

Application Guidelines: Use of Granular, Linear Anionic Polyacrylamide (LA-PAM) in Water Delivery Canals for Seepage Control

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September 2007

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Prepared by

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U.S. Bureau of Reclamation, Denver, CO

In cooperation with

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EXECUTIVE SUMMARY

Polyacrylamides are a broad family of polymers that possess a wide range of physical and chemical properties. One formulation, granular, linear anionic polyacrylamide (LA-PAM), has recently been used for water conservation purposes. When applied to an unlined water delivery canal, LA-PAM flocculates suspended sediment and settles to the bottom of the canal forming a layer that can reduce seepage. This document provides guidelines for applying LA-PAM to unlined water delivery canals in a manner that reduces the risks associated with treatment, while still providing seepage reduction benefits.

These guidelines manage environmental health risks by requiring the use of LA-PAM certified to have a low concentration of the residual acrylamide monomer (AMD), a known animal and suspected human carcinogen. In addition, the quantity of LA-PAM applied is limited to only those canal reaches known to have significant seepage rates and by limiting the rate of LA-PAM applied to no more than 10 lbs/canal acre per treatment and no more than 20 lbs/canal acre per year. The application rate of LA-PAM should be further reduced when optimum suspended sediment concentrations are not available. Although the human health risk from LA-PAM is small, common-sense safety procedures are required to minimize both direct contact and the accidental creation of secondary health hazards, such as slip hazards. As the canal water can transport LA-PAM beyond the treatment reach, downstream stakeholders and the potential for unintended consequences must also be considered before application commences.

These guidelines describe application techniques that can maximize seepage reduction effects. Techniques include applying LA-PAM only when there is sufficient suspended sediment to react with all the LA-PAM added, and applying LA-PAM upstream of the desired treatment reach to account for the time that LA-PAM needs to hydrate before it becomes reactive.

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1.0 INTRODUCTION AND OBJECTIVE

Polyacrylamide consists of a broad family of polymers having varying physical and chemical properties that have been used extensively in food packaging, paper manufacturing, and wastewater treatment. Over the past decade, linear anionic polyacrylamide (LA-PAM) has been used to reduce erosion and sediment transport from crop fields under furrow irrigation (Wallace and Wallace, 1986; Lentz and Sojka, 1994; Lentz *et al.*, 2001; Al-Abed *et al.*, 2003) and on construction sites (Soupir *et al.*, 2004; Hayes *et al.*, 2005; Orts *et al.*, 2007). Recent empirical evidence suggests that the application of LA-PAM to unlined water delivery canals can reduce water lost to seepage.

In 2005, the Desert Research Institute (DRI), in collaboration with the U.S. Bureau of Reclamation (USBR), initiated field and laboratory studies to assess the benefits and risks of applying LA-PAM in granular form to unlined water delivery canals as a method for reducing seepage. The scope of these studies was broad, as the performance and environmental impacts of an individual formulation of LA-PAM cannot be predicted based solely on its chemical or physical properties. To date, DRI has applied or monitored the application of LA-PAM to 13 canal reaches in the western United States (Susfalk *et al.*, in preparation). In addition, DRI has conducted a risk characterization (Young *et al.*, 2007a) and numerous laboratory studies investigating the mechanisms, impacts on water quality and aquatic species, and the fate and transport of LA-PAM (Young *et al.*, 2007b; Epstein *et al.*, in preparation) when applied to water delivery canals.

The objective of this document is to present guidelines for the application of LA-PAM to water delivery canals for water conservation purposes that responsibly reduce and manage the risks associated with LA-PAM application. The guidelines are intended to reduce, to the extent possible, concentrations of the acrylamide monomer (AMD), which is found as a residual compound from the manufacturing of LA-PAM. The guidelines within this document are intended to be used by USBR or other agencies when developing specific LA-PAM application protocols, and are not intended for use directly by stakeholders without assistance from agency field personnel. The guidelines presented here are based on the experience gained during multiple field applications of granular LA-PAM and supported by additional field studies conducted by DRI, USBR, and Colorado State University, and laboratory studies conducted by DRI and the University of Nevada, Reno. The guidelines themselves are presented in Section 2, and are followed by a narrative discussion to provide context and further explanation in Section 3. To facilitate use by agencies and stakeholders, English and Metric units are used throughout this document, when appropriate. Calculations presented in Section 2 are listed in the Appendix for easy reference. These guidelines are subject to revision as ongoing or future studies continue to provide new information that better identify and define the risks and benefits of using LA-PAM in water delivery canals.

