Evaluation of Linear Anionic Polyacrylamide (LA-PAM) Application to Water Delivery Canals for Seepage Reduction

Richard Susfalk[1]
Don Sada[1]
Chad Martin[3]
Michael Young[2]
Timothy Gates[3]
Chris Rosamond [1]
Todd Mihevc[1]
Todd Arrowood[2]
Margaret Shanafield[1]
Brian Epstein[1]
Brian Fitzgerald[1]
Alexandra Lutz[1]
Jim Woodrow[5]
Glenn Miller[5]
Delbert Smith[4]

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Prepared by
[1]Desert Research Institute, Reno, NV
[2]Desert Research Institute, Las Vegas, NV
[3]Colorado State University, Fort Collins, CO
[4]U.S. Bureau of Reclamation, Denver, CO
[5]University of Nevada, Reno, NV

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EXECUTIVE SUMMARY

Introduction and Objectives

There is little doubt that seepage from unlined water delivery canals occurs on a local and regional scale and that losses may be significant in particular areas. Traditional seepage-abatement technologies such as compacted earth, reinforced or unreinforced concrete, and buried geomembranes are typically used in situations where seepage rates are elevated and projected water savings offset their high construction and maintenance costs. However, as water resources become further constrained in the arid western United States, there is a need for cost-effective seepage reduction technologies that can be used in locations where traditional methods are cost-prohibitive. A cost-effective technology could also be used on a regional scale to address regional problems such as seepage-induced high groundwater tables or the mobilization of subsurface salts to surface water. The granular form of linear anionic polyacrylamide (LA-PAM) has been identified as one such technology capable of cost-effectively reducing seepage rates from unlined water delivery canals. Granular LA-PAM is one type of a broader family of polyacrylamides that has a variety of uses, including as a flocculant in wastewater treatment, in food packaging, and paper manufacturing. Over the last decade, polyacrylamides have found increased use as an agent to reduce erosion and sediment transport from crop fields and construction sites.

In 2005, the Desert Research Institute (DRI), in collaboration with the U.S. Bureau of Reclamation, initiated a series of field and laboratory studies to assess the benefits and risks of LA-PAM used as a method to reduce seepage from unlined water delivery canals. The primary objectives of this research were to:

1. Quantify potential seepage reduction benefits, water savings, and typical application cost.
2. Address potential risks of LA-PAM use emphasizing the downstream transport and fate of LA-PAM, the release and fate of the residual acrylamide (AMD) monomer, and the potential impacts on aquatic organisms.
3. Gain a better understanding of how LA-PAM achieves seepage reduction in water delivery canal systems and how various environmental factors affect the ability of LA-PAM to reduce seepage.

The results presented here detail field studies conducted along 17 canal reaches located in the Grand Valley of western Colorado, the Yellowstone River Valley in Montana, and the Lower Arkansas River Valley (LARV) of eastern Colorado, in conjunction with Colorado State University. Results from several laboratory studies directly related to the field application of LA-PAM are also presented. This report complements previous DRI reports that characterized the risk of LA-PAM use in water delivery canals (Young *et al.*, 2007a) and discussed specific LA-PAM application guidelines that reduce environmental exposure while maintaining seepage reduction benefits (Susfalk *et al.*, 2007). In addition, the results of several previous laboratory studies that investigated the mechanisms of seepage reduction, potential impacts on water quality and aquatic species, microbial degradation, and fate and transport of LA-PAM (Young *et al.*, 2007b) are presented.

Benefits of LA-PAM Application

Granular LA-PAM was applied to specific canal reaches at a rate of approximately 11 kg ha^{-1} (10 lbs ca^{-1}) based on the average wetted perimeter of each canal. Short-term measurements conducted within 24 hours of each application indicated that LA-PAM reduced seepage rates between 28 and 87 percent in 8 of 11 experiments. For example, the application of LA-PAM along 4 km (2.5 mi) of the LARV Rocky Ford Highline Canal (RFH) in 2006 reduced pretreatment seepage rates of 0.06 m^2 s^{-1} km^{-1} by 59 percent. Over a season, the amount of water salvaged from this 4-km reach was estimated to be 1.6 x 10^6 m^3 yr^{-1} (1,300 acre ft^{-1} yr^{-1}). The application of LA-PAM to the entire RFH canal would salvage an estimated 7 x 10^6 to 24 x 10^6 m^3 yr^{-1} (5,400 to 19,000 acre ft^{-1} yr^{-1}) of water for a canal that typically diverts 95 x 10^6 m^3 yr^{-1} (77,000 acre ft^{-1} yr^{-1}).

