# Integration of Surface Irrigation Techniques to Reduce Sediment Loading in the Yakima River Basin

**by**

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**Abstract:** Furrow irrigation has been identified as one of the main sources of excess sediment in the Yakima River Basin. In turn, this source of water-quality degradation is thought to be one of the causes for declining salmon runs in the Yakima River. The Washington Department of Ecology has set a sediment limit for irrigation return flows of 25 NTUs (56 mg/l). Some irrigators are converting their rill irrigation systems to either sprinklers or drip irrigation at a cost of $750 to $2500 per hectare. Other furrow irrigators are applying Polyacrylamide (PAM) and successfully decreasing sediment loads from furrows by 80 to 90 percent. Unfortunately, this cleaner water often erodes sediment from the tailwater ditch causing elevated NTU levels still too high to be returned to irrigation district canals and drainage ditches. The focus of this research was on inexpensive methods to further reduce sediment and nutrient loads from furrow irrigation by using PAM ($50/ha per year) with Surge irrigation ($300/ha), tailwater drains ($185/ha), tailwater checks ($60/ha), and grass-lined tail ditches ($25/ha).

During the 2001 growing season after monitoring 5 irrigation events on 2 fields, PAM with a grassed lined tailwater ditch was the only treatment to maintain suspended solids below the required 25 NTUs (56 mg/l). The treatments in order of best to worst water quality were PAM with grass lining, PAM with check dams, PAM with drains, PAM with Surge irrigation, and PAM alone. Eleven more irrigation events have been evaluated during the 2002 growing season and this data will be analyzed to determine whether the same trends have been repeated.

**Keywords:** non-point pollution, erosion, sediment transport, surface irrigation, Yakima River, polyacrylamide, surge irrigation, tailwater, surface drains, check dams, grass lining.

**Introduction:** In the Yakima Basin of Washington State USA, irrigators are being forced to adapt to stricter water use regulations as part of an effort to enhance salmon recovery and improve the aquatic habitat of the Yakima River. Recently, the National Marine Fisheries Service listed several species of salmon as endangered in the Yakima: both diminished flows and high sediment loads are being blamed for the salmon's demise. In particular, surface irrigation has been identified as one of the main sources of excess sediment. The soils of the Yakima valley are easily eroded by furrow irrigation and the suspended particulate in return flows are being carried to the river via drainage ditches. For example, the United States Geological Survey (USGS) measured sediment concentrations in excess of 1000 mg/l in the Granger Drain (Rinella et al., 1992). In 1997, the WA Department of Ecology set water quality standards for the Yakima that included a limit of 56 mg/l (25 NTU) for sediment in return flows (Patterson & Patterson, 1997). Currently, the Sunnyside and Roza Irrigation Districts' Board of Joint Control are taking proactive strides to comply with the sediment load standards. Since 1998, they have been notifying irrigators of water quality violations. Irrigators who have received violations must submit and implement a plan to remove sediment from their return flow or risk a reduction in their water allotment. The joint board is also constructing sediment basins in drainage ditches and offering irrigators low-interest loans to convert their rill irrigation systems to sprinkler and drip irrigation. In addition, local National Resource Conservation Service Offices and local Conservation Districts are offering cost-share programs for drip/sprinkler conversion through the Environmental Quality Improvement Program (EQIP).

Properly designed sprinkler and drip irrigation systems significantly reduce the potential for run-off and erosion from the farm. However, the cost of such conversion is high. Set-move sprinklers such as wheel lines and hand sets are the least expensive alternative at $750 per hectare but are difficult to move in tall crops like corn, tree fruit, grapes and hops. Center Pivot sprinklers can cost $1500 to $1750 per hectare under Yakima Basin Conditions because low-soil intake rates, easily erodible soil, sloping terrain, and smaller property holdings often require circle sizes less than the standard quarter section. Solid set sprinklers and drip suited for tree fruit, grapes and hops (drip only) often cost around $2,500 per acre. Sprinkler and drip conversion represent a large investment in irrigated agriculture at a time when farm gate prices are low. Low-interest loans and cost-share help producers make conversions, but the availability of such programs is considerably less than the demand.