2.0 GUIDELINES

2.1 LA-PAM Formulation

For use in water delivery canals, the specific LA-PAM product needs to have the following characteristics:

1. Conform to the National Sanitation Foundation International / American National Standards Institute – NSF/ANSI Standard 60;
2. Conform to the American Water Works Association standard for polyacrylamide, ANSI/AWWA B453-06;
3. Be a linear PAM (not deliberately branched) with an anionic charge density of $30 \% \pm 5 \%$;
4. Possess a molecular weight of at least 12 million g/mole;
5. Contain no more than 0.05 % acrylamide monomer, by weight;
6. Be in the dry granular/powder form. The use of emulsified or dispersed forms of LA-PAM is not suggested until their potential environmental impacts can be further studied; and,
7. Adhere to state and local regulations regarding the use of chemical additions to drinking water.

2.2 Worker Safety

While LA-PAM itself has not been shown to be toxic in many industrial applications, workers should handle and use this product in accordance with good industrial hygiene safety practices. These practices include avoiding eye and prolonged skin exposure, and avoiding inhalation or ingestion of LA-PAM. Persons applying LA-PAM should use appropriate personal protective equipment, which includes but is not limited to protective eyewear, dust masks, and gloves used in accordance with label/MSDS recommendations or other state rules and guidelines.

2.2.1

It is recommended that a uniform Job Hazard Analysis (JHA) be developed and used so that minimum standards of protection become routine and uniform from site to site. Additionally, all applicable state and federal Right-to-Know laws must be observed.

2.2.2

Excess LA-PAM must be cleaned up immediately after staging (e.g., weighing, transfer to applicator) and after application. When LA-PAM is exposed to water, it becomes extremely slippery and is not easily cleaned. Granular LA-PAM that remains on concrete, roadways, and bridges will become a hazard when it becomes wet. Follow the clean-up instructions in the LA-PAM product's literature, including the Material Safety Data Sheet and, if these are not available, the guidelines in ANSI/AWWA Standard B453-06.

2.3 LA-PAM Application

LA-PAM application rates are determined using the units of pounds per canal-acre (lbs/canal acre). Using guidelines set by USBR, application rates must not exceed 10 lbs/canal acre, based on wetted perimeter, per treatment. The wetted perimeter is that portion of the canal-channel cross section that is in contact with water. Multiple applications are acceptable, as long as a 30-day period is maintained between applications and the aggregate amount of LA-PAM does not exceed 20 lbs/canal acre during the water year. The canal acres within the treatment

reach are determined by taking its average wetted perimeter, in feet, multiplying by its length, in miles, and multiplying that product by 0.121 (acre ft⁻¹ mile⁻¹).

2.3.1

Where possible, LA-PAM treatments should target specific areas known for high seepage losses, rather than treating the entire length of the canal. Laboratory results have shown that LA-PAM can be very effective in reducing seepage through sandy substrates, but treatment is not very effective in finer-grained (silty or clayey) substrates.

2.3.2

The application of granular LA-PAM to a flowing canal should start at the bottom of the treatment reach and progress upstream, where possible.

2.3.3

LA-PAM should not be applied to dry canals because this may increase concentrations of LA-PAM and AMD in the leading edge of water entering the canal.

2.3.4

LA-PAM should not be applied during high winds or during rain. Winds and wind gusts can potentially spread granular LA-PAM to areas other than the canal (i.e., the application boat, roads, and bridges). When exposed to rain (or any water), LA-PAM will become difficult to apply and immediately create a slip hazard as it begins to hydrate.

2.3.5

LA-PAM application rates should not be exceeded. Studies have shown that overdosing provides no additional seepage control or benefit. Also, overdosing increases potential environmental impacts, wastes money, and unnecessarily limits future LA-PAM treatments during the remainder of the water year. The mass of LA-PAM applied to the water should not exceed the ability of suspended sediment to remove the LA-PAM through the formation of LA-PAM-sediment flocs. The application of excess LA-PAM will result in higher concentrations of LA-PAM in the water column near the treatment reach, an overall loss of LA-PAM from the desired treatment zone as it is transported downstream, and the potential for elevated concentrations in downstream return waters.

