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Runoff from agricultural lands into Upper Klamath Basin rivers and lakes can cause water quality problems affecting fish and wildlife. Excessive eutrophication in Upper Klamath Lake is linked to high nutrient input (particularly phosphorus) stemming from both lake sediments and watershed tributaries.

On a unit area load basis the Wood River Valley contributes a much greater load of phosphorus to Upper Klamath Lake than other regions. The purpose of this study was to measure the export of nutrients from flood irrigated cattle pasture in the Wood River Valley to; 1) compare irrigation water quality with background sources, 2) determine the sources and transport mechanisms of sediment and nutrients on flood irrigated pastures and 3) consider opportunities for water quality improvement.

Subsurface and surface water quality samples and water flow measurements were taken on two flood irrigated and grazed pastures. Limited samples were also collected at two additional pasture sites and during a storm. Water samples were analyzed for concentrations of sediment, dissolved organic carbon (DOC), total dissolved nitrogen (TDN), total dissolved phosphorus (TDP), orthophosphate (OP), ammonia (NH_4^+-N) and nitrate (NO_3^--N). Nutrient and sediment loads were calculated and flow weighted concentrations were compared. A nutrient and sediment budget was estimated during two irrigations.

On a 70 ha study plot, the TDP and TDN concentrations were highest when cattle were causing disturbance in actively flowing irrigation ditches which had mean values of 0.50 mg TDP L^{-1} and 2.55 mg TDN L^{-1}. When cattle were not present the dissolved nutrient concentrations in tailwater ditches were lower with mean values of 0.07 mg TDP L^{-1} and 0.85 mg TDN L^{-1}. An irrigation headwater canal had a seasonal flow weighted concentration (FWC) of 0.03 mg TDP L^{-1} and 0.22 mg TDN L^{-1} while seasonal FWC for tailwater ditches was 0.84 mg TDN L^{-1} and 0.06 mg TDP L^{-1}.

On a 2 ha study plot, irrigation tailwater samples were collected directly from pasture runoff. DOC, TDN, TDP and OP concentrations were 2.8, 6.3, 2.8 and 3.2 times greater, respectively, in tailwater than in headwater. A first flush was evident as greatest dissolved nutrient concentrations occurred early in the irrigation runoff period. The mean net export for two irrigations was 24 kg sediment ha^{-1}, 7.4 kg DOC ha^{-1}, 0.43 kg TDN ha^{-1} and net accumulation of 0.02 kg TDP ha^{-1}. TDN and DOC export progressively decreased during runoff but showed significant net export throughout the entire irrigation. TDP was more variable with an export rate of 0.2 kg TDP ha^{-1} during the first flush followed by insignificant export and accumulation later during the irrigation runoff period. Most dissolved-N in surface water was in the organic form, NH_4^+-N was low and NO_3^--N was undetected. Sediment concentration in irrigation runoff did not follow the first flush pattern and was dependent on original background levels or on cattle disturbance.

Shallow groundwater had low mean concentrations of TDP ($\leq$ 0.06 mg TDP L^{-1}) and high mean concentrations of dissolved-N (0.65 mg TDN L^{-1} and 0.13 mg NH_4^+-N L^{-1}). Stormwater runoff flow volume was low from the 2 ha pasture and contained low sediment and high dissolved nutrient concentrations.

Cattle disturbance to canals and nutrient flushing during irrigation were important transport mechanisms for all nutrients. Management considerations for decreasing nutrient export to sensitive waterways in the Wood River Valley include reducing irrigation surface runoff, enhancement of riparian wetlands and vegetation and limiting and excluding livestock access to waterways.

Water Quality of Runoff from Flood Irrigated Pasture in the Klamath Basin, Oregon

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WATER QUALITY OF RUNOFF FROM FLOOD IRRIGATED PASTURE IN THE KLAMATH BASIN, OREGON

INTRODUCTION

The transport of nutrients and soil from agricultural land to surface waters is a national environmental concern. USEPA (1996) found that eutrophication is a critical problem in most surface waters with impaired water quality and that agriculture is the source of nutrients for 50% of lakes and 60% of rivers with impaired water quality. Watershed management requires that a distinction be made between natural and anthropogenic nutrient sources and identification of the amounts and types of nutrients being exported from an agricultural catchment (Nelson, 1996).

For many years Upper Klamath Lake in southern Oregon has experienced excessive algal growth and nutrient enrichment. While Upper Klamath Lake would have been considered eutrophic over 100 year ago, settlement of the drainage and modern land uses including wetland drainage and agricultural discharge to the lake may have accelerated the lakes eutrophic status and impaired aquatic habitat (Snyder and Morace, 1997; and Gearheart et al. 1995). A decline in the populations of two of Upper Klamath Lake's native fish species, the Lost River (*Deltistes luxatus*) and shortnose sucker (*Chasmistes brevirostris*), led to their listing under the federal Endangered Species Act in 1988 (USFWS 1988).

Section 303d of the federal Clean Water Act requires that each state develop water quality standards to protect the beneficial uses of waterways within a state. The state must also develop a list of all the waterways that do not meet the water quality standards. Upper Klamath Lake sub basin was listed on the 1998 Oregon 303(d)1 list for: temperature, dissolved oxygen (DO), chlorophyll-a, pH, and habitat modification. Low DO concentrations and elevated pH are attributed to the cyanobacterium Aphanizomenon flos-aqaue (Kann and Smith 1993). The pollutant targeted in the Upper Klamath and Agency Lake TMDL is total phosphorus (TP). Reducing TP is the most practical way to attain the water quality standards for pH and dissolved oxygen and to reduce algal biomass (ODEQ 2002). Reducing total phosphorus by 40% is the target level for the Upper Klamath Lake TMDL (ODEQ 2002). Nitrogen (N) concentration is also considered a contributing nutrient to increased algal growth but phosphorus (P) reduction was shown to be the best long-term nutrient management option for controlling algal biomass in Klamath and Agency Lakes (Kann 1993; and Walker 1995).

Approximately 61% of the P loading in Upper Klamath Lake occurs by internal means when lake bottom sediments are regenerated and P is released into the water column (Kann and Walker 2001). External sources, which include surface and subsurface drainage, account for approximately 39% of the P load to Upper Klamath Lake (Walker 2001). The primary anthropogenic contributors to the external TP load, drained wetlands and agricultural land use, are estimated to be 47% of the total external load (ODEQ 2002). Snyder and Morace (1997) documented drained wetlands as a source of nutrients to Upper Klamath Lake. Wetland drainage accelerates aerobic decomposition of peat soils; nutrients are leached into drainage canals and are pumped into Klamath Lake and its tributaries. An early nutrient loading study (Miller and Tash 1967) showed agricultural input from pumps and canals to account for 31% of the annual external (TP) budget for Upper Klamath Lake.

Agricultural drainage from properties adjacent to Upper Klamath Lake contributes to nutrient enrichment (Rykbost and Charlton 2001). Alternative watershed and land use management strategies could reduce TP enrichment to Upper Klamath Lake (Gearheart et al. 1995; Anderson 1998). Private landowners and conservation organizations are currently implementing irrigation and cattle management strategies in the Upper Klamath Basin that are intended to reduce nutrient export from agricultural lands.

The Wood River Valley, which empties into Agency Lake, is an important place to examine possibilities for reducing nutrient inputs to Upper Klamath Lake. While the Wood River Valley occupies only 5% of the area of the Upper Klamath Basin it holds 50% of the cattle and provides about 25% of the water feeding Agency and Upper Klamath Lakes. On a unit area load basis Sevenmile Creek, also located in the Wood River Valley, and the Wood River contribute a much greater load of P to Upper Klamath Lake than do the Williamson and Sprague Rivers (Kann and Walker 2001).

Previous studies have examined the relationship between water quality and land use in the Wood River Valley. Monitoring of canals and streams within the Wood River Valley by the Klamath Basin Rangeland Trust (KBRT) during the 2002 and 2003 growing seasons found an increase in TP, soluble reactive phosphorus (SRP) and total nitrogen (TN) from upstream to downstream sampling locations. West Canal which contains irrigation tailwater originating from Annie Creek, Sevenmile Creek and Wood River, had increased concentrations of TP, SRP and TN (Graham Mathews and Associates 2003).

The Bureau of Reclamation monitored nutrient loading in canals draining 705 ha of pasture in the Wood River Valley during a 1991 to 1993 study. They found there was a net export of TP and SRP five and four times out of 8 sampling events, respectively. Flood irrigated pastures in the Wood River Valley acted as both a source and sink for nutrients in irrigation water (Ehinger 1993).

These studies suggest a relationship between pasture runoff and water quality in the Wood River Valley. There remains uncertainty, however, as to specific source areas of nutrients, particularly the distinction between anthropogenic sources and background sources of P. There is also a need to understand how nutrients are transported from land to canals and waterways in the Wood River Valley. Specifically, a more focused assessment of water quality in relation to irrigation, cattle grazing and storms may provide data to help develop strategies for nutrient management in the Wood River Valley.

The objective of this research project was to examine the export of nutrients from irrigated and cattle grazed pastures in the Wood River Valley. To achieve this objective we monitored small pasture catchments (2 to 70 ha). Specific catchments were chosen because their topography was such that surface irrigation runoff did not mix with runoff from other fields. This approach allowed for a direct comparison between headwater and tailwater quality for individual irrigation events. The goal of the project was to answer these questions:

1. How does background water quality compare with irrigation tailwater quality?

2. What are the sources and transport mechanisms of sediment and nutrients on the flood irrigated pastures?

3. What opportunities are there for water quality improvement based on data results and observations of flood irrigation and cattle grazing practices?

Water flow and water quality were monitored on grazed pastures during 12 irrigation events in 2003 and 2004. Water samples were collected from pasture runoff, shallow groundwater wells, headwater and tailwater ditches and one storm event. Periodic observations of cattle during sampling were recorded. This information may be useful for identifying opportunities for reducing nutrient export from the Wood River Valley.

LITERATURE REVIEW

Grasslands

Many natural grasslands are productive pastures when sufficiently irrigated (Buol et al., 1989). The combination of irrigation with high concentrations of livestock on these lands, however, may impact the physical, chemical and biological properties of stream water (Gary et al., 1983). Determining the effects of irrigated and grazed pasture on water quality requires consideration of hydrology and nutrient cycling on grasslands. In doing this we must consider the impact that irrigation and livestock have on natural grassland systems. Nutrient enrichment problems in streams require a nutrient source and means of transport to a sensitive waterway (Sharpley et al., 2001). This section examines the fundamentals of nutrient cycling on grazed pastures, nutrient movement, and the potential consequences of nutrient loss from land to waterways.

Grassland soils and vegetation

Natural grasslands normally overlay deep, dark, and fertile soils with a mollic topsoil horizon or epipedon (Buol et al., 1989). The dominant soil-forming process in the formation of a mollic soil horizon is melanization or the darkening of the soil through additions of organic matter. The process specifically involves the extension of roots into the soil profile, partial decay of organic material, reworking of soil organic material by rodents, earthworms, ants and other organisms, and the formation of dark ligno proteins resistant to quick biological breakdown (Hole and Nielsen, 1970). Biological activity in grassland soil is greater than that found in forest soil (Telfair et al. 1957). Grassland soils contain many more earthworms than soils under cultivation, and although microbes play the major role in organic matter breakdown, earthworms are important in the early stages of decomposition. Death and decay of grass roots and shoots return large amounts of nutrients to grassland soils. Water movement in these soils is greatly influenced by tunnels and channels resulting from roots and organisms (Buol et al., 1989). Natural grasslands are often deficient in nutrients and conservative in their water use (Ripley and Sauger, 1978). Grassland pastures generally use more water than bare soils but less than forest systems (Rodda, 1976; Bosch and Hewett, 1982).

Livestock and grasslands

Before European settlement most of America's grasslands were occupied by various wild grazing animals that generally grazed at the carrying capacity of the natural grassland. If forage became scarce in an area the animals either migrated or died, bringing their population into balance with the carrying capacity of the range. By the 1930's livestock numbers in the US far exceeded the carrying capacity of many of the available ranges (Meehan and Williams, 1978). Rangeland management practices have greatly improved since the 1930's. Proper grazing techniques currently in use cause minimal or no damage to natural resources. Overgrazing continues to be a problem however, resulting in physical damage to grasslands. Overgrazing can increase soil erosion. Intense grazing can also reduce the vegetation cover and cause soil compaction leading to reduced infiltration (Rhoades et al., 1964; Gifford and Hawkins, 1978). Cattle management practices influence the vegetation cover and soil structure of grasslands and therefore have a great impact on the overall water balance of a pasture (Dunin, 1990).

A nutrient cycle involves the movement of a particular nutrient through the various pools in which it is found within the environment (Russelle, 1992). Nutrient cycling rates and pathways differ on natural and managed grasslands. These differences arise because of nutrient inputs and greater vegetative consumption due to increased livestock density. Animal excreta affect the spatial distribution and speed of nutrient cycling and can be a major factor lending to nutrient loss from a pasture (Titlyanova et al., 1990). The loss of phosphorus (P) and nitrogen (N) are of most concern since these are major nutrients contributing to water pollution (Mueller D.K., Helsel D.R). Carbon (C) enrichment also leads to water quality problems (Nelson, 1996). Since the cycling of these nutrients differs they will be discussed individually.

Nutrients and Pastureland

Organic matter and carbon

Briefly stated, the carbon cycle begins with photosynthesis and ends with decomposition. Photosynthesis utilizes carbon dioxide (CO_2), sunlight and water to create simple sugars. Plants and animals utilize the sugars for growth and activity. When plants and animals die they are decomposed by decay organisms and the C contained within the dead bodies may remain as soil organic matter, or may be released to the atmosphere in the form of CO_2 (Plaster, 1992).

The non-nitrogenous compounds which make up soil organic matter are comprised mostly of the plant cells cellulose and lignin. These plant cells break down at different rates. Cellulose is composed of glucose units bound together in long chains and is quickly and easily broken down by microorganisms (Evangelou, 1998). Lignin is more resistant to decomposition and serves to add rigidity to plant cell walls (Raven, 1992). When animal and plant tissues are broken down the C within them is utilized by microorganisms, transformed into other compounds or released to the atmosphere as CO_2. Oxidation of carbohydrates gives the organic material a black coloration and decreased volume since microbes have broken down the original cell structures. The resulting material is humus, made up of about 50% C, 5% N and 0.5% P (Plaster, 1992).

Nutrients are constantly being immobilized or mineralized within the soil at any given time. The balance between these two processes is highly dependent on the C:N ratio of the material being broken down. A C:N ratio of less than 25:1 in the soil will likely result in mineralization (Whitehead, 1986). The relative proportion of lignin to cellulose will also influence decomposition rate (Herman et al, 1977).

Significant amounts of C export from land to water can occur. Schepers and Francis (1982) found that grazing livestock increased total organic carbon by 11% in runoff waters as a result of increased soil erosion and production of animal wastes. Highly productive wetlands can also generate massive amounts of organic matter that enter lakes, primarily in a dissolved form (Kowalczewski 1978, Wetzel 1990, 1992).

Nitrogen

N goes through a series of cyclic pathways; it can exist as a gas, a dissolved cation or anion, a precipitated salt, and interlayer ion in clay, and dissolved or organic molecules (Russelle, 1992). Total nitrogen (TN) is a measure of all forms of N both inorganic and organic. Figure 1 shows the various pools and pathways of N on a typical pasture. Just as important as the size of the N pool is the flux of N from one pool to another. Soil organisms, including protozoa, amoebae and nematodes, where found to be the fastest N mineralizers. Bacteria were found to be slower mineralizers, but they were in greater numbers, and therefore had greater overall yearly rates of N mineralization (Hunt et al., 1987).

N in the atmosphere is 16,000 times more than the amount found in soils (Russelle, 1992). Grassland production depends greatly on the ability of bacteria to convert atmospheric-N (N_2) to proteins (Floate, 1990). Bacteria from the genus *Rhizobium* form a symbiotic relationship with many leguminous grasses. Symbiotic N fixation by legumes can be several hundred pounds per acre in temperate humid regions (Heichel, 1987; Hoglund and Brock, 1987). On grazed lands legumes are often less competitive since they are selectively grazed, and pastures already receive abundant inorganic N from cattle excreta (Matches, 1992; Coleman, 1992).

When N fixing bacteria die their proteins are broken down by microbes and the organic-N is converted to ammonium ions (NH_4^+) (Floate, 1990). Volatilization takes place when ammonium ions are converted to ammonia gas (NH_3^+) which may be released to the atmosphere. This conversion occurs more rapidly on dry, alkaline and coarse soils (Plaster, 1992).

N continues to change form as ammonia-N (NH_3) is converted by *Nitrosomonas* bacteria to nitrite-N (NO_2^- -N) ions. Nitrite-N is then converted to nitrate-N ions (NO_3^-) by the bacteria *Nitrobacter*. The process of converting NH_4^+-N to nitrate NO_3^--N is called nitrification (Raven, 1992). N may also enter the atmosphere through the process of denitrification. In denitrification NO_3^--N is converted by bacteria into atmospheric-N. Since denitrifying bacteria are anaerobic the process occurs rapidly under saturated soil conditions (Plaster, 1992). Losses of N from denitrification are only a small portion of the TN loss from a pasture (Steele, 1987).

Plants take in and convert inorganic-N, mostly NH_4^+-N and NO_3^--N, into an organic form (Evangelou, 1998). Organic-N is recycled to the plant, consumed by herbivores, or returned to soil organic matter (Evangelou, 1998). An estimated 97 to 99% of soil N is tied up as organic matter, leaving only a small percentage available in a usable form for plants (Plaster, 1992). Nitrate-N and NH_4^+-N make up 1% of the total soil N (Russelle, 1992). Atmospheric N may also be transformed to nitrogen dioxide (NO_2) by lightning and dissolve in water vapor before falling to the earth (Evangelou, 1998).

N is lost from a grazed pasture in different ways: ammonia volatilization, denitrification, wind erosion, runoff, nitrate leaching, fire and animal losses exported as a product (Steele, 1987). The two pathways of N loss that are of concern in regard to water quality are leaching and runoff. Leaching is the movement of soluble material from soil in percolating water and occurs when precipitation exceeds evapotranspiration (Steenvoorden et al., 1986). N is often leached in the NO_3^--N form because it is negatively charged and can move freely around negatively charged soil particles (Evangelou, 1998). Surface runoff occurs when water present on the soil surface fails to be absorbed and is transported by gravity across the surface. Surface runoff is more likely when there is a high groundwater table or sloped surface. Organic and inorganic-N may be picked up by water flowing across the land surface as soil and organic particles are detached and transported. N may also be transported in the dissolved form if chemical incorporation of N occurs when ions diffuse from soil solution to runoff water (Bondurant, 1971).

Nitrogen and grazing animals

Hunt et al. (1987) examined a short grass prairie grazed by domestic animals. It was found that all combined animals on the surface represented less than 0.1% of the TN in the system and that below ground biomass was an order of magnitude greater. Although the below ground soil organisms are very proficient N processors, the above ground animals are the main cause for N loss from the system. This is because grazing animals speed up the rate at which N transformations occur and shortens the N cycle (Cowling, 1977). Grazing animals are found to increase soil microorganism decay activity (Ruess and McNaughten, 1987).

The majority of N consumed in pastures by grazing animals is returned to the land in the form of dung and urine (Fraser et al., 1994). Dung and urine patches are usually not distributed evenly throughout a pasture; their deposition, however, is a continual process as long as animals are present on the pasture. Petersen et al. (1956) found urine and dung deposition to be most concentrated in the vicinity of water and along fences. The excretion of N in urine is generally greater than that found in dung. About 80% of N excreted by ruminants is contained in urine, primarily in the form of urea (Garwood, 1986).

Cattle create a major transport of N by removing vegetation and depositing excreta. During grazing the N distribution on a field becomes more heterogeneous since N is more concentrated in small spots (Russelle, 1992). Herbivores generally retain less than 15% of the N that they consume. Both sheep and cattle excrete about 8 lbs of N per 100 lb dry herbage consumed (Steele, 1982). N concentrations under urine spots are equivalent to around 700 kg ha^{-1} of fertilizer N application (Stout et al., 1997). Less than 30% of the N found in these spots is recovered by plants (Ball et al., 1979). Stout et al., (1997) found that N in urine is more susceptible to leaching than to volatilization since urea infiltrates into soil where it is quickly hydrolyzed to ammonia and nitrified. Feces on the hand remain at the soil surface and the organic N contained within is more susceptible to volatilization. In a lysimeter study Stout (1997) found that N leaching from lysimeters with applied N in the form of feces were lower than those with applied urine. These results were attributed to the lower amounts of N in the feces, the increased volatilization of N from the feces (Ryden, 1986) and that most of the fecal N is in an organic state (Stout et al., (1997).

The N in urine is often readily available to plants since urea is quickly hydrolyzed into ammonium NH_4^+-N and NO_3^--N (Ball et al., 1979). The N can also be quickly lost to the system in this form (Russelle, 1992). Much of the N lost in urine patches is volatilized. There may be as much as 90% loss of N in urine spots in semiarid climates since ammonia volatilization increases with aridity (Steele, 1987). Increased water supply in high N content areas such as urine patches can lead to nitrate leaching (Russelle, 1992).

N in the dung, on the other hand, is mostly in the organic form. Decay and mineralization of the N in the dung is slowed at first by anaerobic conditions in the dung pat, then by dry conditions as the pat dehydrates (Stevenson and Dindal, 1987a). The presence of dung beetles and other insects will greatly increase the speed of N cycling through the excrement since they will increase aeration and microbial activity (Stevenson and Dindal, 1987b).

Pastures not fertilized with nitrogen generally have higher C:N ratios and longer periods of N immobilization and organic matter decomposition. Animals grazed on pastures with little or no N fertilizer release dung and urine with similarly high C:N ratios, resulting in slower rates of decomposition. Mineralization of N in urine does, however, remain comparatively rapid (Whitehead, 1986). Jarvis and Pain (1990) found that one urination from a cow can have between 40 to 120 g N m^{-2}. Cattle urine spots are optimal sites for denitrification because they are areas of high soil moisture, nitrate-N, and a readily available source of C. Fraser (1994) studied the fate of 15N-labelled synthetic urine (50 g N m^{-2}) applied to an irrigated pasture. Pasture plants recovered 43%, 20% remained in the soil, 8% was leached and 28% was lost to denitrification.

Garwood (1986) provides a brief description of the fate of nitrate in applied cattle slurry. In the first two weeks N loss from manure primarily occurs through runoff and volatilization of ammonia. At this time residual inorganic N is recovered by pasture vegetation. Additional nitrate NO_3^--N is created as a result of mineralization of organic-N present in excreta. In autumn, winter, and spring plant uptake is small and NO_3^- will be lost through leaching, denitrification and runoff.

Phosphorus

P is an essential nutrient for the growth of both plants and animals. P occurs in soil by the weathering of minerals such as calcium phosphate. Elemental P is extremely reactive and will combine with oxygen when exposed to air. In most natural systems P is present as phosphate which is an atom of P surrounded by four oxygen atoms. Orthophosphate (PO_4^{3-}) is the simplest form of phosphate and also referred to as soluble reactive phosphorus (SRP), orthophosphate (OP), soluble-P, dissolved-P or soluble inorganic-P. Filtration is used to determine if P is soluble or particulate. In water, orthophosphate takes the form of $H_2PO_4^-$ in acidic conditions and HPO_4^{2-} in alkaline conditions (Busman et al., 2002). These two forms are the most common types of inorganic P. P in the orthophosphate form may be utilized by plants (Evangelou, 1998).

Total phosphorus (TP) is the measure of all the P forms. Filtration is used to separate the TP into its soluble and particulate forms. Soluble P (SP) or dissolved P (DP) is the fraction that can pass through a 0.45 μm filter; particulate P (PP) is the fraction retained. Although SP and DP are not considered the particulate fraction, P can be associated with $<$0.45 sized particles. TP ($<$0.45) refers to the total dissolved P content in water (Haygarth, 2000).

TP may be separated chemically using the Mo blue reaction. Mo reactive P includes orthophosphate as well as loosely bound organic and inorganic forms of P, collectively referred to as the reactive P (RP) fraction. Unreactive P (UP) is that fraction of the TP that is not Mo reactive, mostly organic forms of P as well as condensed forms such as polyphosphates. The terms inorganic-P and organic-P in place of RP and UP, respectively, are not recommended because neither fraction of P is purely organic or inorganic (Haygarth, 2000).

Phosphorus and grazed pastures

Only a small portion of the overall P content of soil is found in solution, readily available for plant uptake. This is commonly referred to as available or bioavailable P. Sharpley, (2000) recommends the term algal available P to provide a more specific definition. Between 25% and 90% of the P in soil is in organic matter (Plaster, 1992). As plants remove P from the soil solution more P is released from organic matter and soil particles. P in fertilizers and manure is made available in this manner. Manure contains soluble, organic and inorganic phosphate compounds. As much as 80% of the P in dung is in the inorganic form (Haynes and Williams 1993). The rate at which availability occurs is dependent on temperature, moisture, pH, and minerals already present in the soil solution. Although the movement of P away from manure and fertilizer particles is slow, it may be increased by rainfall and irrigation (Busman et al., 2002).

Uptake of P by plants happens mainly near the soil surface due to its often immobile state in the soil solution (Gillingham et al, 1980). In managed pastures most P intake by animals occurs by grazing of plant material or soil ingestion (Gillingham, 1990). Younger, more palatable plants, which frequently have a higher P content, are often selectively grazed (Minson et al, 1960).

P is returned to pasture soil primarily in dead plant material and in animal excreta (Gillingham, 1990). Unlike N, the excretion of P occurs largely in the feces and not in the urine. The amount and type of P returned by grazing animals is determined by the P content of the plant material and the amount of material consumed. Livestock normally avoid plant material high in crude fiber and favor material high in protein which also tends to be higher in P (Arnold, 1960). The rate of P mineralization in organic matter is generally higher when the P and N content of the plant material is high. (Kaila, 1954).

Phosphorus transport

Losses of P can occur both above and below ground. P losses occur mostly in the surface runoff since leached P tends to bind with P deficient soil (Sharpley et al., 2001). Most soils have the ability to retain even large additions of fertilizer P. P can be removed from the soil solution by forming complexes with reactive iron, aluminum, and calcium. P moves by desorption, dissolution and extraction of P from soil, organic matter or fertilizer. This initial process happens when water interacts with the surface soil as it moves over land (Sharpley et al., 1994).

Soil P levels and water quality

Evidence shows that there can be significant subsurface P loss when soils receive a P quantity above their holding capacity (Coale, 2000). Organic soils in particular can release P to solution (White and Thomas 1981). When organic matter breaks down it releases humic acids. Humic acids can act on P compounds, releasing P to the water solution. Other soils of low P sorption capacity include soils that are sandy, waterlogged, and those with structure allowing preferential flow through the soil profile (Sharpley et al., 1979). Organic P in the labile form derived from dung and plant litter may be more mobile than the inorganic form and may cause some leaching losses (Elliot, 1972). Groundwater sources of P may also be high in places where there are anoxic soil conditions or soils are of volcanic origin (Correll, 1998).

Orthophosphate concentration in runoff is often directly correlated to the soil test P level (Bjorneberg, 2002). Sharpley et al. (1996) grouped soil test P values into four categories based on what affect their P level had on crop growth and water quality. Soil with <30 mg P kg^{-1} required additional P for optimal crop growth, these soils are typically in wooded areas. Crops grown on soils with 30 to 100 mg P kg^{-1} show some response to additional P and there is limited P in runoff. There is generally no crop response when P is added to soils with 100 to 200 mg kg^{-1} but there will be some enrichment of surface waters. Grazed pasture is generally between 100 and 200 mg kg^{-1}. Soils containing over 200 mg P kg^{-1} are generally above crop requirement and surface water enrichment with P will be expected. Fields with over 200 mg kg^{-1} are typically cropped with applied fertilizers or manure.

Since orthophosphate is very susceptible to sorption by soil, its movement occurs mostly in soil macropores (Jensen, 1998). Gachter (1998) found that TP concentration in the soil macropore walls was higher than the TP concentration in the soil matrix. The faster flowing water in the soil macropores was found to not significantly decrease in P content as it flowed preferentially.

Turner and Haygarth (2000) performed a lysimeter study to determine forms and concentration of P in leachate from four different grassland soil types. P concentrations in leachate did not correspond to soil P content. Most P leachate was in the dissolved form (<0.45 μm). TP concentration was higher in a sandy soil (240 μg L^{-1}) than in a clay soil (179 μg L^{-1}). The reactive fraction of the TP in leachate from clay was 71% and from the sand was 62%. The difference in leached RP was attributed to high calcium levels in the sandy soil causing precipitation of inorganic P. P in the soluble form was not always reactive and consisted of various particle sizes of P bound to inorganic and organic colloids. These colloidal forms are more easily leached because they are not readily sorbed in the soil the way that inorganic P binds with Ca, Fe, Al and sorbed to clays. P that is soluble and unreactive has a high risk for subsurface transfer (Turner and Haygarth, 2000).

Surface transport of phosphorus

The surface transport factors controlling the movement of P are erosion and surface runoff (Sharpley et al., 2001). The surface loss of P may occur in the dissolved and particulate forms. P may attach to sediment or organic matter forming PP. Sources of PP may be stream or canal channels, topsoil, animal excreta or plant material. The P content of eroded material is often higher than source soil material. This is due to the often higher reactivity of finer particles which are moved during erosion compared to coarser particles left behind (Burwell 1975). The algal bioavailability of P in runoff water with particulate matter may vary from 10 to 90%. Because there is such a variation in the bioavailability of P within particulate matter, the impact it has on the primary productivity of a receiving waterbody is site specific (Coale, 2000).

P may also be transported in the soluble form if P is released by organic matter, soil and suspended sediments into surface water as it travels over a field (Sharpley et al., 2001). A majority of P loss occurs in the particulate form. Research, however, reveals high levels of SP loss as well. Runoff from grassland and forest land often contains little sediment and is therefore dominated by SP (Sharpley et al., 1994). An estimated 10 to 25% of the TP lost from conventionally tilled fields is found to be SP. More than 50% of the TP load exported from pasture and no-till fields can SP. The environmental impact of SP loss is serious for fresh water since most of it is immediately available to algal communities (Coale, 2000).

Water Quality and Nutrients

Eutrophication is the process in which surface waters are enriched by nutrients leading to dense or accelerated primary production (Brooks et al., 2003). Eutrophication has been a national water quality concern for decades. It is identified as the main problem in surface waters having impaired water quality (US EPA, 1996). It may result in thick mats of algae or cyanobacteria causing anoxia, fish kills and a reduction in aquatic biodiversity. Many waterbodies progress from being low to moderately productive (oligotrophic or mesotrophic) to overenriched (hypertrophic or eutrophic) (Correll D.L. 1998). These stages can be accelerated and changes in trophic conditions may occur when nutrients are transported from human sources. It is generally beneficial from a human standpoint to reduce the rate of eutrophication of a waterbody for health, aesthetic and economic reasons.

Eutrophication and Phosphorus

Primary production in an aquatic system requires N, C, and P. N is often more limiting in estuaries (Sharpley et al., 1994). In most freshwater aquatic ecosystems P is the limiting nutrient to primary production. Both C and N can be obtained from the atmosphere while P is delivered to lakes and rivers primarily by surface waters and is therefore generally present in lesser amounts than the other essential nutrients (Correll, 1998).

Primary producers will utilize P in an aquatic system very efficiently in order to maximize growth. If large amounts of P are introduced, as occurs from certain human activities, primary productivity will increase rapidly. When P becomes readily available N becomes the limiting nutrient, and N-fixing organisms such as cyanobacteria are able to out-compete other producers and form large blooms (Grobbelaar and House 1995). Photosynthesis of cyanobacteria raises the pH and the quantity of un-ionized ammonia-N in solution, which is toxic to aquatic organisms (Bortleson and Fretwell 1993). The rapid increase in growth of primary producers also leads to rapid decomposition, resulting in oxygen depletion within an aquatic system. This process may result in fish kills as well as alteration in the aquatic species composition. The thick growth of producers can also limit the amount of sunlight penetration to submerged aquatic plants and phytoplankton, further reducing ecosystem diversity (Correll, 1998).

Nitrates and microorganisms

An important water quality concern with nitrogen is methemoglbinemia (blue baby syndrome) which occurs when high nitrate levels in drinking water result in the reduction of oxygen transport in the bloodstream. Methemoglbinemia is of particular concern for infants since they lack the enzyme necessary to correct the condition (Mueller and Helsel, 1996).

Microorganisms are present in all surface waters but increased nutrient additions can lead to increases of certain bacteria that have a negative impact on aquatic species. Agricultural runoff and direct livestock access to spring systems has resulted in elevated levels of ammonia and nitrites as well as bacteria such as *Pseudomonas aeruginosa* and *Aeromonas hydrophila* and coliforms resulting in fish mortality (Taylor et al., 1989). Bacterial coliforms are harmful to humans and many aquatic species. A study done in Brownie Spring, Nevada examined fish populations of a stream during cattle presence and after their removal. Presence of cattle was associated with an increase in fish mortality, and subsequent removal of cattle was related to increase in populations of fish. While the increased mortality was partly attributed to increases in nutrients (0.25 ppm NH_3^+), the gills of *Crenichthys baileyi baileyi* where found to have the bacteria *P. s aeruginosa* and *A. hydrophila* present. Both are pathogenic to humans and fish (Taylor et al., 1989).

Organic carbon

Dissolved organic carbon (DOC) provides an indication as to the amount of organic matter in a water solution. DOC can have a strong influence on physical, chemical and biological properties of freshwater systems (Gergel et al., 1999).

