00	105.00	116.00
STDEV			2.07	0.12	0.035	0.008	0.039	33.44	11.55	31.20
COUNT			11.00	12.00	12.000	12.000	11.000	12.00	12.00	12.00

Data-East Fk. Dairy '90

Site	Source	Date	Temp-C	pH	TP	SP	PP	TS	TDS	TSS
RM 1.4	USA	O5/23/90	12.00	7.70	0.094	0.036	0.058	100.00	82.00	17.90
RM 1.4	USA	6/6/90	13.00	7.50	0.074	0.019	0.055	86.00	74.60	11.40
RM 1.4	USA	6/20/90	16.00	7.60	0.078	0.024	0.054	94.00	82.70	11.30
RM 1.4	USA	7/11/90		7.60	0.088	0.035	0.053	98.00	89.00	8.94
RM 1.4	USA	7/18/90	16.00	7.50	0.086	0.038	0.048	90.00	80.60	9.38
RM 1.4	USA	8/1/90	16.00	7.60	0.118	0.024	0.094	114.00	111.00	3.48
RM 1.4	USA	8/15/90	17.00	7.70	0.120	0.053	0.067	90.00	84.60	5.40
RM 1.4	USA	8/29/90	17.00	7.70	0.072	0.032	0.040	84.00	73.40	10.60
RM 1.4	USA	9/12/90	15.00	7.70	0.090	0.030	0.060	84.00	79.00	5.48
RM 1.4	USA	9/26/90	15.00	7.30	0.089	0.025	0.064	98.00	90.30	7.72
RM 1.4	USA	10/10/90	10.00	7.40	0.114	0.024	0.090	78.00	75.00	3.04
RM 1.4	USA	10/24/90	8.00	7.50	0.108	0.014	0.094	104.00	102.00	2.48
MEAN			14.09	7.57	0.094	0.030	0.065	93.33	85.35	8.09
MIN			8.00	7.30	0.072	0.014	0.040	78.00	73.40	2.48
MAX			17.00	7.70	0.120	0.053	0.094	114.00	111.00	17.90
STDEV			2.84	0.12	0.016	0.010	0.017	9.64	10.88	4.27
COUNT			11.00	12.00	12.000	12.000	12.000	12.00	12.00	12.00

Data-East Fk. Dairy '91

Site	Source	Date	Temp-C	pH	TP	SP	PP	TS	TDS	TSS
RM 20	ODF	05/08/91	9.50	7.80	0.040	0.035	0.005			2.40
RM 20	ODF	05/21/91	8.90		0.047	0.039	0.008			2.40
RM 20	ODF	06/04/91	7.80	7.20	0.050	0.039	0.011			3.30
RM 20	ODF	06/18/91	8.90	6.85	0.053	0.038	0.015			2.40
RM 20	ODF	07/02/91	12.10	6.47	0.061	0.045	0.016			2.80
RM 20	ODF	07/16/91	11.90	6.59	0.052	0.050	0.002			2.40
RM 20	ODF	07/30/91	13.90		0.081	0.061	0.020			3.00
RM 20	ODF	08/13/91	12.70	7.57	0.047	0.063				7.00
RM 20	ODF	08/27/91	15.60		0.069	0.064	0.005			2.40
RM 20	ODF	09/10/91	11.50	7.13	0.076	0.061	0.015			2.40
RM 20	ODF	09/26/91	13.90		0.087	0.067	0.020			5.40
RM 20	ODF	10/10/91	10.00		0.084	0.066	0.018			1.80
RM 20	ODF	10/24/91	9.40		0.084	0.066	0.018			9.20
MEAN			11.24	7.09	0.064	0.053	0.013			3.61
MIN			7.80	6.47	0.040	0.035	0.002			1.80
MAX			15.60	7.80	0.087	0.067	0.020			9.20
STDEV			2.27	0.45	0.016	0.012	0.006			2.13
COUNT			13.00	7.00	13.000	13.000	12.000			13.00

Data-East Fk. Dairy '91

Site	Source	Date	Temp-C	pH	TP	SP	PP	TS	TDS	TSS
RM 16.8	ODF	05/08/91	9.50	7.86	0.044	0.036	0.008			3.20
RM 16.8	ODF	05/21/91	9.20			0.041				3.80
RM 16.8	ODF	06/04/91	7.20	7.10	0.052	0.042	0.010			3.70
RM 16.8	ODF	06/18/91	8.80	6.88	0.068	0.038	0.030			2.60
RM 16.8	ODF	07/02/91	11.60	6.54	0.063	0.043	0.020			3.20
RM 16.8	ODF	07/16/91	11.30	6.58	0.054	0.045	0.009			2.40
RM 16.8	ODF	07/30/91	12.20		0.070	0.052	0.018			3.80
RM 16.8	ODF	08/13/91	11.50	7.56	0.065	0.052	0.013			4.40
RM 16.8	ODF	08/27/91			0.076	0.052	0.024			3.20
RM 16.8	ODF	09/10/91	10.60	6.92	0.063	0.049	0.014			1.00
RM 16.8	ODF	09/26/91	12.20		0.064	0.054	0.010			3.00
RM 16.8	ODF	10/10/91			0.065	0.049	0.016			0.80
RM 16.8	ODF	10/24/91			0.064	0.057	0.007			9.80
MEAN			10.41	7.06	0.062	0.047	0.015			3.45
MIN			7.20	6.54	0.044	0.036	0.007			0.80
MAX			12.20	7.86	0.076	0.057	0.030			9.80
STDEV			1.58	0.45	0.008	0.006	0.007			2.09
COUNT			10.00	7.00	12.000	13.000	12.000			13.00

