Removing soluble phosphorus in irrigation return flows with alum additions

A.B. Leytem and D.L. Bjorneberg

ABSTRACT: Phosphorus (P) losses from irrigated cropland transferred to surface waters via irrigation return flows, can impair regional water quality. Best management practices to reduce soil erosion on fields and sediment concentration in return flows do little to reduce soluble P concentrations, which can exceed total maximum daily load (TMDL) limits for total P. Laboratory and field tests were conducted to evaluate the effect of alum on soluble P concentration in return flow water from an irrigation tract in southern Idaho. The laboratory study used two water sources (tap and irrigation), three sediment concentrations (0, 100 and 1000 mg L⁻¹), two added P concentrations (0 and 1 mg L⁻¹), and five alum concentrations (0, 5, 10, 20 and 40 mg L⁻¹). Field tests were conducted at sediment ponds on two irrigation drains with 20 to 500 mg L⁻¹ sediment and 0.09 to 0.19 mg L⁻¹ dissolved P in inflow water. Regression analysis of laboratory data showed a 53 percent reduction in soluble P concentration with 20 mg L⁻¹ alum, which was similar to field data. Applying 40 mg L⁻¹ alum to irrigation water reduced soluble P concentrations up to 98 percent in the field. Achieving 50 percent soluble P reduction would cost about $0.007 m⁻³ ($8.25 per ac ft) at the current alum cost of $0.33 kg⁻¹ ($0.15 lb⁻¹). Although alum effectively reduced soluble P in irrigation return flow, the cost of applying alum may be too high for routine use in many irrigation districts.

Keywords: Alum, irrigation, phosphorus, return flow, water quality

Irrigation of agricultural land is important for food production in the United States. Only 15 percent of the harvested cropland in the United States is irrigated, but almost 40 percent of the crop value is produced on the 20 million hectares (50 million acres) of irrigated land (National Research Council, 1996). Forty-four percent of the irrigated land in the United States is surface-irrigated, and about half of the surface-irrigated land is furrow irrigated (USDA, 2003). In furrow irrigation, water flows by gravity over the soil in small streams. Runoff is often planned with furrow irrigation to improve infiltration uniformity by reducing the difference in infiltration opportunity times between upper and lower ends of fields. Twenty to fifty percent of applied water may run off a field, depending on crop, management, water supply, and field conditions (Berg and Carter, 1980; Trout, 1996).

Runoff water from surface irrigated fields is often reused on downstream fields within an irrigation tract. Water that cannot be captured and reused is normally discharged to a river or other surface water body, and is commonly referred to as irrigation "return flow." Even irrigation districts that are primarily sprinkler irrigated have return flow because sprinkler systems are shutoff temporarily without notifying the irrigation district and additional water is diverted to ensure that all users receive their allocation. In southern Idaho for example, the Twin Falls Canal Company is 75 percent surface irrigated and about 10 percent of the diverted water returns back to the Snake River while the Northside Canal Company is 95 percent sprinkler irrigated and returns about 5 percent of the diverted water back to the river.

During furrow irrigation events, water flowing over soil detaches, transports, and deposits sediment, as well as nutrients that are often attached to sediment. These nutrients can then be transported to surface waters via irrigation return flows. In many regions, phosphorus (P) transport to surface waters from agricultural lands has become a signifi-cant water quality issue (Sharpley et al., 2003). In the 1998 water quality assessment sent to the U.S. Environmental Protection Agency, states and other jurisdictions reported that 35 percent of assessed streams were impaired. Agriculture was the source of impairment for 60 percent of the stream miles and nutrients were the leading pollutant on 30 percent of the stream miles (USEPA, 2000). Within the state of Idaho, over 800 sections of rivers, streams, and lakes are identified as impaired and subject to total maximum daily load (TMDL) regulations, according to the Idaho Department of Environmental Quality. Of these 800 identified waterways, 213 water bodies in the state list nutrients as a pollutant, specifically phosphorus, nitrogen and potassium (IDEQ, 2003). In the Mid-Snake River watershed in southern Idaho, 14 segments have TMDLs established regulating total phosphorus loading, which at the present time is set at 0.075 mg L⁻¹ (ppm) total phosphorus. Because irrigation return flow is considered a nonpoint pollution source, irrigation districts will be responsible for meeting TMDL limits. Some irrigation districts in turn have adopted rules giving them authority to terminate water delivery to farmers causing major compliance problems.

Typically, more than 90 percent of the phosphorus in runoff from row crop fields is attached to sediment; however, closed-seeded crops like alfalfa and small grain have little erosion so often dissolved phosphorus concentrations are more than 80 percent of total P (Berg and Carter, 1980). Phosphorus is quickly desorbed (less than one minute) from detached sediment in irrigation furrows, which can lead to appreciable amounts of soluble P in return flow (Westermann et al., 2001). Best management practices have been developed to reduce sediment loads in these return flows with the goal of reducing total P loads (Bjorneberg et al., 2002). Converting from furrow to sprinkler irrigation retains essentially all applied water on the field and therefore eliminates return flow from these fields. Sediment ponds installed on fields or in return flow streams remove the sediment and particulate P from water (Brown et al., 1981). Unfortunately, these ponds do little to

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reduce dissolved P concentrations, which often exceed the TMDL goal of 0.075 mg L^{-1} (ppm) total P (Leytem and Bjorneberg, 2003, unpublished data). In order to meet the TMDL goal for total P, practices need to be developed and implemented that reduce soluble P in return flows.