Water discoloration caused by DOC can reduce light penetration into a waterbody. With less light entering the water, aquatic primary production can decrease. If DOC concentrations are reduced the transparency of a waterbody will increase (Fee at al., 1996). In terms of water quality DOC generates brown color, bad taste, odor, and bacterial growth (Nelson, 1996). Major costs are associated with removing DOC from drinking water reservoirs on a continuous basis. DOC may also cause lower dissolved oxygen; when organic material is broken down decomposer populations grow, causing a biological oxygen demand. The larger the carbon or organic content, the more oxygen is consumed. DOC is also found to influence the availability of P to phytoplankton (Steinberg and Muenster, 1985).

Sediment

Erosion and sedimentation processes are a natural occurrence and vary greatly from one region to another and over time. Excessive sediment can result from disturbances in a watershed and cause water quality problems by adding sediment to aquatic habitat. Sediments in suspension consist largely of silt sized particles or colloids of organic material. Suspended sediment will restrict the amount of sunlight reaching submerged aquatic plants. Sediment can coat gravel bottomed streams, smothering benthic communities and destroying spawning habitat (Brooks, 2003).

Turbidity

Turbidity is the measure of suspended particles in a water column. Particles that cause increased turbidity include silt, clay, organic material and microorganisms. Increased turbidity will reduce the amount and depth to which sunlight can penetrate a body of water (Heathcote, 1998).

Dissolved Oxygen and Temperature

Dissolved oxygen (DO) is the measure of the amount of oxygen dissolved in water and is a fundamental water quality trait for aquatic life. It also affects the solubility and availability of nutrients. There are numerous factors affecting the level of DO in water including photosynthetic activity, decomposition, temperature and turbulence. (Dahlberg et al., 1968)

DO concentrations will increase when water flow becomes turbulent, such as in riffle areas and waterfalls. Oxygen concentrations are higher in the air and the oxygen will dissolve into the water as more water surface area is exposed. Decomposition also plays a role in controlling levels of DO in water. When organic material is broken down, decomposer populations grow causing a biological oxygen demand. The presence of aquatic vegetation will affect DO levels through photosynthesis and respiration. These processes may account for large variations in DO levels from day to night. During the night DO concentrations will decline, since the loss of oxygen through respiration and decomposition is not supplemented by photosynthesis. The DO levels may be lowest just before dawn, as photosynthesis begins (Ritchey et al., 1975).

Temperature is the measure of heat stored in a volume of water. Temperature increases can cause increased oxygen demand and lower oxygen solubility (Brooks et al., 2003). The water to gas saturation level will change as temperature changes. Therefore the colder streams often found in headwater areas may hold more DO than warmer streams. Temperature is particularly important during summer months when stream water is warmer, as oxygen may be limited by the waters capability to hold adequate levels (Ritchey et al., 1975).

pH

pH is the measurement of the hydrogen ion concentration of water. A pH value of 7 is neutral, below 7 is acidic and above 7 is basic. Natural fresh water ranges from a pH of 4 to 10. The pH levels control the solubility of ammonia and heavy metals (Brooks, 2003).

Specific conductivity

Specific conductivity is the measurement of the ability of water to conduct electricity. Water with high ion content, such as dissolved metals or dissolved salts, will have a high conductivity (Heathcote, 1998).

Criteria for Nutrients

The U.S. Environmental Protection Agency provides guidelines for general stream water quality impairment levels. The recreational water use level for bacterial coliforms is <200 fecal coliforms per 100 mL. and <1 fecal coliforms per 100 mL for drinking water. The maximum NO_3^--N level for drinking water is 10 mg N L^{-1} (Gary et al., 1983). Maximum ammonia levels were established by EPA to protect aquatic organisms. The ammonia toxicity level is dependent on both temperature and pH. A general guideline for most natural surface waters is ammonia concentrations above 2 mg L^{-1} are toxic to fish (Mueller, 1996). Research suggests that the phosphorus threshold concentration to induce eutrophic conditions in streams is 20 µg L^{-1} (Trlica et al., 2000). EPA has developed no national criteria for P levels in surface waters but recommends that phosphate not exceed 0.05 mg L^{-1} at a point in a stream where it empties into a lake or reservoir and 0.1 mg L^{-1} in streams that do not discharge directly into lakes or reservoirs (Mueller, 1996).

P water quality levels may be difficult to attain on agricultural areas since critical P concentrations for crop growth (0.2 - 0.3 mg L^{-1}) are greater than the concentration for eutrophication control (Heathwaite, 2000). The Clean Water Act section 402 requires that all point sources of pollution to acquire a National Pollutant Discharge Elimination System (NPDES) permit to discharge to waterways in the USA. Concentrated animal feedlot operations are the only agricultural pollution source required to have a permit. Irrigation and stormwater runoff from agriculture are not considered point sources of pollution and do not need an NPDES permit. For waterways that remain in poor condition regardless of laws and programs, states must develop a total maximum daily load (TMDL) of pollutants. The development of TMDL's will potentially increase the emphasis on nonpoint sources of agricultural pollution (Parry, 1998).

Pasture Management and Runoff

Irrigation of pastures

Grasslands often exist because the soil moisture supply is too low to support a forest (Buol et al., 1989). Irrigation of dry grasslands allows increased duration and intensity of livestock grazing. Fields may be grazed throughout the hottest and driest times of the year, when without irrigation the grass species would normally be dormant. The method and manner in which irrigation water is applied has a significant effect on both vegetative growth and nutrient movement (Bjorneberg, 2002).

Subsurface and trickle irrigation produce little to no sediment loss because they produce minimal overland flow. Most irrigation however, occurs with surface irrigation. Surface irrigation flow which is not absorbed by the soil is transported overland. During flood irrigation the pasture is at least partially saturated or submerged in water for several hours or days. This water may be a direct source of N and P since these nutrients may be leached out of organic material (Mundy et al., 2003).The risk for surface runoff is greater for sloped areas or soils with a high groundwater table. Leaching will take place when precipitation or irrigation exceeds evapotranspiration (Steenvoorden et al., 1986).

Ultimately a farmer wants to apply water evenly across a field by determining the optimal irrigation rate which allows infiltration of the upper field to equal that of the lower field. If irrigation water supply is low an irrigator may use low application rates allowing all water to infiltrate, which may result in the lower field not being sufficiently irrigated. In contrast an abundant water supply where runoff is 50% or more may cause excessive runoff of soil and nutrients (Bjorneberg, 2002). Increases in irrigation inflow rate by 30% to 50% increased soil erosion by 3 to 10 times on two Idaho fields. This occurred because both runoff and sediment concentration increased (Trout, 1996).

Excessive runoff is often reused downstream or discharged to a surface water body. When irrigation runoff is reused, a pasture can become a sink for nutrients and sediment. Bondurant (1971) measured sediment in headwater and tailwater from a furrow irrigated tract. Sediment concentration in return flow was two times higher than that found in headwater. Because 85% of the applied water infiltrated, the mass of nutrients and sediment in the surface runoff was less than that found in the headwaters. Since runoff volume was so small (only 16 - 20% of the headwater volume) the nutrient concentration in the runoff would have to be five times that in the headwater for there to be net nutrient movement in the irrigation runoff. A smaller nutrient load in surface runoff does not necessarily signify improved water quality it does however mean that the receiving body of water has increased its nutrient content by an amount that is relative to the quantity and concentrations of nutrients involved.

Runoff from native grassland

Studies of runoff and nutrient loads transported from native prairies in Minnesota provide baseline data to compare with pollutant loads from grazed and irrigated pasture. A rain-induced runoff study examined the nutrient contributions of a native prairie for five years. Annual total nitrogen (TN) loss was 0.8 kg N ha^{-1}, and total phosphorus (TP) was 0.1 kg P ha^{-1} (Timmons and Holt, 1977).

Runoff from grazed pasture

Miller (1978) examined the importance of irrigation flow rate, vegetation and the presence of livestock as factors in water quality impairment in Carson, Nevada. From this study P and biological oxygen demand (BOD) were the main pollutants of concern. Orthophosphate loading to the stream ranged from 0 to 3 kg P ha^{-1}

while BOD ranged from 10 to 52 kg P ha^{-1}. Flood irrigation lowered the DO level in tailwater. The decreases in DO were attributed to increasing water temperature and BOD as irrigation water flowed across the field. All nutrient levels were consistently higher in the return flows than in source irrigation waters. High irrigation flow rates tended to have more suspended organic materials, including manure and vegetation, and contributed larger proportions of TN and TP. Slower flow rates carried more soluble pollutants. The study found that levels of nutrients corresponded more to flow rates and presence of the fertilizer than to the presence or absence of animals.

Runoff quality was compared on four pastures in Ohio. All of the pastures were rotationally grazed during the summer and one was used for winter feeding. The study revealed that the concentration of chemicals in runoff increased after winter pasture was used by cattle. The summer-winter grazed catchment had TP loads of 0.4 kg P ha^{-1} in summer and 1.2 kg P ha^{-1} in the winter. Three summer grazed catchments had a TP load < 0.1 kg P ha^{-1} for summer and winter. The increased winter load was due to decreased vegetation, accumulation of waste and excess water movement during the winter (Chichester et al., 1979).

Fertilizer and pasture runoff

Fertilizer may have an impact on water quality, depending on whether irrigation is used. In Victoria, Australia, four rates of superphosphate (250, 500, 750, and 1,000 kg P ha^{-1}) applications were applied to flood irrigated pasture. The TP concentrations measured in the tailwater ranged from 40 mg P L^{-1} to 120 mg P L^{-1} for the 250 and 1000 kg P ha^{-1} rates, respectively. The phosphorus concentration in runoff increased linearly with the application rate. Initial irrigation applications contained the highest levels of TP (Austin et al., 1996). A non-irrigated pasture fertilized with superphosphate in North Carolina resulted in very little P enrichment to runoff. The two study catchments in North Carolina were fertilized at rates of 48 kg P ha^{-1} and 192 kg P ha^{-1} and resulted in drainage water consistently under 0.01 mg P L^{-1} TP (Kilmer et al., 1974).

Cattle grazing and pasture runoff

Scheppers and Francis (1982) studied pasture runoff in Nebraska. TP and BOD in runoff were directly related to cattle grazing density. Grazing livestock increased total dissolved solids concentration by 52% and chemical oxygen demand by 7%. Mundy, (2003) found that P in runoff from a flood irrigated and grazed pasture was derived from both pasture and feces. The N and P concentration of runoff water from a pasture with high cattle stocking rate was higher than that with a low stocking rate only for the first irrigation. The cumulative P loading rate for four irrigations was 0.84 kg P ha^{-1} for a pasture with zero cows per ha and 1.08 kg P ha^{-1} for a pasture with 375 cows per ha. The load of N in pasture runoff was more dependent on cattle density 1.31 kg N ha^{-1} for zero cows per ha and 2.35 kg N ha^{-1} for 375 cows per ha. These results suggest that a majority of the P in the runoff was from pasture vegetation while N in runoff was more influenced by the presence of cattle urine and feces (Mundy, 2003).

Gary et al., 1983 studied a stream flowing through a pasture in Colorado to quantify the impacts of cattle grazing on chemical and bacterial levels. Cattle presence increased fecal coliforms by 1.6 to 12.5 times. When cattle were removed the fecal coliform level dropped to a level similar to drainage from an ungrazed pasture. Only minor increases in nutrients were identified while cattle where present.

A runoff study done on Colorado pastures with a rain simulator resulted in concentrations of N and P that were significantly greater during the first 13 minutes of rain-simulated runoff. Overall runoff was 70% greater for a grazed plot compared to a non-grazed plot (Trlica et al., 2000). Scheppers et al. (1982) studied runoff from a pasture in Nebraska. Concentrations of ammonium-N, TP, total organic carbon and chemical oxygen demand were directly related to livestock density. Manure and standing plant litter were identified as the most likely sources of nutrients in the rainfall induced runoff.

In a grazed catchment in Ohio, NO_3^--N concentrations in runoff from one rainfall event were 3.8 mg N L^{-1} (Owens et al., 1983). Researchers compared sediment concentrations from the same catchment for 2 years without livestock (0.8 g L^{-1}), three years with summer grazing only (1.3 g L^{-1}) and an additional six years grazing all year round (3.2 g L^{-1}) (Owens et al., 1989; Owens et al., 1983).

Runoff from a grazed pasture near Potlach, Idaho had annual TN loads ranging from 1 to 4 kg ha^{-1}, and TP from 0.1 to 0.17 kg P ha^{-1}. The study concluded that cattle grazing increases nutrient runoff, and only phosphorus loading to the stream was increased during the summer grazing season. The bulk (60 - 90%) of the nutrient runoff occurred during the first precipitation event following the summer grazing period (Jawson et al., 1982).

Boundorant (1971) studied the water quality changes caused by irrigation of a fertilized field planted to wheat in Paul Idaho. Average NO_3^--N concentration in head and tail water was 0.1 mg N L^{-1}; average phosphate concentrations were 2.72 mg P L^{-1} in irrigation runoff and 2.60 mg P L^{-1} in headwater. Tailwater samples taken during initial runoff had higher nutrient levels than headwater samples but headwater and tailwater nutrient concentrations were similar throughout the remainder of the irrigation.

Mundy (2003) found that the spreading of dung pats caused higher TP in irrigation runoff during the first irrigation event of the year. The action of dispersing and breaking up dung pats may lead to increased N and P export because more of the surface area of the dung is exposed to irrigation water. The exposure increases the likelihood that nutrients will runoff with the irrigation water. Structural damage to pasture, such as mowing and grazing, increased the concentration of nutrients in runoff. Mundy postulates that P and N are leached from plants due to the damage incurred when vegetation is cut and plant exudates are dissolved.

Nutrients and freshwater

Understanding the ability of a waterway to dilute and self purify helps determine what levels of pollutants are permissible in a fluvial system and how to achieve those levels (Elosegui, 1995). In a stream nutrients and particulate matter have a shorter residence time and the DP concentration is of most importance to algal growth. In a lake where the residence time for nutrients and particulate matter is longer, the TP load becomes increasingly important to algae growth because bound up P has more opportunity to be released in an algal available form (Osburne and Wiley, 1988). Algal growth and utilization of P is more efficient in standing water than in flowing water for a given amount of P (Sobell and Kimmel, 1987). A river may be a transport mechanism for P to be moved to a P sensitive water body such as a lake (Edwards, 2000). In this case the accumulative P load delivered on an annual basis may be an important factor (Edwards, 2000). The stream process of algal uptake of P acts only as a short term storage for P, delaying its transport downstream (Edwards, 2000).

Gbureck and Sharpley (1998) found that P concentrations decreased going downstream in an agricultural watershed in Pennsylvania. They attributed this decrease in P to dilution caused by subsurface flow in to the stream channel, sorption of DP by sediments, bank and bed material. They also attributed the decrease in P concentration to the possibility that P contributions were different from different areas of the watershed. The study found that the near stream soil P level had a greater influence on P export than did overall soil P throughout the watershed.

Elosegui (1995) studied the nutrient retention capacity of a stream in Spain that received sewage. The nutrient showing greatest retention frequency was phosphate; NO_3^--N and NH_4^+-N were high as well. The greatest amounts of nutrients were retained during periods without floods, which allowed algal populations to develop. Stream water quality recovery occurred quickly in the absence of pollution sources. In the case of the Elosegui study, recovery of the stream occurred on sections of the stream between towns where there were no sewage discharges.

Nutrient Management

Controlling nitrogen and phosphorus runoff

It is often cheaper to treat the causes of eutrophication instead of dealing with the effects (Sharpley, 2000). Strategies for controlling N and P runoff often differ and may be in conflict due to the differences in chemistry and transport between these two nutrients. An example of this conflict would be the reduction of P in surface runoff through conservation tillage which may cause increased nitrate leaching (Heathwaite et al., 2000). N losses may occur from many locations in a watershed, and prevention of N loss to a waterway should target a broad area of a watershed. P runoff prevention measures should be applied broadly to a watershed as they are with N. P, however, also requires the use of more stringent management strategies that should target the sites most vulnerable to P loss (Heathwaite et al., 2000).

A general goal for farm nutrient management is to balance the nutrient inputs in feed and fertilizer with outputs in harvested products (Sharpley, 2000). Manure application rates are often based on crop N requirements and not on the soil P content. Therefore added manure or fertilizers may contribute greatly to P loss of an area since the added P is beyond crop requirements. The imbalance in the N/P ratio is made worse due to volatilization of N in the manure and the slow mineralization of organic N (Sharpley et al, 1996).

Critical source areas are important for determining where P will be exported from. 90% of annual P from a hill-land watershed in Pennsylvania was derived from 10% of the land area (Pionke et al., 1997). N loss, on the other hand, tends to occur on a watershed wide scale because most N loss is associated with nitrate movement; N loss is dependent on the amount of nitrate in the soil and the amount of water moving through a soil profile (Heathwaite, 2000). Johnes (1997) found that areas contributing nutrients that are more than 50 m from the drainage system were not as crucial as the near stream areas since nutrient transported over longer distances will most likely be taken up by plants or sorbed to soil.

Johnes and Heathwaite (1997) examined integrated N and P management for reducing loads to surface waters. They determined that the best method for simultaneous reduction of N and P was to focus on near stream areas. Strategies including reduced grazing and fertilizer input on near stream land with an overall reduction in cattle density by 75% had the greatest impact on N and P reduction.

Phosphorus source areas and transport

Past efforts of P control were aimed at reducing soil P levels by closer management of applied manure and fertilizers to crop land. This method of P management was not very successful since the transport mechanisms were not being addressed (Sharpley et al., 1994). Preventing P loss must target P source areas within a watershed such as high level P soils along with areas that have high potential for runoff and erosion (Gburek, JW and AN Sharpley. 1998).

Gburek and Sharpley (1998) studied two agricultural watersheds in eastern Pennsylvania and found that DP concentrations were greatest during storm events (0.043 mg P L^{-1}) that carried higher sediment loads compared to non sediment storm flow (0.027 mg P L^{-1}). The DP concentration increases because PP when in suspension is acting as a source of P to the stream. The storm period therefore offers the greatest opportunity for P control from the watershed. Runoff was highest in specific parts of the watershed particularly those areas where the groundwater table is close to the land surface usually near a stream. During a storm, shallow groundwater areas expanded rapidly up slope causing both overland and subsurface flow area to increase.

Attempts to apply a single nutrient management plan to a particular region are complicated by the unpredictability of P runoff. For example, bordering fields may have similar soil P test levels but have contrasting topography and management (Sharpley, 2000). Methods for reducing surface P transport include protection of riparian zones, terracing, constructed wetlands and settling basins. These management practices are better at removing PP than they are at removing DP and will work where subsurface pathways are not an important form of P transport (Sharpley, 2000).

The best strategy for reducing P export from a watershed will target critical source areas within a drainage that are most vulnerable to P loss (Heathwaite, 2000). Management techniques aimed at reducing P transport from a watershed may not be effective in reducing eutrophication if they concentrate on PP and increase the DP export (Heathwaite, 2000).

Sediment reduction

Reducing sediment concentration can reduce TP. Applying polyacrylamide (PAM) with irrigation water was found to reduce soil erosion on research plots by more than 90%. PAM is a synthetic water-soluble polymer made from monomers of acrylamide. PAM causes suspended particles in water to bind and settle out. The use of PAM also reduced P levels in runoff and chemical oxygen demand (Trout et al., 1995).

In the Columbia River Basin pollutants in runoff were reduced significantly when sediment control practices were implemented. Sediment pools were installed, earthen ditches were replaced by pipes, and furrow irrigation was converted to sprinkle irrigation. These practices did not reduce runoff volume but did reduce sediment load by 80% and P load by 50% (King et al., 1982).

Runoff reduction in riparian areas

Riparian areas consisting of a mixture of grasses, shrubs and trees are found to reduce agricultural non point source pollution in the Great Plains and Upper Midwest (Brooks, 2003). The riparian area along a grass seed field in the Willamette Valley, Oregon was studied to examine how riparian areas process N and affect water quality. Nitrate-N levels averaged 2.24 mg N kg^{-1} soil in the riparian zone and 3.45 mg N kg^{-1} soil in a fertilized grass field. These differences were more than could be attributed solely to the presence of fertilizer on the grass field. The lower nitrate-N levels in the riparian soil were attributed to soil nitrate processing, denitrification, plant uptake, and dilution from riparian zone and groundwater mixing (Griffith, 1997). Vellidis et al. (2003) found denitrification to be the main process responsible for N removal from a forest riparian wetland bordering a fertilized pasture in the Georgia Coastal Plain.

Wigington et al., (2003) found that the riparian area has potential for reducing nitrates in shallow groundwater when the groundwater has contact with the riparian zone. However, in a stream in the Willamette Valley, Oregon it was found that only a small portion of the groundwater reaching the stream follows the flow path through the riparian zone. Instead most of the groundwater flow is in saturated form in swales. Conservation practices for NO_3^--N transport to waterways should be applied to the field by reducing nutrient additions to active channels and swales that may allow more direct transport to a waterway.

Preferential flow paths allowed a nitrate plume to progress deep into a riparian forest wetland in the Georgia Coastal plain. The NO_3^--N plume had an initial concentration of 10 mg NO_3^--N L^{-1} and was reduced to 4 mg NO_3^--N L^{-1} within 25 m of the riparian wetland. The riparian buffer was a total 38 m in width. The retention rates of the riparian wetland for TP and NO_3^--N where 66% and 78%, respectively (Vellidis et al., 2003).

Pasture stubble height and buffer strips

USDA recommends a pasture stubble height of 7.5 cm to ensure sediment entrapment and improve water quality of runoff (Clary and Webster, 1987). Field study results however do not provide strong support for the recommendation. Studies by Clary and Webster (1987) recommend a stubble height of 9.5 to 15 cm to ensure proper filtering of sediment in pasture runoff. P and N loads in irrigation runoff from pasture decreased significantly when pasture height increased from 6.3 to 15.5 cm (Mundy, 2003). Fink (2000) found that stubble heights of 7.5 and 15 cm did little to improve water quality in runoff from pastures.

Buffer strips along riparian areas and grazed and cropped fields may serve as sediment and nutrient sinks. Evidence shows that vegetative filter thickness is an important factor for reducing sediment and nutrient runoff. Phosphorus trapping efficiency was 89% for vegetative filters that were 15 m in width (Majed et al., 2003). Hook (2003) found that buffer vegetation type was not as important as width and that 6 m vegetated buffer strips retained 94 to 99% of sediment from a Montana foothills meadow. Buffer strip effectiveness may decline over time. Cooper et al. (1995) found that buffer strips used for grazing for twenty years exported the same amount of DP that they trapped.

PROJECT SETTING

Introduction

The Wood River Valley is in Klamath County, south central Oregon. The center of the valley is at approximately 121°59', and 32" west longitude and 42° 43' 28"north latitude. The 77 km valley floor is around 1200 m elevation with slopes ranging from 0% to 3%. It is surrounded by steep mountain ridges of the Cascades to the north, east and west, and Agency and Upper Klamath Lakes to the south (Figure 1).

Climate

The climate is semi-arid, with most precipitation occurring during the cold winter months. Summers are typically hot and dry. Average annual precipitation in the Wood River Valley varies from 406 to 607 mm and average annual air temperature is 5.5 to 6.7° C. About 44% of the moisture occurs in winter, 22% in spring, 26% in fall and 8% in summer. The valley receives cold air drainage from the Cascades and Crater Lake and has a growing season of less than 50 days, restricting agricultural land use to pasture (Klamath County Soil Survey, Oregon, 1985)

Hydrology

The Wood River Valley encompasses both the Wood and Sevenmile drainages. The Wood River and Sevenmile creek basins drain southward into Agency Lake, which is connected to Klamath Lake. The Wood River is one of three major tributaries to Upper Klamath Lake. The Cascade Mountains feed the Wood River Valley with snow melt and numerous spring creeks. Spring discharges originate along mountain slopes and lowlands throughout the Wood River Valley. In most parts of the valley a water table is located within a few feet of the ground surface (Klamath Basin Rangeland Trust, 2002).

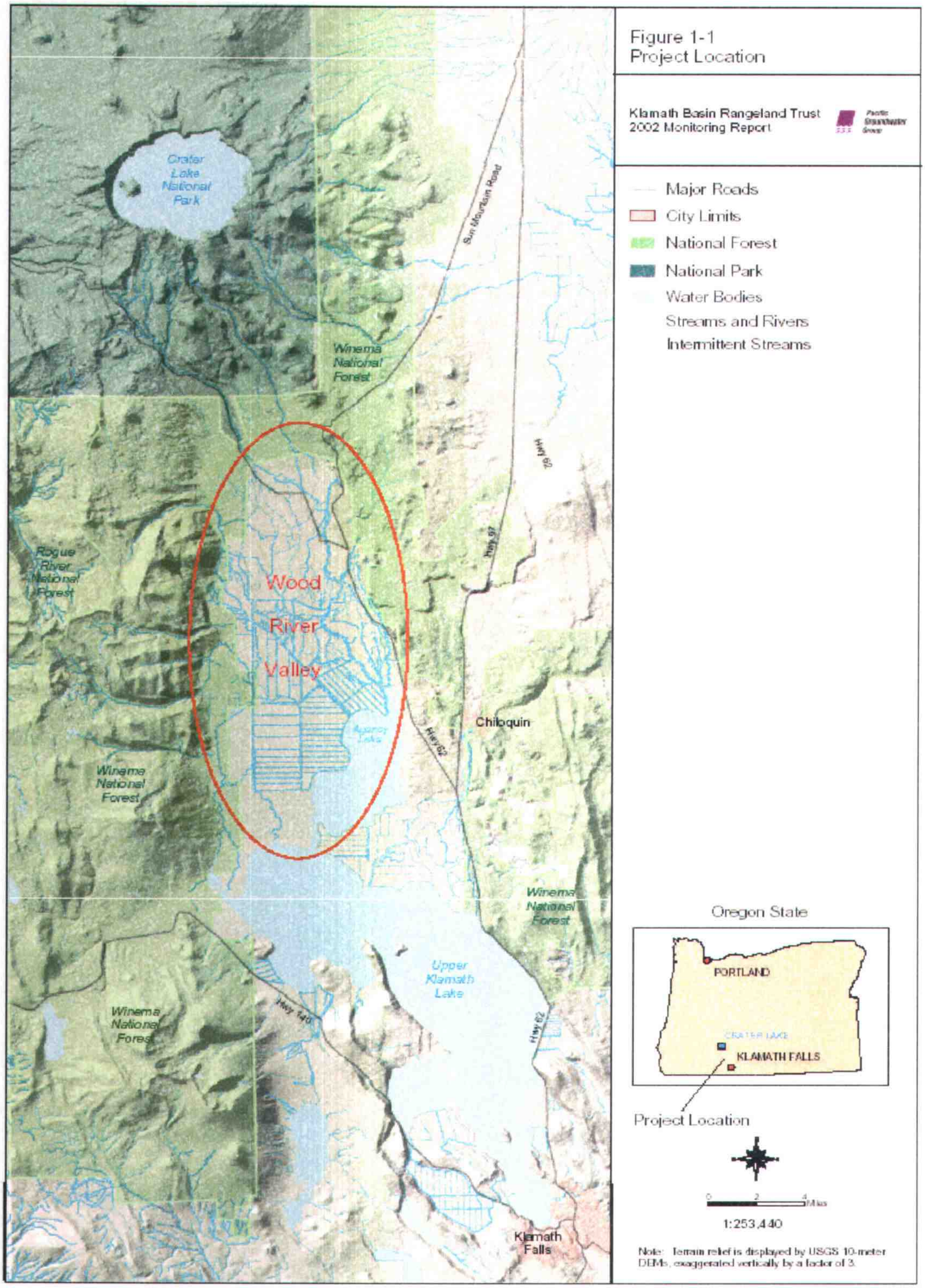


Figure 1. Wood River Valley location within Klamath County, Oregon. (Pacific Groundwater Group, 2002).

Soils

The soils of the Wood River Valley were primarily influenced by the eruption of Mount Mazama which formed Crater Lake. The following description is from the Klamath County Soil Survey.

> The final eruptions at Crater Lake are estimated to have happened about 6,500 years ago, covering the Wood River Valley with a thick mantle of pumacious ash and cinders. The major soil series formed were Kirk and Chock. These poorly drained soils are on flood plains and formed in alluvial deposits of ash and cinders. Slopes range from 0 to1% and the water table is located at a depth of 30 to 91 cm for both soils. The Chock series is dark grey loam down to 152 cm. The Kirk series is loamy at the surface changing to gravelly and sandy loam below one foot. These soils have moderate to rapid permeability (Klamath County Soil Survey, Oregon, 1985).

Vegetation and Land Use

The majority of the Wood River Valley is dominated by pasture plants including Kentucky bluegrass *(Poa pratensis* L.*)* and alsike clover (*Trifolium hybridum* L.*)*. Trees and shrubs are present in riparian areas. Most of the valley is privately owned. Irrigated pasture management began in the late 1800's. Canals and ditches were dug to create an earthen canal system which distributes water to pasture plants by surface and subsurface irrigation. Waterways throughout the valley are intensively utilized to support gravity fed flood irrigation. The primary source of irrigation water is the Wood River. There are smaller sources as well, such as Sevenmile Creek and Annie Creek, which were used in this study. Some landowners in the Wood River Valley have adjudicated water rights, while others are in the adjudication process, having made water claims based on historical water use.

Most ranchers in the Wood River Valley graze cattle and irrigate from April through September. Fields are flood irrigated every 10 to 14 d throughout the summer months for a period of about 24 to 48 h per irrigation event. The irrigation schedule, however, varies throughout the valley and season depending on rainfall, cattle density, land conditions and other management objectives. Pastures are typically not chemically fertilized. Cattle that graze the valley are commonly shipped from California by truck in early spring and are shipped back to California feedlots in early fall. Pastures are typically grazed at a rate of 2 head per acre.

Most of the surrounding uplands of the Cascade Range are publicly owned, including Winema National Forest to the east and west and Crater Lake National Park to the north. These areas have tree cover greater than 60% and are dominated by stands of Douglas-fir *(Pseudotsuga menziesii* (Mirbel) Franco*)* and Ponderosa Pine (*Pinus ponderosa*).

Study Site Descriptions

This research project was carried out on two irrigated pasture test plots in the Wood River Valley. The sites were chosen for several factors:

- Representative of the soils and vegetation for the Wood River Valley
- Cooperative landowners whose pasture management activities were typical of the Wood River Valley
- Ability to accurately measure irrigation flows going on and coming off the pasture
- Presence of a fresh irrigation water source allowing for the comparison of pasture runoff water quality with background water quality levels

2003 Study Plot

The 2003 study plot was located in the northern region of the Wood River Valley, 4.8 km west of the town of Fort Klamath, OR (Figure 2). The area of the study plot was 2 ha. This plot was part of a fenced pasture totaling 28.3 ha. The 2 ha plot was delineated from the rest of the field because it was a defined catchment where a water budget could be estinated. Slope on the study plot ranged from 0 to 2% . The site was irrigated a total of seven times from June 1 through August 26, 2003. Individual flood irrigation events typically occurred every 12 d and lasted about 24 to 48 h. The site was irrigated by water from Sevenmile Creek just after it flowed out of the Winema National Forest. The site was grazed from June 1st to September 30th by Holstein dairy cows. These cows were brought from California and stocked at a rate of 0.5 head ha^{-1}.

Vegetation on the site was observed during the 2003 irrigation season. A transect line was drawn across the study site from relatively high ground, sloping down to low ground. Vegetation communities were characterized. The entire site is dominated by Baltic rush (*Juncus balticus* Willd.) and *P. pratensis* L.. Although P. pratensis appeared to be the most common bluegrass, there were other bluegrass species present.. Scattered mesic-forbs occured, most notably dandelions (*Taraxacum sp.),* cinquefoil (*Potentilla sp.),* Yarrow (*Achillea millefolium* L.*),* and a few mustard (*Brassica*) species. Ponding from irrigation resulted in slightly different vegetation community structure in the low ground areas, where *J. balticus,* Alsike/White clover (*Trifolium hybridum/repens),* and Nebraska sedge (*Carex nebraskensis)* are the dominant species.

2004 Study Plot

The 2004 site was located on a pasture in the northern part of the Wood River Valley, 1.6 km north of the town of Fort Klamath (Figure 2). The pasture study plot was 70 ha and stocked with beef cattle at a rate of 1.6 head per ha from May 15 to September 30, 2004. Flood irrigation took place every 10 to 14 d starting in May and lasting until September, 2004. The plot was irrigated by water from Annie Creek which flows out of Crater Lake National Park.