2.3.5.1

Laboratory and field studies suggest that 150 to 300 part per million (ppm) of suspended sediment in the water column is sufficient to create an effective LA-PAM-sediment floc. Application of LA-PAM to water with low suspended sediment concentrations may result in higher concentrations of LA-PAM in the water column. There appears to be no upper limit of suspended sediment concentration.

2.3.5.2

LA-PAM addition can be timed to occur the day after precipitation events that naturally raise the suspended sediment concentrations within the water column.

2.3.5.3

The manual addition of sediment to the water column is not advised, must be carefully considered, and must be consistent with state and local regulations regarding the addition of material into the water, especially related to discharge permits. If sediment must be added, the following guidelines apply:

2.3.5.3.a. Added sediment should raise the suspended sediment concentration to between 150 and 300 mg/L.

2.3.5.3.b. Added sediment must have a clay or clay loam texture. Larger soil particles, such as in sandy textured soils, settle quickly, do not react well with LA-PAM, and have no benefit.

2.3.5.3.c. Added sediment should occur downstream of the LA-PAM addition and progress upstream at the same rate as LA-PAM application. The distance between LA-PAM application and sediment addition, in miles, is calculated by taking the average water velocity in feet/sec and multiplying that by 0.341.

2.3.6

The use of other LA-PAM application methods is not advised if optimum suspended sediment concentrations cannot be achieved.

2.3.7

The area where granular LA-PAM is added to the canal should be upstream of the actual area targeted for seepage reduction, to account for the time LA-PAM needs to hydrate, react with sediment, and settle to the canal bottom. Research has shown that LA-PAM reactivity with suspended sediment can begin in as little as 10 minutes and that a “clear zone” (i.e., zone where suspended sediment is effectively removed from the water column) can form in about 25 minutes in waters with a temperature of about 77°F (25°C).

2.3.7.1

The starting point of LA-PAM application should be extended upstream into the target area by a distance, in miles, calculated by multiplying the average water velocity in foot/second (ft/sec) by 0.11. The 0.11 factor assumes that PAM reactivity starts 10 minutes after application and incorporates a unit conversion from feet to miles.

2.3.7.2

The ending point of LA-PAM application should be extended upstream of the target area by a distance, in miles, calculated by multiplying the average water velocity in ft/sec by 0.51. The 0.51 factor assumes that PAM reactivity continues up to 45 minutes after application and incorporates a unit conversion from feet to miles. For example, LA-PAM application to a 2.0-mile-long reach, with an average water velocity of 2 ft/sec, would start 0.22 miles into the treatment reach and extend 1.0 mile upstream of the treatment reach.

2.3.7.3

Colder water temperatures will slow the hydration rate of LA-PAM, requiring longer offsets. Laboratory data show that the hydration time for LA-PAM increases by 12 % for every 10°F (5.5°C) drop in water temperature from 77°F (25°C) (Woodrow and Miller, 2007). For example, it will take 18 % longer for LA-PAM to hydrate in water at 62°F compared to water at 77°F. Therefore, increase the starting and ending offsets by 18 % (multiply by 1.18) to account for LA-PAM hydration time in this example.

2.3.8

LA-PAM can be applied at a slower rate (i.e., over a longer period of time) to maintain downstream LA-PAM concentrations of less than 1 ppm. The speed of application should be less than 1 mile per hour in waters with low turbidity, but can be increased to 3 miles per hour in water with higher turbidity levels. The calculated LA-PAM application rate in lbs/hour is calculated by multiplying the desired speed of application, in miles per hour, by the total weight of LA-PAM to be applied, in pounds, and dividing by the total miles of the application reach.

2.3.9

LA-PAM must be added to the water in a manner that avoids the formation of agglomerates of partially hydrated particles that do not fully go into solution. Agglomerates typically form when a slug of granular LA-PAM is added to a small surface area of water, such as when pouring LA-PAM directly out of its shipping container and into water. To avoid agglomerates, a seed or fertilizer spreader, or equivalent, is used to disperse a small amount of granular LA-PAM to a large surface area of water.