Fortunately, conversion from furrow irrigation is not the only possible solution; surface irrigation can also be improved at a much lower cost. Polyacrylimide (PAM) is already being widely applied in the Yakima basin at around $50.00 per hectare per year. Most PAM studies have shown an 80 to 90% reduction of sediment exiting furrows when the product is used correctly. However, it has been noted that clean water exiting the furrows often picks up new sediment in the tailwater ditch, or "curds" of PAM/sediment have been observed moving off the field via the tailwater ditch. Consequently, to further reduce sediment escaping a field, additional conservation practices need to be applied. Surge irrigation at $300/ha has a cutback cycle that would reduce tailwater and thus the potential for tailwater erosion. Additionally, end of field drains at $180 per hectare would remove water from the tailwater ditch at short intervals and thus reduce the amount of water that flows in any one segment of the ditch. Tailwater check structures at $60 per hectare will reduce the slope of the water surface reducing erosive energy and provide retention time for sediment settling. Finally, the tailwater ditch could be seeded to a perennial grass at $60 per hectare. The grass lining would slow the water velocity in the ditch and hold the soil together against the erosive force of water.

PAM in combination with surge flow irrigation, tailwater drains, tailwater checks or grass-lined ditches could keep rill irrigators in compliance with water-quality standards at an affordable price. Determining the effectiveness of these practices will be the focus of this research so that producers who are faced with limited financial margins can continue operating without the expense of converting irrigation systems. If effective, the lower cost of improving rill irrigation could help distribute low-interest loans and cost share money to a greater number of producers in a shorter time frame.

**Literature Review:** Most of the documented PAM research in furrow irrigation has come from USDA researchers in Idaho. Sojka et al. (1998) have measured greater than 90% sediment reduction and found that continuous furrow flows could be doubled with a 75% reduction in sediment. The higher furrow flow reduced furrow advance time, increased application uniformity, and indicated that cutting back furrow flow after advance could further reduce erosion and sediment transport. However, their research only measured sediment load as it exited the furrow and not after the flow from multiple furrows was collected in the tailwater ditch. Tailwater ditch erosion has been cited as a major source of sediment in the San Joaquin River as documented by the Soil Conservation Service's Sediment Reduction Plan for California's Central Valley (SCS, 1992). According to sediment transport theory expressed by the Yalin Equation (Hann et al., 1994), cleaner tailwater from PAM treatment has greater potential to erode new sediment from the tailwater ditch than water that is already sediment laden.

Surge irrigation caused nearly a 50% reduction in sediment transport from furrows when compared against continuous furrow flows according to Evans et al. (1992). This is most likely due to the Surge cutback cycle that alternates water between two sets of furrows, a 50% cutback in flow. Less flow in the furrow after water has advanced to the end of the field means less potential for soil erosion and sediment transport. In addition to cutback after advance, Surge irrigation also decreases advance time and thus increases application uniformity (Yonts et al., 1996). However, Yonts et al. (1998) combined Surge and PAM and did not observe a reduction in sediment transport or advance time when compared with PAM alone. Again their research was restricted to flow exiting individual furrows. The proposed study seeks to determine if using PAM with Surge together will place less water in the tailwater ditch than would PAM alone, and thereby reduce the potential for soil erosion and sediment transport from the entire field.

Another way to reduce the amount of water in a tail ditch is through closely spaced surface drains that drop tailwater into an underground pipe before it can swell to erosive quantities. This practice is fairly common in managing excess surface water from precipitation events, spring thaws and hillside seeps (Jarrett, 1997), but only one reference was located for removing tailwater from furrow irrigation and unfortunately sediment reduction was not quantified (Manges,1997). PAM in the furrows should help prevent drain pipe clogging from excess sediment.