Data-East Fk. Dairy '91

Site	Source	Date	Temp-C	pH	TP	SP	PP	TS	TDS	TSS
RM 8.4	USA	06/06/91	11.00	7.30	0.042	0.018	0.024	86.00	81.00	4.76
RM 8.4	USA	06/20/91	11.00	7.40	0.034	0.024	0.010	90.00	81.00	9.16
RM 8.4	USA	06/27/91	11.00	7.40	0.035	0.022	0.013	76.00	66.00	10.20
RM 8.4	USA	07/11/91	15.00	7.30	0.056	0.027	0.029	84.00	80.00	3.68
RM 8.4	USA	07/25/91	15.00	7.50	0.080	0.032	0.048	54.00	53.00	1.38
RM 8.4	USA	08/08/91	17.00	7.50	0.060	0.029	0.031	70.00	57.00	12.90
RM 8.4	USA	08/22/91	18.00	7.50	0.073	0.030	0.043	118.00	110.00	8.36
RM 8.4	USA	09/05/91	16.00	7.40	0.054	0.043	0.011	84.00	76.00	7.96
RM 8.4	USA	09/19/91	16.00	7.50	0.069	0.044	0.025	72.00	61.00	10.70
RM 8.4	USA	10/03/91	12.00	7.20	0.189	0.024	0.165	110.00	49.00	61.10
RM 8.4	USA	10/17/91	10.00	7.50	0.122	0.032	0.090	114.00	97.00	17.40
RM 8.4	USA	10/31/91	4.00	7.30	0.060	0.016	0.044	94.00	74.00	20.20
MEAN			13.00	7.40	0.073	0.028	0.044	87.67	73.75	13.98
MIN			4.00	7.20	0.034	0.016	0.010	54.00	49.00	1.38
MAX			18.00	7.50	0.189	0.044	0.165	118.00	110.00	61.10
STDEV			3.76	0.10	0.042	0.008	0.042	18.29	17.20	15.10
COUNT			12.00	12.00	12.000	12.000	12.000	12.00	12.00	12.00

Data-East Fk. Dairy '91

Site	Source	Date	Temp-C	pH	TP	SP	PP	TS	TDS	TSS
RM 1.4	USA	05/09/91	7.00	7.40	0.066	0.022	0.044	92.00	78.30	13.70
RM 1.4	USA	05/23/91	11.00	7.30	0.062	0.016	0.046	84.00	73.00	11.00
RM 1.4	USA	06/06/91	11.00	7.40	0.022	0.021	0.001	108.00	106.00	2.00
RM 1.4	USA	06/20/91	11.00	7.30	0.099	0.027	0.072	90.00	78.00	12.20
RM 1.4	USA	06/27/91	12.00	7.30	0.048	0.025	0.023	98.00	87.00	11.10
RM 1.4	USA	07/11/91	14.00	7.20	0.064	0.043	0.021	82.00	74.00	8.00
RM 1.4	USA	07/25/91	16.00	7.30	0.044	0.038	0.006	76.00	68.00	7.88
RM 1.4	USA	08/08/91	17.00	7.50	0.050	0.033	0.017	58.00	56.00	1.84
RM 1.4	USA	08/22/91	18.00	7.20	0.062	0.041	0.021	148.00	142.00	5.88
RM 1.4	USA	09/05/91	16.00	7.50	0.068	0.050	0.018	86.00	80.00	6.36
RM 1.4	USA	09/19/91	16.00	7.60	0.094	0.046	0.048	66.00	61.00	5.12
RM 1.4	USA	10/03/91	11.00	7.40	0.170	0.030	0.140	66.00	59.00	6.68
RM 1.4	USA	10/17/91	9.00	7.40	0.134	0.031	0.103	104.00	102.00	1.84
RM 1.4	USA	10/31/91	5.00	7.20	0.048	0.020	0.028	76.00	76.00	0.02
MEAN			12.43	7.36	0.074	0.032	0.042	88.14	81.45	6.69
MIN			5.00	7.20	0.022	0.016	0.001	58.00	56.00	0.02
MAX			18.00	7.60	0.170	0.050	0.140	148.00	142.00	13.70
STDEV			3.76	0.12	0.038	0.010	0.038	21.69	21.80	4.12
COUNT			14.00	14.00	14.000	14.000	14.000	14.00	14.00	14.00