Based on these field applications, the cost of applying granular LA-PAM ranged from \$78 km^{-1} (\$126 mi^{-1}) for smaller canals to \$213 km^{-1} (\$344 mi^{-1}) for larger canals. On a 10-year annualized basis, this represented between \$111 to 202 ha yr^{-1}, or between 0.2 and 3 percent of the total annualized cost of conventional technologies. Stakeholders and/or canal employees that have been trained in the proper field safety and application protocols can apply granular LA-PAM using simple or automated fertilizer spreaders. However, current application devices tend to promote both an uneven distribution and the over-application of LA-PAM. These issues could be eliminated by the development of application devices tailored to this use.

The application of LA-PAM remained effective throughout the remainder of the irrigation season based on repeated measurements conducted at four sites. Seepage reduction benefits were, however, not maintained across the winter season when the canals were dewatered. The need for yearly LA-PAM applications provides greater flexibility in controlling seepage rates compared to traditional methods. For example, some districts may choose to use LA-PAM only during drought conditions when water resources are scarce. Others might delay the use of LA-PAM by several weeks to provide canal seepage to adjacent resources (e.g. wetlands) during the early season when water is more plentiful. Yet others might delay LA-PAM application towards the middle or end of the irrigation season to help stretch the use of dwindling water resources. There is even the potential to halt seepage reduction benefits mid-season by disturbing the LA-PAM induced seal if they are no longer required.

Factors Contributing to a Successful LA-PAM Application

Linear anionic PAM was not always effective at reducing canal seepage, a result of inadequate field conditions necessary to promote flocculation between the polymer and suspended sediment. Granular LA-PAM should only be added to water in canals having a suspended sediment concentration (SSC) of approximately 150 mg L^{-1} or greater, and a total dissolved concentration (TDS) of approximately 200 mg L^{-1} or greater. The most common issue was the lack of a sufficient SSC, which could be alleviated by applying LA-PAM during elevated turbidity events such as seasonal snowmelt or after summer thunderstorms. Granular LA-PAM should not be used in canal systems that are chronically devoid of suspended sediment and/or are characterized by low TDS levels that suppress the formation of PAM-sediment flocs. Artificially increasing SSC through dredging the canal bottom or the addition of canal tailings should be avoided due to the difficulty in timing sediment additions with LA-PAM hydration rates.

The failure to follow these requirements, the application of excessive LA-PAM, and/or the poor choice of application methods and techniques can increase potential environmental exposure through the downstream transport of LA-PAM in the water column. The most critical factor in reducing exposure was the use of an LA-PAM application rate that was related to the level of suspended sediment in the water column and not simply the wetted perimeter, as traditionally done. Results from this study indicate that a nominal application rate of 11 kg ha^{-1} (10 lbs ca^{-1}) resulted in an over-application of LA-PAM to smaller canals (<2.8 m^3 s^{-1} or < 100 cfs) and potentially resulted in the under-application to larger canals. Smaller canals had less water per unit area, resulting in higher observed concentrations of LA-PAM in these canals. Laboratory studies indicated the formation of PAM-sediment flocs was optimized when LA-PAM concentrations were between 1 to 2 mg L^{-1} in the water column and that higher polymer concentrations provided little additional benefit. The Clear Zone Index (CZI) was introduced as a diagnostic aid to assess if the mass of LA-PAM exceeded the assimilative ability of suspended sediment levels in the canal. A partially developed CZI was desired, indicating the formation of PAM-sediment flocs and the utilization of added polymer. A fully developed CZI should be avoided, as it indicates exhaustion of suspended sediment and the potential presence of excess LA-PAM that can remain mobile in the water column. It is strongly advised that current application guidelines based on a canal's wetted perimeter be depreciated in favor of the development of application rates based on the concentration or load of suspended sediment in the water column.