A grass-lined tailwater ditch will protect the soil surface from erosion and reduce the flow velocity as indicated by the design procedures for open channels (Schwab, 1966). In addition to less erosion, the slower water velocity in a grass-lined channel will allow existing sediment to settle out. The SCS (1992) found that tailwater filter strips reduced sediment loads by 45%, but this practice was not used in conjunction with PAM.

Another way to trap sediment in the tail ditches is with small portable check structures. In this scenario, the flow velocity is decreased by decreasing the slope of the water surface, similar to drop structures in open channels (Jarrett,1997). The SCS (1992) found that tailwater checks reduced sediment loads by 35%; however, again this practice was not used in conjunction with PAM. It is hoped that PAM can make this practice more viable by reducing the frequency of sediment removal from the tail ditch. If the tailwater checks were designed to dewater slowly, the checks would not require manual removal to prevent waterlogging of the crop at the end of the field.

Most nutrient losses from surface-irrigated fields occur via runoff. According to Lentz et al. (1998), soluble and total phosphorus runoff losses from PAM-treated furrows were five to seven times smaller than in the non-PAM control treatment. Nitrate concentration levels in furrow runoff were low (< 0.6 mg/l), but they did not differ among treatments. Since most of the phosphorus was associated with the eroded sediment, they concluded that phosphorus losses were minimized by reducing sediment losses when PAM was applied.

A review of the current literature while establishing that various techniques can reduce sediment loading, does not validate the effectiveness of these techniques in conjunction with PAM. The proposed research seeks to find efficient, cost-effective solutions that enable surface irrigators to return water to river systems within the regulated limits for non-point pollution.

**Objectives:** Objective 1 is to determine the effectiveness of five furrow irrigation practices at reducing sediment and nutrient loss at two “on-farm” sites: 1) PAM alone, 2) PAM and SURGE, 3) PAM and tailwater drains, 4) PAM and tailwater checks, and 5) PAM and a grass-lined tail ditch. The treatments will be monitored for water on/off the field, soil moisture before and after an irrigation, and sediment/nutrient load transported from the treatments for the entire growing season.

Objective 2 is to produce research and extension materials from the results of the field plots. An article for newsletters/newspapers, an extension fact-sheet for print/web posting and a thirty minute presentation for workshops will be prepared in both English and Spanish. The educational materials will inform irrigators of the options for preventing sediment loss and provide guidance for conservation programs that are providing loans and cost-share money. Also, a presentation and paper will be prepared for two conferences of a professional society.

**Method:** The five treatments were: Treatment 1) PAM alone as the control, Treatment 2) PAM and Surge irrigation, Treatment 3) PAM and closely spaced surface drains in the tailwater ditch, Treatment 4) PAM with a grass-lined tailwater ditch, and Treatment 5) PAM and tailwater checks. These treatments were installed on two "on-farm" sites with cooperating producers. One producer in the Wapato Irrigation District cooperated on a 16-hectare, rill irrigated, grain corn field with 400 meter furrows and a 0.2% slope on the tailwater ditch. Another producer in the Roza Irrigation District cooperated on a 12-, rill irrigated, Concord grape field with 250 meter furrows and a 1.2% slope on the tail water ditch. Five data collection runs were completed on these fields during the 2001 growing season. The treatments were randomized at each site and the treatments were large enough to allow 24 and 16 furrows, respectively to flow into the tailwater ditch.

Each treatment was monitored for inflow, outflow, soil moisture, sediment load, nutrient concentration. Inflow was estimated by measuring the time needed to fill a bucket of a known volume. Outflow from each treatment was measured by a flow meter that received water from a collection sump and sump pump. Soil moisture was monitored with the neutron probe and access tubes. The average advance time was also recorded. Sediment samples were collected at periodic intervals during irrigation runoff. These samples were analyzed with an NTU meter and gravimetrically with filter paper.