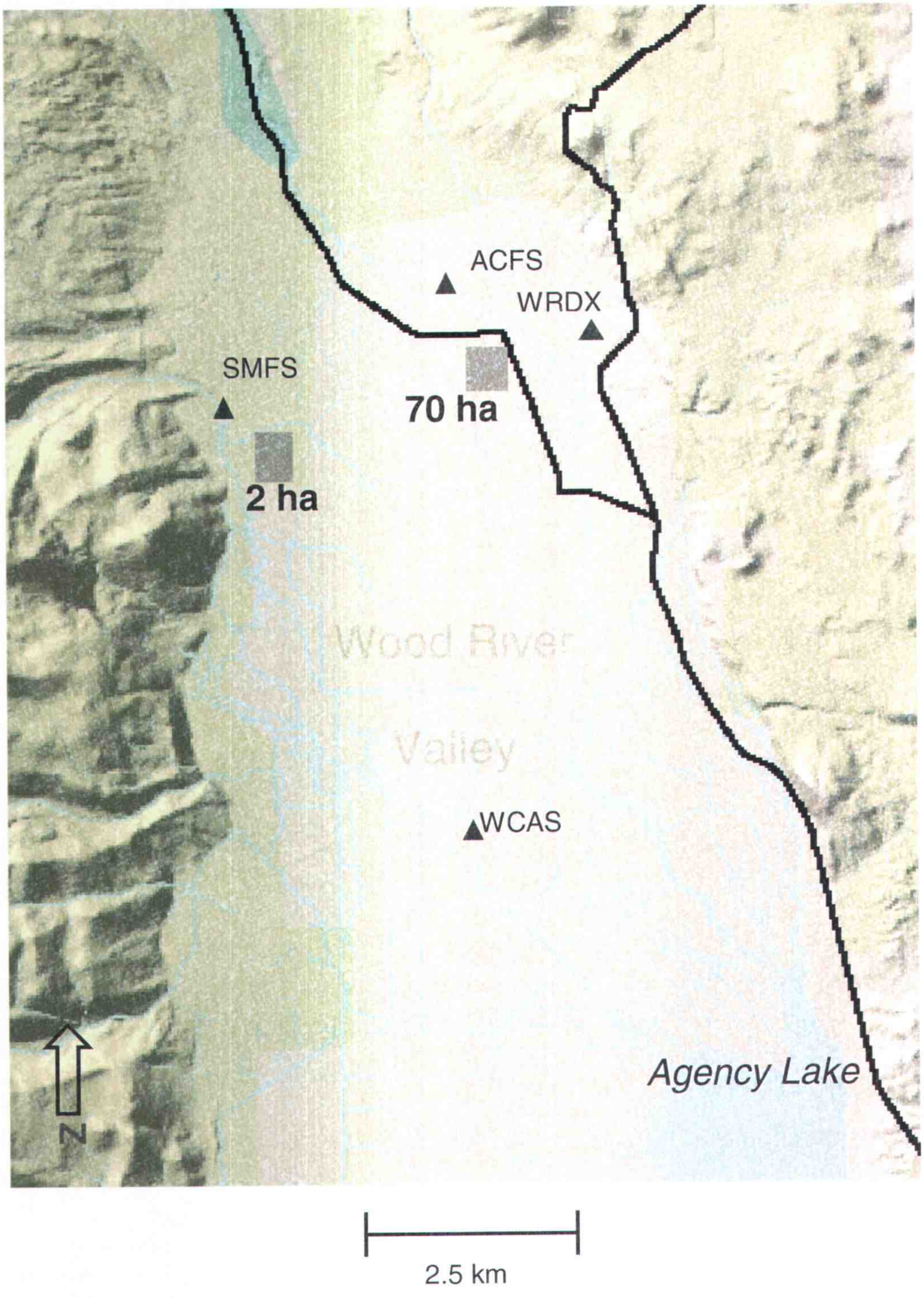


Figure 2. West (2 ha) and East (70 ha) study plots and water quality sampling sites at two headwater areas Sevenmile Creek Forest Service (SMFS), Annie Creek Forest Service (ACFS) and Wood River at Dixon Road (WRDX) and West Canal Above Sevenmile (WCAS) . (Map adapted from Pacific Groundwater Group, 2002)

The predominant soil series on both study plots is Kirk classified as Ashy-pumiceous, glassy, nonacid Typic Cryaquands (Klamath County Soil Survey, Oregon, 1985). Physical descriptions are provided from soil well borings from the West and East Plots (Tables 1 and 2).

(a)

Depth (m)	% Gravel	% Sand	% Fines	Remarks
0 - 0.3	0	5	95	Sod root mat, black loam with high organic content
0.3 – 0.6	0	15	85	Brown and black loam with high organic matter
0.6 - 0.9	0	50	50	Brown and black sandy loam
0.9 - 1.2	0	80	20	Red brown loamy sand
1.2 - 1.5	5	85	10	Brown and gray coarse sand

(b)

Depth (m)	% Gravel	% Sand	% Fines	Remarks
0 - 0.3	5	10	85	Sod root mat, brown loam with high organic content
0.3 – 0.6	5	10	85	Brown loam with some gravel and organic matter
0.6 - 0.9	5	20	75	Brown loam, reduced organic matter
0.9 - 1.2	5	50	45	Brown loamy sand and red mottles
1.2 - 1.5	5	65	30	Brown loam red mottles

Table 1a and b. Soil logs at well borings p2 (a) and p6 (b) on the West Plot, 2003.

(a)

Depth (m)	% Gravel	% Sand	% Fines	Remarks
0 – 0.15	0	10	90	Sod root mat, brown loam, high organic matter
0.15 – 0.3	0	40	60	Black sandy loam
0.9 – 0.6	10	60	30	Black loamy sand
0.6 – 0.9	10	70	20	Brown loamy sand

(b)

Depth (m)	% Gravel	% Sand	% Fines	Remarks
0 – 0.15	0	5	95	Sod root mat, brown loam, high organic matter
0.15 – 0.3	0	5	95	Black loam with high organic matter
0.9 – 0.6	0	35	65	Brown sandy loam
0.6 – 0.9	0	55	45	Brown loamy sand

Table 2a and b. Soil logs at well borings p1 (a) and p2 (b) on the East Plot 2004.

Site	pH	P ppm	C %	S %	N %
East Plot	5.9	21	2.91	0.02	0.20
East Plot	6.1	87	2.73	0.02	0.26
East Plot	6	10	2.41	0.03	0.21
West Plot	5.9	12	1.26	0.01	0.14
West Plot	6.1	12	0.32	0.01	0.10

Table 3. Soil pH, phosphorus (P), carbon (C), sulfur (S) and nitrogen (N) content on East and West Plots.

Soil samples were collected from the West Plot and East Plot and analyzed for nutrient content. East Plot soils had slightly higher P and N than the soils on the West Plot (Table 3).

MATERIALS AND METHODS

This was a two-year study of background levels, sources, and loading of nutrients on flood irrigated grazed cattle pasture in the Wood River Valley. The original intent of this project was to use the same pasture study plot for the 2003 and 2004 irrigation seasons. However, the 2003 plot was not irrigated in 2004 because it was on a property that was entered into a water conservation program. A new study site was chosen for 2004 on a nearby property. The new site had similar soils, pasture and management but the irrigation water source was from a different creek.

Standard livestock management and irrigation practices were not adjusted for this study. Each cattle grazed plot was flood irrigated for about 24 to 48 h every 9 to 14 d between the beginning of June and the end of September. A nutrient budget was estimated and water quality indicators were measured on each plot.

2003 Surface Water Sampling

Surface water quality samples were collected at headwater and tailwater discharges from the 2 ha study plot during five flood irrigation (Figure 3). The study plot was part of a larger fenced pasture, therefore the Holstein dairy cows were not constantly present on the plot during irrigation and sampling. Cows were free to traverse and graze the plot; their presence was noted during sampling. The overall frequency and density with which they were present on the pasture plot is unknown. Dung pat concentration was estimated along 9 m transects at 3 random locations on the plot. Water samples were collected from the headwater canal about three times during each irrigation. Three tailwater samples were collected from two concentrated runoff areas as runoff flow increased. Once runoff flow reached equilibrium, two additional tailwater samples were collected. Water was collected as a grab sample in 250 mL polyethylene bottles and placed on ice, then transported to the USDA Agricultural Research Service (ARS) National Forage and Seed Production and Research Center in Corvallis, OR. Samples not arriving at the lab within 48 h were frozen at 0° C.

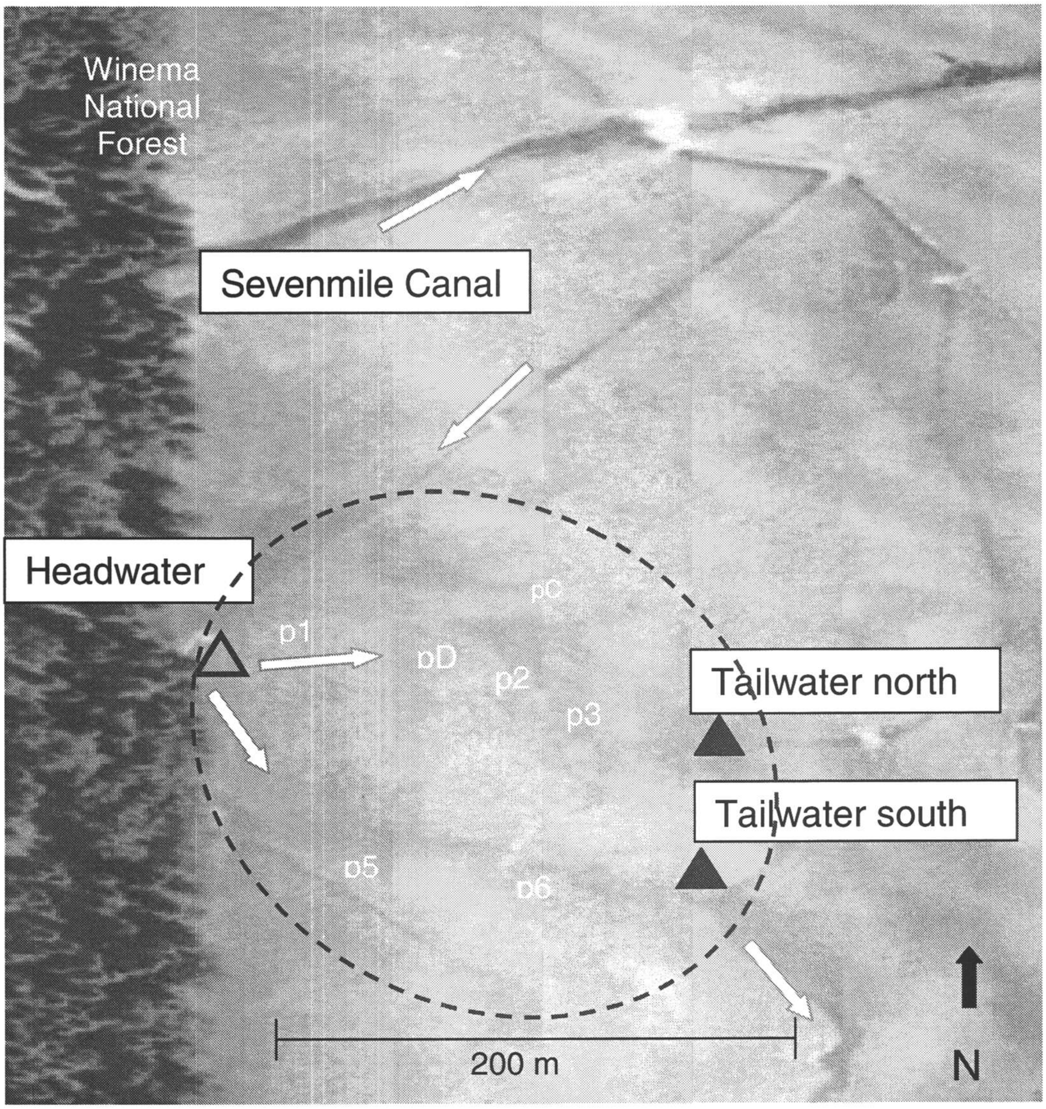


Figure 3. West Plot headwater (Δ), tailwater (▲), shallow groundwater (p(x)) quality sampling sites, irrigated area (O) and irrigation flow direction (→).

2004 Surface Water Sampling

Sampling procedures in 2004 were similar to those in 2003. Figure 4 displays an aerial photo view of 2004 East Plot pasture with water sampling sites. Tailwater samples were taken from three drainage ditches and one pasture runoff area. The Southeast (SE) ditch was the main tailwater drainage for the 70 ha plot. Smaller drainage ditches were also sampled including East (E) ditch and South (S) ditch. Tailwater was collected directly from the pasture surface. Headwater samples were collected from a canal in the northwest corner of the pasture plot.

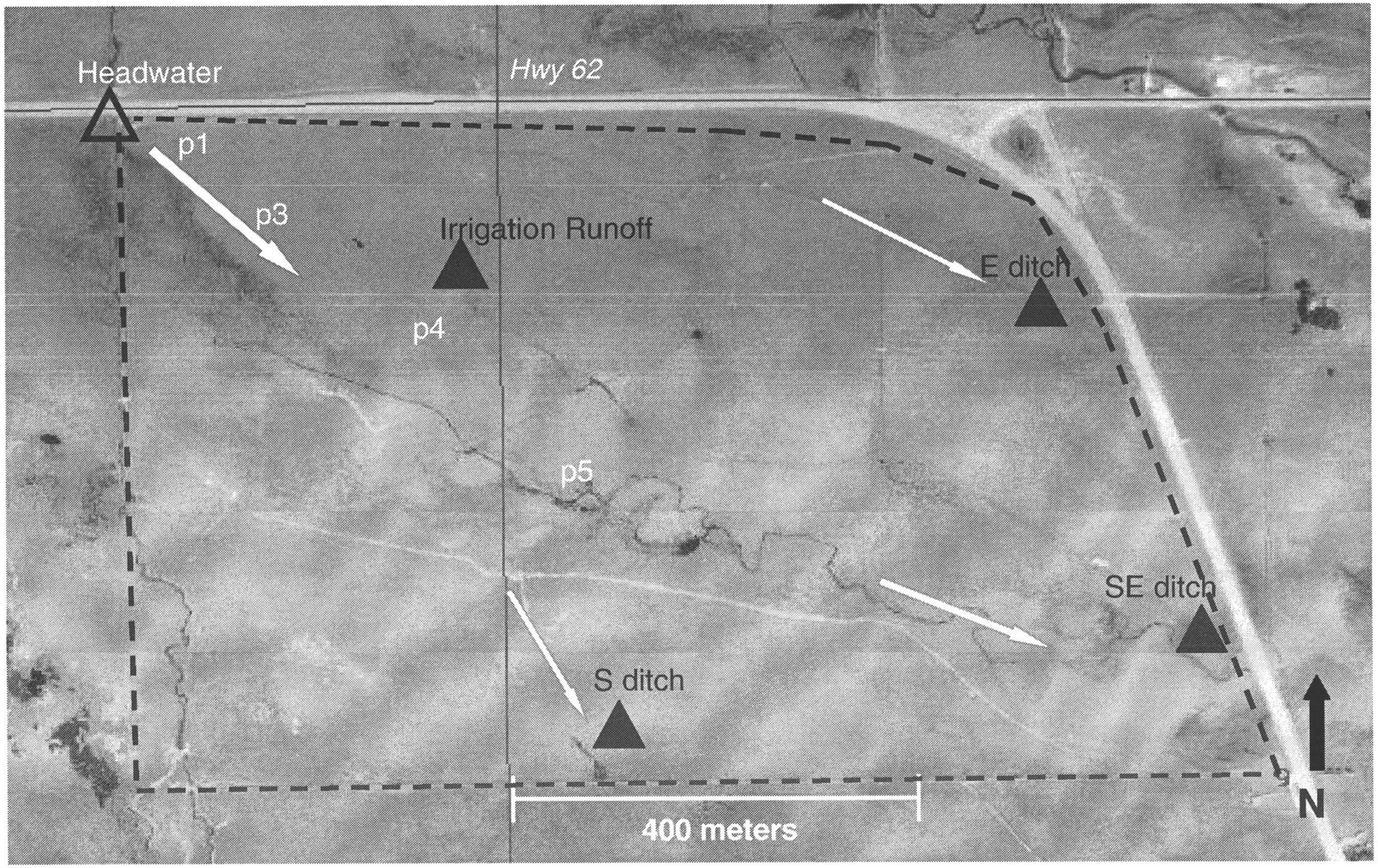


Figure 4. East Plot headwater (Δ), tailwater (▲), and shallow groundwater (p(x)) sampling sites, plot boundary (- - -) and general irrigation flow directions (→).

Sample Analysis

Samples were analyzed at the NFSPRC laboratory for turbidity, sediment, dissolved organic carbon, total nitrogen, total phosphorus, ammonium-N, nitrate-N, OP, pH, and conductivity. Table 4 summarizes the methods, reporting units and sample types.

Once samples reached the laboratory they were tested immediately for pH, turbidity, and conductivity. After these initial analyses, the samples were filtered through a 0.45 mm pore size filter. The filters were then oven dried at 105° C for 24 hours and weighed for sediment mass. At least 135 mL of the filtered sample was refrigerated at 4°C and used for total nitrogen, nitrate-N, and ammonia-N. At least 50 mL of the filtered sample was refrigerated for the analysis of ortho-phosphate, total phosphorus, and dissolved organic carbon.

Temperature and Dissolved Oxygen

Water temperature and dissolved oxygen levels were measured in the field during the 2003 study at headwater and tailwater locations. Readings were made with a Hydrolab Quanta multi-parameter water quality sensor. The sensor was calibrated prior to each use according to manufacturers instructions outlined in the instrument manual.

Procedure	Units	Detection Limit	Method of Analysis
Ammonium	mg N/L	0.05 mg N/L	Flow Injection Analysis Colorimetry
Dissolved Organic Carbon	mg C/L	0.004 mg C/L	High Temperature Catalytic Combustion Shimadzu TOC-V
Nitrate	mg N/L	0.05 mg N/L	Flow injection Analysis Colorimetry QuikChem Method 10-107-04-1-A
Nitrogen, Total	mg N/L	0.01 mg N/L	Chemiluminescence Shimadzu TN
Phosphate, Ortho	mg P/L	0.01 mg P/L	Flow Injection Analysis Colorimetric Quik Chem method 10-115-01-1-B
pH	pH	0.001	Orion Microprocessor pH/millivolt Soils Meter Model 811
Sediment	mg /L	0.1 mg/L	filtered through 0.45 µm glass fiber filters, oven dried at 105° C and weighed
Conductivity	mS	10 megohms/cm	Hydrolab Quanta multi-parameter water quality sensor.
Total Phosphorus	mg P/L	0.01 mg/L	Flow Injection Analysis Colorimetry (Potassium persulfate degestion method) QuikChem method 10-115-01-4-S" Lachat Instruments

Table 4. Analytes and procedures with corresponding units and methods

Water Flow

Irrigation headwater and tailwater flow was measured with a flow meter (122 cm top-set wading rod, JBS Instruments AquaCalc 5000 –Advanced Stream Flow Computer and Pygmy meter). Headwater and tailwater flows were taken two to four times throughout the irrigation application. In order to get more frequent flow readings during the rising and falling limbs of the runoff hydrograph, rectangular weirs were installed for two irrigations during the 2003 study. The weirs were constructed according to US Bureau of Reclamation conditions needed for all types of sharp-crested weirs. The Francis equation (1) was used to compute the runoff rate (United States Department of Interior Bureau of Reclamation, 1997):

$$(1)\ Q = 3.33h_1^{3/2}(L-0.2h_1)$$

Q = discharge in ft^3/s

L = the length of weir in ft

h_1 = head on the weir in ft

Evapotranspiration

Potential evapotranspiration was estimated for study plots from a Hobo weather station on a nearby pasture. The Food Agricultural Organization (FAO) 56 Penman-Monteith was used to calculate potential evapotranspiration.

Shallow Groundwater Monitoring, 2003 Study Plot

Ten peizometer PVC wells (5 cm dia.TIMCO) were used to measure shallow groundwater levels and six of the ten wells were used to collect samples for water quality analysis. Well transects were placed downslope across the pasture. Two wells were installed 6 m outside of the study plot area for monitoring groundwater levels. PVC wells were installed to a depth of 1 to 1.8 m and one steel piezometer was driven to a depth of 3.4 m . Well bores were dug with a soil auger and described. The ground around each well was packed with 15 cm of bentonite clay.

Groundwater levels were measured with a Hebron Well Sounder. Levels were measured frequently during irrigations and at least twice between irrigation events. Water quality samples were taken from PVC wells during two irrigations. Wells were purged prior to sampling. Groundwater samples were collected with a polyethylene tube and 250 mL syringe. A different tube was used for each well. The syringe was washed with well water before each sampling. A new syringe was used for each irrigation event. Samples were placed in 250 mL polyethylene containers and placed on ice. Samples not transported to NFSPRC within 48 h were frozen.

Shallow Groundwater Monitoring, 2004 Study Plot

Five 1.9 cm dia. PVC peizometers were spaced evenly down slope across the pasture. Wells were purged prior to sampling. Well locations are displayed in Figure 4. Sampling procedures were the same as those for the 2003 study plot.

Data Analysis

The chemical and flow data were organized on a seasonal and per irrigation basis. The 2003 data allowed for the estimation of a nutrient budget using the equation (2):

(2) Net nutrient export = Tailwater load/irrigation - Headwater load/irrigation

Nutrient loads were calculated by multiplying chemical concentration by water flow measured at the time of water sample collection. A simple paired t-test was the only statistical analysis used for this study. The t-test was applied to indicate any significant differences between headwater and tailwater quality.

Water Flow and Load Computations

The headwater nutrient load was estimated with equation (3):

(3) Total nutrient load = Mean nutrient loading rate x Irrigation application time

Estimation of the 2003 surface tailwater nutrient load required interpolation of the changing loading rates throughout the runoff period. Weirs installed for the fourth and fifth irrigations in 2003 allowed for frequent flow measurements during the rising and falling limbs of the runoff hydrograph. Linear interpolation of runoff flow and chemical concentration determined nutrient load changes at 15 min intervals throughout the total runoff period. Total subsurface flow was estimated from measurements of surface flow and ET using equation (4):

(4) Total subsurface runoff = Total applied water – (Total surface runoff + ET)

Concerns Regarding Nutrient Budget Estimation

Various assumptions were made in order to estimate nutrient budgets for irrigation events. The nutrient load data should be used with the following assumptions:

1. For the 2003 data, tailwater flow and nutrient concentration are assumed to change linearly between sample collections. This assumption was not always true. Both flow and nutrient concentration fluctuated between sample collections, however the nutrient concentration generally decreased throughout the irrigation and flow generally increased until irrigation application ceased.

2. During the 2003 study the headwater flow and nutrient concentration were assumed to be stable throughout the irrigation application. However, when headwater flow was measured frequently during the July 23rd-25th irrigation the flow was 30% lower on the first day of irrigation than on the third day. Due to this significant change in flow, interpolation was used to determine the nutrient loading rate for the July 23rd-25th irrigation. The headwater flow rate measured for the August 8th irrigation was, however, within 13% of the seasonal mean headwater flow. Certain headwater nutrient concentrations were more variable during the July 25th and August 8th irrigations than they were for the rest of the season. Headwater TN concentration was 55% higher on July 25th than the seasonal mean TN concentration. Headwater concentration of TP was 54% higher on August 8th than the seasonal mean TP concentration. I assumed these higher than average levels represented the headwater nutrient concentration and

used them to determine the headwater nutrient loading rate. Concentrations of OP and DOC were similar to the mean seasonal concentration.

3. Subsurface runoff at the West Plot was assumed to seep into a drainage ditch at the bottom of the pasture. Some subsurface runoff, however, flowed to a neighboring pasture.

4. The 2003-study plot area was only 7% of a larger fenced in pasture area. I assumed the study plot was grazed at a similar intensity as the rest of the field. This assumption was made based on observations of cow movement, pasture stubble height and fecal deposition on the study plot compared to that on the entire fenced in pasture. In 2004 a larger plot was used that encompassed nearly an entire fenced in field. This larger plot was more representative of cattle and nutrient movement as it incorporated most of a fenced pasture. Estimating a nutrient budget for the large plot however, introduced more error in water flow estimation because it had multiple flood irrigation events occurring at different times.

RESULTS

Data were collected on three pasture catchment plots (2 to 5 ha) during the 2003 irrigation season. In 2004 data were collected from one study plot that was a 70 ha fenced in pasture. The primary study sites were the West and East Plots located at the northern part of the Wood River Valley (Figure 2).

2003 Irrigation Season

The mean air temperature for May through September 2003 was 15.63° C. Total precipitation for May through September 2003 was 3.6 cm. On September 9, 2003 2.6 cm of precipitation fell within a 24 hour period. Most other precipitation events were less than 0.5 cm day^{-1}.

Sampling

Most 2003 sampling occurred at the West Plot. A total of 60 tailwater samples,16 headwater samples and 30 subsurface (shallow groundwater) water samples were taken at the West Plot during five irrigation events from June through August 2003 and 1 storm event on September 9, 2003. All West Plot headwater samples were collected at a canal headgate that controlled irrigation flow onto the pasture. Tailwater samples were collected at two swales (north and south tailwater) at the low end of the plot. Groundwater was sampled in wells along two transects from the headgate to the north and south tailwater areas (Figure 3).

Cattle Presence

Holstein dairy cows were stocked on the West Plot in 2003 at a rate of 0.5 cows ha^{-1}; the cows roamed across the plot during and after irrigation. Since the plot was not fenced, the extent of livestock presence noted during sampling and the density of cow dung was estimated at the end of the season. There were three irrigations when cows were concentrated on the West Plot during sampling. On July 7, 2003 approximately 30 cows were present on the drainage area of the flood irrigation plot. Approximately 10 cows were present around the tailwater sampling sites during the August 9^{th} to 10^{th} , 2003 and August 26, 2003 irrigations. Cow dung pat number and density averaged 2.9 per 9 m transect.

Surface Water Quality

Headwater generally had lower nutrient concentrations than tailwater.
Mean TDN concentration was 0.11 mg TDN L^{-1} in headwater and 0.44 mg TDN L^{-1} in tailwater. Organic N was determined by subtracting NH_4^+-N and NO_3^--N concentration from the TDN concentration. Most dissolved-N was organic in both headwater and tailwater samples. NO_3^--N was not detected in surface water and NH_4^+-N concentrations were rarely detected in surface water. Mean TDP concentration was 0.07 mg TDP L^{-1} in headwater and 0.15 mg TDP L^{-1} in tailwater. Most dissolved P in tailwater and headwater was in the OP form. DOC and sediment were generally higher in tailwater than they were in headwater (Table 5).

Site		Sediment mg/L	DOC mg/L	TDN mg/L	TDP mg/L	NH_4^+-N mg/L	NO_3^--N mg/L	OP mg/L	Dissolved Organic-N mg/L
Headwater (16n)	minimum	0.6	1.32	0.01	0.05	<.05	<.05	0.05	0.01
	maximum	37.3	16.56	0.46	0.13	0.05	<.05	0.09	0.46
	median	5.4	9.91	0.08	0.07	-	<.05	0.07	0.07
	mean	13.7	10.06	0.11	0.07	-	<.05	0.06	0.11
Tailwater North (34n)	minimum	0.5	1.48	0.08	0.05	0.05	<.05	0.03	0.03
	maximum	43.4	45.21	1.52	0.52	0.12	<.05	0.50	1.40
	median	6.0	16.27	0.32	0.11	0.07	<.05	0.08	0.32
	mean	16.5	18.53	0.47	0.15	0.07	<.05	0.13	0.44
Tailwater South (26n)	minimum	0.6	10.2	0.12	0.05	0.06	<.05	0.05	0.12
	maximum	42.6	31.9	0.98	0.55	0.15	<.05	0.32	0.98
	median	5.2	16.5	0.41	0.13	0.07	<.05	0.10	0.35
	mean	16.6	18.0	0.42	0.16	0.09	<.05	0.13	0.39
Storm Water (5n)	minimum	2.9	30.31	1.64	0.14	0.05	<.05	0.01	1.60
	maximum	9.0	43.67	2.48	0.26	0.17	<.05	0.11	2.35
	median	5.3	33.96	1.97	0.16	0.07	<.05	0.04	1.90
	mean	5.5	35.12	2.01	0.19	0.10	<.05	0.05	1.91

Table 5. Surface Irrigation and stormwater nutrient concentration summary for sediment, dissolved organic carbon (DOC), total dissolved nitrogen (TDN), total dissolved phosphorus (TDP), NH4+-N, NO3--N, orthophosphate (OP) and dissolved organic-N; West Plot, 2003.

Stormwater

There were 5 storm samples taken during one storm on September 9, 2003. Flows were low at the tailwater north and tailwater south sampling sites. Since the stormwater was only seeping over the weirs, flows were not measured. TDP and TDN concentrations in stormwater were high, particularly the dissolved organic-P and N fractions (Table 5). When compared to irrigation tailwater and headwater, a lesser portion of the TDP in stormwater runoff was in the OP form. TDN concentration was 400% higher in the stormwater than it was in irrigation runoff. Maximum and minimum TDN values in storm runoff were 2.48 mg TDN L^{-1} and 1.64 mg TDN L^{-1}, respectively. Maximum sediment concentration in storm runoff was low (<9.0 mg sediment L^{-1}). NH_4^+-N concentrations were higher in stormwater runoff than e in irrigation tailwater samples. NH_4^+-N was detected in all 5 stormwater samples and ranged from 0.05 mg NH_4^+-N L^{-1} to 0.13 mg NH_4^+-N L^{-1}.

Shallow Subsurface Water Quality

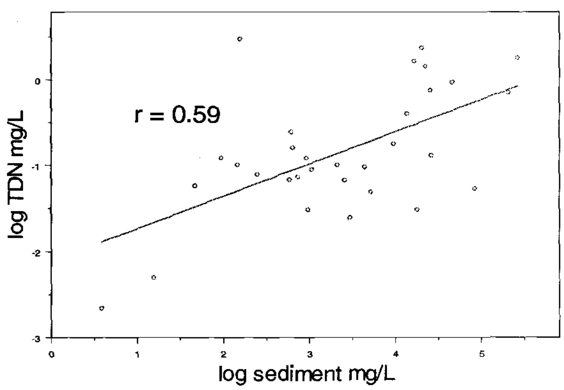
Subsurface groundwater was sampled on the West Plot during three irrigations and one storm. Mean TDN and TDP concentrations in groundwater were 0.36 and 0.07 mg L^{-1}, respectively (Table 6).

Shallow Groundwater 2003 (33n)	Sediment mg/L	DOC mg/L	TDN mg/L	TDP mg/L	NH_4^+-N mg/L	NO_3^--N mg/L	OP mg/L
minimum	1.8	1.96	0.07	0.02	<0.05	<0.05	0.01
maximum	226.7	43.42	1.61	0.13	0.94	0.10	0.06
median	30.2	25.36	0.37	0.05	0.11	<0.05	0.02
mean	51.0	23.86	0.55	0.06	0.16	0.01	0.03

Table 6. Shallow Groundwater nutrient concentration summary for sediment, dissolved organic carbon (DOC), total dissolved nitrogen (TDN), total dissolved phosphorus (TDP), NH_4^+-N, NO_3^--N, and orthophosphate (OP) West Plot, 2003.

TDN concentrations were higher in groundwater than in both the irrigation surface headwater and tailwater. TDP concentrations, however, were lower in groundwater than in surface headwater and tailwater. Mean TDP was 0.06 mg L^{-1}. There was no clear relationship between the landscape position of a well and the resulting nutrient concentration of shallow groundwater. Basic analysis showed mean TDN concentrations were higher in the wells placed at the lower half of the field, NH_4^+-N however was higher in wells in the upper half and TDP levels were similar for all wells. Some TDN concentration values in groundwater may be elevated due to sediment contamination during sample collection. Sediment content of the groundwater sample was correlated to the concentration of TDN (Figures 5a and b).

(a)



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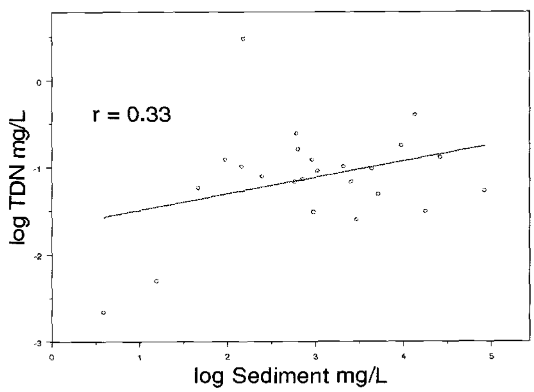


Figure 5a-b. (a)Relationship between sediment and total dissolved-N (TDN) in shallow groundwater samples on West Plot, 2003. (b) After 7 samples were removed.

Samples containing particularly high sediment and TDN concentrations were removed before further analysis was performed. The sediment concentration of the groundwater samples did not, however, have a strong relationship with dissolved-P (r = -0.25). Well DP-6 had elevated TP and OP concentrations (0.40 mg and 0.36 mg L^{-1}). The sample was removed because the well was only sampled once and may have been contaminated.

Background Water Quality

The West Plot is irrigated with water from Sevenmile Creek. Sevenmile Creek in the Winema National Forest (SMFS) is assumed to be background water quality for the irrigation water used at the West Plot (Figure 2). The East Plot is irrigated by water from Annie Creek. Annie Creek at sampling station (ACFS) is assumed to be background water quality for the East Plot. TP and TN are low at SMFS and ACFS relative to West Canal (WCAS) which is a major tailwater drainage way for the Wood River Valley (Figures 6 and 7).