Data-Council '90

Site	Source	Date	Temp-C	pH	TP	SP	PP	TS	TDS	TSS
RM 5.0	USA	5/23/90	15.000	7.300	0.110	0.011	0.099	98.000	80.200	17.800
RM 5.0	USA	6/6/90	17.000	7.200	0.120	0.076	0.044	120.000	119.000	1.440
RM 5.0	USA	6/20/90	16.000	7.300	0.146	0.076	0.070	152.000	150.000	1.800
RM 5.0	USA	7/11/90		7.300	0.130	0.071	0.059	158.000	153.000	4.940
RM 5.0	USA	7/18/90	11.000	7.500	0.450	0.057	0.393	1130.000	1090.000	42.300
RM 5.0	USA	8/1/90	15.000	7.300	0.240	0.023	0.217	196.000	164.000	32.200
RM 5.0	USA	8/15/90	16.000	7.300	0.410	0.044	0.366	194.000	162.000	32.400
RM 5.0	USA	10/10/90		7.400	0.065	0.013	0.052	48.000	32.000	15.800
RM 5.0	USA	10/24/90	10.000	6.800	0.172	0.079	0.093	86.000	83.700	2.320
MEAN			12.500	7.267	0.205	0.050	0.155	242.444	225.989	16.778
MIN			10.000	6.800	0.065	0.011	0.044	48.000	32.000	1.440
MAX			17.000	7.500	0.450	0.079	0.393	1130.000	1090.000	42.300
STDEV			2.491	0.183	0.129	0.027	0.130	317.229	308.425	14.697
COUNT			7.000	9.000	9.000	9.000	9.000	9.000	9.000	9.000

Data-Council '90

Site	Source	Date	Temp-C	pH	TP	SP	PP	TS	TDS	TSS
RM 0.9	USA	5/7/90	12.00	7.40	0.110	0.055	0.055	154.00	152.00	2.46
RM 0.9	USA	5/14/90	10.00	7.40	0.145	0.041	0.104	232.00	175.00	56.60
RM 0.9	USA	5/23/90	14.00	7.40	0.190	0.069	0.121	158.00	156.00	2.20
RM 0.9	USA	5/29/90	14.40	7.40	0.128	0.020	0.108	142.00	141.00	1.24
RM 0.9	USA	6/6/90	14.00	7.30	0.105	0.038	0.067	164.00	162.00	1.86
RM 0.9	USA	6/11/90	14.00	7.30	0.124	0.055	0.069	146.00	145.00	1.34
RM 0.9	USA	6/20/90	17.00	7.40	0.114	0.043	0.071	220.00	214.00	6.12
RM 0.9	USA	6/25/90	16.40	7.40	0.104	0.024	0.080	196.00	192.00	3.60
RM 0.9	USA	7/11/90		7.20	0.144	0.023	0.121	246.00	221.00	25.30
RM 0.9	USA	7/18/90	16.00	7.40	0.270	0.025	0.245	254.00	236.00	18.40
RM 0.9	USA	7/23/90	16.60	7.50	0.180	0.025	0.155	284.00	219.00	64.80
RM 0.9	USA	8/1/90	17.00	7.40	0.250	0.014	0.236	260.00	251.00	8.96
RM 0.9	USA	8/6/90	16.80	7.00	0.504	0.015	0.489	334.00	216.00	118.00
RM 0.9	USA	8/15/90	17.00	7.30	0.418	0.009	0.409	324.00	286.00	37.60
RM 0.9	USA	8/20/90	16.80	7.20	0.340	0.044	0.296	264.00	236.00	28.30
RM 0.9	USA	8/29/90	10.00	7.50	0.800	0.014	0.786	738.00	590.00	148.00

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Data-Council '90

RM 0.9	USA	9/4/90	15.60	7.40	0.274	0.054	0.220	220.00	210.00	10.30
RM 0.9	USA	9/12/90	15.00	7.30	0.490	0.016	0.474	364.00	248.00	116.00
RM 0.9	USA	9/17/90	14.90	7.30	0.290	0.050	0.240	216.00	210.00	5.92
RM 0.9	USA	9/26/90	15.00	7.20	0.444	0.039	0.405	322.00	247.00	74.80
RM 0.9	USA	10/1/90	13.30	7.40	0.322	0.045	0.277	230.00	209.00	21.40
RM 0.9	USA	10/10/90	10.00	7.10	2.700	0.036	2.664	280.00	230.00	49.60
RM 0.9	USA	10/15/90	11.40	7.50	4.200	0.030	4.170	300.00	225.00	75.30
RM 0.9	USA	10/24/90	9.00	7.10	1.900	0.120	1.780	372.00	330.00	41.50
RM 0.9	USA	10/29/90	9.60	7.20	1.960	0.202	1.758	286.00	262.00	24.40
MEAN			13.99	7.32	0.660	0.044	0.616	268.24	230.52	37.76
MIN			9.00	7.00	0.104	0.009	0.055	142.00	141.00	1.24
MAX			17.00	7.50	4.200	0.202	4.170	738.00	590.00	148.00
STDEV			2.65	0.13	0.973	0.039	0.962	115.89	85.46	40.51
COUNT			24.00	25.00	25.000	25.000	25.000	25.00	25.00	25.00