Composite samples were also collected from irrigation runoff events for nutrient analysis. Samples were taken as water fell into the tailwater sumps. Samples were kept at 4 $^{o}$C until chemical analyses. All water quality analyses were performed using EPA methods (U.S. EPA, 1983). Soluble compounds were determined in samples filtered with a 0.45μm pore-size membrane and analyzed for ammonium-nitrogen, nitrate-nitrogen, and soluble reactive phosphorus. Unfiltered samples were analyzed for total Kjeldahl nitrogen, and total phosphorus.

After outflow was measured, the tailwater effluent was delivered to a sediment trapping box consisting of slotted apple crate lined with filter fabric to retain sediment. The number of boxes was dependant on the expected tailwater flow. The depth of sediment added to the boxes was measured at the end of the irrigation season.

PAM was applied to all the furrows just below the point of water delivery to the furrow via the patch method. In the cornfield, PAM was only applied during the first irrigation while PAM was applied at the beginning of every irrigation in the concord vineyard. All other cultural practices such as weed control and fertilization were held constant between treatments according to standard production practices.

**Results and Discussion:** The water and sediment data for each treatment was accumulated and presented on an irrigation event basis from flow measurements and samples collected approximately every two hours during each irrigation event. The accumulated flow out of each treatment per irrigation event is shown in Table 1. The flow volume from the cornfield at 0.2% slope was much great than the vineyard at a 1.2 % slope. There were 24 furrows flowing in the cornfield treatments compared to 16 in the vineyard treatments. However, the cornfield irrigations lasted for 24 hours while the vineyard irrigations lasted for 48 hours. It is estimated that the flow from the cornfield furrows was 4 times higher than the vineyard furrows.

Table 1 also shows higher total flow from the control treatment (PAM alone). This seems unusual since treatment locations were chosen at random and the irrigator sets the flow into the treatments in a random manner by attempting to set each furrow to the same flow without knowledge of treatment boundaries. It was possible that some treatments created greater infiltration of water. The checks, drains, and grass caused higher water levels in the tailwater ditch by impeding flow and this created greater hydraulic head that could increase infiltration. The grass also protected the pores on the soil surface from plugging with fine soil particle and thus could keep the infiltration rate from decreasing as fast as the bare soil treatments. The Surge irrigation system is designed to only allow flow in half the treatment furrows at one time and this will naturally create less tailwater.

The concentration of suspended solids was also averaged for entire irrigation events and shown in Table 2. Only PAM in combination with the grass-lined tailwater ditch kept the sediment concentration below the standard of 25 NTUs or 56 mg/l in all five irrigation events. The next best treatment was the PAM with the check dams in the tailwater ditch. In this treatment, the suspended sediment was the next lowest in concentration for 4 out of 5 irrigation event, yet only 2 irrigation events met the standard. Surface drains in the tailwater ditch produced the next lowest sediment concentrations. The Surge Irrigation and control treatments were not below the required sediment concentration for any of the irrigation events. In fact, the Surge irrigation with PAM produce higher sediment concentrations than PAM alone in 2 out of the irrigation events. The soils at both locations are very fine sandy loams to silt loams.

The reasons for the treatment differences shown in Table 2 have not been quantified but several observations will aid our understanding of the situation. The Grass and Check treatments were observed to stop sediment from the furrows as soon as it entered the tailwater ditch. This matched the theory that these treatments would reduce the flow velocity and give more time for sediment to settle out. An unforeseen benefit was that these treatments reduced erosion at the point were water drops out of the furrow and into the tailwater ditch. In the grass treatment, the plant cover and root structure prevent the furrow from eroding down to the level of the tailwater ditch. The Checks create the same benefit by backing water up into the furrows and since water no longer drops into the tailwater ditch, there is less erosion at the transition from furrow to tailwater ditch. The drains seemed to settle out sediment until sediment built up to the top of the riser pipe. The Surge seems to stir up the furrow more than the other treatments by constantly watering and dewatering the furrows. In addition to sediment, more organic matter existed the Surge treatment including plant residues and living organisms such as toads.