2.4. Downstream Impacts

All appropriate precautions should be taken to keep the applied LA-PAM within the canal prism (sometimes called the canal bed) and to minimize its impact on downstream users.

2.4.1 Transport Outside of the Canal Prism

All laterals, wasteways, spillways, and diversions in the LA-PAM-affected area must be closed prior to and for at least 24 hours after LA-PAM is applied. The LA-PAM-affected area includes the entire LA-PAM application reach and the downstream distance that the LA-PAM affected water travels in 10 hours. This distance, in miles, is calculated by multiplying the average water velocity, in ft/sec, by 6.8. The 6.8 factor is itself the product of a unit conversion from ft/sec to mi/hr and the 10 hour safety factor. For example, if LA-PAM is applied to a canal with an average water velocity of 2.5 ft/sec, then all diversions within the application zone and 17 miles downstream of the initial PAM application point must be closed for 24 hours.

2.4.2 Downstream Transport

The LA-PAM application approach must minimize the impact to downstream users. LA-PAM concentrations must be reduced to levels below detection limits in the water column at least one canal mile upstream of a receiving water or other use primarily destined for human consumption.

2.4.2.1 Receiving Waters

LA-PAM must not be allowed to enter receiving waters. Receiving waters include, but are not limited to: waters of the United States, habitats occupied by threatened or endangered species, or any water where the presence of LA-PAM is not intended to decrease seepage loss.

2.4.2.2 Human Consumption

The application of LA-PAM must be conducted in a way to minimize human consumption. Examples of situations to avoid include the use of canal water itself as a drinking water source or by downstream municipal drinking water treatment plants, and collection of water-borne materials (e.g., algae) whose primary use is for human consumption.

2.4.2.3 Notification

Notification should be given to any downstream stakeholder or potential user of the canal water prior to LA-PAM application, following applicable Right-to-Know laws. Notification is necessary to minimize the interaction of livestock, agricultural crops, and humans with LA-PAM-treated water.

2.4.2.4 Sediment Addition to Manage Downstream Transport

Sediment addition to the canal downstream of the LA-PAM treatment zone can be used to reduce the concentration of LA-PAM in the water column.

2.4.2.4.a. Sediment addition must be further downstream than the most downstream extent of LA-PAM application and at least 1.5 canal miles upstream of the receiving water or water destined for human consumptive use.

2.4.2.4.b. Sediment addition should commence after LA-PAM is first applied to the canal. This time lag, in minutes, is calculated by dividing the distance between the start of LA-PAM addition and sediment addition, in miles, by the average water velocity in ft/sec and multiplying by 88.

2.4.2.4.c. Sediment addition should continue until the full extent of LA-PAM-treated water passes the point of sediment application. This time is calculated by multiplying the distance between the point of sediment addition and the upstream point of the last LA-PAM addition, in miles, by 1.47, dividing this product by the average water velocity, in ft/sec, and then adding this number to the calculated application time, in hours. For example, suspended sediment needs to be added for 4.5 hours at the downstream extent of a 2-mile LA-PAM application reach, if LA-PAM is applied for 3 hours to water having an average velocity of 2 ft/sec.

2.4.2.4.d. Sediment addition should attempt to raise target concentrations of suspended sediment to between 150 and 300 mg/L. Sediment added to water should be of clay or fine-silt particle size; sand will not effectively react with LA-PAM. If the background level of suspended sediment is already greater than 150 mg/L, no additional sediment should be added.

2.4.2.4.e. Sediment addition must be consistent with regulations regarding addition of materials into water.

2.4.3 Unintended Consequences of LA-PAM Application

The reduction of canal seepage after LA-PAM application may affect localized groundwater conditions, including the lowering of water levels in wells adjacent to the canal, or the reduction of the water availability for wetlands and croplands that depend on canal seepage. These possibilities should be considered by the potentially affected stakeholders prior to LA-PAM treatment. Additionally, a small risk exists that the AMD could migrate downward to the groundwater and toward water wells. To reduce this risk, the presence of wells adjacent and downgradient to the canal need to be considered in the LA-PAM application plan.