Alum (aluminum sulfate) and aluminum chloride are used in wastewater treatment facilities as flocculating agents with the secondary benefit of removing P from solution. These treatments have also been used to reduce soluble P in dairy, swine, and poultry manure. Adding alum at 0.9 mL L^{-1} to dairy flushwater removed 11 to 17 mg P per mmol Al^{+3} added (Sherman et al., 2000). Walker et al. (2001) used aluminum chloride to reduce soluble P 79 percent in swine slurry held in storage ponds. Moore (1999) documented a 75 percent reduction in P concentration in runoff from small watersheds where alum-treated poultry litter was applied vs. non-treated litter. Alum has also been effective in reducing P concentrations in stormwater runoff, leading to improved water quality in receiving water bodies. Pilot projects in Florida showed that treating stormwater runoff with alum consistently reduced total P concentrations by 90 percent (Harper et al., 1999).

Our objective was to determine if alum application could be used to reduce soluble P in return flow water from a southern Idaho irrigation district. This includes determining the rate of alum application necessary to reduce total P to levels below TMDL thresholds, the efficiency of alum for P removal, and the potential economics associated with the use of alum for treatment of irrigation return flows.

Methods and Materials

Chemicals. The alum used in this study was obtained from the General Chemical Company and labeled as Liquid Al+ Clear[®1]. The alum was 48.5 percent hydrated aluminum sulfate, or 28 percent $Al_2(SO_4)_3$, with a pH of 2.4 and a specific gravity of 1.33. All alum concentrations used in this study were calculated as $Al_2(SO_4)_3$.

Laboratory study. The laboratory study used two water sources, three sediment concentrations, two P concentrations, and five alum concentrations with three replications for a total of 180 samples. Water for the laboratory study was collected from the Snake River at Milner dam (irrigation water) or from the tap at the Northwest Irrigation and Soils Research Laboratory (untreated

Figure 1

View of Twin Falls Canal Company I-drain ponds. Picture is taken from between the two ponds looking up towards the inflow of pond one.

groundwater). Soil was added to 300 mL water samples at rates of 0, 100, and 1000 mg L^{-1} 24 hours before alum addition. The soil was Portneuf silt loam (coarse silty mixed superactive mesic durinodic Xeric Haplocalcids) that had been ground and passed through a 50 μm (0.002 in) sieve and had an Olsen P concentration of 57 mg kg^{-1}. Samples were shaken for 30 seconds immediately following soil addition. After adding soil, potassium phosphate solution was added to half of the samples to increase the soluble P concentration 1 mg P L^{-1}. Samples were shaken again 4 hours after soil and P addition and immediately prior to adding alum. Samples were placed on a stir plate and alum was added at rates of 0, 5, 10, 20, or 40 mg L^{-1}. Samples were stirred continuously for 5 minutes, and then a 10 mL (0.34 fl oz) subsample was collected and immediately filtered with a 0.45 μm (0.000018 in) Whatman filter to determine soluble P. Subsamples were analyzed the same day by inductively-coupled plasma optical–emission spectrometry for P, Ca, Fe, Al, and Mg.

Twin Falls Canal Company I-drain. The I-drain is a component of the return flow system within the Twin Falls irrigation district (Figure 1). Runoff from furrow irrigated fields flows in the I-drain through two ponds in series. The combined volume of the

ponds is approximately 350 m³ (12,300 ft³) with a retention time of one to two hours depending on I-drain flow rate. The average inflow sediment concentration during the testing ranged from 200-500 mg L^{-1}. Flow rate was measured with a trapezoidal flume installed in the outlet channel. Alum was added to the inflow of the first pond at rates of 10, 20, 40, or 45 mg L^{-1} on four different days. Alum was applied by gravity from a small tank and the application rate was controlled by a valve. Alum was applied below the water surface to improve mixing with flowing water. Water samples (50 mL [1.7 fl oz]) were collected upstream from alum application and at the outlets of ponds one and two. The first samples were collected before alum application started to determine the change in P concentration in the ponds without alum addition. Samples were collected by hand at one to two hour intervals during the five to seven hours that alum was applied. Subsamples were immediately filtered with a Whatman 0.45 μm (0.000018 in) filter and acidified with H_3BO_3 for storage prior to analysis for soluble P (Murphy and Riley, 1962). Unfiltered samples were analyzed for total P by acid persulfate digestion with P measured by the molybdate blue method (APHA, 1992).

Cedar Draw. The Cedar Draw site is

Figure 2
Example of Cedar Draw abandoned aquaculture raceways.

comprised of abandoned aquaculture raceways that were converted to wetlands for a water quality demonstration project (Figure 2). Each raceway has two cells that are 6 m wide and 53 m long (20 ft by 175 ft), constructed with concrete walls and earthen bottoms. The average inflow sediment concentration over the time period of the testing was 70 mg L^{-1}. Inflow to the raceways is controlled by Waterman^{TM} canal gates from a common lateral. A 0.9 m (3 ft) rectangular weir between the upper and lower cells was used to measure flow rate through the raceways. The target flow rate of 0.04 to 0.06 m^3 s^{-1} (1.5 to 2.0 ft^3 s^{-1}) had water depths of approximately 0.45 m (1.5 ft) in the upper cell and 0.75 m (2.5 ft) in the lower cell. The greater water depth in the lower cell was

caused by dense vegetation and the outlet elevation. Water flowed freely from the lower cells to a common channel. Flow rates to each raceway were set five days before the first test in order for water flow and depth to become stabilized before alum treatment. Flow rates were periodically checked and gates adjusted so the rates were equal for all raceways during a test.

Vegetation in the lower cells was a dense mixture of mostly cattail (*typha latifolia*) and hardstem bullrush (*scirpus acutus*) with a small amount of Sego pondweed (*potamogeton pectinatus*). The upper cells contained shorter plants, such as Sego pondweed and water smartweed (*polygonum amphibium*), and a small amount of cattail (less than five percent of surface area) along the edges of the raceways.

Five days before the first test, a board was inserted to raise the weir elevation 0.2 m (8 in) to increase water depth in the upper cell to 0.45 m (1.5 ft), which increased retention time and submerged most of the vegetation. Retention time in the upper cells was approximately 45 to 60 minutes, assuming uniform flow through the cells. Retention time was not estimated in the lower cells due to the thick vegetation.