Sediment concentration alone may not provide the complete picture of water quality benefits if the treatments are reducing tailwater as explain from Table 1. Table 3 shows the total sediment load exiting the treatments. Total sediment load is a combination of flow (Table 1) and sediment concentration (Table 2). For example, Surge irrigation produced fairly high concentrations of sediment, along with a reduction in tailwater resulting in reduced total sediment when compared with the control treatment. At the cornfield (0.2% slope), Surge also advanced water to the end of the furrows in the same length of time with half the water of the conventional irrigation treatments.

Figures 1 & 2 were developed to examine the flow and sediment results at the same time by normalizing the data with respect to the control treatment for all the irrigation events in a field. This graphic representation also reveals how the treatments are affecting water quality regardless of whether the flow differences were caused by the treatments or simply part of experimental error.

Figure 1 shows the sediment concentration as a percentage of the control compared with the flow volume as a percentage of the control at the Vineyard site (1.2% slope). For all the treatments, the irrigation events show a similar reduction in sediment concentration no matter the flow rate. As an example, the grass treatment reduced the sediment concentration to less than 5% of the control even when the flow varied from 40 to 95% of the flow measured in the control. However, there is an exception: one of the surge events only reduced sediment concentration by 60% when the flow was 60% of control. The two other Surge events had sediment concentrations less than 15% of control.

On the other hand, Figure 2 shows less positive treatment effect in the cornfield (0.2% slope). The Drain treatment was 25% and 75% of sediment concentration in the control when the flow was 25% and 75%, respectively. This indicated no improvement in the Drain treatment as related to the control. If a line were drawn between these two points on Figure 2, any data points above the line would mean that the irrigation event produced higher sediment concentrations than the control while any events below the line would indicate performance better than the control. Both events from the grass treatment were below the line while only one of the two Check events was below the line. Both Surge events are above the line indicating higher sediment concentrations were produced even when the flow volume was less than the control. Of course more data points are needed to strengthen the arguments for or against the relationships observed in Figures 1 and 2.

**Conclusion:** Thus far, it has been concluded that a grass-lined tailwater ditch in combination with PAM treated furrows provided the greatest reduction in sediment load. In fact, the water quality standard of 25 NTUs (56 mg/l) was meet in all five irrigation events. The same cannot be said for the other four treatments. The treatment order corresponding to the greatest reduction of sediment in furrow irrigation was Grass with PAM, Checks with PAM, Drains with PAM, Surge with PAM, and PAM alone. More irrigation events need to be monitored to verify the relationships observed thus far. During the 2002 growing season, 11 more irrigation events have already been monitored but the data has yet to be analyzed. Even if these emerging relationships are verified by future experiments, an economic analysis is required to compare the costs versus the benefits. The cost/benefit analysis should also be applied to converting systems from furrow to sprinkler and drip irrigation. It is also possible that other combinations of Best Management Practices (BMPs) could be better at addressing the water quality requirements of furrow irrigation.

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Table 1. Total volume of runoff water (x 100 liters) at several irrigation events in 2001.

| Treatment | Site | | | | |
|---|---|---|---|---|---|
| | Vineyard | | | Cornfield | |
| | June 12-14 | July 22-24 | Aug 13-15 | July 16-18 | July 28-30 |
| Grass | 430 | 445 | 680 | 1460 | 2235 |
| Check | 322 | 430 | 953 | 2978 | 1604 |
| Surge | 201 | 380 | 681 | 1418 | 1341 |
| Subsurface drain | 468 | 477 | 866 | 595 | 1271 |
| Control | 448 | 1118 | 1185 | 2445 | 1582 |

Table 2. Average concentration of suspended solids (mg/L) in the runoff water at several irrigation events in 2001.