3.0 DISCUSSION

3.1 LA-PAM Formulation (Guidelines Section 2.1)

Because of the possibility that canal water could be used directly or indirectly for human consumption, the application of LA-PAM to water delivery canals must be consistent with the Phase II Rule National Primary Drinking Water Regulations issued by the U.S. Environmental Protection Agency (40 CFR §141.111). The maximum use level is based on an acrylamide polymer application of 1.0 mg/L and an AMD concentration of 0.05 % in the polymer, or equivalent, for a carryover of not more than 0.5 ppb of AMD into the finished water.

The LA-PAM applied to water delivery canals must also be NSF/ANSI Standard 60 certified by the manufacturer or distributor. The NSF/ANSI-60 Drinking Water Treatment Chemicals – Health Effects Standard is the national health effects standard for chemicals used to treat drinking water. Requirements for NSF/ANSI-60 include a formulation review and a Good Manufacturing Practices audit. The requirement of NSF/ANSI Standard 60 LA-PAM is consistent with existing guidelines approved by the United States Natural Resources Conservation Service (NRCS) for the use of LA-PAM in the environment.

In addition, LA-PAM should comply with ANSI/AWWA B453-06 for the use of polyacrylamide in water supply service. This standard provides minimum requirements for LA-PAM products and includes standardized testing methodologies for verifying the LA-PAM product. In addition, ANSI/AWWA B453-06 provides minimum safety requirements, spill cleanup, packaging, labeling, and shipping requirements.

When possible, LA-PAM that exceeds NSF/ANSI 60 by containing a lower residual AMD concentration should be used. The European Union already mandates a maximum monomer concentration of 0.025 %. Thus, if the manufacturing process used for LA-PAM to be distributed in the United States is the same as the product to be distributed in the European Union, then existing LA-PAM products sold in the United States may already contain residual AMD concentrations significantly less than 0.05 %. For example, the LA-PAM used by DRI during laboratory and field studies was found to contain 0.01 % of AMD (Jim Woodrow, University of Nevada, Reno, personal communication, July 2006). Polyacrylamide that complies with the above NSF/ANSI 60 and ANSI/AWWA B453-06 requirements has been tested in full-scale canals and was shown to create LA-PAM-sediment flocs that reduce seepage under typical canal conditions.

These guidelines specifically pertain to the use of granular LA-PAM. However, these guidelines are also applicable to the use of LA-PAM that is hydrated or partially hydrated in water, which is derived from granular LA-PAM. Partially hydrated LA-PAM is more

complicated to apply in the field because it requires a readily available supply of water, a mixing rig, and a spray applicator system. The use of other forms of LA-PAM, such as emulsified and dispersed forms of LA-PAM, should be avoided at this time until they can be fully evaluated with respect to residual compounds and field application. For example, some emulsified LA-PAM products contain other chemicals, such as polyoxyethylene-containing emulsifying agents and polyoxyethylene alkyl phenols that have not been assessed for potential environmental impacts.

3.2 Worker Safety (Guidelines Section 2.2)

Although the human health risk from exposure to LA-PAM is minimal, proper personal protective equipment is required during application. Granular LA-PAM can easily become airborne while transferring LA-PAM between containers and during application, even when wind is not present. Granular LA-PAM does not immediately dissolve in water; rather, it hydrates on contact with water or sweat, causing it to become viscous and slippery. Granular LA-PAM that enters the eye will hydrate and require extensive flushing with clean water. Therefore, gloves, facemasks, and outerwear such as painter or Tyvek suits are needed to minimize contact with moist skin and to protect clothing. Precautions should be taken to minimize the contact of LA-PAM with water in the immediate application area (e.g., boats, roadways, pickup truck tailgates), as doing so will reduce the risk of a slip hazard. Also, work crews should be briefed on potential job hazards before beginning the application of LA-PAM.

3.3 LA-PAM Application (Guidelines Section 2.3)

The maximum rate of LA-PAM application to a water delivery canal must not exceed 10 lbs/canal acre per application, with a yearly maximum of 20 lbs/canal acre and no more than one application per 30 days (Section 2.3). This guideline limits the amount of LA-PAM released into the environment while still providing enough LA-PAM for maximum seepage control. Under the proper conditions, full-scale field studies with LA-PAM application rates between 10 and 20 lbs/canal acre have resulted in seepage reductions from 30 % to greater than 90 % (Susfalk *et al.*, in preparation). However, several other sites had suboptimal conditions (e.g., colder water with low suspended sediment concentration) with no observed decreases in seepage reduction. Laboratory and smaller-scale test trough studies have indicated that 10 lbs/canal acre (or less) is sufficient to reduce seepage, and that additional amounts do not necessarily improve seepage reduction. These studies were conducted under relatively controlled conditions, so the results may not scale to full-scale canals.