Alum was applied at a constant rate (0, 5, 10, or 40 mg L^{-1}) to the inflow stream of the upper cells during Tests 1 and 2, and at the weir between the upper and lower cells for Test 3. Each raceway had a tank that supplied alum by gravity through flexible tubing. Alum application rate was controlled by a valve and the elevation difference between the fluid level in the tank and the tubing outlet. Application rates were periodically checked and adjusted during a given test. Alum was applied below the water surface to improve mixing with flowing water.

Filtered (Whatman 0.45 μm (0.000018 in)) and unfiltered samples, both 50 mL (1.7 fl oz), were collected at the inflow into the raceway system as well as at the weir and outlet of each raceway. Samples were collected approximately every two hours during a test (tests were run for five to seven hours), with the first sample collected before alum application and the last sample collected before alum application ceased. Filtered samples were acidified with H$_3$BO$_3$ for storage prior to analysis for soluble P by the molybdate blue method (Murphy and Riley, 1962). Unfiltered samples were analyzed for total P by acid persulfate digestion with P measured by the molybdate blue method (APHA, 1992).

Statistics. All statistical analyses of the data were performed using the PROC GLM (general linear models), PROC NLIN (non linear models), and PROC ANOVA procedures of the Statistical Analysis System (SAS). Relationships significant at the 0.05, 0.01, and 0.001 probability levels are marked as *, **, ***, respectively.

Results and Discussion

Laboratory study. The river and tap water varied in the amounts of total Ca, Mg, Fe, and P (Table 1). The tap water had higher Ca, Mg, and Fe concentrations and lower P concentration (0.07 mg P L^{-1}) compared to river water (0.12 mg P L^{-1}). When alum was applied to the solutions, soluble P was reduced for all three sediment concentrations

Table 1. Chemical composition of River and Tap water used in the laboratory study.

| | Water source | |
	River	Tap
Element	——— mg L^{-1} ———	
Ca	39.3	52.3
Mg	17.4	30.1
Fe	0.001	0.014
Al	0.006	0.008
P	0.12	0.07

Figure 3

The reduction in soluble phosphorus (P) from alum application in laboratory jar test with a) river water and b) tap water with no additional P added.

in both water sources with and without added P (Figures 3 and 4). The soluble P reduction increased with increasing alum concentrations. When no additional P was added to the treatments, the average maximum soluble P removal was 67 percent for the river water and 46 percent for the tap water, which occurred at the maximum alum application of 40 mg L^{-1} (Figure 3). When 1 mg L^{-1} P was added to the treatments, the relative effectiveness of alum additions increased. The average maximum soluble P removal was 87 percent in river water and 78 percent in tap water (Figure 4). Since the initial soluble P concentration was 1 mg L^{-1} P greater, the mass of P removed was also greater. At the 40 mg L^{-1} alum rate for example, 0.96 and 0.80 mg L^{-1} P were removed from river and tap water, respectively, with additional P compared to only 0.11 and 0.07 mg L^{-1} P without the added P.

There was no significant interaction between sediment concentration and alum rate in the river water samples with or without added P, however the interaction was significant for the tap water in both cases (P = 0.01). When no additional P was added, the maximum soluble P removal in the tap water was 35 percent at the 0 and 100 mg L^{-1} sediment concentrations and 56 percent at the 1000 mg L^{-1} sediment concentration (Figure 3). Since the soluble P concentration in the tap water increased from 0.07 mg L^{-1} to 0.12 mg L^{-1} as sediment concentration increased from 100 mg L^{-1} to 1000 mg L^{-1}, we did not attribute the reduction in soluble P with alum additions to adsorption on the added sediment.

Phosphorus removal efficiency was assessed by calculating Al:P molar ratios for all of the treatments. The P removal efficiencies were poor for treatments without added P, with Al:P ranging from 32 to 314. The alum was more efficient at removing P in the river water (Al:P ratios of 32 to 73), while it performed poorly in the tap water treatment (Al:P 66 to 314). When no additional P was
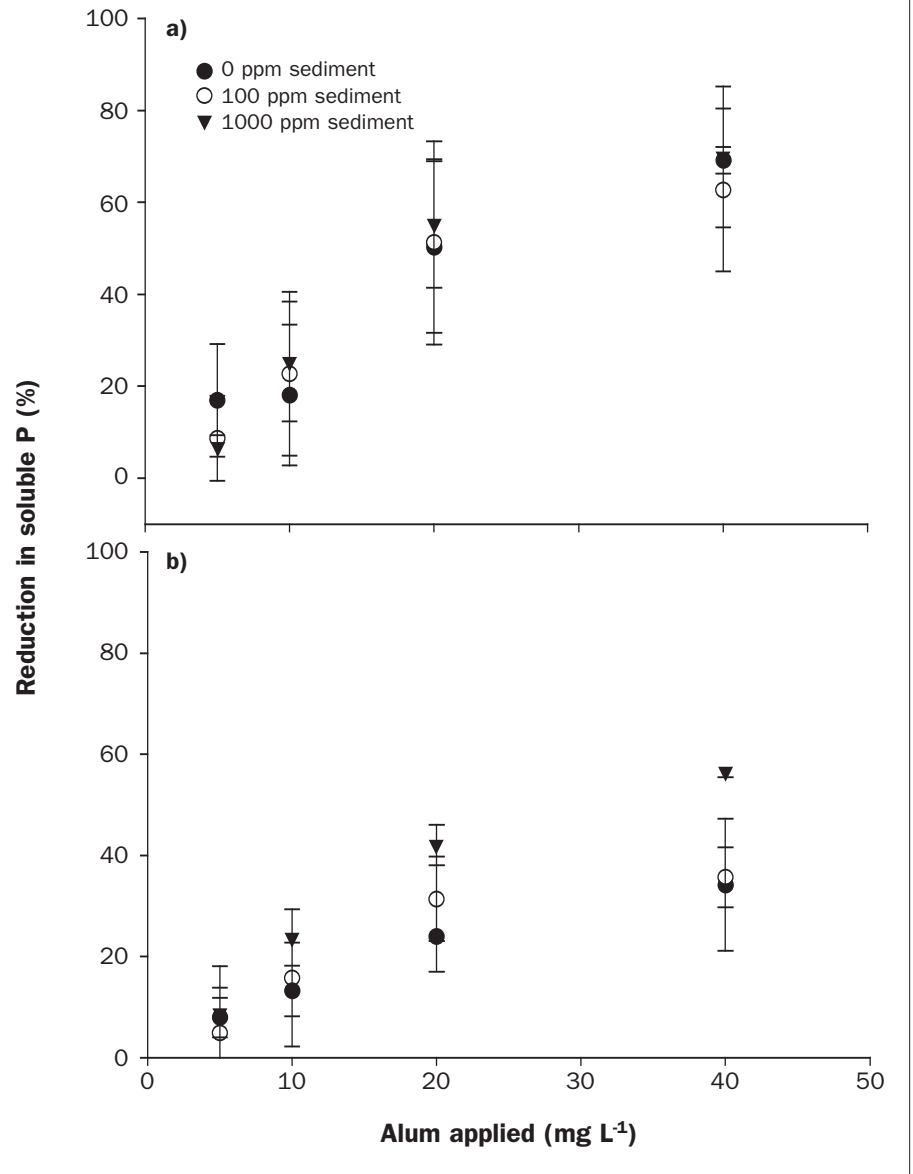
added, there was a significant effect of water source and sediment on Al:P ratios (P < 0.001). Phosphorus removal efficiencies increased in the treatments receiving additional P with Al:P ratios ranging from 6 to 10 with no significant interactions of water or sediment in these treatments (P > 0.05).