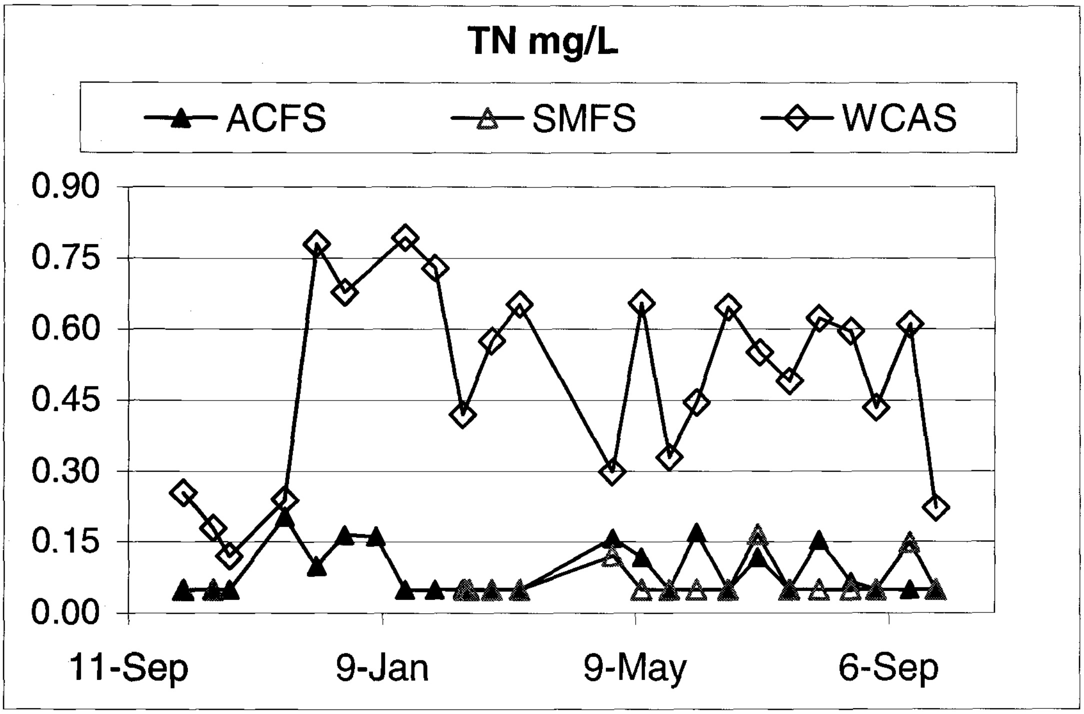


Figure 6. Total-N (TN) in Annie Creek at Forest Service Gauge (ACFS), Sevenmile Creek at the Forest Service Gauge (SMFS) and West Canal above Sevenmile (WCAS), 2004. (Data from Graham Mathews and Associates, 2004)

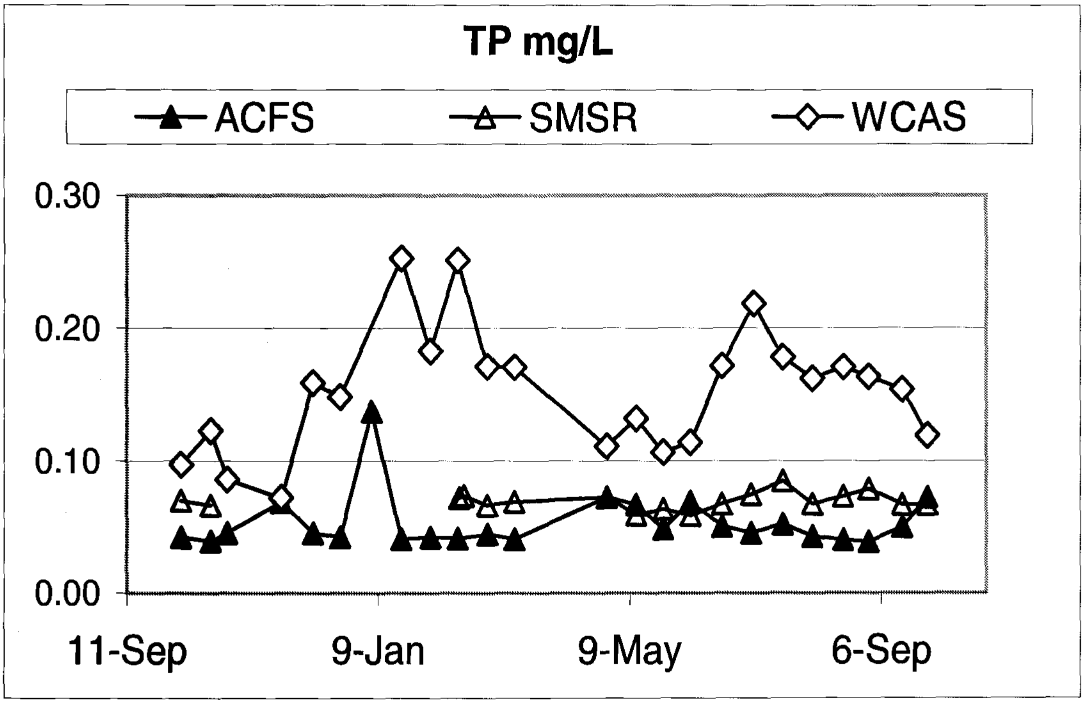


Figure 7. Total-P (TP) in Annie Creek at Forest Service Gauge (ACFS), Sevenmile Creek at the Forest Service Gauge (SMFS) and West Canal above Sevenmile (WCAS), 2004. (Data from Graham Mathews and Associates, 2004)

TDN and TDP concentrations in irrigation headwater, tailwater and stormwater runoff at West Plot were compared relative to Sevenmile Creek at the SMFS sampling site (Figures 8 and 9). The Sevenmile Creek total-P (TP) and total-N (TN) concentration values represented in the box plots include the particulate-N and P fractions (> 0.45 μm) while all other sites are dissolved concentrations of TDP and TDN. Sevenmile Creek had a mean TN and TP concentration of 0.09 mg TN L^{-1} and 0.06 mg TP L^{-1}. These nutrient concentration values were similar to West Plot irrigation headwater and lower than surface tailwater and stormwater runoff. TDN and TDP concentration values were wider ranging in irrigation tailwater than in headwater, stormwater or Sevenmile Creek during the 2003 season. Subsurface tailwater TDP was generally lower than Sevenmile Creek TP concentration. Subsurface TDN, however, was higher than the TN concentration in Sevenmile Creek.

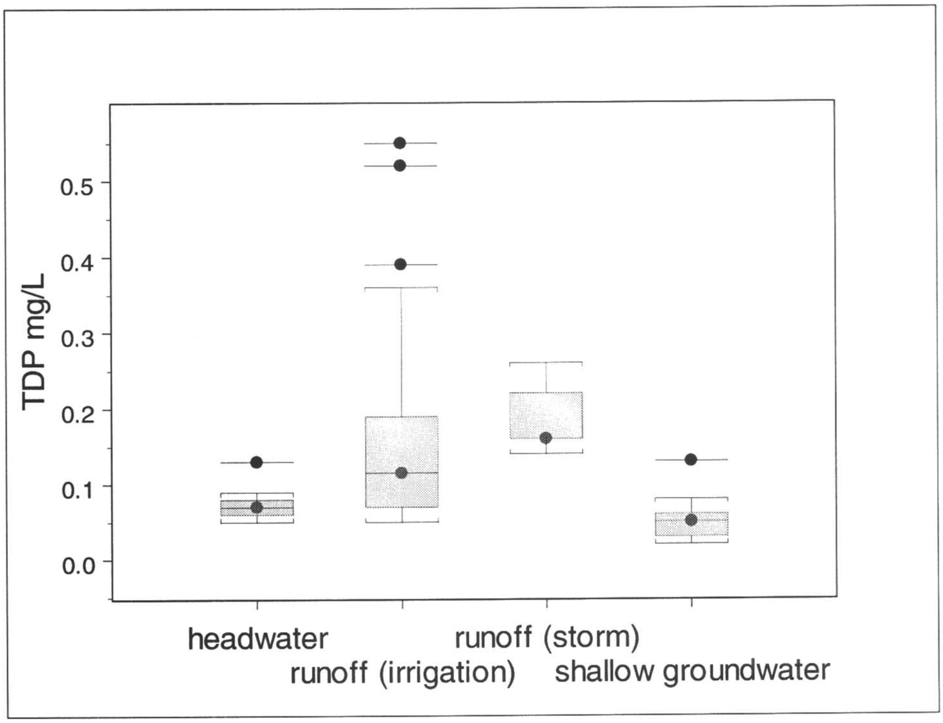


Figure 8. Total dissolved-P (TDP) mg L^{-1} in pasture irrigation headwater, tailwater, groundwater and stormwater.

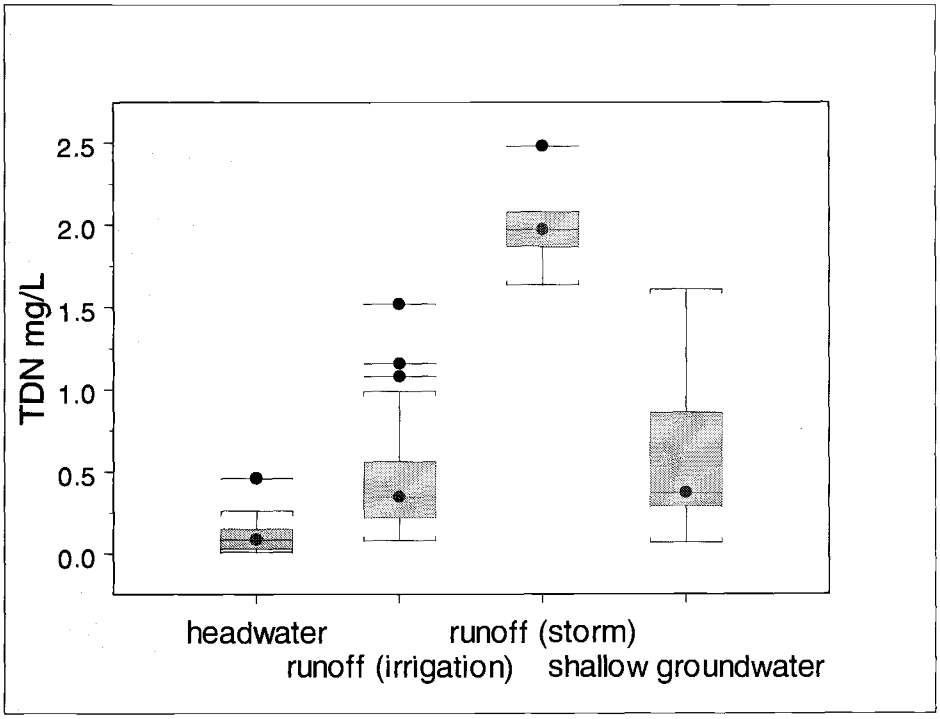


Figure 9. Total dissolved-N (TDN) mg L^{-1} in West Plot pasture irrigation headwater, tailwater, groundwater and stormwater.

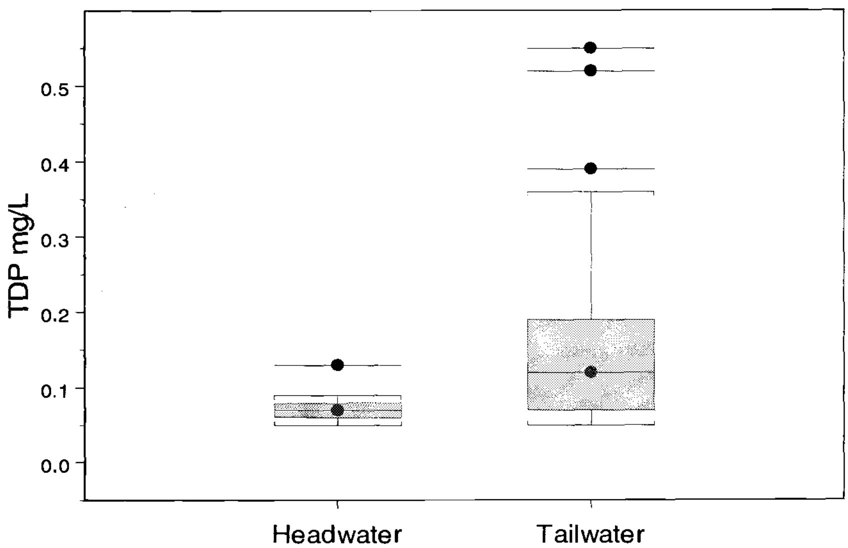


Figure 10. Variation in total dissolved-P (TDP) concentrations found in irrigation headwater and tailwater on the West Plot, 2003.

The Sevenmile Creek TN concentration was undetected (<0.1 mg TN L^{-1}) for all samples and given a value of ½ the detection limit, 0.05 mg TN L^{-1} for display purposes.

A standard two-sample T-test was performed for nutrient concentration in headwater vs. surface tailwater. The mean increase in TDN and TDP concentration from headwater to surface tailwater was 0.33 mg (p-value < 0.01) and 0.08 mg L^{-1} (p-value = 0.01), respectively. There was less variability in headwater nutrient concentration than in tailwater (Figure 10). Headwater TDN and TDP concentrations had standard deviations of 0.12 and 0.02, respectively. The standard deviation for tailwater TDN and TDP concentration was 0.30 and 0.12, respectively. The greater variability in tailwater nutrient concentration is primarily due to the first flush of nutrients at the beginning of the tailwater runoff period.

First Flush

High nutrient concentration values in the West Plot surface tailwater runoff were attributed to the first flush which occurred during 4 irrigations (Figures 11-15). Samples at West Plot were collected over the course of the irrigation from 1 headwater and 2 tailwater locations (tailwater north and south). Nutrient concentrations were greatest early in the tailwater runoff period, while headwater concentrations were lower and generally stable. By the end of irrigation runoff the nutrient concentration in tailwater was similar to that in headwater. The two tailwater discharge sites (tailwater north and south) have a similar temporal distribution pattern for all nutrient and sediment concentrations.

TDN and DOC followed similar temporal distribution patterns during all four irrigations. TDP and OP also follow similar patterns. Headwater TDP concentrations were unusually high (0.13 mg TDP L^{-1}) in two samples taken on August 9, 2003. The OP concentration for the same headwater samples was lower (0.07 mg OP L^{-1}) signifying there may have been higher dissolved

(<0.45µm) organic matter or particles in the sample. Most other headwater TDP concentration values were below 0.1 mg TDP L^{-1}. Mean tailwater TDN and TDP concentrations were 31% and 51% higher, respectively, during the first three irrigations than they were during the last two irrigations of the 2003 season.

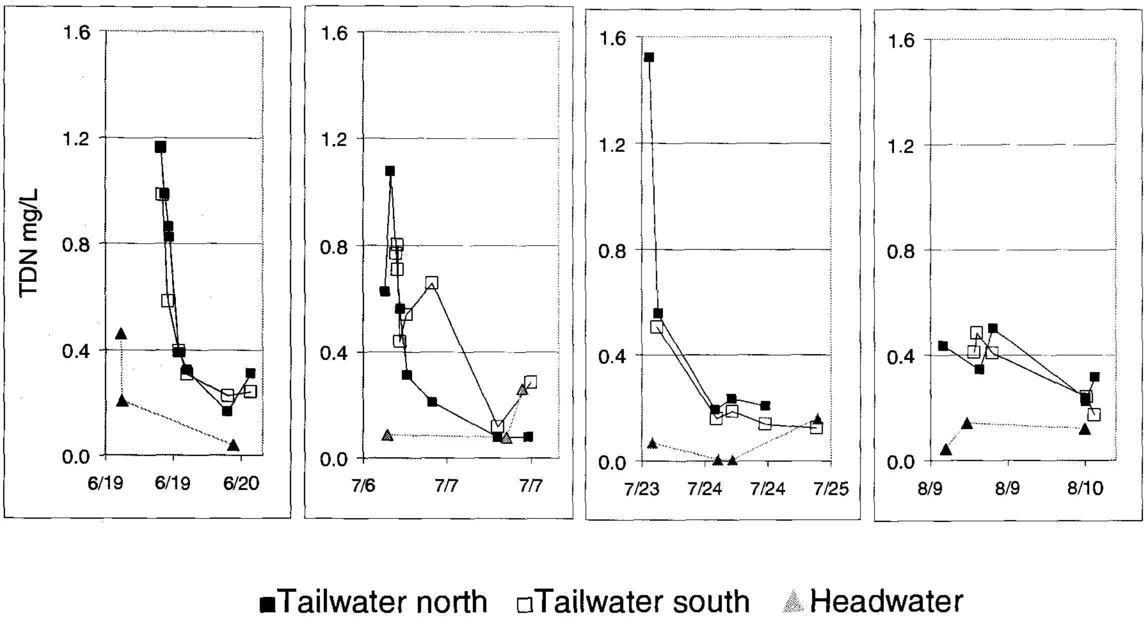


Figure 11. Temporal distribution of total dissolved nitrogen concentration (TDN) in headwater and tailwater during 4 irrigations; June to August, 2003 – West Plot.

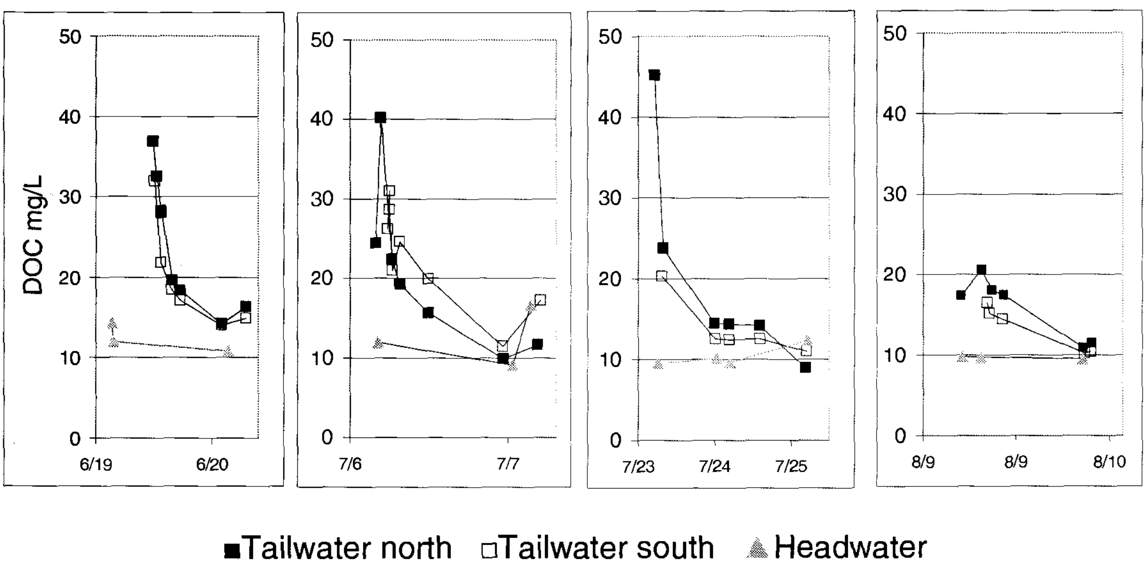
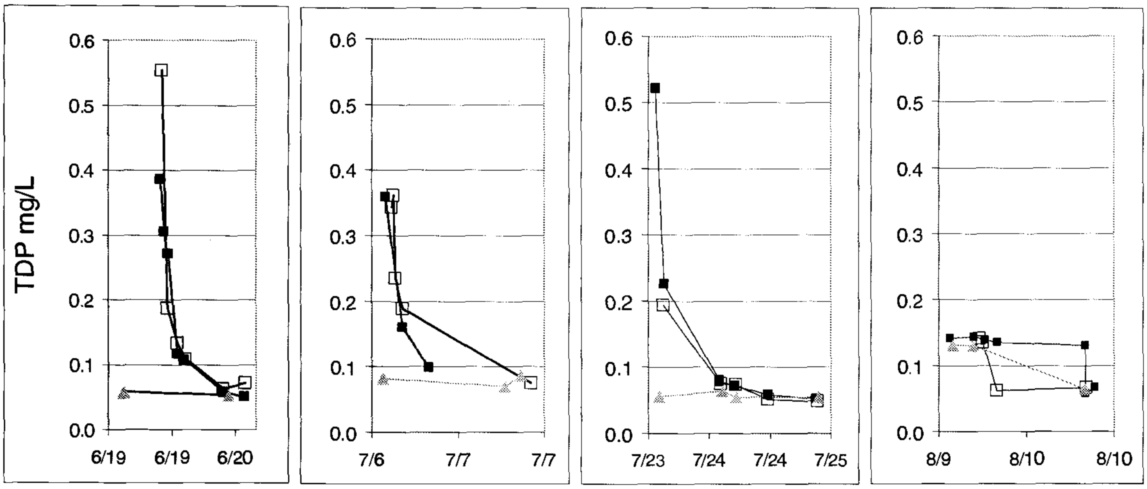
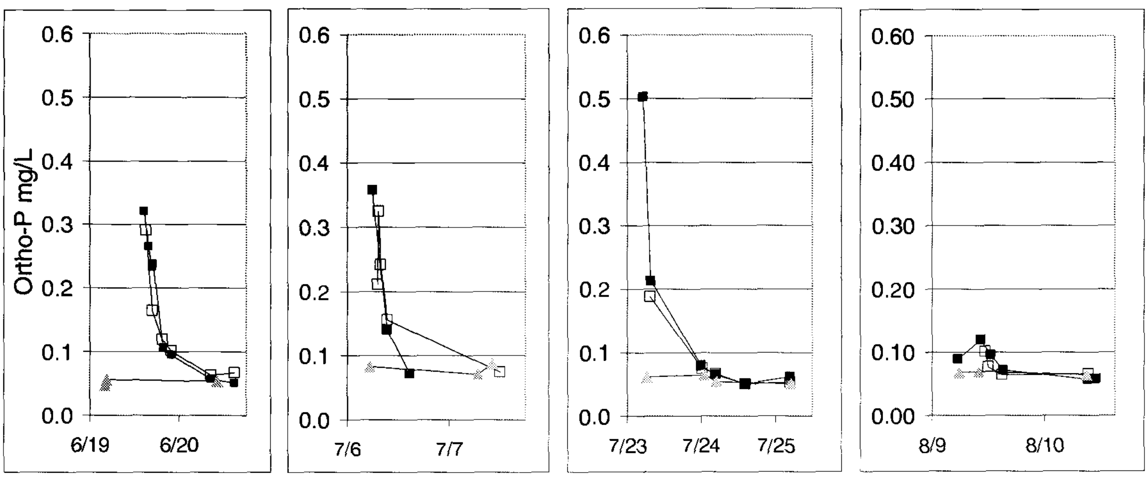


Figure 12. Temporal distribution of dissolved organic carbon (DOC) concentration in headwater and tailwater during 4 irrigations; June to August, 2003 – West Plot.



■Tailwater north □Tailwater south ▲Headwater

Figure 13. Temporal distribution of total dissolved phosphorus (TDP) concentration in headwater and tailwater during 4 irrigations; June to August, 2003 – West Plot.



■Tailwater north □Tailwater south ▲Headwater

Figure 14. Temporal distribution of orthophosphate concentration in headwater and tailwater during 4 irrigations; June to August, 2003 – West Plot.

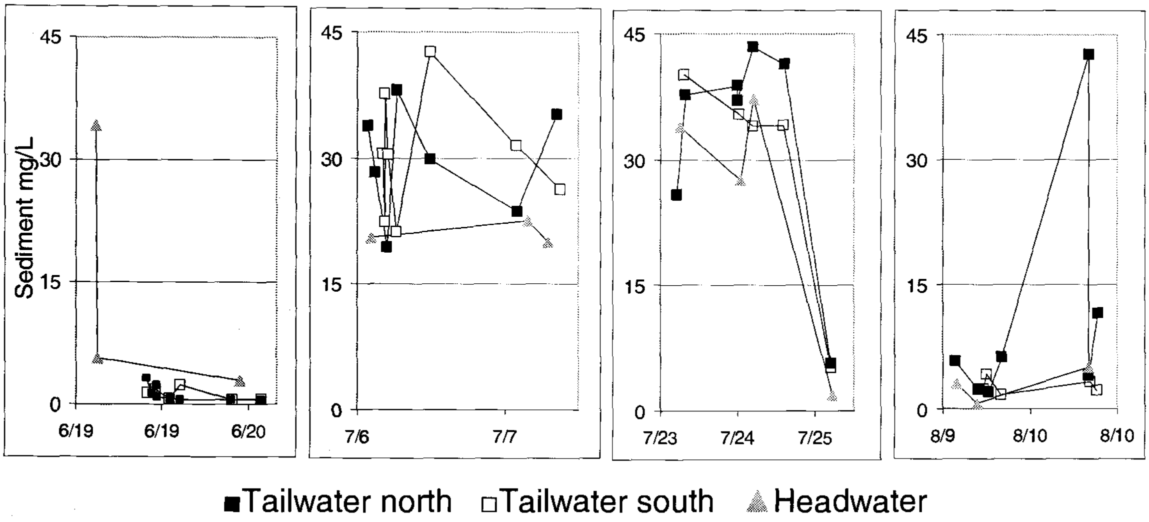


Figure 15. Temporal distribution of sediment concentration in headwater and tailwater during 4 irrigations; June to August, 2003 – West Plot.

Sediment concentration did not follow a first flush pattern but was often higher in tailwater than in headwater. Cattle presence on July 7 and August 10 appears to have increased the tailwater sediment concentration. The water sample taken at Tailwater north on August 10 was cloudy and directly below grazing cattle. Headwater sediment concentration seems to influence tailwater sediment concentration during the July 23 to 25 samplings. On June 19 the high sediment concentration (34.3 mg sediment L^{-1}) in headwater is from flushing of the irrigation canal a few minutes after the irrigation headgate was opened. TDN follows a similar headwater flushing pattern. Headwater sediment and TDN concentration levels decreased within ½ h after the headgate was opened.

The nutrient concentration results for the August 26, 2003 irrigation are presented separately (Figure 16). There were fewer samples collected during this irrigation and the West Plot was flooded from a nearby field for 2 days prior to the August 26th irrigation. There is some indication of a headwater and tailwater flushing of TDN and DOC. Cattle were observed on the West Plot during the August 26th irrigation but maximum sediment concentration was low (2.9 mg sediment L^{-1}). The higher tailwater nutrient concentrations are likely a result of flushing but are lower than tailwater nutrient concentrations of previous irrigations.

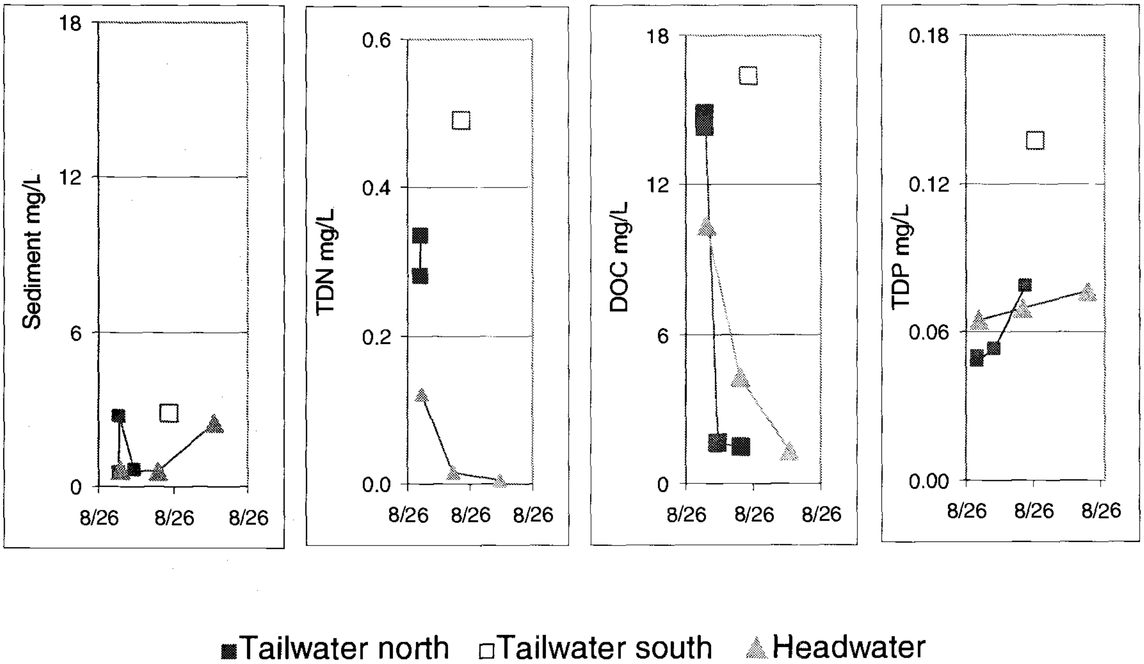


Figure 16. Temporal distribution of sediment, total dissolved N (TDN), dissolved organic-C (DOC) and total dissolved-P (TDP) concentration in headwater and tailwater during on August 26th, 2003 – West Plot.

Flow

Flow was measured at headwater and tailwater locations on the West Plot during the July 23 to 25 and August 9 to10 irrigations. The irrigation applications were controlled manually by a canal headgate and application rate ranged from 41.0 to 58.8 L sec^{-1}. During each irrigation water would saturate the surface of about 2 ha of pasture. Near maximum saturated surface area would occur about 15 hrs after the headgate was opened. Most of the saturated surface was covered with about 1 to 3 cm of sheet flow and water also ponded in depressional areas throughout the plot. Most surface runoff concentrated into two separate swales at the bottom of the field. Weirs were set up at the two swale locations (north and south tailwaters) to measure surface irrigation runoff. Tailwater began flowing over the north tailwater weir crest about eight hours after the start of irrigation and flow started at the south tailwater soon after. The peak runoff rate, which was a combination of the north and south tailwater, was 46.6 L sec^{-1}, this flow was measured 46 hrs after the start of the July 23 to 25 irrigation. Tailwater flows were not measured in irrigations previous to July 23rd because the tailwater weirs failed to completely capture the surface runoff.

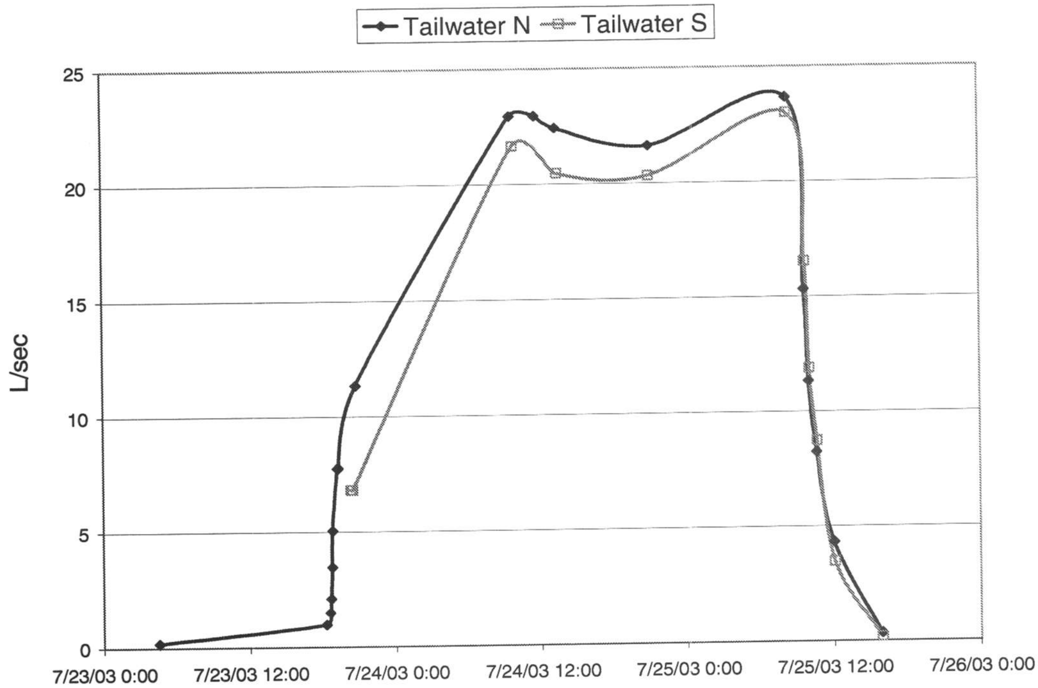


Figure 17. Runoff hydrograph for West Plot north and south tailwater during July 23rd to 25th, 2003 irrigation.

The north tailwater flow was slightly higher than the south tailwater flow and their hydrographs followed similar patterns (Figure 17). The peak runoff flow measured was 80% of the headwater (application) flow. Surface runoff typically increased during the first 24 hr period of irrigation and then stabilized for the remaining hours. There was an estimated 5% decrease in runoff from evening to morning during the July 23 to 25 irrigation, attributed to increased daytime evapotranspiration.

Nutrient Runoff

Nutrient concentrations in tailwater were examined during the rising and equilibrium portions of the runoff hydrograph. Mean nutrient concentration was highest in tailwater for all nutrients during the rising limb of the runoff hydrograph. As surface return flow reached equilibrium the mean nutrient concentration difference between headwater and tailwater decreased (Table 7).

% greater in tailwater relative to headwater	Sediment %	DOC %	TDN %	TDP %	OP %
Rising limb of hydrograph 7/23 – 7/25/03	100.5	151.4	580.8	409.4	386.6
Equilibrium limb of hydrograph 7/23 – 7/25/03	66.1	16.3	39.9	18.5	13.7
Rising limb of hydrograph 8/9 – 8/9/03	14.6	71.0	760.5	7.6	9.3
Equilibrium limb of hydrograph 8/9 – 8/9/03	448.3	9.5	406.3	-34.2	-42.3

* (-) signifies the headwater concentration was higher than tailwater

Table 7. Percent concentration increase in tailwater sediment, dissolved organic-C (DOC), total dissolved-N (TDN), total dissolved-P (TDP) and orthophosphate OP relative to headwater for 2 irrigations on the West Plot, 2003.