Several factors must be considered to maximize potential sealing and cost-saving benefits, while minimizing environmental exposure of LA-PAM. These factors include, but are not limited to, the type of soil that forms the base of the canal prism, the type and concentration of suspended sediment, water temperature, water velocity, water chemistry, and the methods used to apply LA-PAM. In general, observations from field-scale canal treatment have shown that: 1) greater seepage reduction should occur in canal waters containing sufficient concentrations of divalent cations and finer-grained suspended sediments; and, 2) warmer water temperatures and lower water velocities will allow LA-PAM to react faster, thereby reducing the downstream distance that LA-PAM travels before the LA-PAM-sediment flocculate settles. A full description of how these factors affect the field application of LA-PAM is discussed in Susfalk *et al.* (in preparation).

The LA-PAM application rate needs to be balanced with the concentration of suspended sediment in the water column. Laboratory studies indicate that the combination of 1 ppm of hydrated LA-PAM and between 150 to 300 mg/L of suspended sediment in the water column provides optimal conditions for LA-PAM-sediment floc formation. This is in agreement with preliminary field data showing that 1 lb of LA-PAM can flocculate and remove between 100 and 400 lbs of suspended sediment from the water column.

If the concentration of suspended sediment is too low to fully interact with all the LA-PAM added to the canal water, then the water will contain elevated concentrations of LA-PAM and canal sealing will not be maximized. In DRI's field studies, the concentration of LA-PAM typically remained elevated above the EPA drinking water limit (1 ppm) for up to 10 to 15 hours after application began. Smaller canals (four case studies with flow < 30 cubic feet per second, or cfs) were more likely to have higher-average, time-weighted LA-PAM concentrations, ranging from 1.5 to 4.0 ppm. In contrast, larger canals (six case studies with flow >100 cfs) exhibited lower average LA-PAM concentrations ranging from less than the detection limit of 0.1 ppm up to 0.8 ppm. These observed differences are a result of LA-PAM applications being based on the wetted perimeter of the canal and the fact that canals typically carry more water per foot of wetted perimeter as they get larger. For example, in the case studies reported here, the relationship between wetted perimeter and discharge varied from about 1 cfs per foot of wetted perimeter in canals less than 30 cfs, to 5 cfs per foot of wetted perimeter in canals ranging from 100 to 350 cfs, to between 8 to 12 cfs per foot of wetted perimeter in canals larger than 600 cfs. Therefore, the same rate of LA-PAM (e.g., 10 lbs/canal acre) applied to both large and small canals yields different LA-PAM concentrations because of higher dilution in large canals. Also, large canals have a greater mass of suspended sediment per canal, thereby improving its ability to react with and remove LA-PAM from the water column. Both factors would lead to lower LA-PAM concentrations observed in larger canals.

Where possible, limiting the use of LA-PAM to canals having sufficient background concentrations of suspended sediment is advocated. One approach is to apply LA-PAM during high-turbidity events, such as immediately after a summer rainstorm. Application during early-season, snowmelt-derived high water should be carefully considered. Lower water temperatures and typically higher water velocities can transport LA-PAM significant distances downstream before flocs settle. If LA-PAM is applied to water with low suspended sediment concentrations, then the application rate of LA-PAM should be linearly scaled back to minimize the concentration of LA-PAM in the water column, thus ensuring that overdosing LA-PAM does not occur.

Another approach for raising suspended sediment levels is to either add sediment into the canal from a backhoe, or use a backhoe to stir existing sediment from the canal bottom. Either approach must be considered very carefully due to the potential need for a discharge permit and the potential to affect downstream users and aquatic habitats. The manual addition of sediment will not increase suspended sediment concentrations sufficiently along a treatment reach above those caused by a naturally occurring storm. In addition, artificially increasing suspended sediment will likely mobilize coarser sediments that form less effective LA-PAM-sediment flocs. Finally, sediment addition should be limited to small canals, where the water depth is relatively shallow, and the amount of sediment needed will be manageable. Stirring or otherwise disturbing the canal bottom should be avoided, in particular, as this may itself increase seepage.