Other environmental factors must also be taken into account to properly manage the application of LA-PAM. The interaction of water temperature and water velocity, for example, will determine how far LA-PAM will travel downstream before it hydrates and reacts with suspended sediment. Laboratory experiments indicated that granular LA-PAM typically hydrates within 24 to 34 minutes. The time needed for flocculation to occur in the field was not entirely temperature dependent, indicating other site-specific factors such as water mixing, water chemistry, suspended sediment concentration and particle size may also play an important role. For the sites studied, LA-PAM traveled between 196 m (643 ft) and 2,149 m (7,050 ft) downstream from the point of application prior to flocculation and development of a clear zone. Therefore, granular LA-PAM must be applied at greater distances upstream of the target reach under conditions of slow hydration rates and fast water velocities, such as typical of snowmelt-fed canals during the early water season.

Risks of LA-PAM Application

The application of LA-PAM to unlined water delivery canals carries several potential risks related to the application and release of the polymer and the residual AMD monomer that remains occluded in the polymer. When LA-PAM was applied in excess of ambient suspended sediment conditions, LA-PAM concentrations were found to exceed 1 mg L^{-1} for up to four to nine hours depending on the time it took to physically apply the polymer. Excess LA-PAM that remained in the water column could travel significant distances downstream where it could be inadvertently used by unsuspecting stakeholders, such as being diverted to farms for use on crops, or be consumed by livestock, for example. Excess polymer can also negatively impact the aquatic community. In canal systems, the response of benthic macroinvertebrates (BMIs) to LA-PAM was relatively minor because these BMI communities were tolerant of the very harsh conditions present in these types of systems. However, natural surface water systems are comprised of more sensitive BMI species that were found to respond negatively to the presence of LA-PAM. The primary approach for mitigating these risks is to reduce or eliminate the transport of polymer downstream of the treatment zone by applying LA-PAM in a manner that assures it is quickly removed from the water column. This requires proper water chemistry, use consistent with guidelines developed for LA-PAM application to canals, and the application of LA-PAM at a rate that will not fully deplete the load of suspended sediment carried by the canal. These requirements may rule out or delay the use of LA-PAM until sufficient sediment levels are present, or even prevent its use if there is a possibility that natural surface waters may be impacted.

The most likely human health risk was to persons applying LA-PAM, either through inhalation, accidental eye contact, or from slipping on the slick polymer as it hydrated. These risks were significantly reduced through the proper use of protective gear and application guidelines (Susfalk *et al.*, 2007). The incidental release of the AMD monomer, a cumulative neurotoxin and a suspected human carcinogen, also presents potential human health and environmental risks. Unlike the polymer, AMD is a small, mobile molecule that can enter groundwater. The potential risks of AMD release associated with LA-PAM applications to canal systems were more fully discussed in Young *et al.* (2007a). Acrylamide concentrations in canal water were observed to be orders of magnitude below the chronic levels needed to impact human health. In addition, there was evidence that elevated AMD and LA-PAM concentrations were linked, suggesting that the methods discussed above to eliminate excess polymer addition should also reduce the potential for elevated monomer concentrations. The successful formation of a PAM-sediment-induced seal will also decrease the likelihood of AMD entry into groundwater through the reduction of the seepage rate. Acrylamide entering groundwater was found to be diluted by both canal water and groundwater, a dilution of up to four orders of magnitude at one site. Acrylamide released into the environment was found to be susceptible to microbial degradation, with an estimated half-life of 30 to 42 hours. Finally, conservative transport models indicated that AMD concentrations 10 times greater than actually measured in canal water would be undetectable within 25 m of the canal due to microbial degradation and dilution processes. Therefore, the contamination of groundwater by AMD associated with the application of LA-PAM to water delivery canals using the methods of Susfalk *et al.* (2007) was considered to be very unlikely.

The successful use of granular polyacrylamide includes: 1) the selection of the proper type of LA-PAM for use in canals; 2) determination if the proper water chemistry and suspended sediment concentrations exist; 3) an application plan that minimizes worker contact and accounts for environmental impacts on hydration time; and 4) an assessment of the potential risks including potential impacts on downstream users and receiving waters. Stakeholders and/or agencies responsible for the use of granular LA-PAM must assess if potential site-specific risks outweigh the benefits of using LA-PAM for water conservation purposes.