When alum is used for water treatment, the following reaction takes place:
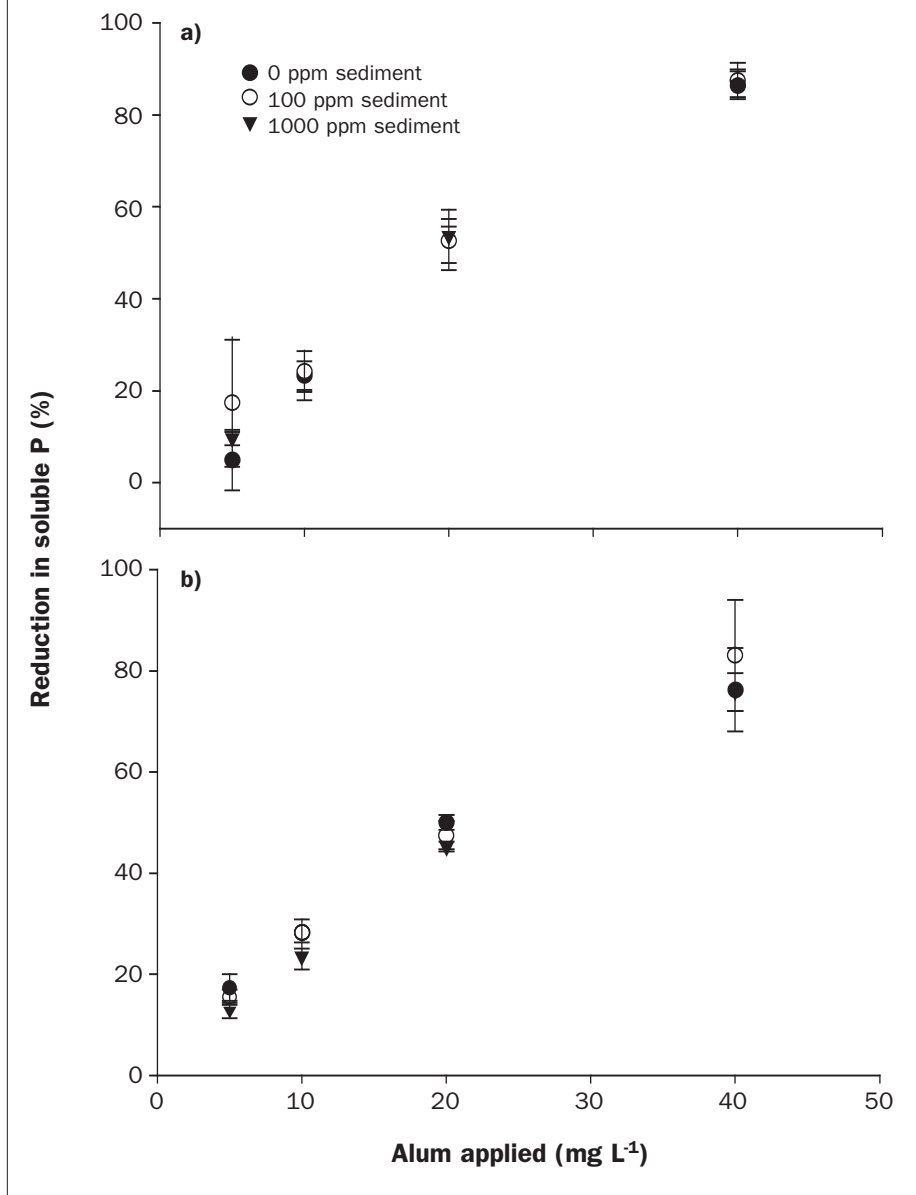$$Al_2(SO_4)_3 \cdot 18H_2O + 3Ca(HCO_3)_2 \leftrightarrow 3CaSO_4 + 2Al(OH)_3 + 6CO_2 + 18H_2O$$

The insoluble aluminum hydroxide, Al(OH)$_3$, is a gelatinous floc that settles slowly through the water, sweeping out suspended material (Ebeling et al., 2003). At low P

concentrations (< 20 mg L^{-1}), P is removed largely by adsorption of P ions onto formed Al(OH)$_3$ flocs (presumably outer sphere complexation). To form sufficient Al(OH)$_3$ flocs, excess alum at higher Al:P molar ratios is required. The higher the initial Al^{3+} concentration, the higher the concentration of colloidal Al(OH)^3 particles, and the higher the rate of aggregation/sedimentation. On the other hand at higher P concentrations, AlPO$_4$ mainly forms and a high efficiency in P removal can be possible with lower alum quantity (Özacar and Şengil, 2003).