The final alternative for increasing suspended sediment availability is to add LA-PAM to the canal bottom before water enters the canal for the first time in the season. The application of granular LA-PAM to a dry canal should only be considered as a last resort, because it potentially accumulates LA-PAM as the leading edge of water travels down the canal. Leading edge samples collected from smaller-scale test trough experiments were found to have average LA-PAM concentrations of 293 and 57 ppm at 20 and 60 feet downstream of granular LA-PAM applications, respectively. However, more studies need to be conducted to fully assess whether LA-PAM concentrations are likely to be elevated in the leading edge during field-scale applications. In addition, the time between application and the presence of water should be minimized as dry LA-PAM may be more susceptible to degradation after exposure to the sun (J. Woodrow, University of Nevada Reno, personal communications, 2007).

Granular LA-PAM requires time to hydrate before it becomes reactive (Section 2.3.7). Though additional studies are being conducted to more fully understand LA-PAM reactivity, laboratory column studies show that LA-PAM can become reactive in as little as 10 minutes and remain reactive for up to 45 minutes before reaching equilibrium (Woodrow and Miller, 2007). In the field, noticeable reductions in water column turbidity occurred in about 20 minutes with water temperatures of about 77°F (25°C). These observations have been incorporated into the LA-PAM application protocols. For example, the calculation of start position for LA-PAM application (Section 2.3.7.1) is based on how far the LA-PAM-laden water will travel in 10 minutes. The calculation for stop position (Section 2.3.7.2) is based on the distance the water will travel in 45 minutes. As water temperatures cool, LA-PAM needs more time to hydrate and react with sediment. LA-PAM will thus move further downstream before settling. Preliminary laboratory studies indicate that the hydration time of LA-PAM increases by 22 % for every 18°F change from 77°F (Woodrow and Miller, 2007).

The speed of LA-PAM application (lbs/hr) should be chosen based on field conditions (Section 2.3.8). Slower rates of LA-PAM application will reduce the concentration of LA-PAM in the water column and expose the reactive LA-PAM to a greater load of suspended sediment. Both factors are critical in canals with low suspended sediment concentrations but are less important in canals with suspended sediment concentrations that are sufficient to fully react with LA-PAM. Field studies have not been conducted to support specific application speeds. However, we suggest that derivative protocol documents include application speed requirements similar to those conducted during field studies:

Manual application (hand fertilizer spreader) requiring walking within the canal prism.	0.3 miles/hr
Manual application (hand fertilizer spreader) requiring walking the banks of the canal	0.4 to 0.8 miles/hr
Manual application (hand fertilizer spreader) from a moving boat	0.9 to 1.0 miles/hr
Automated applicator mounted on a moving boat	1.3 to 3.0 miles/hr

3.4 Downstream Impacts (Guidelines Section 2.4)

This guideline requires the use of all reasonable precautions to eliminate the potential transport of LA-PAM out of the canal prism and to minimize the impact of LA-PAM application on downstream users.

Properly applying LA-PAM, as described in Section 2.3, is the first step toward minimizing potential downstream transport. In certain situations, however, additional precautions must be taken. In particular, the possibility exists that LA-PAM-laden canal water could be used for sprinkle irrigating crops, if diversions are not closed during LA-PAM application. Crops with little post-harvest processing prior to human consumption could increase human risk, as LA-PAM can remain on the surface of the crop and be ingested by humans. Examples of these types of crops include lettuce and spinach.

Additional precautions must also be taken to prevent LA-PAM from entering receiving waters. The one mile set-back also has the built-in safety factor of dilution as the canal water enters the receiving water. In situations where additional safety is needed, adding additional sediment to the water could further remove any LA-PAM remaining in the water column.