Flow Weight Concentration

The flow weighted concentration at a particular sampling site may be more representative of water quality than computing loading rates. A waterway with a high flow volume and low constituent concentration would have more dilution potential but may have the same loading rate as a waterway with low flow and high constituent concentration. A flow weighted concentration is an overall measure of water quality for a particular sampling site and the weight assigned to a concentration is relative to the flow (Sether, 2004). FWC was computed for sampling sites according to equation (5):

$$(5)\ FWC = \frac{\text{Total of constituent loads measured at a sampling site}}{\text{Total of flow volumes measured at a sampling site}} = \sum L / \sum Q$$

Instantaneous headwater and tailwater nutrient and sediment loads were measured during the July 23rd to 25th and August 9th to 10th irrigations. Tailwater flow weighted concentrations mg L^{-1} (FWC) were calculated for each irrigation (Tables 8 and 9). Headwater flows were measured less frequently than tailwater, therefore headwater FWC was calculated from flows and water quality measured during three irrigations in July and August (Table 10). The FWC for nutrients were mostly higher in tailwater than in headwater. Tailwater had an FWC of 0.32 mg TDN L^{-1} in July and 0.21 mg TDN L^{-1} in August compared to the mean FWC for headwater, 0.09 mg TDN L^{-1}. Tailwater FWC for TDP in July was 0.08 mg TDP L^{-1} and 0.11 mg TDP L^{-1} in August. Headwater FWC for TDP was 0.06 mg TDP L^{-1}.

Time and Date	L/sec	Sediment mg/sec	DOC mg/sec	TDN mg/sec	TDP mg/sec	OP mg/sec
7/23/03 18:35	1.5	38.8	67.88	2.29	0.78	0.75
7/23/03 20:20	18.1	542.3	407.24	9.74	3.88	3.69
7/24/03 9:38	44.6	1658.3	602.73	7.88	3.46	3.50
7/24/03 11:39	44.6	1618.4	601.81	7.87	3.40	3.50
7/24/03 13:20	42.9	1669.2	574.47	9.07	3.16	2.83
7/24/03 21:00	41.9	1589.5	560.17	7.32	2.31	2.12
7/25/03 8:18	46.6	148.0	463.08	5.98	2.03	1.99
Flow Wt Concentration		30.2	13.64	0.21	0.08	0.08
Minimum	1.5	38.8	67.88	2.29	0.78	0.75
Maximum	46.6	1669.2	602.73	9.74	3.88	3.69
Median	42.9	1589.5	560.17	7.87	3.16	2.83
Mean	34.3	1037.8	468.20	7.16	2.72	2.63

Table 8. Tailwater surface nutrient loads and flow weighted concentrations (FWC) for sediment, dissolved organic-C (DOC), total dissolved-N (TDN), total dissolved-P (TDP) and orthophosphate (OP) for July 23rd to 25th, 2003 irrigation.

Time and Date	Flow L/sec	Sediment mg/sec	DOC mg/sec	TDN mg/sec	TDP mg/sec	OP mg/sec
8/9/03 11:27	1.0	5.7	16.93	0.43	0.14	0.09
8/9/03 15:23	11.9	40.0	233.20	2.13	1.70	1.32
8/9/03 17:10	29.3	77.3	483.17	10.99	3.94	2.19
8/9/03 19:20	38.0	168.6	618.23	17.72	5.13	2.62
8/10/03 9:43	40.7	1169.6	501.50	11.28	4.71	1.95
8/10/03 10:05	39.4	1036.9	487.72	11.14	4.38	1.88
8/10/03 11:20	29.1	161.7	277.21	6.03	1.72	0.96
Flow Wt Concentration		14.1	13.83	0.32	0.11	0.06
Minimum	1.0	5.7	16.93	0.43	0.14	0.09
Maximum	40.7	1169.6	618.23	17.72	5.13	2.62
Median	29.3	161.7	483.17	10.99	3.94	1.88
Mean	27.0	380.0	374.00	8.53	3.10	1.57

Table 9. Tailwater surface nutrient loads and flow weighted concentrations (FWC) for sediment, dissolved organic-C (DOC), total dissolved-N (TDN), total dissolved-P (TDP) and orthophosphate (OP) for August 9th to 10th, 2003 irrigation.

Sample Date	Flow liters/sec	Sediment mg/sec	DOC mg/sec	TDN mg/sec	TDP mg/sec	OP mg/sec
7/6/03	52.6	1080.2	626.74	4.55	4.21	4.21
7/7/03	54.0	1219.3	489.04	4.21	4.05	3.78
7/23/03	41.0	1393.6	390.08	2.82	2.54	2.46
7/25/03	58.8	111.7	722.58	9.31	3.25	2.95
8/9/03	50.4	156.5	493.04	2.35	6.60	3.46
Flow Wt Concentration		15.4	10.59	0.09	0.06	0.05
Minimum	41.0	111.7	390.08	2.35	2.54	2.46
Maximum	58.8	1393.6	722.58	9.31	6.60	3.78
Median	52.6	1080.2	493.04	4.21	4.05	3.46
Mean	51.4	792.3	544.30	4.65	4.13	3.37

Table 10. Headwater surface nutrient loads and flow weighted concentrations (FWC) for sediment, dissolved organic-C (DOC), total dissolved-N (TDN), total dissolved-P (TDP) and orthophosphate (OP) for July 23rd to 25th, 2003 irrigation.

West Plot Nutrient Budget

A nutrient and sediment budget was estimated for the July 23 to 25 and August 9 to 10 irrigations. The surface headwater and tailwater nutrient and sediment loads were estimated by interpolating water flow, chemistry and sediment data throughout the 2 irrigation application and runoff periods. Subsurface flow was calculated from surface flow and ET data.

Cuenca et al. (1992) characterized the Klamath Basin as having a crop water requirement (ET_{crop}) for pasture of 196 and 155 mm for the months of July and August, respectively. FAO penman montieth reference evapotranspiration (ET_o) was determined from meteorological data at a weather station about 1000 m east of the West Plot. Based on these data an average daily estimated reference ET was determined to be 5 mm day^{-1} and 4.5 mm day^{-1} for July and August, respectively.

Net infiltration was calculated for each irrigation (total infiltrated = total applied irrigation – total surface runoff). During the July 23 to 25 irrigation there was a total infiltration of 2859.6 m^3 which was 33% of the total applied irrigation water volume. The August 9 to 10 irrigation had a total infiltrated volume of 1262.1 m^3 which was 29% of the total applied water.

Subsurface tailwater flow volume was estimated (subsurface flow = Total infiltrated - ET) to be 1626 m^3 during the July irrigation and 164 m^3 during the August irrigation. The subsurface runoff volumes were 19 and 4% of the headwater irrigation application during the July and August irrigations, respectively. Differences between the July 23 to 25 and August 9 to 10 water budget estimates may in part be explained by the increased shallow lateral seepage into canals which occurred during the July (47 h) irrigation period. The longer irrigation application caused more water to pond in depressional areas along canals at the lower end of the field. A source of error in the subsurface flow estimation was lateral seepage to neighboring pastures.

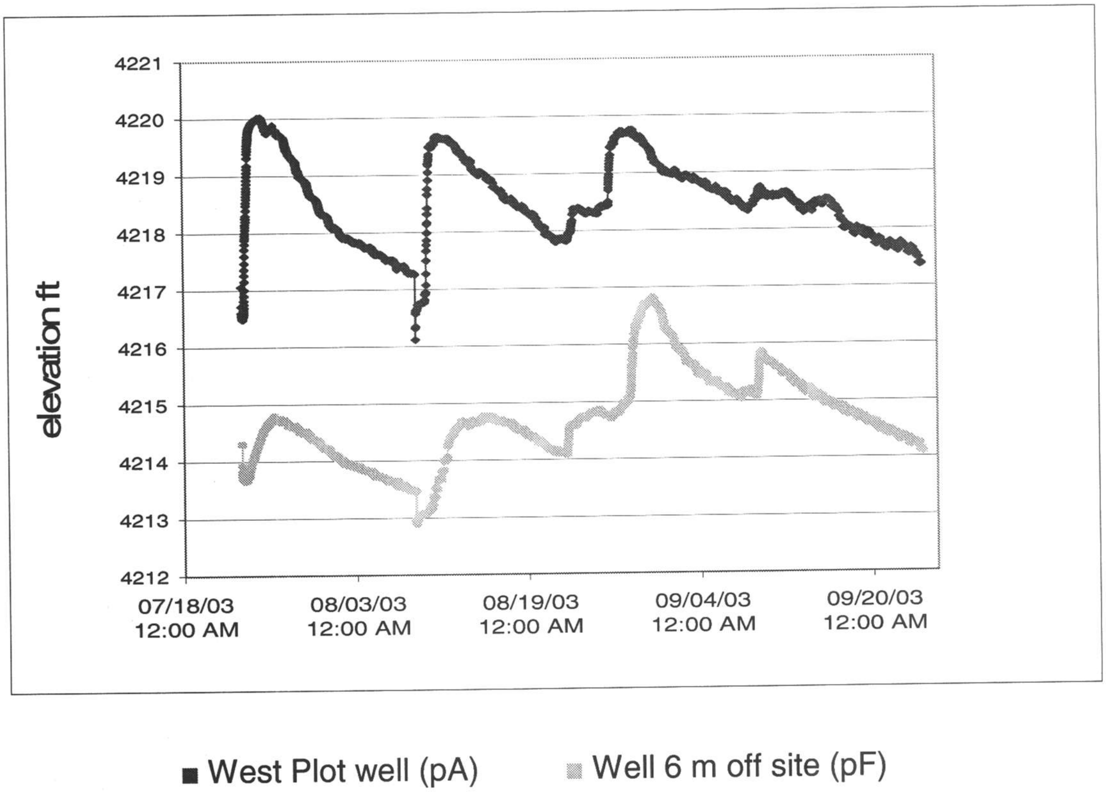


Figure 18. Shallow groundwater levels on the West Plot and on a pasture immediately below the West Plot, 2003.

Subsurface water levels were measured on the West Plot and just below on a neighboring pasture. The data shows there was likely subsurface loss to the neighboring pasture during irrigations (Figure 18).

Since nutrient and sediment concentration and flow were not measured continuously throughout the irrigations it was necessary to estimate the overall loading rates from instantaneous measurements. Instantaneous sediment and nutrient loading rates were calculated (Constituent loading rate (mg sec^{-1}) = Constituent concentration (mg L^{-1}) * Flow rate (L sec^{-1})) intermittently during the irrigation. Linear interpolation was used to estimate changes between known loading rates using equations 2, 3 and 4:

$$(2)\ M = (y2-y1)/(x2-x1)$$

$$(3)\ B = y2 - (x2 * M)$$

$$(4)\ y = Mx + B$$

y2 = Loading rate at time 2

y1 = Loading rate at time 1

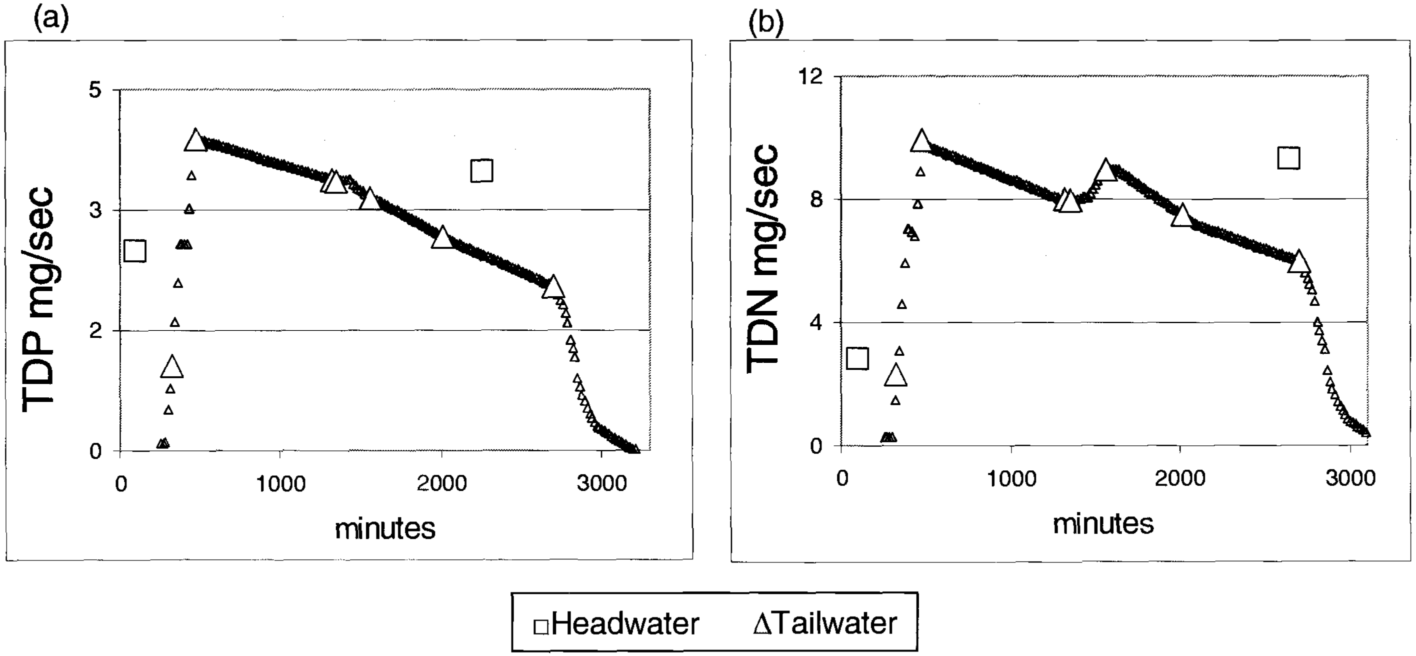
x2 = Time 1

x1 = Time 2

y = Interpolated loading rate for time (x)

x = Time at interpolated loading rate (y)

The slope (M) and the offset (B) of the line were calculated and unknown loading rates (y) computed according to time (x). The measured and interpolated values are displayed for the July 23 to 25 irrigation (Figures 19a and b). Both TDP and TDN show a first flush response in the tailwater runoff. It was assumed that headwater flow did not fluctuate considerably during the irrigation. This however was a flaw in the sampling procedure as demonstrated during the July 23 to 25 when the headwater load of TDP and TDN increased significantly from the first to second sample due to a significant increase in headwater flow.



Figures 19a and b. Headwater and tailwater load graph for total dissolved-P (TDP) and total dissolved-N (TDN) July 23rd to 25th irrigation, 2003. Δ and □ signify an instantaneous nutrient load was measured and Δ signifies an interpolated tailwater load.

The interpolated loading and flow rates were used to estimate overall sediment, nutrient and water budgets during two irrigations. The irrigation nutrient budget showed an estimated export of 0.56 kg TDN ha^{-1} during the July 23 to 25 irrigation and 0.31 kg TDN ha^{-1} during the August 9 to 10 irrigation (Table 11a and b). There was an export of 0.01 kg TDP ha^{-1} during the July 23 to 25 irrigation and an accumulation of 0.05 kg TDP ha^{-1} during the August 9 to 10 irrigation. Export was greater for all nutrients and sediment during the July 23 to 25 irrigation.

Surface tailwater nutrient export coefficients were estimated for TDP and TDN during the first 22 hours of the July 23 to 25 irrigation. This time frame was chosen because it was during the surface tailwater nutrient flushing period. There was 0.2 kg TDP ha^{-1} and 1.8 kg TDN ha^{-1} exported during the flushing period of the July 23 to 25 irrigation. The TDP export (0.2 kg ha^{-1}) during the nutrient flush period is 20 times greater than it was estimated for the entire 47 hour irrigation period (0.01 kg ha^{-1}). TDN was 3.2 times greater during the surface tailwater nutrient flush (1.8 kg ha^{-1}) than it was during the full 47 hour irrigation period (0.56 kg ha^{-1}).

Irrigation	July 23 to 25	August 9 to 10
Total Irrigation Time h	47	23
Water Applied m^3	8600	4355
Surface Runoff m^3	5740	3093
Total Infiltration m^3	2860	1262
Evapotranspiration m^3	1233	1098
Subsurface Runoff m^3	1626	164

Table 11a. Water budget during two irrigations on West Plot, 2003.

Irrigation	July 23 to 25	August 9 to 10
Sediment kg ha^{-1}	28.33	19.6
DOC kg ha^{-1}	12.46	2.4
TDN kg ha^{-1}	0.56	0.31
TDP kg ha^{-1}	0.01	*-0.05
OP kg ha^{-1}	0	*-0.04

*A negative sign signifies a net accumulation

Table 11b. Net export of Sediment, dissolved organic-C (DOC), total dissolved-N (TDN), total dissolved-P (TDP) and orthophosphate (OP) during two irrigations on the West Plot, 2003.

Water Quality Indicators

Temperature, dissolved oxygen (DO), pH and conductivity were measured in the field at headwater and tailwater sampling sites (Table 12).

Tailwater	Temp °C	pH	Conductivity mS/cm	Dissolved Oxygen mg/L
minimum	10.14	6.02	0.05	4.46
maximum	28.14	6.76	0.10	10.13
median	17.00	6.51	0.06	6.56
mean	18.43	6.51	0.06	6.84
Headwater	Temp °C	pH	Conductivity mS/cm	Dissolved Oxygen mg/L
minimum	7.8	6.89	0.052	9.17
maximum	12.53	7.11	0.06	11.04
median	9.82	6.97	0.053	10.29
mean	9.79	6.99	0.06	10.23

Table 12. Headwater vs. tailwater temperature, pH, conductivity and dissolved oxygen measured in field at West Plot, 2003.

The minimum and maximum tailwater temperatures were 10.1° and 28.1° C. Minimum and maximum headwater temperatures were 7.8° and 12.5° C. DO generally decreased as water flowed across the field and temperature increased. Minimum and maximum DO concentrations in tailwater were 4.4 and 10.1 mg DO L^{-1}. Headwater minimum and maximum DO concentrations were 9.1 and 11.0 mg

DO L^{-1}. pH values were similar in headwater and tailwater and ranged between 6.5 and 7.1. Headwater and tailwater conductivity levels were also similar and had values ranging from 0.05 to 0.10 mS cm^{-1}.

Water samples were also tested in the laboratory for turbidity, pH and conductivity (Table 13). Turbidity was higher in tailwater samples. Maximum turbidity for the two tailwater locations was 26 and 21 Nephelometric Turbidity Units (NTU). Maximum headwater turbidity was 8.4 NTU. Headwater turbidity was generally below 5 NTU. pH and conductivity values measured in the lab were similar to those measured in the field.

Tailwater north	Turbidity NTU	Ph	Conductivity mS
minimum	0.60	6.80	0.05
maximum	26.00	7.45	0.07
median	3.05	7.12	0.06
mean	5.93	7.12	0.06
Tailwater south			
minimum	2.50	6.84	0.047
maximum	21.00	7.35	0.063
median	5.25	7.02	0.052
mean	8.05	7.05	0.053
Headwater			
minimum	0.55	7.20	0.05
maximum	8.40	7.41	0.07
median	2.70	7.35	0.05
mean	2.94	7.33	0.05

Table 13. Headwater vs. tailwater pH, conductivity and turbidity measured in laboratory, West Plot, 2003.

South and North Plots

Limited water quality samples were collected from two other flood irrigation sites during the 2003 monitoring season (Table 14). The two sites, South Plot and North Plot, had similar pasture and management conditions as the West Plot. South Plot TDN concentration was high in both headwater and tailwater samples with headwater having a minimum concentration of 0.17 mg TDN L^{-1}. A water sample taken on August 13, 2003 had a sediment concentration of 271 mg L^{-1}. Cattle were not observed disturbing the canal at the time of sampling, however, the water was cloudy. The North Plot had lower TDN and TDP values. Both plots were sampled at an undetermined time after initial runoff and first flush responses were not detected. Headwater loads were generally higher than those found in tailwater (Table 15). The difference in loading rate between headwater and tailwater was mostly attributed to the lower measured water flows in the tailwater. There was substantial surface runoff in the form of sheet flow that was not measured or present in the tailwater loading calculations.

Site	Sample Date	Sediment mg/l	DOC mg/L	TDN mg/L	TDP mg/L	NH_4+-N mg/L	NO_3^--N mg/L	OP mg/L	Organic-N mg/L
North Study Plot									
Tailwater	6/20/2003	3.4	7.58	0.07	0.02	<.05	<.05	0.02	0.07
Tailwater	7/16/2003	50.6	7.94	0.10	0.03	<.05	<.05	0.02	0.10
Tailwater	7/17/2003	49.4	8.51	0.10	0.02	<.05	<.05	0.02	0.10
Headwater	6/20/2003	25.4	7.15	0.02	0.02	<0.05	<0.05	0.02	0.02
Headwater	7/16/2003	31.3	6.67	-	0.03	-	-	0.03	-
Headwater	7/17/2003	54.3	6.60	-	0.03	-	-	0.03	-
South Study Plot									
Tailwater	7/9/2003	36.3	17.09	0.35	-	<0.05	<0.05	-	0.35
Tailwater	7/9/2003	34.7	17.07	0.32	-	<0.05	<0.05	-	0.32
Tailwater	7/9/2003	30.3	24.18	0.67	-	<0.05	<0.05	-	0.67
Tailwater	08/13/03	1.5	11.99	0.22	0.07	<0.05	<0.05	0.06	0.22
Tailwater	08/13/03	29.1	10.24	0.21	0.04	<0.05	<0.05	0.02	0.21
Headwater	7/9/2003	33.7	11.84	0.17	-	<0.05	<0.05	-	0.17
Headwater	08/13/03	271.2	37.02	1.35	0.06	0.29	<0.05	0.03	1.07

Table 14. Irrigation headwater and tailwater sediment, dissolved organic carbon (DOC), total dissolved-N (TDN), total dissolved-P (TDP), NH4+-N, N03-N, orthophosphate (OP) and dissolved organic-N concentration data for North and South Plots, 2003. A (-) signifies data removed because total dissolved N and P value was lower than the NH4+-N, N03-N and OP values.

Site	Sample Date	Flow L/sec	Sediment mg/sec	DOC mg/sec	TDN mg/sec	TDP mg/sec	OP mg/sec
North Study Plot							
Tailwater	7/16/2003	93	4704.7	738.41	9.28	2.52	2.19
Tailwater	7/17/2003	118	5848.5	1006.84	12.04	2.60	2.24
Headwater	7/16/2003	153	4781.3	1021.26	-	4.10	4.10
Headwater	7/17/2003	123	6683.2	811.42	-	3.46	3.38
South Study Plot							
Tailwater	7/9/2003	21	750.9	12833.52	4553.33	-	-
Tailwater	7/9/2003	21	718.3	12261.07	3912.51	-	-
Tailwater	7/9/2003	21	626.7	15153.94	10092.52	-	-
Headwater	7/9/2003	83	2806.0	33223.46	5601.48	-	-

Table 15. Irrigation headwater and tailwater sediment, dissolved organic carbon (DOC), total dissolved-N (TDN), total dissolved-P (TDP), NH_4^+-N, $N0_3$-N, orthophosphate (OP) and dissolved organic-N load data for North and South Plots, 2003. A (-) signifies data removed because total dissolved N and P value was lower than the NH_4^+-N, $N0_3$-N and OP values.

2004 Irrigation Season

The mean temperature for May through September 2004 was 14.62° C. Precipitation for May through September 2004 was 5.2 cm. The largest storm event was on June 30, 2004 producing 0.44 cm in 1 d and did not produce sufficient runoff for surface water sample collection. Most precipitation events were below 0.25 cm d^{-1}.

Cattle Presence

The East Plot was a 70 ha flood irrigated and grazed pasture (Figure 4). Cattle were stocked at a rate of 1.6 head ha^{-1}. Samples were taken on the site at surface runoff areas and canals. The presence of cattle in pasture and canals above sampling areas was noted. Cattle dung pat concentration was 2.5 per 9 m transect.

Sample Collection

From May through August, 2004 there were 24 headwater, 55 tailwater and 15 groundwater samples collected on the East Plot pasture. Headwater was sampled in a canal at the northern border of the pasture. Tailwater was sampled directly from pasture runoff and at three tailwater collection ditches near the perimeter of the field. Groundwater was sampled from wells in a transect along the pasture extending from headwater to tailwater drainage ditches. The East Plot was irrigated by one headwater canal which was supplied with water by Annie Creek.

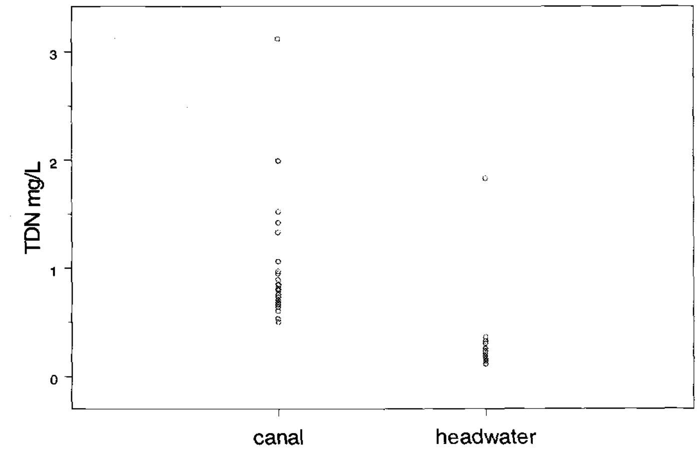
Removal of Data Outliers

Certain headwater and tailwater sample data that were extreme outliers were removed prior to statistical analysis (Figures 20a, b and c). There were 1 TDN and 2 sediment extreme outliers in headwater. The highest headwater sediment concentration was 201 mg sediment L^{-1}, a duplicate sample taken contained only

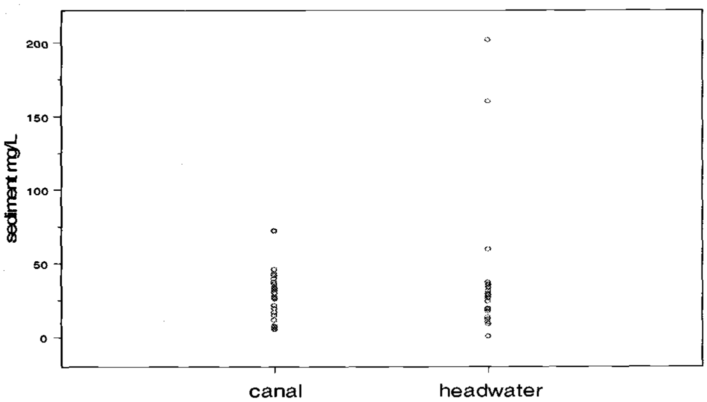
12 mg sediment L^{-1}. The second headwater outlier removed contained a concentration of 160 mg sediment L^{-1}. Turbidity was strongly correlated with sediment concentration ($r = 0.8$) yet turbidity for the two headwater samples with outlier sediment concentration was low (≤ 4 NTU).

Four samples were removed from the tailwater drainage ditch sample data. The samples were deliberately collected in drainage ditches where cattle lingered and caused excessive sedimentation and particulate matter to be transported in the ditch. There were only 4 samples collected and the samples were collected at locations that were not regularly sampled and considered to be from a separate treatment group. This sample data will, however be discussed later in the context of nutrient sources and transport mechanisms. Exclusion of these outliers will allow a closer examination of the treatment effect of pasture irrigation on water quality.

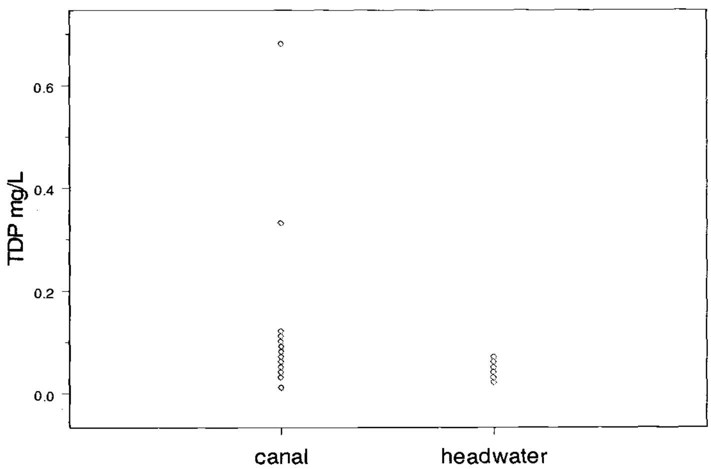
(a)



(b)



(c)



Figures 20a b and c. (a)Total dissolved-N (TDN), (b) total dissolved-P (TDP) and (c) sediment concentration data outliers in tailwater (canal) and headwater.

Nutrient Concentrations

TDN and TDP concentrations were significantly higher in pasture runoff and tailwater ditches than in headwater (p-value < 0.01) (Table 16). Headwater TDN and TDP concentrations were 0.22 and 0.04 mg L^{-1}, respectively. Mean TDN and TDP in surface pasture runoff was 0.85 and 0.06 mg L^{-1} respectively. Collection ditches were also sampled and found to have mean concentrations of 0.85 mg TDN L^{-1} and 0.07 mg TDP L^{-1}. Sediment concentrations were often higher in headwater than in pasture runoff but similar to those found in drainage ditches (Figure 21)..

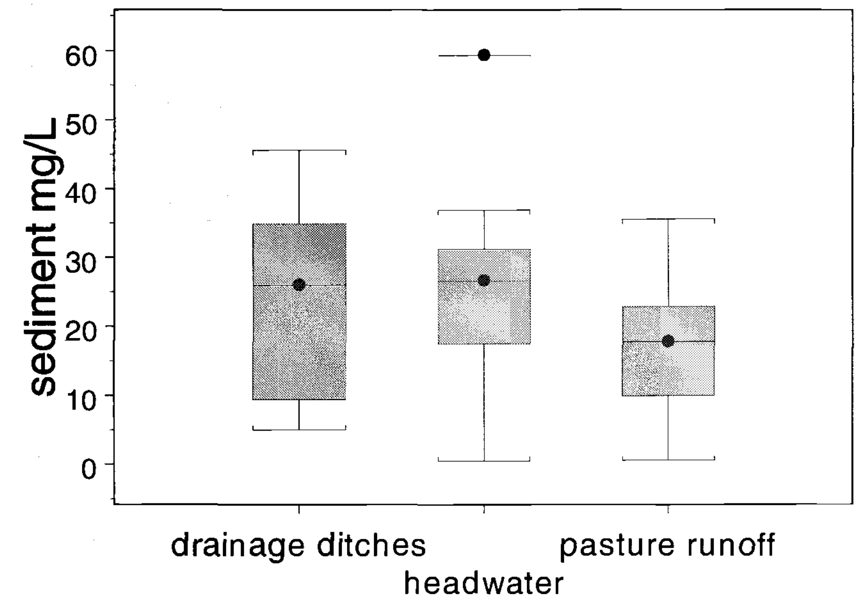


Figure 21. Sediment concentration in headwater relative to drainage ditches and pasture runoff at East Plot, 2004

.

Sample type		Turbidity NTU	Ph	Conductivity mS	Sediment mg/l	DOC mg/L	TDN mg/L	TDP mg/L	NH_4^+-N mg/L	NO_3^--N mg/L	OP mg/L
Headwater (24n)	min	3.00	6.84	0.03	0.54	3.99	0.14	0.02	0.03	0.03	<0.01
	max	9.40	8.61	0.06	59.33	6.53	0.36	0.07	0.03	0.06	0.05
	median	5.05	7.33	0.05	26.63	4.31	0.21	0.03	0.03	0.03	0.02
	mean	5.09	7.59	0.05	24.60	4.72	0.22	0.04	0.03	0.03	0.02
Tailwater runoff (27n)	min	2.80	6.88	0.04	0.59	5.87	0.20	0.02	0.03	0.02	0.01
	max	9.00	8.65	0.10	35.56	30.66	1.59	0.15	0.09	0.09	0.15
	median	4.30	7.20	0.06	17.82	14.29	0.74	0.06	0.03	0.03	0.01
	mean	5.02	7.37	0.06	16.74	16.50	0.85	0.06	0.03	0.03	0.03
Tailwater drainage ditches (28n)	min	3.00	7.02	0.06	5.00	5.64	0.50	0.01	0.03	0.03	0.01
	max	11.00	8.22	0.08	45.63	19.91	1.52	0.12	0.10	0.03	0.08
	median	4.30	7.37	0.07	25.99	12.19	0.82	0.07	0.03	0.03	0.03
	mean	4.89	7.44	0.07	23.65	12.54	0.85	0.07	0.05	0.03	0.03
Shallow groundwater (15n)	min	5.00	6.83	0.10	47.50	10.44	0.41	0.01	0.05	0.03	0.01
	max	69.00	7.58	0.35	691.43	109.90	1.94	0.09	0.17	0.10	0.03
	median	20.00	7.02	0.21	160.77	26.32	0.81	0.02	0.09	0.03	0.01
	mean	26.53	7.12	0.21	237.21	32.40	1.03	0.03	0.10	0.03	0.01

Table 16. Nutrient concentration summary for dissolved organic-C (DOC), total dissolved-N (TDN), total dissolved-P (TDP), NH4-N, NO3-N, and orthophosphate (OP) in the East Plot headwater and tailwater, 2004.