Data-McKay '90

Site	Source	Date	Temp-C	pH	TP	SP	PP	TS	TDS	TSS
RM 8	USA	05/23/90	13.00	7.60	0.060	0.011	0.049	84.00	80.00	4.00
RM 8	USA	06/06/90	14.00	7.50	0.062	0.012	0.050	74.00	67.30	6.70
RM 8	USA	06/20/90	16.00	7.50	0.090	0.015	0.075	108.00	99.10	8.92
RM 8	USA	07/11/90		7.40	0.080	0.023	0.057	100.00	93.20	6.80
RM 8	USA	07/18/90	16.00	7.70	0.138	0.036	0.102	100.00	96.00	4.04
RM 8	USA	08/01/90	18.00	7.50	0.104	0.018	0.086	124.00	118.00	5.76
RM 8	USA	08/15/90	18.00	7.30	0.552	0.130	0.422	166.00	153.00	12.70
RM 8	USA	08/29/90	17.00	7.50	0.114	0.059	0.055	92.00	87.90	4.12
RM 8	USA	09/12/90	16.00	7.60			0.000	116.00	114.00	1.76
RM 8	USA	09/26/90	15.00	7.30	0.110	0.038	0.072	116.00	110.00	5.84
RM 8	USA	10/10/90	9.00	7.50	0.128	0.023	0.105	94.00	90.00	4.16
RM 8	USA	10/24/90	8.00	7.40	0.114	0.013	0.101	120.00	117.00	2.52
MEAN			14.55	7.48	0.141	0.034	0.098	107.83	102.13	5.61
MIN			8.00	7.30	0.060	0.011	0.000	74.00	67.30	1.76
MAX			18.00	7.70	0.552	0.130	0.422	166.00	153.00	12.70
STDEV			3.20	0.11	0.132	0.033	0.102	22.74	21.30	2.85
COUNT			11.00	12.00	11.000	11.000	12.000	12.00	12.00	12.00

Data-McKay '90

Site	Source	Date	Temp-C	pH	TP	SP	PP	TS	TDS	TSS
RM 2	USA	05/07/90	11.00	7.50	0.050	0.029	0.021	76.00	71.80	4.22
RM 2	USA	05/14/90	10.00	7.60	0.070	0.038	0.032	106.00	102.00	4.30
RM 2	USA	05/23/90	14.00	7.60	0.084	0.033	0.051	100.00	95.50	4.50
RM 2	USA	05/29/90	13.40	7.50	0.110	0.009	0.101	82.00	72.90	9.06
RM 2	USA	06/06/90	14.00	7.60	0.069	0.022	0.047	88.00	81.80	6.18
RM 2	USA	06/11/90	12.60	7.60	0.080	0.022	0.058	78.00	70.00	7.84
RM 2	USA	06/20/90	16.00	7.60	0.102	0.032	0.070	104.00	98.80	5.20
RM 2	USA	06/25/90	17.20	7.60	0.080	0.037	0.043	88.00	77.80	10.20
RM 2	USA	07/11/90		7.60	0.098	0.071	0.027	124.00	112.00	12.00
RM 2	USA	07/18/90	18.00	7.60	0.120	0.100	0.020	122.00	117.00	5.20
RM 2	USA	07/23/90	19.40	7.70	0.129	0.100	0.029	118.00	110.00	7.96
RM 2	USA	08/01/90	17.00	7.70	0.160	0.077	0.083	144.00	138.00	6.04
RM 2	USA	08/06/90	19.80	7.70	0.139	0.061	0.078	134.00	125.00	8.88
RM 2	USA	08/15/90	18.00	7.70	0.202	0.060	0.142	174.00	165.00	8.72
RM 2	USA	08/20/90	18.10	7.60	0.141	0.064	0.077	150.00	132.00	18.10
RM 2	USA	08/29/90	17.00	7.70	0.122	0.074	0.048	120.00	113.00	6.76

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Data-McKay '90

RM 2	USA	09/04/90	17.00	7.60	0.148	0.098	0.050	104.00	98.00	5.56
RM 2	USA	09/12/90	16.00	7.70	0.158	0.088	0.070	134.00	129.00	5.04
RM 2	USA	09/17/90	15.50	7.50	0.180	0.110	0.070	122.00	114.00	7.96
RM 2	USA	09/26/90	15.00	7.40	0.160	0.079	0.081	128.00	122.00	6.12
RM 2	USA	10/01/90	13.70	7.50	0.121	0.087	0.034	128.00	125.00	3.36
RM 2	USA	10/10/90	10.00	7.40	0.152	0.067	0.085	120.00	117.00	3.16
RM 2	USA	10/15/90	11.40	7.60	0.180	0.063	0.117	108.00	105.00	2.84
RM 2	USA	10/24/90	9.00	7.40	0.170	0.035	0.135	130.00	126.00	3.88
RM 2	USA	10/29/90	9.70	7.40	0.170	0.050	0.120	110.00	106.00	3.68
MEAN			14.70	7.58	0.128	0.060	0.068	115.68	108.98	6.67
MIN			9.00	7.40	0.050	0.009	0.020	76.00	70.00	2.84
MAX			19.80	7.70	0.202	0.110	0.142	174.00	165.00	18.10
STDEV			3.18	0.10	0.040	0.028	0.034	22.91	22.32	3.29
COUNT			24.00	25.00	26.000	25.000	25.000	25.00	25.00	25.00