In the case of the tap water, alum was probably more effective at the higher sediment

Figure 4
The reduction in soluble phosphorus (P) from alum application in laboratory jar test with a) river water and b) tap water with 1 mg L⁻¹ P added.

water. The data fit best with a power function:

$$(y = ae^{b/x}, r^2 = 0.92^{***}) \tag{1}$$

where:
  y = soluble P reduction (percent),
  x = alum concentration (mg L⁻¹),
  a = 110.8, and
  b = –14.8 (Figure 5).

This equation was later used to compare the applicability of the lab data to a field situation.

Twin Falls Canal Company I-drain and Cedar Draw. The addition of 45 mg L⁻¹ of alum at the inflow to a series of two sediment ponds (Twin Falls Canal Company -I-drain) decreased soluble P concentrations to almost zero (Figure 6). The inflow P concentration remained at approximately 0.16 mg P L⁻¹ during this test, while adding alum removed 95 percent of the soluble P. There was also a visible reduction in sediment load at this alum rate (Figure 7). Total P was reduced from 0.55 to 0.01 mg L⁻¹, or 98 percent, with 45 mg L⁻¹ alum compared to 50 percent or less reduction without alum. The effect of alum application occurred within two hours in the first pond, while the effects did not occur at the second pond outlet for an additional hour. Once alum application stopped at this site, soluble P returned to the initial concentration within four hours. This same trend in response to alum addition occurred at the Cedar Draw raceways, although the response times were shorter due to the shorter water retention times (data not shown).
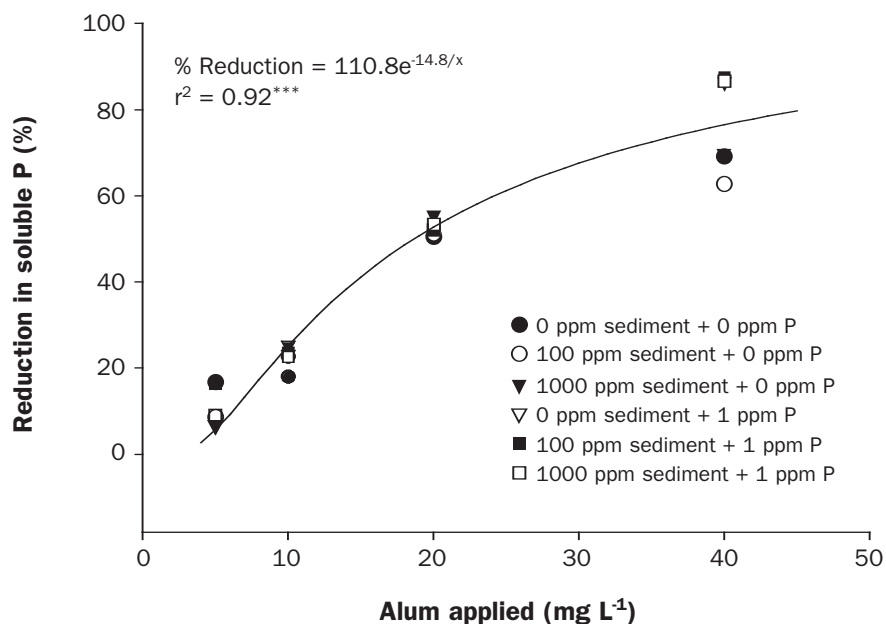
Data from both field sites were combined to assess the effectiveness of alum application on reducing both soluble and total P (Figure 8). Inflow and outflow soluble P concentrations were similar to each other on the I-drain without the addition of alum (~ 0.18 mg L⁻¹). Soluble P concentration changes between inflow and outflow in control raceways at cedar draw ranged from six percent increase to eight percent decrease, with an overall average reduction of two percent. Applying alum reduced soluble P below the inflow concentrations at Twin Falls Canal Company I-drain (0.18 mg P L⁻¹) and Cedar Draw (0.09 mg P L⁻¹), with soluble P reductions increasing as alum application rate increased (Figure 8a). The maximum percent soluble P reduction was 95 percent at the two highest alum application rates (40 and 45 mg L⁻¹). There was a slight

concentration because more soluble P was available to be removed and there was also the potential that additional suspended material assisted in the initial flocculation process. The interaction between alum and sediment concentration was not significant with river water because the relative increase in soluble P concentration with sediment was less and the river water contained ample suspended material for initiation of flocculation. The Al:P ratio found by Özacar and Şengil (2003) at 1 mg L⁻¹ P was 17.6, which is close to the values that we observed for both the river and tap water at 1 mg L⁻¹ P. However, they

did not test solution concentrations less than 1 mg L⁻¹ P. When our P solution concentrations dropped to less than 0.2 mg L⁻¹ P, the Al:P ratios increased dramatically because excess alum was required for removal of P at these low concentrations.