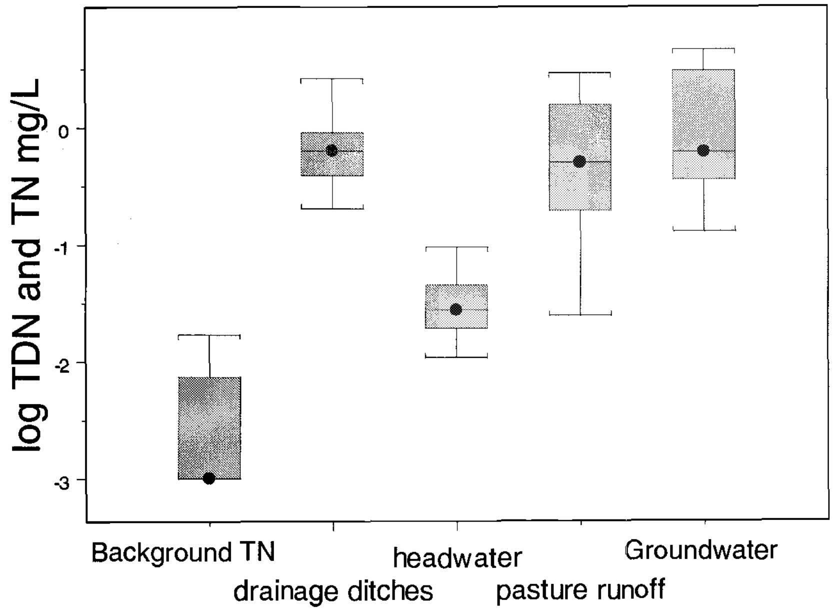
Background Water Quality

The East Plot received its irrigation water from Annie Creek. Annie Creek was sampled by KBRT in the Winema National Forest (ACFS) every 2 weeks during the summer of 2004 (Figure 2). The ACFS sampling site is located above where Annie Creek receives drainage from pasture and is assumed to be background water quality for irrigation water at the East Plot (Table 17).

AnnieCr at Forest Service (ACFS)	TOTAL-P	Soluble Reactive-P	NH_4^+-N	NO_3^--N + NO_2^--N	TOTAL-N
minimum	0.04	0.03	0.005	0.005	0.05
maximum	0.07	0.03	0.018	0.044	0.17
median	0.05	0.03	0.005	0.014	0.05
mean	0.05	0.03	0.007	0.016	0.08

Table 17. Nutrient concentration summary for Annie Creek at the ACFS sampling site, May to September 2004.

(a)



(b)

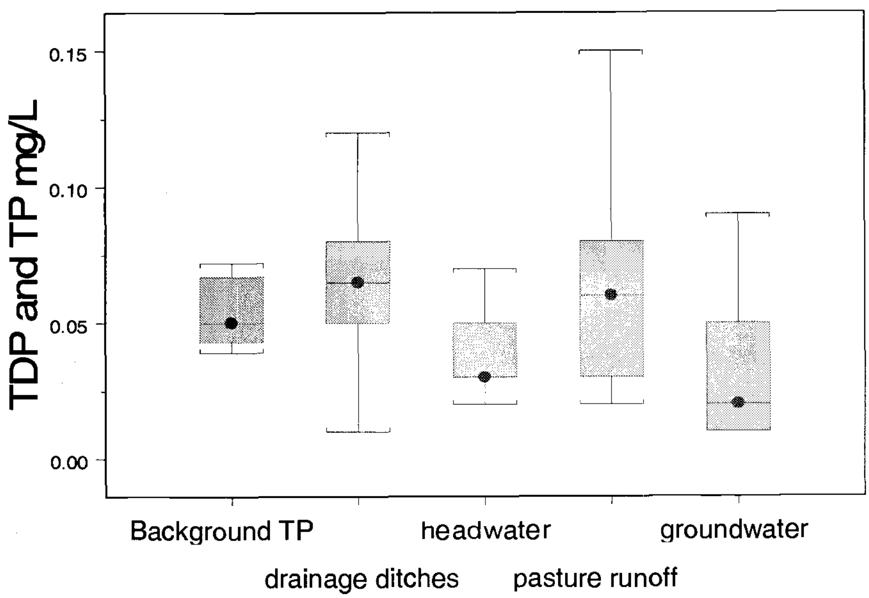


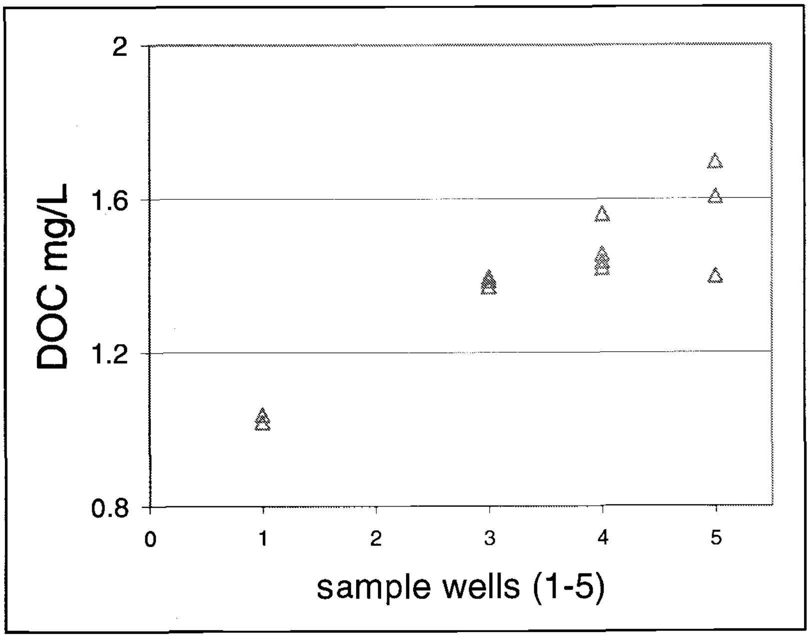
Figure 22a and b. (a) Total dissolved-N mg L^{-1} in East Plot pasture irrigation headwater, tailwater and groundwater compared with total-N (TN) mg L^{-1} in Annie Creek, 2004 and (b) Total dissolved-P mg L^{-1} in East Plot pasture irrigation headwater, tailwater and groundwater compared with total-P (TP) mg L^{-1} in Annie Creek, 2004.

Box plots depict the increase in TDN and TDP concentrations in tailwater runoff (Figures 22a and b). Both the direct pasture runoff and water in drainage ditches have higher TDN and TDP concentrations than the background nutrient levels found in Annie Creek. TDN levels increased in the headwater canal as it carried water from Annie Creek to the East Plot. This indicates the headwater canal likely received inputs from pasture runoff prior to its use as irrigation water at East Plot. TDP in the headwater canal is only slightly below TP at Annie Creek ACFS.

Subsurface Water Quality

Subsurface TDN concentrations were high relative to surface samples, 1.27 mg TDN L^{-1}. TDP concentration was low in subsurface water samples with a mean of 0.03 mg TDP L-1. Some subsurface samples were contaminated with sediment during collection resulting in high sediment concentration levels. There was a negative correlation between TDN and sediment concentration ($r = -0.5$). There were progressively higher nutrient concentrations found in wells at lower elevation. Highest DOC and TDN concentrations are found in well 5 which was located at the low end of the pasture near a drainage ditch (Figure 23a and b). The soil at well 5 had the deepest organic surface horizon. TDP did not show such a trend and was relatively low for all wells, with a mean concentration of 0.03 mg L-1. Well p2 was damaged and not sampled.

(a)



(b)

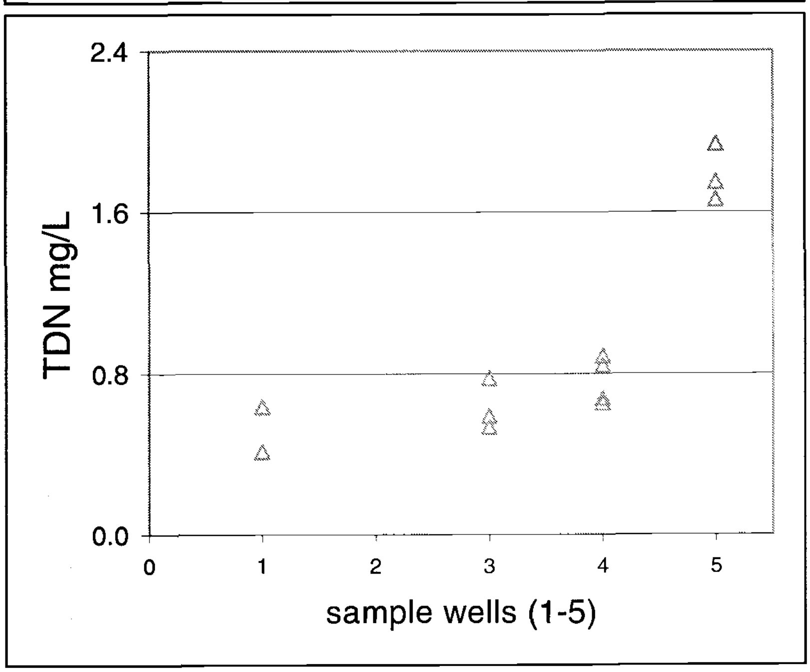


Figure 23a and b. (a) Dissolved organic-C (DOC) and (b) total dissolved-N (TDN) concentration in subsurface water along a well transect going from high to low elevation in the East Plot, 2004.

Flow Weighted Concentration and Nutrient Loading

Since flow in the headwater canal was consistently higher than the flows measured in pasture runoff or drainage canals, simply comparing loading rates of headwater with tailwater does not provide a full picture of the nature of nutrient and sediment movement in relation to the pasture. Flow weighted nutrient and sediment concentrations (FWC) where calculated in headwater, pasture runoff and drainage canals. FWC for nutrients were generally lowest in the headwater and highest in the drainage canals (table 18). The FWC for individual drainage ditches is also displayed (table 19). The highest FWC occurred when cattle where causing disturbance in drainage canals.

Site		flow L/sec	Sediment mg/sec	DOC mg/sec	TDN mg/sec	TDP mg/sec	NH_4^+-N mg/sec	NO_3^--N mg/sec	OP mg/sec
Headwater (16n)	minimum	56.8	66.7	226.7	9.15	1.50	1.42	1.42	1.43
	maximum	163.2	9685.6	899.2	51.28	9.22	4.08	7.84	6.25
	median	142.8	2760.8	604.7	28.51	4.68	3.57	3.57	2.86
	mean	127.9	3111.8	590.0	28.52	4.66	3.20	3.51	2.96
	FWC	-	24.3	4.6	0.22	0.03	0.03	0.03	0.02
Drainage ditches (16n)	minimum	5.6	85.0	31.6	2.78	0.26	0.28	0.14	0.09
	maximum	57.7	2248.4	886.4	46.66	4.17	4.51	1.44	2.13
	median	27.2	622.3	330.9	24.58	1.47	1.11	0.68	0.63
	mean	30.0	801.3	380.5	25.15	1.87	1.26	0.77	0.84
	FWC	-	26.7	12.7	0.84	0.06	0.04	0.03	0.03
Irrigation runoff (12n)	minimum	9.9	26.7	58.2	3.34	0.23	0.25	0.19	0.13
	maximum	24.6	604.2	755.4	39.15	3.60	0.62	0.62	0.63
	median	18.4	161.2	171.7	10.17	0.87	0.38	0.36	0.20
	mean	17.5	224.3	232.8	12.70	1.18	0.43	0.43	0.30
	FWC	-	10.7	12.2	0.67	0.06	0.02	0.02	0.02

Table 18. Flow weighted concentrations and nutrient and sediment loading summary for East Plot irrigation, 2004.

	Headwater (16n)	Irrigation runoff (13n)	SE ditch (10n)	E ditch (6n)	S ditch (4n)	E ditch (2n) §	S ditch (2n) §
Flow L sec^{-1}	130.4	18.5	36.3	15.7	50.0	17.5	42.3
Sediment mg L^{-1}	36.5	12.4	29.9	27.2	39.8	30.8	71.8
DOC mg L^{-1}	4.56	15.08	13.57	13.31	10.02	15.06	10.27
TDN mg L^{-1}	0.34	0.88	0.82	1.02	0.73	2.56	0.75
TDP mg L^{-1}	0.03	0.06	0.06	0.06	0.06	0.51	0.04
NH_4^+-N mg L^{-1}	*	*	*	0.06	0.07	0.72	0.06
$N0_3^-$-N mg L^{-1}	*	*	*	*	*	0.38	*
OP mg L^{-1}	0.02	0.02	0.03	0.02	0.02	0.33	0.01

Table 19. Flow Weighted Concentrations (FWC) of total dissolved phosphorus (TDP), sediment, ammonium (NH4+), nitrate (N03—N), total dissolved nitrogen (TDN) and orthophosphate (OP) in headwater and tailwater irrigation canals at East Plot, 2004.

* Analyte was below detection limit (<0.05 mg/L)

§ Cattle were in the ditch during sampling

Turbidity, conductivity and pH were similar in all surface waters. The elevated turbidity and conductivity in subsurface samples were likely due to increased sediment concentrations (Table 20).

Site		Turbidity NTU	Ph	Conductivity mS
headwater	min	3.0	6.8	0.03
	max	9.4	8.6	0.06
	median	5.1	7.3	0.05
	mean	5.1	7.6	0.05
drainage canals	min	3.0	7.0	0.06
	max	11.0	8.2	0.08
	median	4.3	7.4	0.07
	mean	4.9	7.4	0.07
pasture runoff	min	2.8	6.9	0.04
	max	9.0	8.7	0.10
	median	4.3	7.2	0.06
	mean	5.0	7.4	0.06
shallow groundwater	min	5.0	6.8	0.10
	max	69.0	7.6	0.35
	median	20.0	7.0	0.21
	mean	26.5	7.1	0.21

Table 20. Summary of turbidity, pH, and conductivity at East Plot, 2004.

DISCUSSION

2003 Tailwater Nutrient Concentration

Surface nutrient flushing in the early stages of irrigation runoff was the most frequent cause of increased nutrient load and concentration in tailwater from the West Plot in 2003. Tailwater TDN and TDP concentrations were 580% and 409% greater, respectively, in tailwater than in headwater during the rising limb of the runoff hydrograph during the July 23, 2003 irrigation. This first flush pattern appears in the three irrigations previous to the July 23rd irrigation; it is not as apparent during the August irrigations.

When runoff initially flows over the grazed pasture it detaches and transports organic matter from the surface. The runoff also incorporates dissolved nutrients as they diffuse from pasture surface to the runoff water (Fraser et al, 1994; Bondurant, 1971). The source of the dissolved constituents may include organic matter from soil, vegetation and livestock. Mundy (2003) found that P in runoff from a flood irrigated and grazed pasture was derived from both pasture and feces. N and P concentration in irrigation runoff from a pasture with high cattle stocking rate was higher than that with a low stocking rate only for the first irrigation (Mundy, 2003).

The West Plot has < 3% slope, so the irrigation runoff was slow. Nutrient dissolution into runoff is an important nutrient transport mechanism during the West Plot tailwater flush events. Even when tailwater sediment concentration was low (<5.0 mg L^{-1}) on June 19, 2003, the tailwater TDN, TDP and DOC concentration levels were high during the early stages of runoff.

For most irrigations on the West Plot, over 80% of the TDP in surface headwater and tailwater was in the OP form. The dissolved organic P was estimated by subtracting OP from TDP. The August 9, 2003 irrigation had high organic-P levels (30%) in both headwater and tailwater. Since particulate-P (>0.45 μm) was not measured the P content of the irrigation water is likely underestimated. Coale (2000) found that around 50% of the TP exported from pasture and no-till fields to be in the dissolved-P form. Dissolved-P can have a greater impact on fresh water than particulate-P since virtually all of the TDP is immediately available to algal communities (Coale, 2000). The tailwater OP level was normally above the EPA recommendation of 0.1 mg L^{-1} for streams that do not discharge directly into lakes or reservoirs (Mueller, 1996). Background levels of OP at Sevenmile Creek were at or above the EPA recommended maximum level of 0.05 mg L^{-1} for streams that empty directly into lakes or reservoirs (Mueller, 1996).

Although particulate-P concentration of irrigation water was not tested for in this study, monitoring of P concentration in streams throughout the Wood River Valley by KBRT revealed an increase in the particulate-P concentration from upstream to downstream locations (Graham Mathews and Associates, 2003). The increase was especially evident in the Sevenmile Creek system as the particulate-P fraction of the TP increases from about 10% at SMFS located in Winema National Forest to about 40% at Sevenmile Creek below West Canal. The increase in particulate-P occurs below where irrigation return flow is diverted into the Sevenmile system (Graham Mathews and Associates, 2003). Ehinger (1993) also found considerable levels of particulate-P in irrigation return water measured on pastures near the Wood River. It is likely that a fraction of the irrigation tailwater TP at the West Plot contains particulate-P. Particulate-P may be more associated with the sediment concentration of the tailwater and may not follow the first flush response as distinctly as the dissolved-P fraction.

Most of the TDN in the West Plot tailwater was organic-N. The NH_4^+–N and NO_3^-–N concentrations where both undetectable (<0.05 mg L^{-1}) in most surface samples. NH_4^+–N was present in greatest concentration (0.15 mg NH_4^+–N L^{-1}) in tailwater during the July 6, 2003 irrigation at which time organic-N (ON) concentration was also high (0.77 mg ON L-1). In most samples when NH_4^+–N was present it made up only a small fraction of the TDN. DOC is an indicator for the amount of organic matter in a water solution (Gergel et al., 1999). The DOC concentration closely follows the flush pattern of TDN during all of the 2003 West Plot irrigations.

Headwater Nutrient Concentration

In most cases the irrigation headwater nutrient and sediment concentration was similar to the background source. The headwater irrigation canals that were sampled at West Plot were along the perimeter of the Wood River Valley and had minimal exposure to tailwater runoff or livestock. The main instance when headwater nutrient and sediment concentration was high was at the time the flood headgate is opened to begin an irrigation. Opening of the headgate caused a flushing of sediment and organic debris out of the irrigation canal onto the pasture. The headwater flush of nutrients and sediment occurred if the irrigation canals where empty or flowing low in-between irrigations, then suddenly received a large volume of water.

While this phenomenon was noted several times, headwater flush samples were not taken during most irrigations, therefore the West Plot tailwater nutrient concentration graphs in the results section (Figures 11 through 16) depict the occurrence on June 19, 2003 only. Sediment concentrations were 34.2 mg L^{-1} and 5.7 mg L^{-1} at 10 and 25 minutes, respectively, after the headgate was opened. The water turbidity was 8.4 and 4.5 NTU at 10 and 25 minutes after opening the irrigation headgate. TDN concentration was high during the irrigation headwater flush (0.46 mg TDN L^{-1}) and TDP was low (0.06 mg TDP L^{-1}). Typically the flushing lasted for about 20 minutes, during which time the flood irrigation water returned to near background water quality levels.

The headwater flushing events only occurred for a few minutes at the beginning of the irrigation but they involved high flow volumes carrying high concentrations of particulate matter. At the West Plot the particulates would generally settle out as the water was used to irrigate a field. These events may have a significant effect if they drain directly into natural waterways or major canals.

Cattle Presence

Cattle presence on the West Plot pasture during irrigation was often noted but only directly corresponded twice to elevated sediment concentration levels and this was attributed to cattle directly above the north tailwater sampling location during sample collection. Cattle presence on the pasture during irrigation did not appear to have a significant effect on dissolved nutrient concentration. It is important to remember that most of the samples collected from West Plot in 2003 are direct pasture runoff from a fully vegetated field and not from earthen canals and ditches.

Nutrient Budget

A net export of TDN, DOC and sediment was estimated during the July 23 to 25 and the August 9 to 10 irrigations at the West Plot (Figure 24). There was little to no TDP export estimated during the course of the entire irrigation runoff period. The pasture may have been a sink or source of TDP and OP since both export and accumulation were small (<0.1 kg ha^{-1}) during the two irrigations.

The TDP concentration values are considerably high in headwater and low in tailwater during the August 9 to10 irrigation. On that particular irrigation TDP (0.13 mg TDP L^{-1}) in headwater was the maximum for the season and much higher than the background levels at Sevenmile Creek (SMFS) (0.07 mg TP L^{-1}) during the summer of 2003. The organic fraction of the TDP was particularly high (50%) compared to previous headwater samples. This may be a result of organics picked up in the canal. Tailwater nutrient concentrations during the August 9 to 10 irrigation were lower than those measured in previous flood irrigations which may result from a decrease in the erosion and nutrient dissolution potential as the irrigation season progressed (Fitzsimmons, 1975).

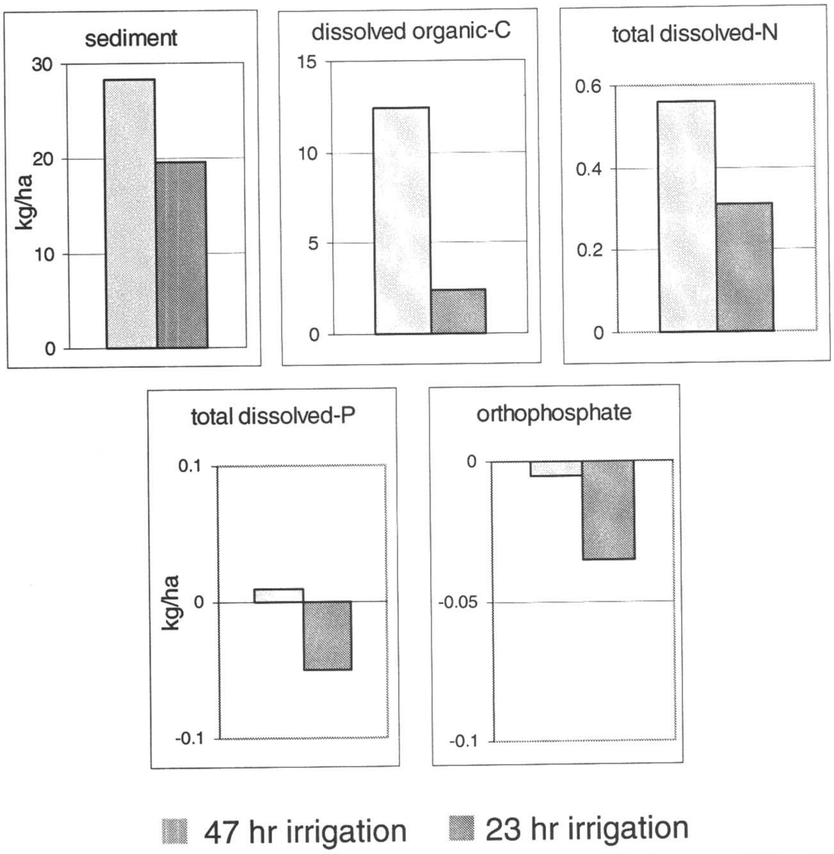


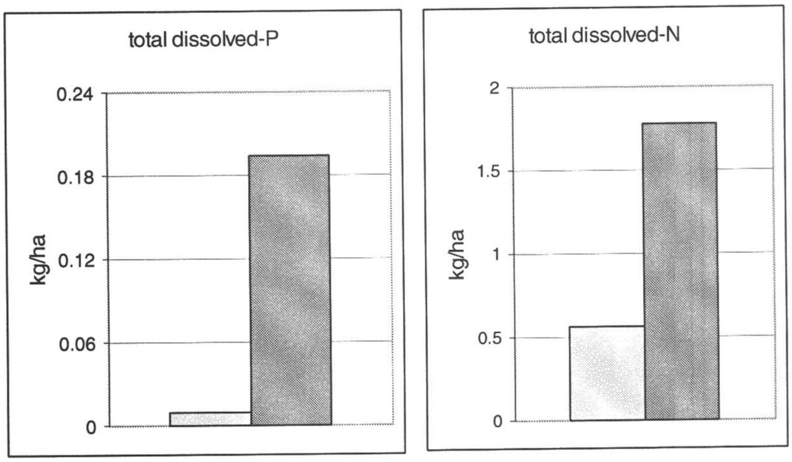
Figure 24. Sediment and nutrient export and accumulation on West Plot during the July 23 to 25 (47 hr) and August 9 to 10 (23 hr) flood irrigations, 2003.

Ehinger (1993), in cooperation with US Bureau of Reclamation, examined water quality in irrigation canals in the Wood River Valley about 3 miles south of the West Plot. The study found that P accumulated in the pasture more often than N. In the study TP accumulation occurred three times and TDN accumulation occurred one time out of eight samples. Ehinger (1993) estimated average yearly export rates to be 9.7 kg TN ha^{-1} yr^{-1} and 1.3 kg TP ha^{-1} yr^{-1}. Yearly average nutrient export rates for the West Plot were 2.6 kg TDN ha^{-1} yr^{-1} and an accumulation of 0.1 kg TDP ha^{-1} yr^{-1}. The West Plot export rate was estimated by averaging the two export coefficients for July and August and multiplying by six flood irrigations which occurred during the 2003 growing season.

The TDN and TDP export estimates on the West Plot are within the range of the Ehinger results. The West Plot export estimates are, however, expected to be somewhat lower since they do not include the particulate N and P fraction. There are additional differences between the two studies which limit the extent with which they may be compared. The Ehinger study plot was lower in the valley where nutrient concentrations in irrigation water tend to be higher. The Ehinger plot (140 ha) was also larger and samples were taken from tailwater collection ditches and not directly from the pasture as was done on the West Plot. The results, however, were similar as both studies found that the irrigated pastures functioned as both a source and sink for nutrients.

Nutrient Export During First Flush

Sampling of irrigation runoff directly from the pasture before it flowed into drainage ditches and canals limited confounding variables which were difficult to measure, such as mixing of headwater and tailwater or cattle disturbance in the canals. Mundy (2003) found that a majority of the P in runoff from a flood irrigated pasture was from vegetation while N in runoff was more influenced by the presence of cattle urine and feces. Sampling directly from the field therefore allowed a closer look at water quality changes relative to the water presence on the pasture. Observation of tailwater nutrient flushing would be unlikely in most canals, including those at the West Plot, since tailwater mixed with runoff from other pastures after entering the canals. Examination of the July 23 to 25 load graphs and comparison of TND loading rates in headwater and tailwater indicate export of N and P early in the irrigation runoff period.



Net export for entire irrigation   Net export during first flush

Figure 25. Export of total dissolved nitrogen (N) and phosphorus (P) during entire irrigation runoff and during the first flush, West Plot July 23 to 25 irrigation, 2003

The net surface export of TDN and TDP during the July 23 tailwater flushing period (initial 22 hours) was compared with total nutrient export for the entire July 23 to 25 irrigation (47 hours) (Figure 25). The tailwater flush at the West Plot was the main transport mechanism for both TDP and TDN. Net TDP and TDN export is substantially greater during the tailwater flush than it is during the entire irrigation period.

Fitzsimmons (1975) observed irrigation runoff from a flood irrigated sugar beet field in Idaho and noted a decrease in the export of solids as the time of irrigation increased. The same study noted that while there was a small net loss of P, more soluble-P and TP were lost in earlier irrigations than in those later in the season.

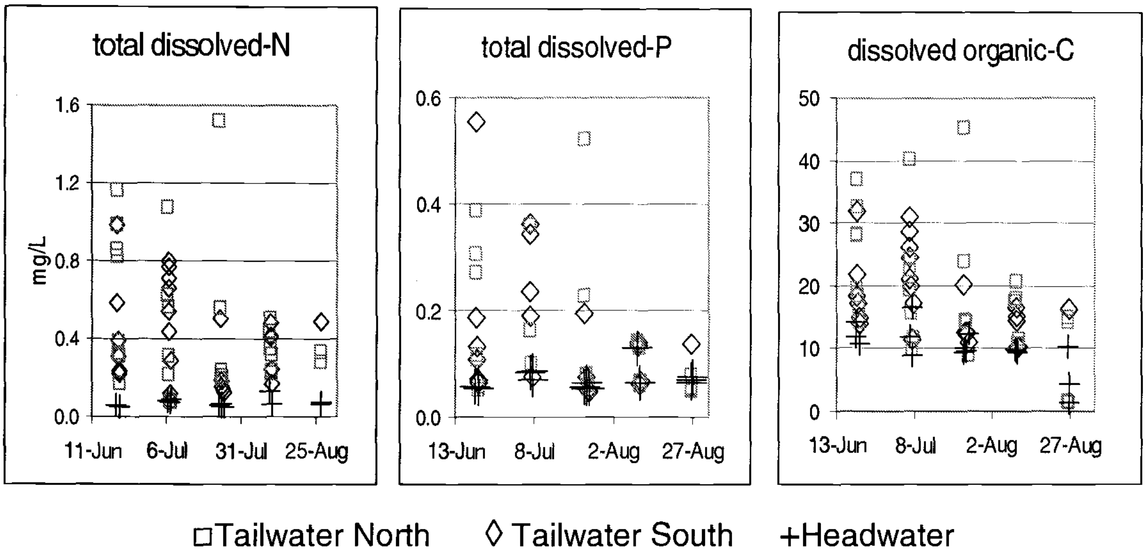


Figure 26. Total dissolved-N, total dissolved-P and dissolved organic-C concentration in tailwater and headwater at West Plot during five irrigations, 2003.

Halbach and Falter (1974) found that phosphate concentration in Idaho rivers receiving irrigation drainage increased slowly during the course of the growing season. By the end of the season soluble phosphates were 7 and 8 times higher in the mouth of the river than in the headwaters. The tailwater flushing on the West Plot follows a seasonal flushing pattern for TDN, TDP and DOC with highest concentrations occurring in June and July and lowest concentrations occurring in August (Figure 26). Since flows were not taken during tailwater runoff at the earlier part of the season it is impossible to determine if the June and early July tailwater P and N load during flushing was significant. It was shown, however, that during the July 23 to 25 West Plot irrigation the only significant P export (0.2 kg TDP ha^{-1}) occurred during the initial tailwater flushing period. If this is assumed for other irrigation events it becomes less likely that a net export of dissolved-P will occur from the West Plot as the irrigation season progresses.

2004 East Plot Surface Tailwater

The East Plot had high variability from mixing of tailwater from another pasture and its headwater source contained tailwater drainage from another pasture. This made it difficult to replicate the 2003 sampling methods used at the West Plot. Instead of monitoring a small catchment, the study was expanded to include water quality of an entire fenced in pasture (70 ha). The expanded area allowed an examination of potential P and N source and transport methods not evident at the smaller scale (2 ha) West Plot pasture. Sharpley et al. (1998) found that P concentration in surface runoff differed considerably on $2m^2$, 2 ha, and 40 ha study plots. Primary locations sampled at the East Plot were headwater canals, tailwater drainage ditches, pasture runoff and subsurface water. Nutrient and sediment concentration and FWC were compared. Nutrient concentrations were slightly higher in tailwater canals and ditches. Nutrient loads, however, were generally higher in the headwater canal. The highest loads measured on the East Plot were in drainage canals when cattle were present. Many of the tailwater drainage canals on the East Plot had easy access for cattle and commonly had cattle in or around them.

The 2004 sampling allowed a close look at changes in water quality across a pasture with multiple irrigations occurring. The FWC of nutrients generally increased as water flowed from headwater over the pasture to drainage canals. The decrease in nutrient content of water from pasture runoff to tailwater ditches is likely a result of dilution, since ditch water generally contained some headwater and subsurface drainage and possible nutrient sorption to the canal surface. Most of the TDN in the ditches was in organic form. NH_4^+ -N levels where, however, considerably higher in drainage ditches than on the field.

There were two instances when drainage ditches were sampled while cattle were causing a disturbance either walking through or standing in and around ditches. There was an observed increase in turbidity for at least 30 minutes due to cattle presence in and around flowing ditches. Two samples were collected during each cattle disturbance. The event on August 27, 2004 occurred in the South Ditch (S Ditch) where cattle gathered in a flooded partially barren depressional area along a drainage ditch. The mean sediment concentration was 3 times higher in the canal when the cattle were present. The second event occurred on September 11, 2004 in the E Ditch and had the highest concentrations of surface NH_4^+-N and NO_3^--N measured for the season. The instantaneous loads for TDP and TDN increased by 8 and 3 times, respectively.

About ½h after cattle left the ditch, water clarity improved and FWC were 0.88 mg TDN L^{-1} and 0.06 mg TDP L^{-1}. The frequency at which events such as this occur is unknown. They are likely important sources of P enrichment particularly where ditches empty directly into sensitive waterways. It is important to note, however, the variability in nutrient and sediment content between the August 27th occurrence at the S ditch and the September 11 occurrence at the mid-ditch. The mid-ditch had high dissolved nutrients with low sediment and the S ditch had high sediment and low dissolved nutrients. These results are indicative of the variability of P source areas. Sharpley (1998) found that areas controlling a majority of P transport are from a limited part of the agricultural landscape.

It is important to note the difference in mean OP concentrations in tailwater at the West Plot (0.13 mg L^{-1}) and at the East Plot (0.03 mg L^{-1}). This is partly attributed to the background water quality differences of their respective irrigation headwaters. Irrigation headwater from Sevenmile Creek (West Plot) has a mean OP concentration of 0.06 mg L^{-1} and irrigation headwater from Annie Creek (East Plot) was only 0.02 mg L^{-1}. Annie Creek also had high background sediment concentrations which may regulate the OP levels (Klotz, 1988). The differences in OP concentration of tailwater at the two study sites emphasizes the variability of P source areas and that the nature of irrigation source water in the Wood River Valley may have significant effect on export of bioavailable-P from flood irrigated pasture.

2003 and 2004 Subsurface Tailwater

The results from the 2003 and 2004 subsurface water quality were similar. The TDP concentration in the subsurface was low in both seasons (0.05 mg TDP L^{-1}). Evangelou (1998) found that unlike N, the excretion of P occurs largely in cattle feces and not in the urine which often leaches into the soil. P concentrations in subsurface runoff may also be low because P tends to bind with P deficient soil particles (Sharpley et al., 2001). Sharpley (1996) found that 9% of P applied to a field was lost in surface runoff and less than 1% in subsurface.