Data-McKay '91

Site	Source	Date	Temp-C	pH	TP	SP	PP	TS	TDS	TSS
RM 30	ODF	05/08/91	8.50	7.53	0.038	0.009	0.029			21.60
RM 30	ODF	05/21/91	8.30		0.014	0.011	0.003			10.00
RM 30	ODF	06/04/91	6.70	6.50	0.013	0.011	0.002			1.70
RM 30	ODF	06/18/91	8.40	7.51	0.015	0.013	0.002			1.00
RM 30	ODF	07/02/91	10.20	6.99	0.013	0.007	0.006			6.00
RM 30	ODF	07/16/91	10.80	6.19	0.015	0.007	0.008			20.20
RM 30	ODF	07/30/91	11.70		0.022	0.009	0.013			1.80
RM 30	ODF	08/13/91	13.00	7.14	0.013	0.010	0.003			2.00
RM 30	ODF	08/27/91	12.20		0.019	0.010	0.009			8.00
RM 30	ODF	09/10/91	11.00	6.71	0.021	0.007	0.014			1.60
RM 30	ODF	09/26/91	12.80		0.020	0.008	0.012			6.80
RM 30	ODF	10/10/91	10.00		0.020	0.013	0.007			5.30
RM 30	ODF	10/24/91	9.40		0.023	0.010	0.013			4.00
MEAN			10.23	6.94	0.019	0.010	0.009			6.92
MIN			6.70	6.19	0.013	0.007	0.002			1.00
MAX			13.00	7.53	0.038	0.013	0.029			21.60
STDEV			1.85	0.47	0.007	0.002	0.007			6.54
COUNT			13.00	7.00	13.000	13.000	13.000			13.00

Data-McKay '91

Site	Source	Date	Temp-C	pH	TP	SP	PP	TS	TDS	TSS
RM 16	USA	7/11/91		7.30	0.050	0.020	0.030	84.00	83.00	0.60
RM 16	USA	7/25/91	15.00	7.50	0.013	0.027		66.00	66.00	0.48
RM 16	USA	08/08/91	16.00	7.50	0.020	0.020	0.000	64.00	63.00	0.74
RM 16	USA	08/22/91	16.00	7.90	0.200	0.099	0.101	170.00	166.00	4.40
RM 16	USA	09/05/91		7.40	0.027	0.034		80.00	76.00	3.64
RM 16	USA	09/19/91	14.00	7.60	0.061	0.031	0.030	72.00	69.00	2.94
RM 16	USA	10/03/91	10.00	7.40	0.157	0.018	0.139	82.00	65.00	16.70
RM 16	USA	10/17/91	8.00	7.60	0.155	0.022	0.133	106.00	103.00	2.96
RM 16	USA	10/31/91	4.00	7.30	0.068	0.011	0.057	80.00	78.00	1.74
MEAN			11.86	7.50	0.083	0.031	0.070	89.33	85.44	3.80
MIN			4.00	7.30	0.013	0.011	0.000	64.00	63.00	0.48
MAX			16.00	7.90	0.200	0.099	0.139	170.00	166.00	16.70
STDEV			4.29	0.18	0.065	0.025	0.051	30.78	30.76	4.75
COUNT			7.00	9.00	9.000	9.000	7.000	9.00	9.00	9.00

Data-McKay '91

Site	Source	Date	Temp-C	pH	TP	SP	PP	TS	TDS	TSS
RM 2	USA	05/09/91	9.00	7.50	0.068	0.023	0.045	106.00	103.00	2.92
RM 2	USA	05/23/91	10.00	7.00	0.059	0.020	0.039	96.00	92.10	3.94
RM 2	USA	06/06/91	12.00	7.50	0.056	0.027	0.029	124.00	122.00	1.68
RM 2	USA	06/20/91	12.00	7.30	0.034	0.043		124.00	112.00	12.10
RM 2	USA	06/27/91	12.00	7.00	0.108	0.040	0.068	100.00	97.00	2.72
RM 2	USA	7/11/91	16.00	7.30	0.079	0.054	0.025	118.00	112.00	5.88
RM 2	USA	7/25/91	17.00	7.00	0.100	0.072	0.028	108.00	103.00	5.04
RM 2	USA	08/08/91	18.00	7.50	0.120	0.076	0.044	110.00	107.00	3.12
RM 2	USA	08/22/91	19.00	7.30	0.040	0.037	0.003	134.00	129.00	4.80
RM 2	USA	09/05/91	16.00	7.40	0.124	0.077	0.047	118.00	114.00	4.40
RM 2	USA	09/19/91	15.00	7.70	0.253	0.125	0.128	130.00	127.00	2.80
RM 2	USA	10/03/91	11.00	7.40	0.211	0.070	0.141	112.00	109.00	3.84
RM 2	USA	10/17/91	9.00	7.50	0.215	0.075	0.140	148.00	147.00	1.40
RM 2	USA	10/31/91	5.00	7.20	0.106	0.038	0.068	108.00	107.00	1.08
MEAN			12.93	7.33	0.112	0.056	0.062	116.86	112.94	3.98
MIN			5.00	7.00	0.034	0.020	0.003	96.00	92.10	1.08
MAX			19.00	7.70	0.253	0.125	0.141	148.00	147.00	12.10
STDEV			3.88	0.21	0.066	0.028	0.044	13.64	13.82	2.63
COUNT			14.00	14.00	14.000	14.000	13.000	14.00	14.00	14.00