In order to predict removal rates of P due to alum treatment in the field, we used the NLIN procedure in SAS to fit a curve to the river water data with and without added P. These data were used because the concentrations of P and other elements in the river water are more representative of those found in irrigation return flow than those in the tap

increase in soluble P concentration (0.01 mg P L^{-1}) between the first pond outlet and the second pond outlet on the Twin Falls Canal Company I-drain at all alum application rates. This increase in soluble P could be due to a lag in the retention time between the first and second pond (i.e. not steady state), or there may have been P released by the sediment and vegetation in the second pond. Soluble P concentrations tended to increase in the lower cells by a greater amount at Cedar Draw, and the concentration change increased as alum rate increased (Figure 9). At the highest alum application rate at Cedar Draw, inflow soluble P concentration decreased from 0.10 to 0.02 mg P L^{-1} in the upper cell and then increased to 0.06 mg P L^{-1} in the lower cell. Soluble P likely increased as P desorbed from the sediment or thick vegetation growing in the lower cell, which indicates that alum treatment should occur close to the discharge point rather than at locations within the irrigation district.

Total P concentrations were reduced 26 to 62 percent (44 percent average) on the I-drain with no alum application (Figure 8b). Inflow was less variable at Cedar Draw and total P concentrations decreased 24 to 37 percent (29 percent average). Total P reductions from alum additions were similar to those seen in soluble P (Figure 8b). Inflow was seven to 43 percent soluble P (average = 21 percent) at the I-drain ponds and 38 to 50 percent soluble P (average = 43 percent) at Cedar Draw. The greatest total P reduction was 98 percent at the highest alum application rate (45 mg L^{-1}). As with soluble P, there was little difference between the reductions in total P in the two ponds on the Twin Falls Canal Company I-drain while at Cedar Draw the total P concentrations increased in the second cell as soluble P concentration increased.

The exponential model defined by laboratory data to predict soluble P reduction with alum addition was applied to the combined field data. This model fit the field data well ($P < 0.001$, Figure 10). Soluble P reduction increases quickly at lower application rates then the efficiency decreases as application rates exceed 20 mg L^{-1}. Predicted soluble P reduction is 53 percent at 20 mg L^{-1} alum application rate, which is slightly less than the 65 percent average reduction measured in the field. Ebeling et al. (2003) reported an average soluble P reduction of 35 percent at 20 mg L^{-1} alum additions in aquaculture effluent discharge. The decreased efficiency

in this case may be due to the high total suspended solids in the effluent interacting with the alum floc.

The alum efficiency at the field sites varied, with the Al:P ratios being smaller at the Twin Falls Canal Company I-drain site than at Cedar Draw. This difference is thought to

be due to the lower inflow soluble P concentration at Cedar Draw (0.09 mg P L^{-1}) vs. at the Twin Falls Canal Company I-drain site (0.18 mg P L^{-1}). There was little difference in the Al:P ratio between the outlets of the first and second ponds at Twin Falls Canal Company I-drain, ranging between 27 and

Figure 5
Reduction in soluble phosphorus (P) with alum application for all lab data with river water.

% Reduction = 110.8e$^{-14.8/x}$
r^2 = 0.92***

- ● 0 ppm sediment + 0 ppm P
- ○ 100 ppm sediment + 0 ppm P
- ▼ 1000 ppm sediment + 0 ppm P
- ▽ 0 ppm sediment + 1 ppm P
- ■ 100 ppm sediment + 1 ppm P
- □ 1000 ppm sediment + 1 ppm P

Figure 6
Reduction in soluble phosphorus (P) in the Twin Falls Canal Company I-drain sediment pond system with addition of 45 mg L^{-1} Alum over an eight hour period.

TMDL

Alum application stopped

- ●— Inflow
- ○···· 1st Outlet
- ▼-- 2nd Outlet
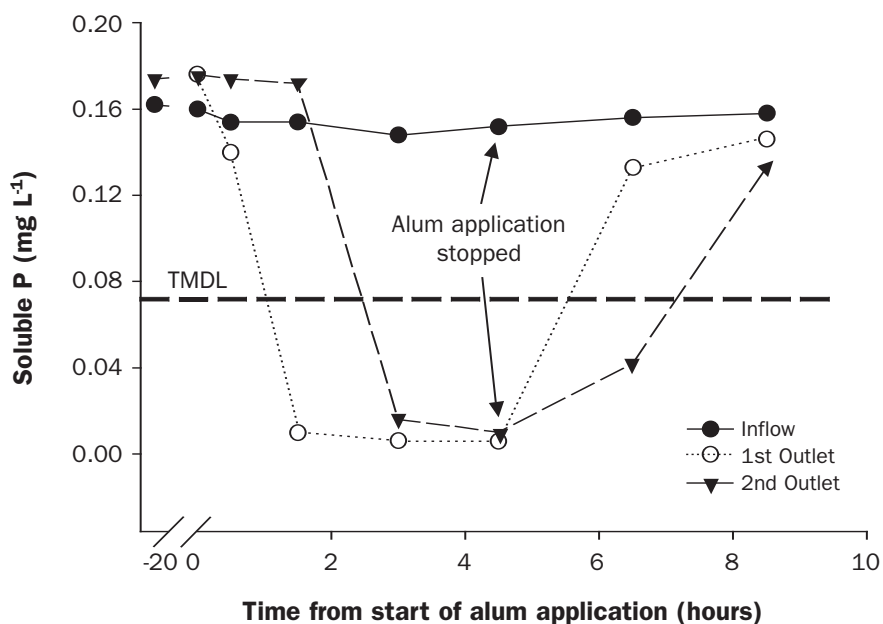
Figure 7

The reduction in sediment at the outflow of the Twin Falls Canal Company I-drain second sediment pond following addition of 45 mg L^{-1} Alum.