The TDN concentration in subsurface runoff was high with a mean of 0.55 and 1.06 mg TDN L^{-1} during the 2003 and 2004 seasons, respectively. Inorganic-N made up about 25% of the TDN concentration in the subsurface water. NH_4^+-N was the primary inorganic-N form, NO_3^--N was not detected. Russelle (1992) found that increased water supply in high N content areas such as urine patches can lead to nitrate leaching. The N in urine is often readily available to plants since urea is quickly hydrolyzed into NH_4^+-N and NO_3^--N (Ball et al., 1979). Fraser (1994) studied the fate of 15N-labelled synthetic urine (50 g N m^{-2}) applied to an irrigated pasture and found that 8% was leached out.

Reducing surface runoff and increasing infiltration rate would likely decrease the P load in tailwater runoff at both the East and West Plots. Sharpley and Syers (1976, 1979a) found that if surface runoff was reduced by 72% as a result of increased infiltration then TP loss was reduced by 50%. Thorrold et al. (1999) found similar results in New Zealand. Caution should be taken however, since if increased infiltration is not accompanied by increased irrigation efficiency the result maybe significantly higher levels of N export. In addition these results simply show subsurface P levels in two pastures in the upper part of the Wood River Valley. Soils lower in the valley near the edges of major drainage ways may have higher P accumulation and decreased P absorption potential (Gillingum and Thorrold, 2000). Wetlands at the northern edge of Agency Lake had large export rates of both TN and TP (Snyder and Morace, 1997). Increasing aeration to these wetland soils by exposing them to air or oxygenated water could increase their decomposition rate (Snyder and Morace, 1997).

Since these soils are not fertilized it is expected they would tend to retain P. Most of the lands on which this study was done were mineral soils. Soil P and N levels were slightly higher in the East Plot soils. The East Plot soils had slightly higher levels of organic matter as well. Since limited soil samples were taken (n = 5) a comprehensive analysis of soil chemistry relative to subsurface water quality was not attempted. It is noted however, that TDN and DOC concentration levels increase considerably from high to low elevation along the irrigation drainage path on the East Plot (Figure 25a and b). The same pattern was not observed on the West Plot. This is likely due to the smaller size of the West Plot (2 ha) which had less distance between wells along it's transect. The well transect on the East Plot followed a natural drainage and the lower well (p5) was in a soil with a thick organic horizon.

Stormwater

There were 5 surface water quality samples from the September 9, 2003 storm. The low sediment concentration of the stormwater was expected since it was collected from a well vegetated pasture (West Plot) and sheet flow was slow. High dissolved nutrient concentrations of stormwater runoff and low sediment were likely a result of slow flow velocity over the pasture giving it more contact time and indicate a preferential transport of N and P rich fine particles.
The dissolved organic fraction of both N and P was high, >50% for all storm samples. Dissolved-N was particularly high in stormwater, relative to the irrigation tailwater. Jawson et al. (1982) found the bulk (60 - 90%) of the nutrient runoff occurred during the first precipitation event following the summer grazing period.

During the two year study the September 9, 2003 storm event was the only time when storm water runoff was observed. It was the largest storm to occur during the 2003 and 2004 irrigation seasons. Storms were infrequent in the Wood River

Valley during the irrigation season and when they did occur the runoff volume at the West and East Plots were small relative to irrigation runoff.

The stormwater sampling results indicate that a large fall storm event on the West Plot resulted in small runoff flows with high dissolved nutrient concentrations. Stormwater nutrient loads from low gradient (< 5 % slope) and vegetated pastures similar to the West Plot are most likely dependent on the antecedent soil moisture (Sharpley, 1998). Therefore, at the field scale, the extent to which pasture runoff contributes nutrients to fall stormwater flushing events is in part contingent on the time of the storm relative to when irrigation season ends or is curtailed. .

Watershed Scale

Most of the irrigation water diverted from Sevenmile Creek, Annie Creek and the Wood River flows to West Canal. Water quality monitoring stations at Sevenmile Creek at Forest Service (SMFS), Annie Creek at Forest Service (ACFS) and Wood River at Dixon Road (WRDX) provide an indication of background water quality for West Canal (WCAS) (figure 2). Figures 27 and 28 compare TP concentration in West Canal with the headwater streams Annie Creek, Sevenmile Creek and Wood River during the 2003 irrigation season and entire 2004 water year. The TP concentration in West Canal is generally higher than the TP concentrations at all the background water quality stations. These results show the accumulative affect of P transport from cattle pasture on tributaries to Agency Lake.

The September 9, 2003 storm was significant at the watershed scale and caused a spike in the TP concentration in West Canal. The spike is likely due to both an increase in background TP concentrations in Annie Creek and increased surface runoff from pastures throughout the Wood River Valley. At the plot scale the September 9, 2003 storm was similar to the first flush during irrigation; a small runoff flow transporting nutrients at high concentrations (0.19 mg TP L^{-1}). The effects of the irrigation first flush and storm water runoff on nutrient enrichment are different at the watershed scale. The September 9, 2003 storm caused surface runoff to occur simultaneously throughout the entire valley while the first flush from irrigation runoff occurs repeatedly throughout the irrigation season at only isolated parts of the valley. Storm runoff results in a brief spike in P concentration for West Canal. Irrigation runoff results in a progressive increase and decrease in P concentration in West Canal over the course of the irrigation season.

Nutrient mobilization processes occurring on irrigated cattle pasture likely have an effect on nutrient export from the valley from June to September. However, the highest concentration of TP in West Canal occurs in winter. During winter storms and snow melt there are periods of pasture runoff which feed drainage ditches throughout the valley and flow to the lake. A majority of the nutrient mobilization effects of cattle grazing and irrigation are therefore not realized until winter when pastures, canals and the lake are hydrologically connected for longer time periods during snow melt and winter storms. The winter storm events have less influence on water quality stations at the perimeter of the valley not receiving pasture runoff.

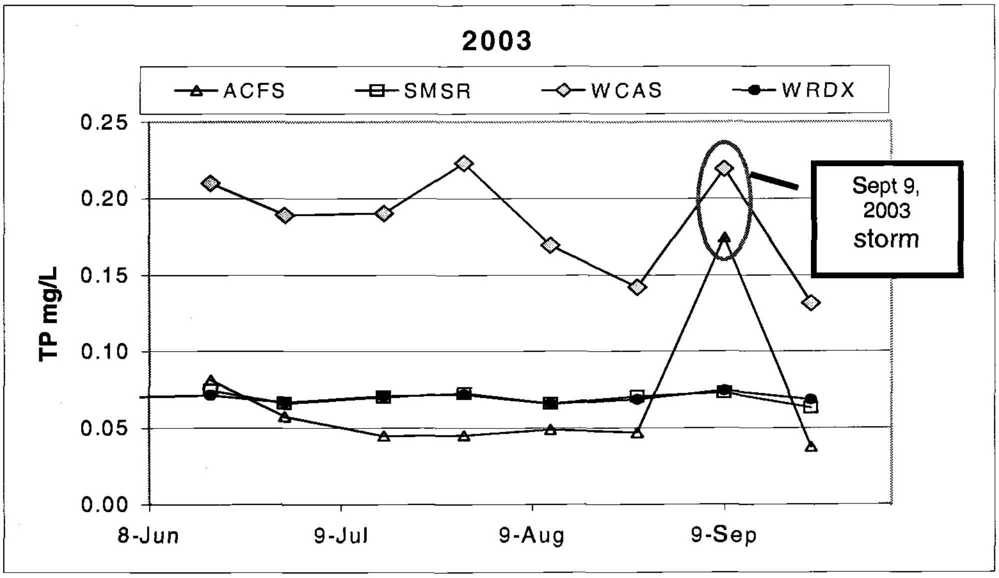


Figure 27. Total phosphorus (TP) mg L^{-1} at the tailwater station West Canal above Sevenmile (WCAS) and at three headwater stations Annie Creek at Forest Service (ACFS), Sevenmile Creek at Forest Service (SMFS) and Wood River at Dixon Road (WRDX) during 2003 irrigation season.

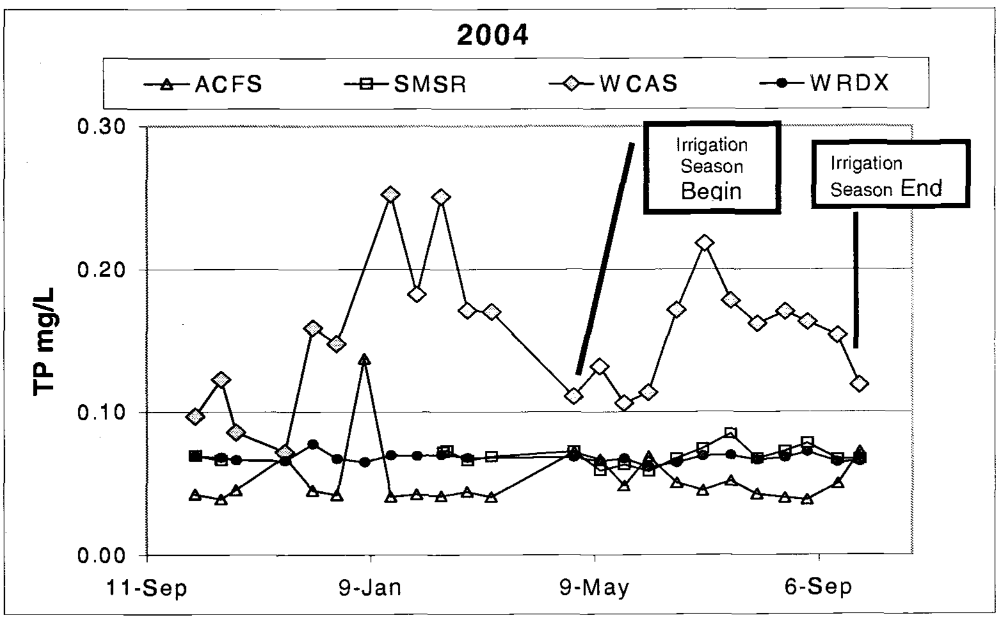


Figure 28. Total phosphorus (TP) mg L^{-1} at the tailwater station West Canal above Sevenmile (WCAS) and at three headwater stations Annie Creek at Forest Service (ACFS), Sevenmile Creek at Forest Service (SMFS) and Wood River at Dixon Road (WRDX) during 2004 water year.

Management

Heathwaite et. al. (2000) recommends an integrated approach to nutrient management with Best Management Practices (BMP's) targeted to critical areas of a watershed that contribute to the export of N and P. Developing BMP's involves identifying specific source areas of P and N at the field and farm scales and their resulting effects at the watershed scale (Gburek et al, 1998). In this study we attempted to identify specific source areas and transport mechanisms of nutrients and sediment in the Wood River Valley. The primary methods of transport were irrigation and storm water flow and source areas of nutrients and sediment were the pasture and canals particularly when cattle were present. This discussion will focus on management options which offer the best opportunities for controlling nutrients and sediment based on the test plots examined during the 2003 and 2004 growing seasons. These management options include reducing irrigation runoff, enhancement of riparian wetlands and vegetation, and limiting and excluding livestock access to canals, drainage ditches and streams.

This study has managed to quantify and compare nutrient losses from specific sources within the Wood River Watershed. The results of this study have some implications for managing P export at the local scale (pasture or farm unit) within the Wood River Valley. Reducing surface irrigation runoff and cattle access to drainage ways appear to be the most effective ways of reducing P export from the study plots examined.

Irrigation

Sharpley found that in a non-irrigated agricultural watershed in Pennsylvania that 70% of the dissolved-P export occurred during stormflow. P was exported from smaller areas of the watershed that were within 30 m of a channel. Flow weighted concentration of dissolved-P in runoff was influenced more by near stream soil P content than by P content at the watershed scale. The variable source area (VSA) concept to hydrology asserts that there is an expanding and contracting subwatershed within a watershed where runoff potential changes during a storm (Ward 1984).

The September 9, 2003 storm did not likely export as much N and P from the West Plot as was exported during irrigation because storm runoff flow was much lower than irrigation runoff flow. Its effect on the watershed, however, was considerable since most of the Wood River Valley was experiencing runoff at the same time, unlike irrigation when only sections of the watershed are being irrigated. On a per area basis flood irrigation likely expands the potential source areas of P export since the increase runoff has more opportunity to come in contact with P on the pasture being irrigated. The system of canals and drainage ditches also increases hydrologic connectivity between runoff and the stream channel. Reducing irrigation runoff in the Wood River Valley could potentially reduce the nutrient export from pastures.

Current water conservation programs in the Wood River Valley are providing compensation to ranchers for reducing the acreage of pasture that is flood irrigated. This is a clear method of significantly reducing irrigation runoff. As organizations and agencies continue researching the impacts of irrigation curtailment on water savings, and pasture and soil health this may emerge as a long-term opportunity for reducing irrigation runoff. Although a reduction of flood irrigation may lead to increased flushing of nutrients during storms it would probably not increase the amount of nutrients currently exported during the irrigation season. June and July are considered the period of peak algal growth in UKL (OR DEQ Upper Klamath TMDL, 2004). Storm runoff in the Wood River Valley during this time is infrequent and would likely export fewer nutrients than flood irrigation of pasture every two weeks.

Economic incentives could also be used to increase irrigation efficiency in the Wood River Valley. Providing technical assistance to ranchers for improving irrigation efficiency would be difficult, however, due to the limited control landowners have over current gravity fed flood irrigation systems. Ranchers have labored for nearly a century in the Wood River Valley fine tuning the flood irrigation system so that water is distributed to most pasture areas throughout the valley. The result has been a complex system of earthen ditches and canals. There is little control as to the amount of water applied since ranchers must apply excessive amounts in order for surface water to fully infiltrate lower tracts of land. This is further complicated by the irrigation scheduling which is in accordance with time intervals dictated by water rights and not according to water use by pasture crops. Even if the pasture has used little soil moisture since the last irrigation a rancher cannot jeopardize a pasture crop by skipping an irrigation until the next time, which may be weeks away.

Improvements to irrigation efficiency would require changes in the way water is delivered and the scheduling of irrigation as well as close monitoring of water flows, soil moisture and evapotranspiration rates (Kerr, 1976). The irrigation efficiency for the two irrigations measured in 2003 was < 34%. This figure may be misleading since under the current irrigation system many pastures in the Wood River Valley are at least partly dependent on tailwater as their irrigation source. Therefore reducing surface runoff may impair irrigation potential at lower elevation. So calculations of irrigation efficiency must consider the amount of tailwater needed to irrigate pastures at lower elevation. Improving irrigation efficiency in the entire Wood River Valley would be a major undertaking and under the current gravity fed system there would be many chances for error.

Kerr (1976) found that often the only surface tailwater entering natural streams is that which comes from fields at the lowest elevations within an irrigated tract. Attempts could be made to improve irrigation efficiency and in effect reduce runoff in the Wood River Valley. This could begin with research focusing on pastures that drain directly into major waterways. Reducing surface runoff would involve reducing the amount of water applied and ultimately finding the smallest flow which can effectively irrigate a pasture (Kerr, 1976). This approach should start at fields that are hydrologically disconnected from fields at higher elevations within the Wood River Valley. These fields do not rely on tailwater for irrigation supply and the operator would have more control over application rates.

Riparian Area Management

Limiting or excluding cattle access in and around natural streams and major drainage ways is a practical method of reducing nutrient and sediment transport caused by cattle disturbance. Along the Middle Fork John Day River, Oregon, livestock removal resulted in significant changes in soil, hydrological, and vegetation properties that would likely have considerable effect on stream channel structure, water quality, and the aquatic biota (Kaufman, 2004). Private landowners and organizations continue to expand riparian area fencing along both ephemeral and continuous streams throughout the Wood River Valley. Maintaining healthy wetlands and vegetated buffers between pastures and waterways has been demonstrated to reduce sediment and NO_3^-—N transport to waterways (Gilliam, 1994; Griffith et al, 1997; Williamson, 1996; Haughen et al., 2004).

P retention in buffers also occurs but often requires the deposition of fine particles (Lowrence et al. 1984; Chescheir et al. 1991; Gilliam, 1994 all from Gilliam 1994). Gilliam (1994) concluded that riparian buffers are effective at the removal of particulate-P and less effective at the removal of dissolved-P. Vegetated buffer strips maybe particularly effective for mobilizing P in the Wood River Valley because of the low gradient landscape and the soils are not P enriched. If sheet flow is produced then vegetated buffer strips are more effective at P removal (Steinhilber, 2000). In New Zealand best management practices which included livestock exclusion and streambank planting of vegetation were found to reduce TP loads by 20% and estimated to reduce the chlorophyll-a concentration enough to change Lake Rotura from eutrophic to mesotrophic (Williamson, 1996).

Another potential method for reducing P export is the use of P immobilizing materials such as organic polymers and aluminum and iron metal salts and coal-combustion ash currently being used for P removal from liquid manure (Thanh, 2003). Lentz (1998) found that anionic polyacrylimide (PAM) was an effective an economical approach to reducing P and organic material loss from surface irrigated fields. Research on the use of chemical amendments to remove P in buffer strips and drainage ditches is limited (Steinhilber, 2000).

The highest nutrient and sediment loads measured in this study were from drainage ditches when cattle were causing disturbance. Based on the results from 2004 at East Plot an area of particular concern was the mid-ditch. The ditch was dug through what was historically the natural drainage for the pasture. The ditch was bordered by deep organic soils and small wetlands. The area provided easy access to cattle due to a low gradient and tended to have high levels of fine particulates and organic matter. Limiting cattle access to mid-ditch could significantly reduce nutrient transport from the East Plot. When considering management options for reducing environmental impacts of sediment and nutrients it is important to consider whether the pollutant can be transported to a sensitive location (Sharpley, 2000). The mid-ditch water at the East Plot did not empty into a natural waterway and was instead used to irrigate another pasture. Other ditches directly connected to a sensitive waterway should be of higher priority for implementation of BMP's. After the implementation of BMP's to protect major canals and natural waterways is complete nearby drainage ditches should then be addressed.

Continued plot scale water quality research in the Wood River Valley:

1. Examine the particulate nutrient fraction in relation to irrigation and livestock presence on pastures.
2. Compare water quality in stormwater and irrigation runoff from ungrazed and grazed pastures.

3. Examine the spatial extent and temporal characteristics of nutrient flushing in the Wood River Valley.
4. Study the effects of irrigation nutrient flushing on downstream water quality.
5. Study the effects of different irrigation and livestock management practices at locations where nutrient and sediment are directly transported to sensitive waterbodies.

CONCLUSION

This study examined nutrient transport on a two ha and a 70 ha flood irrigated pasture plot in the Wood River Valley. Irrigation headwater and tailwater flows were measured and water quality samples collected. Shallow groundwater and runoff from one storm event were also sampled. All samples were filtered (<0.45 μm) prior to analysis for sediment, dissolved organic carbon (DOC), total dissolved nitrogen (TDN), total dissolved phosphorus (TDP), orthophosphate (OP), ammonium (NH_4^+-N) and nitrate (NO_3^--N). Nutrient loads were determined and a nutrient and sediment budget was estimated during one irrigation.

For both study plots the sediment, TDP, OP, TDN and DOC concentrations were generally higher in surface tailwater than in surface headwater. Most dissolved N and P was organic. NH_4^+-N and NO_3^--N were rarely above detection (0.05 mg L^{-1}). Shallow groundwater was high in DOC and TDN concentration and low in TDP concentration relative to irrigation headwater. Stormwater runoff had high dissolved concentrations of all nutrients but low sediment.

The greatest nutrient export at the 2 ha plot occurred during the rising limb of the runoff hydrograph. There was strong evidence of a first flush of TDP, OP, TDN and DOC during four irrigations. There was net export of sediment (28.3 kg ha^{-1}), DOC (12.46 kg ha^{-1}) and TDN (0.56 kg ha^{-1}) measured during one irrigation. There was minimal net export of TDP (0.02 kg ha^{-1}) and no export or accumulation of OP. When nutrient export was estimated during the first flush (rising limb of runoff hydrograph) it was 10 times greater for TDP and 3 times greater for TDN relative to the net export during the entire irrigation.

Stormwater runoff was analogous to first flush of irrigation runoff at the plot scale since both had high nutrient concentrations and small flow volumes. The effect of these two events on nutrient enrichment at the watershed scale may be observed at West Canal a major tailwater canal for the Wood River Valley. Storm runoff results in a brief spike in P concentration for West Canal. Irrigation runoff results in a progressive increase and decrease in P concentration in West Canal over the course of the irrigation season. The highest concentration of TP in West Canal occurs in winter. A majority of the nutrient mobilization effects of cattle grazing and irrigation are therefore not realized until winter when pastures, canals and the lake are hydrologically connected for longer time periods during snow melt and winter storms.

On the 70 ha study plot flow weighted concentrations for all nutrients increased from headwater to tailwater sampling sites. The TDP and TDN concentrations were highest when cattle were causing disturbance in actively flowing irrigation ditches with maximum flow weighted concentration (FWC) of 0.50 mg TDP L^{-1} and 2.55 mg TDN L^{-1}. The irrigation headwater canal for the plot had a seasonal FWC of 0.03 mg TDP L^{-1} and 0.22 mg TDN L^{-1} while seasonal mean FWC for tailwater ditches was 0.06 mg TDP L^{-1} and 0.84 mg TDN L^{-1}.

Cattle disturbance to canals and nutrient flushing during irrigation were important transport mechanisms for all nutrients. Management considerations for decreasing nutrient export to sensitive waterways in the Wood River Valley include reducing irrigation surface runoff, enhancement of riparian wetlands and vegetation and limiting and managing livestock access to waterways. The results of this study provide insight into how nutrient export occurs on pastures in the upper Wood River Valley and can be used with other data to assist in quantifying and prioritizing external nutrient and sediment inputs to Upper Klamath Lake.

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Appendix A. 2003 Nutrient and Sediment Concentrations

Tailwater North (West Plot)							
Sample Date	Sediment mg/l	DOC mg/L	TDN mg/L	TDP mg/L	NH4+ mg/L	N03- mg/L	OP mg/L
6/19/03 16:35	3.2	36.88	1.16	0.39	<0.05	<0.05	0.32
6/19/03 17:27	1.4	32.54	0.99	0.31	<0.05	<0.05	0.27
6/19/03 18:15	2.4	28.17	0.86	0.27	<0.05	<0.05	0.23
6/19/03 18:25	1.0	27.99	0.82	0.27	<0.05	<0.05	0.24
6/19/03 20:34	0.6	19.57	0.39	0.12	<0.05	<0.05	0.11
6/19/03 22:12	0.6	18.32	0.32	0.11	<0.05	<0.05	0.09
6/20/03 6:50	0.5	14.22	0.17	0.06	<0.05	<0.05	0.06
6/20/03 11:48	0.6	16.27	0.31	0.05	<0.05	<0.05	0.05
7/6/03 13:25	33.8	24.41	0.62	-	<0.05	<0.05	-
7/6/03 14:17	28.3	40.11	1.08	0.36	0.05	<0.05	0.36
7/6/03 15:55	19.4	22.38	0.56	-	0.07	<0.05	-
7/6/03 17:09	38.1	19.20	0.31	0.16	<0.05	<0.05	0.14
7/6/03 21:30	29.9	15.62	0.21	0.10	<0.05	<0.05	0.07
7/7/03 8:50	23.7	9.83	0.08	-	<0.05	<0.05	-
7/7/03 14:03	35.2	11.60	0.08	-	0.05	<0.05	-
7/23/03 18:34	25.9	45.21	1.52	0.52	0.12	<0.05	0.50
7/23/03 20:36	37.7	23.78	0.56	0.23	<0.05	<0.05	0.21
7/24/03 9:35	38.8	14.44	0.19	0.08	<0.05	<0.05	0.08
7/24/03 9:36	37.1	14.40	0.19	0.08	<0.05	<0.05	0.08
7/24/03 13:17	43.4	14.30	0.23	0.07	<0.05	<0.05	0.07
7/24/03 21:07	41.4	14.15	0.21	0.06	<0.05	<0.05	0.05
7/25/03 8:40	5.7	8.96	-	0.05	<0.05	<0.05	0.06
8/9/03 11:36	5.8	17.34	0.44	0.14	0.07	<0.05	0.09
8/9/03 15:24	2.3	20.64	-	0.14	-	-	0.12
8/9/03 17:12	2.1	18.00	0.35	0.14	<0.05	<0.05	0.10
8/9/03 19:20	6.2	17.48	0.50	0.14	0.06	<0.05	0.07
8/10/03 9:44	42.7	10.89	0.23	0.13	<0.05	<0.05	0.06
8/10/03 9:45	4.0	10.88	0.22	0.06	<0.05	<0.05	0.06
8/10/03 11:15	11.5	11.47	0.32	0.07	<0.05	<0.05	0.06
8/26/03 11:21	0.6	14.32	0.28	0.05	<0.05	<0.05	0.03
8/26/03 11:21	2.7	14.85	0.34	0.05	<0.05	<0.05	0.03
8/26/03 12:37	-	1.64	-	0.05	-	-	0.03
8/26/03 14:48	0.6	1.48	-	0.08	-	-	0.05

Tailwater South (West Plot)							
Sample Date	Sediment mg/L	DOC mg/L	TDN mg/L	TDP mg/L	NH4+ mg/L	N03- mg/L	OP mg/L
6/19/03 16:55	1.4	31.94	0.98	0.55	<0.05	<0.05	0.29
6/19/03 18:10	1.9	21.80	0.58	0.19	<0.05	<0.05	0.17
6/19/03 20:30	0.7	18.42	0.40	0.13	<0.05	<0.05	0.12
6/19/03 22:14	2.4	17.11	0.31	0.11	<0.05	<0.05	0.10
6/20/03 6:55	0.6	14.02	0.23	0.06	<0.05	<0.05	0.06
6/20/03 11:50	0.6	14.90	0.24	0.07	<0.05	<0.05	0.07
7/6/03 15:20	30.5	26.19	0.77	0.34	0.15	<0.05	0.21
7/6/03 15:35	22.4	30.99	0.80	0.36	0.08	<0.05	0.32
7/6/03 15:35	37.6	28.58	0.71	-	0.09	<0.05	-
7/6/03 16:00	30.4	21.01	0.44	0.24	<0.05	<0.05	0.24
7/6/03 17:06	21.3	24.59	0.54	0.19	<0.05	<0.05	0.16
7/6/03 21:30	42.6	19.89	0.66	-	<0.05	<0.05	-
7/7/03 8:45	31.6	11.38	0.12	-	<0.05	<0.05	-
7/7/03 14:30	26.3	17.21	0.29	0.08	<0.05	<0.05	0.08
7/23/03 20:20	40.1	20.29	0.51	0.19	<0.05	<0.05	0.19
7/24/03 9:51	35.4	12.53	0.16	0.08	<0.05	<0.05	0.08
7/24/03 13:25	34.0	12.41	0.19	0.07	<0.05	<0.05	0.07
7/24/03 21:02	34.2	12.51	0.14	0.05	<0.05	<0.05	0.05
7/25/03 8:45	5.2	10.93	0.12	0.05	<0.05	<0.05	0.05
8/9/03 16:20	2.3	16.46	0.41	-	0.07	<0.05	-
8/9/03 16:50	4.2	15.09	0.48	0.14	<0.05	<0.05	0.10
8/9/03 19:11	1.7	14.43	0.41	0.14	0.06	<0.05	0.08
8/10/03 9:54	3.3	10.23	0.24	0.06	<0.05	<0.05	0.06
8/10/03 11:06	2.2	10.42	0.17	0.07	<0.05	<0.05	0.07
8/26/03 15:31	2.9	16.39	0.49	0.14	0.07	<0.05	0.10

Headwater (West Plot)							
Sample Date	Sediment mg/L	DOC mg/L	TDN mg/L	TDP mg/L	NH4+ mg/L	N03- mg/L	OP mg/L
6/19/03 8:10	34.3	14.32	0.46	0.06	<0.05	<0.05	0.05
6/19/03 8:25	5.7	11.99	0.21	0.06	<0.05	<0.05	0.06
6/20/03 8:12	2.9	10.78	0.04	0.05	<0.05	<0.05	0.05
7/6/03 13:50	20.5	11.91	0.09	0.08	<0.05	<0.05	0.08
7/7/03 10:15	22.6	9.05	0.08	0.07	<0.05	<0.05	0.07
7/7/03 12:55	20.0	16.56	0.26	0.09	<0.05	<0.05	0.09
7/23/03 19:24	34.0	9.51	0.07	0.06	<0.05	<0.05	0.06
7/24/03 10:15	27.5	10.05	0.01	0.07	<0.05	<0.05	0.07
7/24/03 13:35	37.3	9.58	0.01	0.06	<0.05	<0.05	0.06
7/25/03 9:00	1.9	12.28	0.16	0.06	<0.05	<0.05	0.05
8/9/03 11:55	3.1	9.78	0.05	0.13	<0.05	<0.05	0.07
8/9/03 15:15	0.6	9.70	0.14	0.13	<0.05	<0.05	0.07
8/10/03 9:39	5.0	9.50	0.12	0.07	<0.05	<0.05	0.07
8/26/03 11:29	0.6	10.37	0.12	0.07	0.05	<0.05	0.07
8/26/03 14:38	0.6	4.29	0.02	0.07	<0.05	<0.05	0.07
8/26/03 19:15	2.5	1.32	0.01	0.08	<0.05	<0.05	0.07

Stormwater Runoff (West Plot)								
Site	Sample Date	Sediment mg/L	DOC mg/L	TDN mg/L	TDP mg/L	NH4+ mg/L	N03- mg/L	OP mg/L
Tailwater North	9/9/03	5.3	30.31	1.64	0.14	0.05	<.05	0.01
Tailwater North	9/9/03	2.9	43.67	2.48	0.16	0.13	<.05	0.01
Tailwater South	9/9/03	9.0	34.75	1.97	0.22	0.07	<.05	0.09
Tailwater South	9/9/03	4.1	33.96	1.87	0.16	0.07	<.05	0.04
Tailwater South	9/9/03	6.0	32.93	2.08	0.26	0.17	<.05	0.11

Shallow Groundwater (West Plot)								
Site	Sample Date	Sediment mg/L	DOC mg/L	TDN mg/L	TDP mg/L	NH4+ mg/L	N03- mg/L	OP mg/L
DP1	7/24/2003	137.4	12.36	0.28	0.03	<0.05	<0.05	0.02
DP3	7/24/2003	16.3	29.47	0.54	0.05	0.42	<0.05	0.05
DP4	7/24/2003	204.1	39.72	0.86	0.03	0.12	<0.05	0.01
DP-1	08/09/03	19.8	13.42	0.22	0.13	0.06	<0.05	0.03
DP-3	08/09/03	30.2	34.73	0.31	0.13	0.16	<0.05	0.02
DP-4	08/09/03	53.3	37.93	0.47	0.13	0.04	<0.05	0.02
DP-8	08/09/03	16.5	30.17	0.45	0.13	0.13	<0.05	0.03
DP1	08/10/03	20.7	10.99	0.35	0.03	<0.05	<0.05	0.03
DP-2	08/10/03	226.7	34.22	1.29	0.05	0.21	<0.05	0.04
DP-3	08/10/03	11.0	36.16	0.33	0.02	0.19	<0.05	0.02
DP-8	08/10/03	7.2	31.41	0.40	0.06	0.11	<0.05	0.03
DP-7	08/10/03	27.8	24.20	0.37	0.03	0.10	<0.05	0.02
DP-4	08/10/03	68.0	43.42	1.24	0.04	0.08	<0.05	0.03
DP-1	08/13/03	3.3	9.80	0.10	0.06	<0.05	<0.05	0.06
DP-2	08/13/03	1.8	9.23	0.07	0.06	<0.05	<0.05	0.06
DP-8	08/13/03	105.8	41.84	0.97	0.04	0.07	<0.05	0.01
DP-7	08/13/03	5.3	33.51	0.29	0.03	0.17	<0.05	0.01
DP-5	08/13/03	19.4	13.41	0.40	0.07	0.13	0.10	0.06
DP-3	08/13/03	38.2	23.45	0.36	0.06	0.10	<0.05	0.01
DP-4	08/13/03	17.5	29.36	0.32	0.03	0.11	<0.05	0.01
DP-1	08/26/03	41.1	10.66	0.27	0.04	<0.05	0.05	0.03
DP-2	08/26/03	82.1	35.00	0.88	0.06	0.30	<0.05	0.02
DP-1	08/26/03	32.1	10.32	0.20	-	<0.05	<0.05	-
DP-2	08/26/03	62.3	22.32	0.67	0.05	0.21	<0.05	0.03
DP-3	08/26/03	3.6	4.05	-	0.08	-	-	0.02
DP-4	08/26/03	94.0	1.96	-	0.06	-	-	0.02
DP-2	09/09/03	77.7	34.38	1.16	0.05	0.16	<0.05	0.02
DP-3	09/09/03	8.7	28.82	0.37	0.04	0.11	<0.05	0.01
DP-4	09/09/03	74.1	35.49	1.44	0.05	0.08	<0.05	0.01
DP-8	09/09/03	83.0	25.36	0.41	0.03	0.12	<0.05	0.01
DP-5	09/09/03	15.9	9.94	0.31	0.05	0.07	<0.05	0.04
DP-1	09/09/03	70.3	8.33	0.22	0.03	<0.05	<0.05	0.02