Data-Tualatin '84

Site	Date	TP	SP	PP	TSS	TDS	Temp.	pH	Chlpyl-A	Flow	DO
RM 71.5	01/04/84	0.030	0.015	0.015	10.90	43.50	6.50	7.10	0.222	2278.267	13.5
	02/08/84	0.050	0.007	0.043	1.40	58.60	6.00	6.80	0.850	637.915	12.6
	03/07/84	0.066	0.021	0.045	2.50	62.10	6.00	6.80	0.780	1079.349	11.6
	04/04/84	0.069	0.007	0.062	1.90	57.90	7.00	6.70	4.930	827.286	10.8
	05/09/84	0.020	0.005	0.015	2.40	55.40	8.00	7.10	6.530	840.312	11.2
	06/06/84	0.086	0.010	0.076	4.40	62.40	9.50	6.80	0.690	662.475	10.6
	07/05/84	0.020	0.007	0.013	1.70	66.70	15.00	7.10	2.360	241.723	9.2
	08/08/84	0.040	0.005	0.035	0.80	58.40	15.50	7.20	0.400	155.116	10.0
	09/05/84	0.040	0.014	0.026	0.80	61.40	16.00	7.30	0.600	166.750	10.2
	10/03/84	0.030	0.007	0.023	0.60	59.80	11.00	7.30	0.400	147.360	11.2
	10/31/84	0.040	0.009	0.031	0.80	53.80	5.50	6.70	0.210	355.474	13.8
	12/05/84	0.050	0.030	0.020	3.70	53.30	3.50	6.80	0.290	3312.375	12.2
MEAN		0.045	0.011	0.034	2.66	57.77	9.13	6.98	1.522	892.034	11.4
MIN		0.020	0.005	0.013	0.60	43.50	3.50	6.70	0.210	147.360	9.2
MAX		0.086	0.030	0.076	10.90	66.70	16.00	7.30	6.530	3312.375	13.8
STDEV		0.020	0.008	0.020	2.86	5.90	4.30	0.23	2.076	966.406	1.4
COUNT		12.000	12.000	12.000	12.00	12.00	12.00	12.00	12.000	12.000	12.0

Data-Tualatin '85

Site	Date	TP	SP	PP	TSS	TDS	Temp.	pH	Chlpyl-A	Flow	DO
RM 71.5	01/02/85	0.040	0.020	0.020	2.22	46.38	2.00	6.80	0.900	2310.583	13.6
RM 71.5	02/06/85	0.030	0.007	0.023	0.00	52.80	1.50	6.70	1.500	326.390	14.0
RM 71.5	03/06/85	0.040	0.004	0.036	1.60	61.00	4.00	6.60	2.900	674.755	13.8
RM 71.5	04/03/85	0.030	0.007	0.023	4.50	47.90	6.50	7.30	3.000	2068.214	13.6
RM 71.5	05/08/85	0.040	0.009	0.031	0.90	50.50	7.00	7.20	1.600	312.171	11.6
RM 71.5	06/05/85	0.020	0.005	0.015	1.40	64.20	11.00	7.30	1.400	219.102	10.2
RM 71.5	07/10/85	0.040	0.020	0.020	0.82	72.40	16.00	7.29	1.800	136.727	10.4
RM 71.5	08/07/85	0.020	0.009	0.011	0.62	57.98	15.50	6.90	2.000	120.215	10.2
RM 71.5	10/09/85	0.122	0.015	0.107	0.34	68.30	5.00	6.90	1.000	83.375	10.6
RM 71.5	11/06/85	0.040	0.018	0.022	2.08	54.70	9.50	6.30	0.800	241.723	15.2
RM 71.5	12/04/85	0.028	0.015	0.013	3.62	47.80	1.50	6.80	1.100	542.906	11.6
RM 71.5	09/04/85	0.118	0.007	0.111	0.76	83.00	13.00	7.40		135.727	13.4
MEAN		0.047	0.011	0.036	1.57	58.91	7.71	6.96	1.636	597.657	12.4
MIN		0.020	0.004	0.011	0.00	46.38	1.50	6.30	0.800	83.375	10.2
MAX		0.122	0.020	0.111	4.50	83.00	16.00	7.40	3.000	2310.583	15.2
STDEV		0.035	0.006	0.035	1.35	11.33	5.26	0.34	0.750	765.681	1.8
COUNT		12.000	12.000	12.000	12.00	12.00	12.00	12.00	11.000	12.000	12.0