Figure 8

The reduction in a) soluble phosphorus (P) and b) total P with alum application for combined field data.
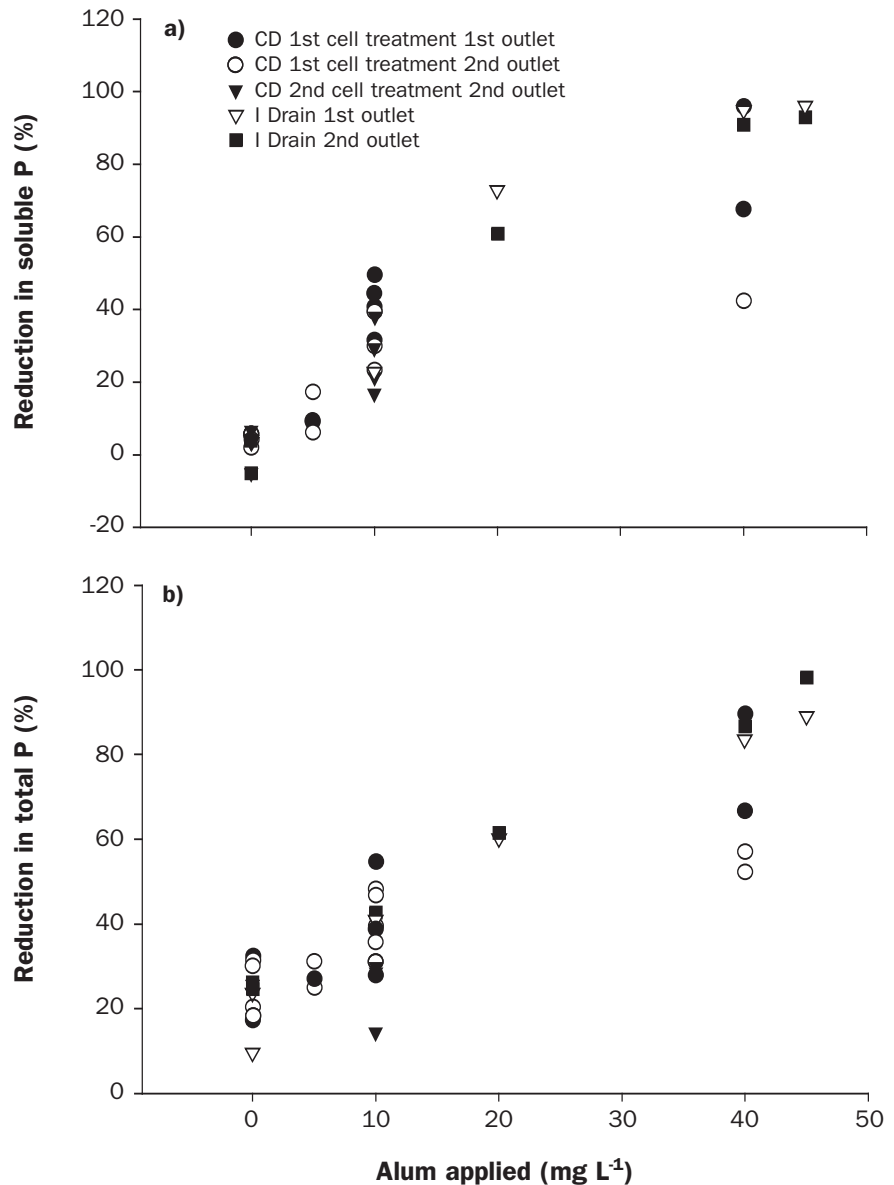

59. There was a difference in the efficiencies at Cedar Draw with the Al:P ratios at the outlets of the upper cells ranging between 38 and 111, while the ratios ranged between 47 and 177 at the outlets of the lower cells. Since soluble P was increasing as water traveled through the lower cells, the calculated Al:P ratios increased.

In the field studies, alum was injected below the water surface at the inflow channel to improve the mixing of alum with inflow water, thereby increasing the interaction of P with the alum. By adding the alum in this turbulent stream, there may have been shearing of the floc during the initial formation which would decrease the alum efficiency. Ebeling et al.
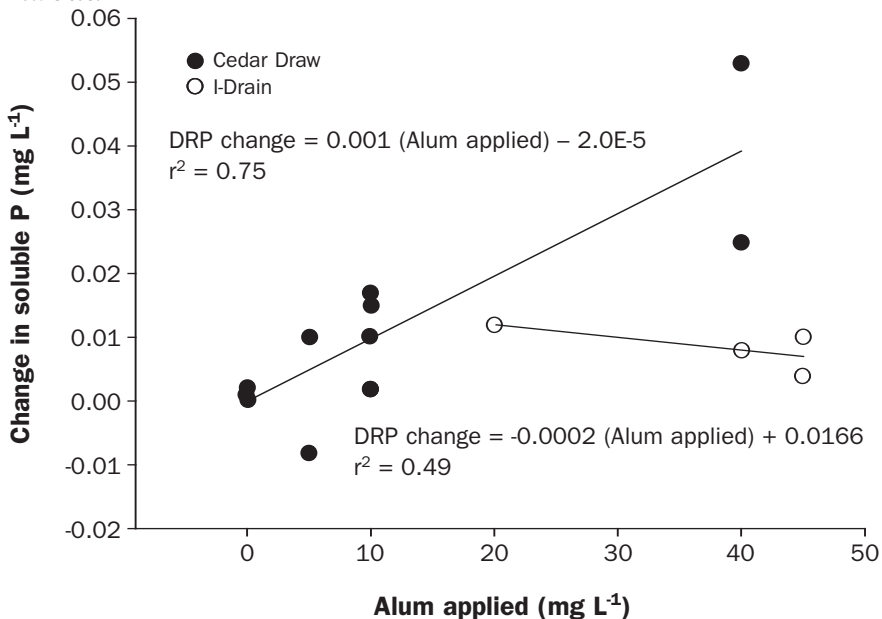
(2003) found that lower mixing speeds improved the removal of turbidity at lower concentrations due to reduced floc shearing. Another option for application would be to spray the alum on the surface of the ponds which may enhance floc formation via increased contact area of the alum with a larger volume of irrigation water thereby increasing the P removal efficiencies at low P concentrations.