| Treatment | Site | | | | |
|---|---|---|---|---|---|
| | Vineyard | | | Cornfield | |
| | June 12-14 | July 22-24 | Aug 13-15 | July 16-18 | July 28-30 |
| Grass | 38 | 10 | 24 | 24 | 24 |
| Check | 164 | 46 | 201 | 256 | 37 |
| Surge | 193 | 70 | 1875 | 210 | 68 |
| Subsurface drain | 185 | 55 | 671 | 49 | 46 |
| Control | 1389 | 613 | 3279 | 181 | 56 |

Table 3. Amount of sediments (g) in runoff water at several irrigation events in 2001.

| Treatment | Site | | | | |
|---|---|---|---|---|---|
| | Vineyard | | | Cornfield | |
| | June 12-14 | July 22-24 | Aug 13-15 | July 16-18 | July 28-30 |
| Grass | 1828 | 462 | 1408 | 4946 | 3964 |
| Check | 3180 | 2554 | 14301 | 39201 | 6318 |
| Surge | 3358 | 2967 | 155205 | 24817 | 7728 |
| Subsurface drain | 6925 | 2498 | 54664 | 4356 | 4750 |
| Control | 67778 | 64267 | 330902 | 31059 | 7144 |

Figure 1: Sediment Concentraion versus Flow in Vineyard with a 1.2% Slope

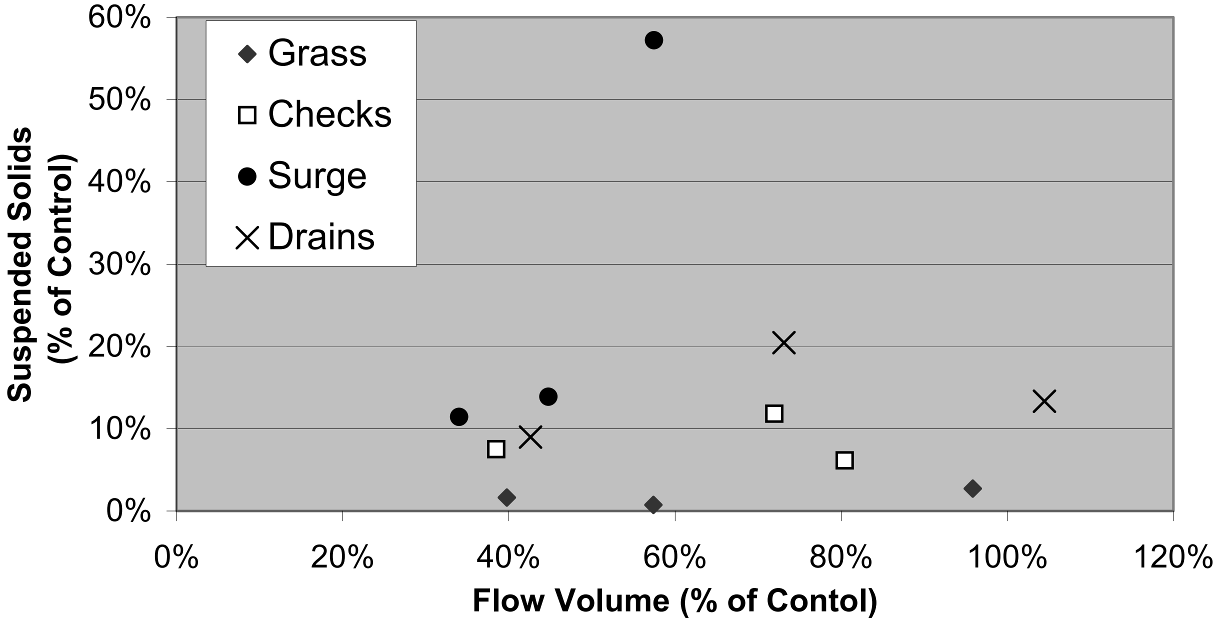

Figure 2: Sediment Concentration versus Flow in the Cornfield with a 0.2% Slope