Data-Gales '90

Site	Source	Date	Temp-C	pH	TP	SP	PP	TS	TDS	TSS
RM 1.5	USA	01/02/90	5.00		0.070	0.019	0.051	100.00	96.00	4.40
RM 1.5	USA	02/05/90	6.00		0.110	0.022	0.088	112.00	67.20	44.80
RM 1.5	USA	03/05/90	6.50		0.048	0.021	0.027	92.00	73.60	18.40
RM 1.5	USA	04/02/90	11.00		0.050	0.007	0.043	100.00	92.60	7.40
RM 1.5	USA	05/07/90	11.00		0.022	0.016	0.006	60.00	55.60	4.36
RM 1.5	USA	05/14/90	10.00		0.042	0.018	0.024	106.00	102.00	3.72
RM 1.5	USA	05/23/90	11.00		0.068	0.077		96.00	88.50	7.50
RM 1.5	USA	05/29/90	13.10		0.074	0.012	0.062	92.00	80.70	11.30
RM 1.5	USA	06/06/90	13.00		0.045	0.011	0.034	98.00	94.40	3.62
RM 1.5	USA	06/11/90	12.40		0.060	0.013	0.047	92.00	82.70	9.34
RM 1.5	USA	06/20/90	17.00		0.070	0.014	0.056	144.00	137.00	7.48
RM 1.5	USA	06/25/90	17.20		0.073	0.020	0.053	100.00	95.00	5.44
RM 1.5	USA	07/11/90	21.00		0.104	0.020	0.084	234.00	110.00	124.00
RM 1.5	USA	07/18/90	18.00		0.144	0.030	0.114	122.00	117.00	4.60
RM 1.5	USA	07/23/90	20.70		0.058	0.028	0.030	118.00	113.00	4.56
RM 1.5	USA	08/01/90	19.00		0.077	0.019	0.058	106.00	88.00	17.60
RM 1.5	USA	08/06/90	20.40		0.031	0.021	0.010	122.00	117.00	5.28
RM 1.5	USA	08/15/90	16.00		0.063	0.020	0.043	134.00	131.00	3.36
RM 1.5	USA	08/20/90	18.60		0.051	0.021	0.030	94.00	90.70	3.28
RM 1.5	USA	08/29/90	14.40		0.090	0.024	0.066	118.00	110.00	8.12
RM 1.5	USA	09/04/90	17.80		0.072	0.025	0.047	102.00	98.00	4.36
RM 1.5	USA	09/12/90	17.00		0.060	0.021	0.039	140.00	137.00	3.16
RM 1.5	USA	09/17/90	16.30		0.060	0.024	0.036	120.00	114.00	6.16
RM 1.5	USA	09/26/90			0.054	0.022	0.032	128.00	122.00	5.56

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Data-Gales '90

Site	Source	Date	Temp-C	pH	TP	SP	PP	TS	TDS	TSS
RM 1.5	USA	10/01/90	14.70		0.048	0.023	0.025	124.00	119.00	4.64
RM 1.5	USA	10/10/90	10.00		0.050	0.017	0.033	118.00	115.00	3.20
RM 1.5	USA	10/15/90	11.70		0.158	0.015	0.143	112.00	109.00	3.48
RM 1.5	USA	10/24/90	8.00		0.052	0.008	0.044	126.00	120.00	6.12
RM 1.5	USA	10/29/90	9.60		0.036	0.009	0.027	92.00	89.60	2.40
RM 1.5	USA	11/05/90	8.70		0.026	0.008	0.018	92.00	90.80	1.16
RM 1.5	USA	11/12/90	9.30		0.028	0.007	0.021	102.00	101.00	0.80
RM 1.5	USA	12/10/90	8.50		0.060	0.009	0.051	86.00	78.40	7.64
MEAN			13.32		0.064	0.019	0.047	111.94	101.12	10.85
MIN			5.00		0.022	0.007	0.006	60.00	55.60	0.80
MAX			21.00		0.158	0.077	0.143	234.00	137.00	124.00
STDEV			4.55		0.030	0.012	0.029	27.95	19.31	21.75
COUNT			32.00		33.000	33.000	32.000	33.00	33.00	33.00