Implications for treating irrigation return flow. Using the model developed from the laboratory study, a 53 percent reduction in soluble P requires an alum application rate of 20 mg L^{-1} or 25 kg per 1230 m^3 (55 lb per 1 acre-ft). Current cost of alum is about $0.33 kg^{-1} ($0.15 lb^{-1}), excluding shipping, which could double the cost depending on distance from a supplier. Thus, removing 50 percent of the soluble P would cost $0.007 m^{-3} ($8.25 per ac ft). To put this in perspective, consider the Twin Falls Canal Company in southern Idaho that annually diverts about 1.4×10^9 m^3 (1,100,000 ac ft) to supply irrigation water to 82,000 ha (203,000 ac) of farm land. Assuming 10 percent of the diverted water returns to the Snake River,

Figure 9

Change in soluble phosphorus (P) between the inlet and outlet on the second pond/cell at both field sites.

DRP change = 0.001 (Alum applied) − 2.0E-5
$r^2 = 0.75$

DRP change = -0.0002 (Alum applied) + 0.0166
$r^2 = 0.49$

● Cedar Draw
○ I-Drain

applying 20 mg L^{-1} to all return flow would cost $900,000 or $11 ha^{-1} ($4.40 ac^{-1}), not including shipping and application costs. This would increase the canal company's annual budget by almost 20 percent. A more realistic scenario might involve treating three to five of the main return flow streams for two to three months in the summer (when soluble P concentrations tend to be greatest), costing approximately $30,000 to $70,000 for alum.

There are also environmental affects that must be taken into consideration when applying alum to any surface water. In waters with low or moderate alkalinity (< 100 mg L^{-1} $CaCO_3$), alum addition at low or moderate alum doses (<15 mg alum L^{-1}), produces a decline in pH and an increase in toxic soluble Al concentrations, both of which can endanger aquatic organisms (Kennedy and Cooke, 1982; Driscoll and Schecher, 1990). The U.S. Environmental Protection Agency (USEPA) recommends a critical maximum concentration of 0.75 mg L^{-1} for soluble Al, with acceptable pH ranges from 6.5 to 9.0, which has been adopted in Idaho as the water quality standard (IDEQ, 2004). The irrigation return flow waters in our studies had approximately 174 mg L^{-1} $CaCO_3$, which provides a large pH buffering capacity. Preliminary studies with alum additions (45 mg L^{-1}) did demonstrate a decline in the pH of irrigation return flow water, but pH levels did not go below 7.5 which are well within the acceptable range. Therefore we do not feel that the addition of alum would have a negative impact in typical irrigation return flows in Southern Idaho due to lowered pH levels. The addition of alum also increased soluble Al at both sites with the maximum soluble Al concentration of 0.28 mg L^{-1} found at Cedar Draw. These Al concentrations are below the critical maximum concentrations established by the USEPA, and therefore do not seem to pose a water quality problem at this time. In addition the floc ($Al(OH)_3$) that is produced in the P removal process would settle to the bottom of retention ponds which would then be removed when ponds are periodically cleaned out, thereby eliminating the possibility of Al desorption back into return flow waters at a later date.

Summary and Conclusion

Applying alum to irrigation water in southern Idaho reduced soluble P concentrations up to 95 percent. Suspended sediment in irrigation water (<1000 mg L^{-1}) did not affect soluble reductions. Models for predicting reductions in soluble P with alum additions were generated in the laboratory and the relationship was best described with a power function ($r^2 = 0.92$). This model predicted that applying alum at 20 mg L^{-1} would reduce soluble P concentration by 53 percent. The model developed in the laboratory was validated in the field and found to be suitable for predicting reductions in soluble P with alum applications ($r^2 = 0.87$). Although alum effectively reduced soluble P concentrations in field tests, the cost of applying alum may be too high for routine use by many irrigation districts.

Figure 10

The reduction of soluble P with alum applied for all field data fit with model developed on laboratory data.

% Reduction = $110.8e^{-14.8/x}$
$r^2 = 0.87^{***}$
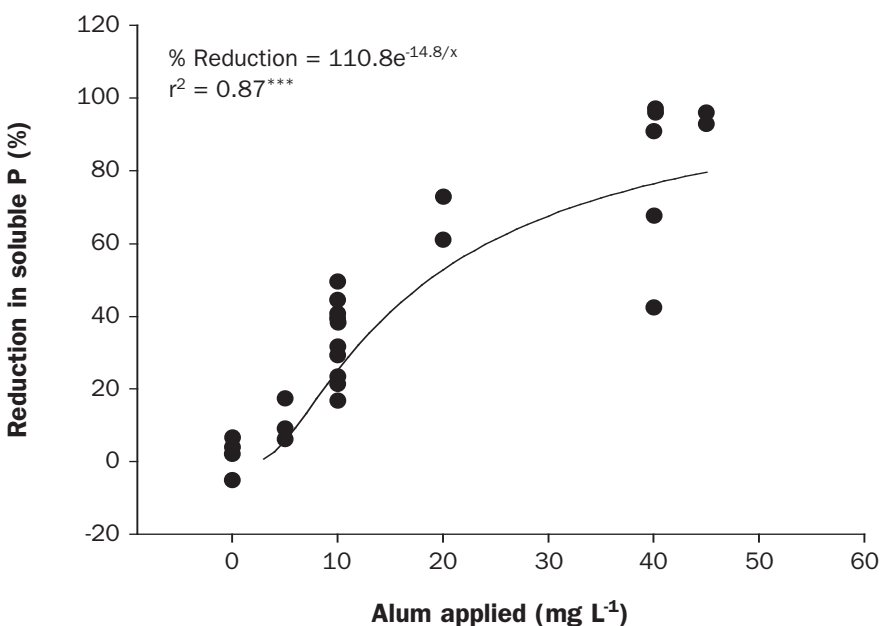
Footnote

[1]Mention of a specific product or vendor does not constitute a guarantee or warranty of the product by the U.S. Department of Agriculture or imply its approval to the exclusion of other products that may be suitable.

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