4.0 CONCLUSION

This document presents guidelines for applying LA-PAM to unlined water delivery canals in a manner that reduces risks associated with canal treatment, while providing seepage reduction benefits. Four steps are suggested for a successful application:

1. Begin with the selection of a product with the proper formulation. LA-PAM products are limited to that certified to meet the NSF/ANSI Standard 60. Furthermore, only these formulations have been shown to reduce seepage under typical canal conditions, thus also limiting the presence of the acrylamide monomer and other residual components in the canal water.
2. Establish adequate worker safety guidelines. The application of LA-PAM represents the most likely pathway for human exposure of LA-PAM. Although the human health risk from LA-PAM is small, common-sense safety procedures are required to minimize both direct contact and the accidental creation of secondary health hazards, such as slip hazards.
3. Consider field conditions before treatment. Favorable conditions (described in this document) can lead to seepage reduction benefits, while minimizing the amount of LA-PAM used, reducing product costs, and minimize potential environmental impacts. This is accomplished by:
 - a. targeting specific canal reaches having high seepage rates, rather than treating the entire canal;
 - b. limiting LA-PAM applications to no more than 10 lbs/canal acre per treatment and no more than 20 lbs/canal acre per year; and
 - c. choosing an application rate of LA-PAM that will fully react with available suspended sediment in the canal. Overdosing LA-PAM (1) will result in measurable concentrations of LA-PAM in the water that can be transported downstream, (2) will not improve seepage reductions, and (3) is wasteful.
4. Consider the time needed for granular LA-PAM to hydrate and become reactive with suspended sediment after it has been applied to the canal. This requires moving the zone of actual LA-PAM application upstream of the target reach based on field conditions, and is determined primarily by water temperature and water velocity.

5. Consider and responsibly manage the potential impacts on users and downstream stakeholders. Specifically, canal water with detectable concentrations of LA-PAM must not be transported out of the canal and must not be allowed to enter receiving waters or affect any waters that are consumed by humans.

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APPENDIX – Calculations for Addition of LA-PAM

1. Treatment area (Section 2.3)

$$\text{Treatment area, in canal acres} = \left(\frac{\text{Average wetted perimeter, in feet}}{\text{Length of treatment section, in miles}} \right) \times 0.121$$

2. Addition of sediment to increase suspended sediment concentration (Section 2.3.5.3.c.)

$$\text{Distance between LA - PAM application and downstream sediment addition, in miles} = \left(\text{Average water velocity, in } \frac{\text{feet}}{\text{seconds}} \right) \times 0.341$$

3. Start and stop locations for PAM addition (Section 2.3.7)

Step 1. Calculate the water temperature correction factor.

$$\text{Water temperature correction factor} = 1 + [(77 - \text{Water temperature, in Fahrenheit}) \times 0.012]$$

Step 2. Calculate the start and stop locations.

$$\text{Start your PAM application this many miles above your downstream treatment boundary} = \left(\frac{\text{Average water velocity, in } \frac{\text{feet}}{\text{seconds}}}{\text{Water temperature correction factor}} \right) \times 0.11$$

$$\text{Finish your PAM application this many miles above your upstream treatment boundary} = \left(\frac{\text{Average water velocity, in } \frac{\text{feet}}{\text{seconds}}}{\text{Water temperature correction factor}} \right) \times 0.51$$

4. Distance to close all downstream diversions (Section 2.4.1)

$$\text{Downstream distance to close all laterals, wasteways, spillways, and diversions for 24 hours, in miles} = \left(\frac{\text{Average water velocity, in } \frac{\text{feet}}{\text{seconds}}}{\text{Water temperature correction factor}} \right) \times 6.8$$

5. Sediment addition timing if using sediment to reduce PAM concentration (Section 2.4.2.4)

$$\text{Start sediment addition this many minutes after PAM addition begins} = \frac{\text{Distance between PAM addition and sediment addition, in miles}}{\left(\frac{\text{Average water velocity, in } \frac{\text{feet}}{\text{seconds}}}{\text{Water temperature correction factor}} \right)} \times 88$$

$$\text{End sediment addition after this many minutes} = \left[\frac{\text{Distance between sediment addition and upstream point of last LA - PAM addition, in miles}}{\left(\frac{\text{Average water velocity, in } \frac{\text{feet}}{\text{seconds}}}{\text{Water temperature correction factor}} \right)} \times 1.47 \right] + \left(\frac{\text{Length of PAM application, in hours}}{\text{Water temperature correction factor}} \right)$$

(See text for the definition of each conversion factor)