Data-Gales '91

Site	Source	Date	Temp-C	pH	TP	SP	PP	TS	TDS	TSS
RM 1.5	USA	01/07/91	2.00		0.062	0.013	0.049	96.00	92.60	3.44
RM 1.5	USA	02/04/91	7.90		0.110	0.011	0.099	120.00	58.30	61.70
RM 1.5	USA	02/21/91	7.70		0.093	0.011	0.082	112.00	76.80	35.20
RM 1.5	USA	03/04/91	7.60		0.121	0.012	0.109	126.00	61.30	64.70
RM 1.5	USA	04/01/91	9.40		0.035	0.014	0.021	62.00	55.10	6.88
RM 1.5	USA	05/06/91	11.80			0.049		102.00	92.90	9.12
RM 1.5	USA	05/09/91	9.00		0.049	0.015	0.034	102.00	95.80	6.24
RM 1.5	USA	05/13/91	10.70		0.055	0.010	0.045	94.00	89.60	4.44
RM 1.5	USA	05/20/91	10.80		0.040	0.012	0.028	82.00	71.90	10.10
RM 1.5	USA	05/23/91	12.00		0.055	0.008	0.047	102.00	97.40	4.60
RM 1.5	USA	05/28/91	11.80		0.020	0.010	0.010	90.00	86.80	3.16
RM 1.5	USA	06/03/91	12.40		0.030	0.005	0.025	94.00	90.00	3.60
RM 1.5	USA	06/06/91	13.20		0.015	0.011	0.004	116.00	113.00	2.60
RM 1.5	USA	06/10/91	16.20		0.029	0.009	0.020	78.00	73.00	4.72
RM 1.5	USA	06/17/91	12.70		0.022	0.017	0.005	80.00	77.00	3.44
RM 1.5	USA	06/20/91	13.50		0.020	0.019	0.001	110.00	103.00	7.28
RM 1.5	USA	06/24/91	13.60		0.010	0.022		90.00	86.00	3.64
RM 1.5	USA	06/27/91	14.00		0.020	0.018	0.002	96.00	95.00	1.36
RM 1.5	USA	07/01/91	14.90		0.043	0.023	0.020	102.00	99.00	2.96

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Data-Gales '91

RM 1.5	USA	07/08/91	18.80	0.030	0.031		114.00	111.00	3.16
RM 1.5	USA	07/11/91	18.75	0.026	0.024	0.002	106.00	101.00	5.28
RM 1.5	USA	07/15/91	18.00	0.029	0.015	0.014	116.00	113.00	3.16
RM 1.5	USA	07/22/91	19.80	0.027	0.023	0.004	108.00	104.00	3.72
RM 1.5	USA	07/25/91	19.00	0.054	0.031	0.023	94.00	92.00	1.72
RM 1.5	USA	07/29/91	19.50	0.028	0.021	0.007	102.00	100.00	1.80
RM 1.5	USA	08/05/91	19.30	0.043	0.023	0.020	124.00	121.00	2.52
RM 1.5	USA	08/08/91	19.75	0.035	0.021	0.014	100.00	97.00	2.96
RM 1.5	USA	08/12/91	18.10	0.030	0.029	0.001	100.00	98.00	1.92
RM 1.5	USA	08/19/91	21.20	0.045	0.028	0.017	100.00	97.00	2.72
RM 1.5	USA	08/22/91	20.80	0.056	0.023	0.033	186.00	180.00	5.84
RM 1.5	USA	08/26/91	16.00	0.064	0.020	0.044	112.00	110.00	1.64
RM 1.5	USA	09/05/91	19.80	0.256	0.080	0.176	210.00	204.00	6.00
RM 1.5	USA	09/09/91	15.90	0.035	0.031	0.004	100.00	97.00	2.76
RM 1.5	USA	09/16/91	16.30	0.038	0.033	0.005	114.00	112.00	2.28
RM 1.5	USA	09/19/91	20.00	0.067	0.037	0.030	110.00	107.00	3.28
RM 1.5	USA	09/23/91	14.80	0.030	0.022	0.008	122.00	119.00	3.08
RM 1.5	USA	09/30/91	15.20	0.030	0.028	0.002	116.00	113.00	3.20
RM 1.5	USA	10/03/91	15.00	0.125	0.021	0.104	108.00	104.00	3.84
RM 1.5	USA	10/07/91	13.10	0.020	0.024		114.00	112.00	2.12

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Data-Gales '91

RM 1.5	USA	10/14/91	12.60	0.029	0.032		138.00	129.00	9.12
RM 1.5	USA	10/17/91	11.00	0.117	0.031	0.086	150.00	144.00	5.96
RM 1.5	USA	10/21/91	12.30	0.020	0.023		120.00	116.00	3.92
RM 1.5	USA	10/28/91	7.20	0.030	0.016	0.014	104.00	103.00	0.84
RM 1.5	USA	10/31/89	5.50	0.056	0.015	0.041	112.00	111.00	1.22
RM 1.5	USA	11/06/91	8.60	0.018	0.028		104.00	102.00	1.70
RM 1.5	USA	11/13/91	10.90	0.010	0.019		98.00	96.00	1.80
RM 1.5	USA	11/20/91	9.00	0.090	0.018	0.072	180.00	93.00	87.00
RM 1.5	USA	11/26/91	8.40	0.100	0.010	0.090	76.00	61.00	15.40
RM 1.5	USA	12/04/91	6.90	0.058	0.016	0.042	84.00	81.00	2.90
RM 1.5	USA	12/11/91	6.10	0.012	0.019		92.00	79.00	13.00
RM 1.5	USA	12/18/91	4.80	0.015	0.016		70.00	66.00	4.14
MEAN			13.21	0.049	0.022	0.035	108.59	99.75	8.81
MIN			2.00	0.010	0.005	0.001	62.00	55.10	0.84
MAX			21.20	0.256	0.080	0.176	210.00	204.00	87.00
STDEV			4.77	0.042	0.012	0.038	26.42	26.01	16.64
EV/MEAN			0.36	0.854	0.551	1.072	0.24	0.26	1.89
COUNT			51.00	52.000	51.000	41.000	51.00	51.00	51.00