Appendix B. 2003 Flows and Loading

Tailwater North Flow and Loading, July 23 to 25, 2003 Irrigation (West Plot)											
Date	Flow liters/sec	Sediment mg/sec	DOC mg/sec	TDN mg/sec	TDP mg/sec	OP mg/sec	Sediment mg/l	DOC mg/L	TDN mg/L	TDP mg/L	OP mg/L
7/23/03 18:00	0.2	-	-	-	-	-	-	-	-	-	-
7/23/03 18:15	1.0	-	-	-	-	-	-	-	-	-	-
7/23/03 18:35	1.5	38.8	67.88	2.29	0.78	0.75	25.9	45.21	1.52	0.52	0.50
7/23/03 18:40	2.1	-	-	-	-	-	-	-	-	-	-
7/23/03 18:45	3.5	-	-	-	-	-	-	-	-	-	-
7/23/03 18:49	5.0	-	-	-	-	-	-	-	-	-	-
7/23/03 19:13	7.7	-	-	-	-	-	-	-	-	-	-
7/23/03 19:19	7.7	-	-	-	-	-	-	-	-	-	-
7/23/03 20:46	11.3	427.2	269.18	6.31	2.56	2.41	37.7	23.78	0.56	0.23	0.21
7/24/03 9:38	23.0	891.6	331.58	4.43	1.88	1.84	38.8	14.44	0.19	0.08	0.08
7/24/03 11:39	23.0	851.7	330.66	4.42	1.82	1.83	37.1	14.40	0.19	0.08	0.08
7/24/03 13:20	22.4	973.7	320.65	5.25	1.63	1.46	43.4	14.30	0.23	0.07	0.07
7/24/03 21:00	21.6	895.2	305.94	4.47	1.26	1.09	41.4	14.15	0.21	0.06	0.05
7/25/03 8:18	23.6	28.6	211.88	-	0.89	0.77	1.2	8.96	-	0.05	0.05
7/25/03 9:40	15.3	-	-	-	-	-	-	-	-	-	-
7/25/03 10:00	11.3	-	-	-	-	-	-	-	-	-	-
7/25/03 10:37	8.2	-	-	-	-	-	-	-	-	-	-
7/25/03 12:00	4.3	-	-	-	-	-	-	-	-	-	-
7/25/03 15:53	0.3	-	-	-	-	-	-	-	-	-	-

Tailwater South Flow and Loading, July 23 to 25, 2003 Irrigation (West Plot)											
Date	Flow Liter/sec	Sediment mg/sec	DOC mg/sec	TDN mg/sec	TDP mg/sec	OP mg/sec	Sediment mg/l	DOC mg/L	TDN mg/L	TDP mg/L	OP mg/L
7/23/2003 20:20	6.8	273.1	138.06	3.44	1.32	1.28	40.1	20.29	0.51	0.19	0.19
7/23/2003 20:30	6.8	-	-	-	-	-	-	-	-	-	-
7/24/2003 9:51	21.6	766.7	271.15	3.45	1.58	1.67	35.4	12.53	0.16	0.08	0.08
7/24/2003 13:28	20.5	695.5	253.82	3.82	1.53	1.37	34.0	12.41	0.19	0.07	0.07
7/24/2003 21:00	20.3	694.3	254.23	2.85	1.05	1.03	34.2	12.51	0.14	0.05	0.05
7/25/2003 8:20	23.0	119.4	251.20	2.81	1.14	1.22	5.2	10.93	0.12	0.05	0.05
7/25/2003 9:44	16.5	-	-	-	-	-	-	-	-	-	-
7/25/2003 10:04	11.9	-	-	-	-	-	-	-	-	-	-
7/25/2003 10:40	8.7	-	-	-	-	-	-	-	-	-	-
7/25/2003 12:05	3.5	-	-	-	-	-	-	-	-	-	-
7/25/2003 15:55	0.2	-	-	-	-	-	-	-	-	-	-

Tailwater North Flow and Load August 9to10, 2003 Irrigation (West Plot)											
Date	Liters/sec	Sediment mg/sec	DOC mg/sec	TDN mg/sec	TDP mg/sec	OP mg/sec	Sediment mg/l	DOC mg/L	TDN mg/L	TDP mg/L	OP mg/L
8/9/03 11:27	1.0	5.7	16.93	0.43	0.14	0.09	5.8	17.34	0.44	0.14	0.09
8/9/03 15:23	11.9	40.0	233.20	2.13	1.70	1.32	3.4	19.65	0.18	0.14	0.11
8/9/03 15:55	15.0	-	-	-	-	-	-	-	-	-	-
8/9/03 16:05	16.2	-	-	-	-	-	-	-	-	-	-
8/9/03 16:15	16.5	-	-	-	-	-	-	-	-	-	-
8/9/03 16:25	17.8	-	-	-	-	-	-	-	-	-	-
8/9/03 16:35	18.1	-	-	-	-	-	-	-	-	-	-
8/9/03 17:10	19.5	40.4	351.52	6.76	2.71	1.87	2.1	18.00	0.35	0.14	0.10
8/9/03 17:46	20.3	-	-	-	-	-	-	-	-	-	-
8/9/03 17:56	20.8	-	-	-	-	-	-	-	-	-	-
8/9/03 18:06	21.6	-	-	-	-	-	-	-	-	-	-
8/9/03 18:16	21.6	-	-	-	-	-	-	-	-	-	-
8/9/03 18:26	23.0	-	-	-	-	-	-	-	-	-	-
8/9/03 18:36	23.0	-	-	-	-	-	-	-	-	-	-
8/9/03 18:46	23.0	-	-	-	-	-	-	-	-	-	-
8/9/03 19:20	23.0	143.5	401.42	11.56	3.10	1.66	6.2	17.48	0.50	0.14	0.07
8/10/03 9:43	25.7	1098.2	280.11	6.04	3.37	1.48	42.7	10.89	0.23	0.13	0.06
8/10/03 10:05	24.3	965.6	266.33	5.91	3.04	1.40	39.7	10.95	0.24	0.12	0.06
8/10/03 10:20	21.6	-	-	-	-	-	-	-	-	-	-
8/10/03 10:35	20.3	-	-	-	-	-	-	-	-	-	-
8/10/03 10:50	16.5	-	-	-	-	-	-	-	-	-	-
8/10/03 11:05	13.0	-	-	-	-	-	-	-	-	-	-
8/10/03 11:20	11.3	130.3	129.84	3.59	0.76	0.67	11.5	11.47	0.32	0.07	0.06
8/10/03 11:35	8.7	-	-	-	-	-	-	-	-	-	-
8/10/03 11:50	6.8	-	-	-	-	-	-	-	-	-	-
8/10/03 12:05	5.3	-	-	-	-	-	-	-	-	-	-
8/10/03 12:20	4.2	-	-	-	-	-	-	-	-	-	-

Tailwater South Flow and Loading August 9 to 10, 2003 irrigation (West Plot)											
Date	Flow Liter/sec	Sediment mg/sec	DOC mg/sec	TDN mg/sec	TDP mg/sec	OP mg/sec	Sediment mg/l	DOC mg/L	TDN mg/L	TDP mg/L	OP mg/L
8/9/03 16:26	5.8	-	-	-	-	-	-	-	-	-	-
8/9/03 16:36	6.7	-	-	-	-	-	-	-	-	-	-
8/9/03 16:50	8.7	36.9	131.66	4.23	1.23	0.89	4.2	15.09	0.48	0.14	0.10
8/9/03 17:05	9.7	-	-	-	-	-	-	-	-	-	-
8/9/03 17:45	11.9	-	-	-	-	-	-	-	-	-	-
8/9/03 17:55	12.5	-	-	-	-	-	-	-	-	-	-
8/9/03 18:00	13.0	-	-	-	-	-	-	-	-	-	-
8/9/03 18:15	13.8	-	-	-	-	-	-	-	-	-	-
8/9/03 18:25	14.4	-	-	-	-	-	-	-	-	-	-
8/9/03 18:35	14.4	-	-	-	-	-	-	-	-	-	-
8/9/03 18:45	15.0	-	-	-	-	-	-	-	-	-	-
8/9/03 18:55	15.0	-	-	-	-	-	-	-	-	-	-
8/9/03 19:05	15.0	-	-	-	-	-	-	-	-	-	-
8/9/03 19:15	15.0	25.0	216.81	6.15	2.03	1.16	1.7	14.43	0.41	0.14	0.08
8/10/03 9:44	21.6	71.3	221.40	5.23	1.34	1.39	3.3	10.23	0.24	0.06	0.06
8/10/03 10:00	21.6	-	-	-	-	-	-	-	-	-	-
8/10/03 10:15	20.3	-	-	-	-	-	-	-	-	-	-
8/10/03 10:30	20.3	-	-	-	-	-	-	-	-	-	-
8/10/03 10:45	17.8	-	-	-	-	-	-	-	-	-	-
8/10/03 11:00	14.1	31.4	147.37	2.43	0.95	0.93	2.2	10.42	0.17	0.07	0.07
8/10/03 11:15	11.9	-	-	-	-	-	-	-	-	-	-
8/10/03 11:30	10.8	-	-	-	-	-	-	-	-	-	-
8/10/03 11:45	7.7	-	-	-	-	-	-	-	-	-	-
8/10/03 12:00	5.9	-	-	-	-	-	-	-	-	-	-
8/10/03 12:15	5.0	-	-	-	-	-	-	-	-	-	-
8/10/03 12:30	3.5	-	-	-	-	-	-	-	-	-	-

Appendix C. 2003 Water Quality Indicators

Tailwater north (West Plot)							
Date Time	Turbidity NTU (Lab)	Ph (Lab)	Conductivity mS/cm (Lab)	Temp °C (Field)	pH (Field)	Conductivity mS/cm (field)	Dissolved Oxygen mg/L (field)
6/19/03 16:35	3	6.99	0.064	-	-	-	-
6/19/03 17:27	3.2	6.98	0.062	-	-	-	-
6/19/03 18:15	4	6.94	0.059	-	-	-	-
6/19/03 18:25	3.1	6.91	0.057	-	-	-	-
6/19/03 20:34	2.8	6.97	0.052	-	-	-	-
6/19/03 22:12	3.3	6.96	0.049	-	-	-	-
6/20/03 6:50	2	7.10	0.050	-	-	-	-
6/20/03 11:48	3	7.13	0.049	-	-	-	-
7/6/03 13:25	-	-	-	27.67	6.37	0.061	5.12
7/6/03 17:09	-	-	-	27.57	6.41	0.059	5.7
7/7/03 8:50	-	-	-	11.6	6.39	0.051	9.54
7/7/03 14:03	-	-	-	23.49	6.45	0.052	6.37
7/23/03 18:34	-	-	-	25.85	6.56	0.098	4.91
7/23/03 20:36	-	-	-	20.47	6.43	0.071	4.46
7/24/03 9:35	-	-	-	13.86	6.6	0.06	8.02
7/25/03 8:40	-	-	-	11.94	6.75	0.059	8.54
7/24/03 21:07	-	-	-	14.79	6.57	0.063	6.44
7/24/03 13:17	-	-	-	-	6.582	0.0702	-
8/9/03 11:36	2.00	7.00	0.054	-	-	-	-
8/9/03 15:24	1.50	7.14	0.061	-	-	-	-
8/9/03 17:12	1.50	7.17	0.059	-	-	-	-
8/9/03 19:20	0.95	7.01	0.067	-	-	-	-
8/10/03 9:44	0.65	7.28	0.059	-	-	-	-
8/10/03 9:45	8.75	7.26	0.056	-	-	-	-
8/10/03 11:15	0.60	7.32	0.051	-	-	-	-
8/26/03 11:21	9.00	7.21	0.058	-	-	-	-
8/26/03 11:21	10.00	7.45	0.058	-	-	-	-
8/26/03 12:37	10.00	7.35	0.062	-	-	-	-
8/26/03 14:48	3.00	7.38	0.059	-	-	-	-
8/26/03 18:50	10.00	7.22	0.056	-	-	-	-
09/09/03	26.00	6.80	0.050	-	-	-	-
09/09/03	22.00	6.98	0.060	-	-	-	-

Tailwater south (West Plot)							
Date Time	Turbidity NTU (Lab)	Ph (Lab)	Conductivity mS/cm (Lab)	Temp °C (Field)	pH (Field)	Conductivity mS/cm(field)	Dissolved Oxygen mg/L (field)
6/19/03 16:55	6	6.95	0.062	-	-	-	-
6/19/03 18:10	4.5	7.05	0.053	-	-	-	-
6/19/03 20:30	3.5	6.93	0.050	-	-	-	-
6/19/03 22:14	2.5	6.98	0.050	-	-	-	-
6/20/03 6:55	2.5	7.11	0.048	-	-	-	-
6/20/03 11:50	2.5	7.15	0.049	-	-	-	-
7/6/03 15:35	-	-	-	28.14	6.61	0.062	5.35
7/6/03 16:00	-	-	-	27.35	6.43	0.058	5.77
7/6/03 21:30	-	-	-	14.05	6.02	0.056	6.67
7/7/03 8:45	-	-	-	10.14	6.6	0.05	10.13
7/7/03 14:30	-	-	-	20.73	6.42	0.052	7.25
7/23/03 20:20	-	-	-	19.21	6.43	0.068	5.32
7/24/03 9:51	-	-	-	13.21	6.69	0.057	8.18
7/24/03 21:02	-	-	-	14.14	6.57	0.061	6.71
7/25/03 8:45	-	-	-	11.13	6.76	0.058	9.06
8/26/03 15:31	11.00	7.35	0.056	-	-	-	-
8/26/03 18:56	6.00	7.16	0.055	-	-	-	-
09/09/03	21.00	6.98	0.047	-	-	-	-
09/09/03	21.00	6.84	0.063	-	-	-	-

Headwater (West Plot)							
Date Time	Turbidity NTU(Lab)	Ph (Lab)	Conductivity mS/cm (Lab)	Temp oC (Field)	pH (Field)	Conductivity mS/cm (field)	Dissolved Oxygen (field)
6/19/2003 8:10	8.4	7.20	0.07	-	-	-	-
6/19/2003 8:25	4.5	7.33	0.05	-	-	-	-
6/20/2003 8:12	3	7.41	0.05	-	-	-	-
7/6/2003 14:50	-	-	-	10.07	6.95	0.053	11.04
7/6/2003 13:50	-	-	-	11.33	6.89	0.053	10.84
7/7/2003 10:15	-	-	-	8.61	7.01	0.053	10.29
7/7/2003 12:55	-	-	-	10.46	6.91	0.053	10.73
7/23/2003 19:24	-	-	-	12.53	7.11	0.059	9.86
7/24/2003 10:15	-	-	-	9.13	6.97	0.06	9.53
7/24/2003 13:35	-	-	-	9.82	6.96	0.052	9.17
7/25/2003 9:00	-	-	-	7.8	7.05	0.059	10.67
7/24/2003 10:38	-	-	-	8.34	7.04	0.06	9.91
08/09/03	0.80	7.35	0.05	-	-	-	-
08/09/03	0.65	7.39	0.05	-	-	-	-
08/10/03	0.55	7.35	0.06	-	-	-	-

Appendix D. 2004 Water Quality Indicators, Sediment and Nutrient Concentration and Loading

Headwater Canal (East Plot)																
Sample Date	Turbidity NTU	Ph	Conductivity mS	Sediment mg/l	DOC mg/L	TDN mg/L	TDP mg/L	NH4+ mg/L	N03- mg/L	OP mg/L	flow L/sec	Sediment mg/sec	DOC mg/sec	TDN mg/sec	TDP mg/sec	OP mg/sec
5/23/04 10:30	5.5	6.84	0.046	33.3	4.85	-	0.03	-	-	0.01	-	-	-	-	-	-
5/23/04 10:30	5.5	7.05	0.044	36.9	4.92	-	0.02	-	-	0.01	-	-	-	-	-	-
5/23/04 10:30	4.5	7.14	0.038	28.1	4.86	-	0.02	-	-	0.01	-	-	-	-	-	-
6/30/04 14:58	4.8	6.93	0.053	26.1	4.11	0.36	0.02	<0.05	<0.05	0.02	140.0	3655.6	575.68	50.27	2.80	2.80
6/30/04 15:30	5	6.95	0.028	29.1	4.20	0.30	0.02	<0.05	<0.05	0.02	140.0	4075.9	587.58	41.62	2.80	2.80
6/30/04 15:00	3.5	6.96	0.037	19.3	4.04	0.14	0.03	<0.05	<0.05	0.01	140.0	2706.7	564.90	19.67	4.20	1.40
6/30/04 19:05	4	6.96	0.04	13.3	4.15	0.21	0.03	<0.05	<0.05	0.01	-	-	-	-	-	-
6/30/04 19:04	6	6.96	0.037	31.2	4.20	0.23	0.03	<0.05	<0.05	0.00	-	-	-	-	-	-
7/1/04 7:33	5.3	6.95	0.035	8.7	4.14	0.17	0.03	<0.05	<0.05	0.01	154.8	1341.9	641.50	26.54	4.65	1.55
7/1/04 7:30	4.5	6.94	0.036	12.0	4.02	1.83	0.03	<0.05	<0.05	0.01	154.8	1858.1	621.99	283.20	4.65	1.55
7/22/04 17:50	3.9	8.52	0.053	10.0	5.21	0.26	0.05	<0.05	<0.05	0.02	123.5	1234.8	643.82	32.13	5.57	3.00
7/22/04 17:00	4.6	8.01	0.053	0.5	4.64	0.18	0.04	<0.05	0.06	0.03	123.5	66.7	572.45	22.14	5.49	3.24
7/23/04 19:25	4	7.69	0.053	18.8	5.70	0.19	0.05	<0.05	<0.05	0.03	147.6	2766.8	841.68	28.51	7.20	3.88
7/23/04 13:36	4.1	7.38	0.055	27.1	6.53	0.32	0.07	<0.05	<0.05	0.05	137.8	3739.2	899.16	44.36	9.22	6.25
8/19/04 13:05	9.4	7.15	0.056	17.5	6.04	0.26	0.05	<0.05	<0.05	0.03	-	-	-	-	-	-
8/19/04 13:25	5.5	7.28	0.054	18.7	6.35	0.19	0.06	<0.05	<0.05	0.03	-	-	-	-	-	-
8/27/04 15:35	5.1	8.35	0.055	34.2	4.24	0.19	0.04	<0.05	<0.05	0.01	-	-	-	-	-	-
8/27/04 15:35	5.7	8.46	0.057	35.4	4.04	0.18	-	<0.05	<0.05	-	149.8	5300.6	604.74	27.44	-	-
9/9/04 17:00	5.9	8.61	0.054	28.3	4.16	0.17	0.05	<0.05	<0.05	0.04	56.8	1610.5	236.40	9.72	3.10	2.44
9/9/04 17:45	5.7	8.59	0.056	29.3	3.99	0.16	0.03	<0.05	<0.05	0.03	56.8	1667.3	226.68	9.15	1.50	1.56
9/10/04 12:50	4	8.39	0.05	24.0	4.09	0.25	0.03	<0.05	<0.05	0.03	64.4	1545.6	263.07	16.38	1.93	1.93
9/11/04 13:58	4	8.45	0.061	160.0	4.13	0.15	0.03	<0.05	<0.05	0.03	-	-	-	-	-	-
9/16/04 15:00	3	8.11	0.053	12.0	4.97	0.21	0.03	<0.05	<0.05	0.03	162.4	1948.8	807.13	34.38	4.71	4.50
9/16/04 15:00	3.5	8.49	0.054	201.5	4.14	0.23	0.02	<0.05	<0.05	0.02	162.4	32729.8	671.52	37.68	3.25	3.25
9/19/04 12:05	7	7.65	0.056	59.3	4.38	0.21	0.04	<0.05	<0.05	0.02	163.2	9685.6	714.83	34.17	5.83	3.74

South East Ditch (East Plot)																
Sample Date	Turbidity NTU	Ph	Conductivity mS	Sediment mg/l	DOC mg/L	TDN mg/L	TDP mg/L	NH4+ mg/L	N03- mg/L	OP mg/L	flow L/sec	Sediment mg/sec	DOC mg/sec	TDN mg/sec	TDP mg/sec	OP mg/sec
7/23/04 17:30	3.2	7.38	0.072	32.5	19.91	0.85	0.07	<0.05	<0.05	0.03	44.5	1446.9	886.39	37.72	3.32	1.30
7/23/04 17:35	4	7.19	0.069	35.9	19.33	0.84	0.08	<0.05	<0.05	0.03	44.5	1596.6	860.57	37.47	3.68	1.31
8/19/04 12:41	4.2	7.02	0.063	42.5	13.95	0.73	0.08	<0.05	<0.05	0.03	-	-	-	-	-	-
8/19/04 12:41	4.4	7.09	0.064	5.5	14.70	0.68	0.07	<0.05	<0.05	0.03	-	-	-	-	-	-
8/19/04 13:45	4.6	7.04	0.062	5.0	13.35	0.67	0.07	<0.05	<0.05	0.03	-	-	-	-	-	-
8/27/04 14:30	7.3	7.31	0.060	71.7	10.15	0.70	0.04	0.07	<0.05	0.01	42.3	3030.1	429.14	29.42	1.56	0.58
8/27/04 14:30	9	7.41	0.060	72.0	10.39	0.81	0.04	0.06	<0.05	0.02	42.3	3044.2	439.29	34.35	1.70	0.66
8/27/04 15:12	6	8.01	0.060	21.3	7.60	0.60	0.03	<0.05	<0.05	0.02	25.8	549.5	195.67	15.53	0.88	0.63
9/9/04 17:55	8.5	7.43	0.073	5.6	10.27	0.75	0.10	0.06	<0.05	0.07	26.3	148.1	270.31	19.62	2.57	1.86
9/9/04 17:52	4	7.35	0.065	14.6	11.45	0.80	0.12	0.05	<0.05	0.08	26.3	384.7	301.36	21.07	3.13	2.13
9/15/04 17:00	4	7.68	0.072	26.4	18.03	1.33	0.01	<0.05	<0.05	0.01	35.0	925.0	631.05	46.66	0.35	0.33
9/11/04 12:27	8	7.2	0.09	31.7	13.54	1.99	0.33	0.42	0.29	0.21	17.6	556.0	237.74	35.01	5.79	3.72
9/11/04 12:28	9	7.1	0.14	30.0	16.57	3.12	0.68	1.01	0.47	0.45	17.6	526.8	290.94	54.71	11.96	7.95
9/16/04 13:51	3.5	8.22	0.075	19.3	13.69	0.95	0.05	<0.05	<0.05	0.01	31.1	599.4	425.49	29.37	1.49	0.37
9/16/04 13:50	3	7.64	0.074	33.1	15.04	1.06	0.05	<0.05	<0.05	0.02	31.1	1028.0	467.44	32.88	1.55	0.60
9/19/04 13:30	3	7.31	0.059	45.6	9.04	0.66	0.05	<0.05	<0.05	0.02	49.3	2248.4	445.54	32.51	2.42	0.82
9/19/04 13:30	4	7.60	0.060	39.2	9.01	0.53	0.04	<0.05	<0.05	0.02	49.3	1933.3	443.82	26.21	2.21	1.06

East Ditch (East Plot)																	
Sample Date	Turbidity NTU	Ph	Conductivity mS	Sediment mg/l	DOC mg/L	TDN mg/L	TDP mg/L	NH4+ mg/L	N03- mg/L	OP mg/L	flow L/sec	Sediment mg/sec	DOC mg/sec	TDN mg/sec	TDP mg/sec	OP mg/sec
8/27/04 15:00	7.5	7.43	0.068	33.8	11.62	0.84	0.05	0.07	<0.05	0.04	9.5	321.3	110.62	7.96	0.45	0.34
9/10/04 13:20	11	7.32	0.080	7.5	17.41	1.42	0.11	0.10	<0.05	<0.01	12.3	92.4	214.49	17.54	1.29	-
9/10/04 13:20	4.5	7.11	0.079	27.1	18.96	1.52	0.12	0.10	<0.05	0.06	12.3	334.4	233.59	18.71	1.44	0.72
9/11/04 13:20	5.5	7.33	0.063	16.7	5.64	0.50	0.05	0.08	<0.05	0.02	5.6	93.3	31.61	2.78	0.26	0.09
9/11/04 13:23	3.5	7.24	0.060	11.3	6.37	0.50	0.06	0.06	<0.05	0.03	-	-	-	-	-	-
9/19/04 13:00	4	8.11	0.065	26.2	12.14	0.97	0.04	<0.05	<0.05	0.02	27.2	710.3	329.72	26.41	0.99	0.42
9/19/04 13:10	5.5	7.45	0.058	37.1	12.23	0.85	0.04	0.05	<0.05	0.01	27.2	1008.8	332.17	22.96	1.21	0.34

South Ditch (East Plot)																
Sample Date	Turbidity NTU	Ph	Conductivity mS	Sediment mg/l	DOC mg/L	TDN mg/L	TDP mg/L	NH4+ mg/L	N03- mg/L	OP mg/L	flow L/sec	Sediment mg/sec	DOC mg/sec	TDN mg/sec	TDP mg/sec	OP mg/sec
8/27/04 14:20	7.3	7.31	0.06	71.7	10.15	0.70	0.04	0.07	<0.05	0.01	42.3	3030.1	429.14	29.42	1.56	0.58
8/27/04 14:30	9	7.41	0.06	72.0	10.39	0.81	0.04	0.06	<0.05	0.02	42.3	3044.2	439.29	34.35	1.70	0.66
9/16/04 14:40	3.5	7.66	0.061	6.7	10.58	0.79	0.06	0.06	<0.05	0.03	57.7	384.5	610.25	45.68	3.70	1.98
9/16/04 14:45	5	7.72	0.071	25.8	9.10	0.64	0.07	0.08	<0.05	0.01	57.7	1490.1	524.66	36.68	4.17	0.69

Irrigation Runoff (East Plot)																
Sample Date	Turbidity NTU	Ph	Conductivity mS	Sediment mg/l	DOC mg/L	TDN mg/L	TDP mg/L	NH4+ mg/L	N03- mg/L	OP mg/L	flow L/sec	Sediment mg/sec	DOC mg/sec	TDN mg/sec	TDP mg/sec	OP mg/sec
5/1/04 6:30	8.00	7.33	0.05	15.0	18.96	0.76	0.02	<0.05	<0.05	0.01	-	-	-	-	-	-
5/1/04 6:30	8.50	7.55	0.10	22.9	18.20	0.49	0.03	<0.05	<0.05	0.01	-	-	-	-	-	-
5/1/04 6:30	8.50	7.51	0.07	22.7	18.18	0.79	0.02	<0.05	<0.05	<0.01	-	-	-	-	-	-
5/1/04 6:30	6.00	7.37	0.10	31.1	26.68	1.27	0.08	<0.05	<0.05	0.15	-	-	-	-	-	-
5/1/04 7:10	8.00	7.71	0.10	35.6	26.64	1.13	0.08	<0.05	<0.05	0.09	-	-	-	-	-	-
5/1/04 7:10	9.00	7.81	0.08	8.3	27.79	1.29	0.09	<0.05	<0.05	0.09	-	-	-	-	-	-
5/23/04 21:20	4.50	7.08	0.05	18.0	25.31	1.42	0.08	0.05	0.09	0.09	-	-	-	-	-	-
5/23/04 21:20	7.50	7.15	0.06	15.4	24.29	1.20	0.07	0.09	0.09	0.09	-	-	-	-	-	-
5/23/04 21:20	7.75	7.20	0.06	25.0	24.99	1.41	0.08	<0.05	0.06	0.09	-	-	-	-	-	-
7/1/04 6:30	3.8	6.88	0.058	19.3	20.26	1.21	0.08	<0.05	<0.05	0.01	-	-	-	-	-	-
7/1/04 4:44	3.9	6.91	0.051	17.6	11.95	0.70	0.06	<0.05	<0.05	0.01	14.4	254.9	172.60	10.17	0.87	0.14
7/1/04 6:30	4.3	6.91	0.053	10.1	20.23	1.15	0.08	<0.05	<0.05	0.01	-	-	-	-	-	-
7/1/04 4:44	3.9	6.92	0.046	11.5	11.89	0.74	0.07	<0.05	<0.05	0.01	14.4	166.7	171.73	10.64	1.01	0.14
7/1/04 14:30	2.8	6.92	0.045	19.4	11.77	0.73	0.02	<0.05	<0.05	0.01	-	-	-	-	-	-
7/1/04 14:18	3.3	6.92	0.041	19.4	11.97	0.71	0.05	<0.05	<0.05	0.01	-	-	-	-	-	-
7/1/04 15:40	3.8	6.92	0.035	0.6	6.43	0.43	0.03	<0.05	<0.05	0.01	45.3	26.7	291.54	19.64	1.36	0.45
7/1/04 15:40	2.8	6.93	0.036	0.8	6.28	0.29	0.03	<0.05	<0.05	0.01	45.3	36.2	284.56	13.11	1.36	0.45
7/1/04 15:34	2.8	6.90	0.044	0.0	10.00	0.74	0.06	<0.05	<0.05	0.03	9.9	0.0	98.55	7.29	0.59	0.30
7/1/04 15:34	3.5	6.91	0.042	3.9	9.78	0.57	0.06	<0.05	<0.05	0.02	9.9	38.3	96.38	5.64	0.59	0.20
7/23/04 10:20	4.1	7.40	0.084	21.9	30.66	1.59	0.15	<0.05	<0.05	0.03	24.6	539.0	755.41	39.15	3.60	0.63

Irrigation Runoff (East Plot)																
Sample Date	Turbidity NTU	Ph	Conductivity mS	Sediment mg/l	DOC mg/L	TDN mg/L	TDP mg/L	NH4+ mg/L	N03- mg/L	OP mg/L	flow L/sec	Sediment mg/sec	DOC mg/sec	TDN mg/sec	TDP mg/sec	OP mg/sec
7/23/04 13:00	4.5	8.28	0.063	6.3	14.19	0.68	0.07	<0.05	<0.05	0.01	24.9	155.8	353.64	16.87	1.84	0.34
7/23/04 12:26	4.4	7.93	0.063	1.3	14.29	0.74	0.07	<0.05	<0.05	0.02	24.6	32.9	352.08	18.24	1.69	0.61
7/23/04 19:20	3.2	7.45	0.050	26.7	6.67	0.20	0.04	<0.05	<0.05	0.01	22.7	604.2	151.07	4.54	0.80	0.20
7/23/04 19:32	4.3	7.14	0.072	27.1	26.42	1.59	0.08	0.06	<0.05	0.04	22.7	613.0	598.57	36.00	1.86	0.81
7/24/04 5:48	5	8.00	0.058	12.5	9.71	0.44	0.04	0.06	<0.05	0.01	2.8	35.4	27.51	1.26	0.11	0.02
9/10/04 9:30	4	8.65	0.058	10.0	6.07	0.43	0.02	<0.05	<0.05	0.02	-	-	-	-	-	-
9/10/04 9:46	3.4	8.33	0.058	32.9	5.87	0.34	0.04	<0.05	<0.05	0.01	9.9	325.7	58.17	3.34	0.39	0.13
9/12/04 0:42	6	7.02	0.063	41.4	12.32	0.97	0.09	<0.05	<0.05	0.04	15.6	645.3	191.90	15.14	1.33	0.63
9/12/04 0:54	8	7.24	0.092	31.7	13.54	1.99	0.33	<0.05	0.29	0.21	17.6	556.0	237.74	35.01	5.79	3.72
9/12/04 0:56	9	7.13	0.138	30.0	16.57	3.12	0.68	1.01	0.47	0.45	17.6	526.8	290.94	54.71	11.96	7.95
9/12/04 3:16	5	7.24	0.071	7.5	9.20	0.89	0.08	0.08	<0.05	0.03	11.3	85.0	104.18	10.12	0.92	0.36

Groundwater (East Plot)											
Sample Date/Time	Well	Turbidity NTU	Ph	Conductivity mS	Sediment mg/l	DOC mg/L	TDN mg/L	TDP mg/L	NH4+ mg/L	N03- mg/L	OP mg/L
7/23/04 14:00	4	43	6.83	0.236	134.8	36.27	0.68	<0.05	0.05	0.01	<0.01
7/23/04 14:05	4	18	7.47	0.354	145.3	109.90	4.58	0.09	0.17	0.06	0.01
9/9/04 17:21	1	20	7.08	0.099	160.8	20.77	1.50	<0.05	0.10	0.02	0.03
9/9/04 17:20	1	30	7.15	0.112	154.1	10.89	0.64	0.06	0.07	0.07	<0.01
9/9/04 17:30	2	40	7.15	0.179	140.8	27.63	1.62	0.05	0.09	0.10	0.02
9/10/04 12:00	4	47	6.97	0.251	691.4	27.33	0.89	<0.05	0.11	0.01	<0.01
9/10/04 15:23	3	69	6.91	0.218	369.2	23.54	0.54	<0.05	0.05	0.00	<0.01
9/15/04 16:35	5	6	7.58	0.106	47.5	25.06	1.66	0.06	0.13	0.02	0.02
9/16/04 14:11	5	10	7.00	0.248	93.1	40.29	1.75	<0.05	0.17	0.01	<0.01
9/17/04 11:42	4	20	7.16	0.254	208.7	28.52	0.84	<0.05	0.14	0.01	<0.01
9/17/04 11:33	3	60	6.95	0.212	684.8	24.39	0.78	<0.05	0.08	0.01	<0.01
9/19/04 12:21	3	10	7.00	0.200	256.7	24.90	0.59	<0.05	0.06	0.01	<0.01
9/19/04 12:05	4	10	7.01	0.111	203.8	26.32	0.65	<0.05	0.09	0.01	<0.01
9/19/04 12:10	1	10	7.02	0.212	173.6	10.44	0.41	<0.05	0.07	0.02	<0.01
9/19/04 12:39	5	5	7.54	0.304	93.6	49.72	1.94	<0.05	0.16	0.02	<0.01