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POTENTIAL USE OF POLYACRYLAMIDE (PAM) IN AUSTRALIAN AGRICULTURE TO IMPROVE OFF AND ON-SITE ENVIRONMENTAL IMPACTS AND INFILTRATION MANAGEMENT

Land & Water Resources Research and Development Corporation **(LWRRDC)**
NPIRD Travel Fellowship

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Project No. UNE39
Polyacrylamides in Irrigated Agriculture

FINAL REPORT

June 2000

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Executive Summary

Polyacrylamide (PAM) has been sold in the United States since 1995 for reducing irrigation-induced erosion and enhancing infiltration. PAM's soil stabilizing and flocculating properties have also substantially improved runoff water quality by reducing sediments, N, ortho and total P, COD, pesticides, weed seeds, and microorganisms in runoff. The first series of practical field tests of PAM was conducted in the U.S. in 1991. Chemical companies, working with "early adopter" farmers, began farm testing of PAM in 1997 in Australia. Australian farmer results have been mixed because of lack of familiarity with PAM chemical and physical attributes, lack of research focused on Australian conditions and a resulting lack of support capability from extension or other public conservation or water management infrastructure. PAM has chemical and physical properties that impart a steeper learning curve than most other typical agricultural chemicals. Nonetheless, in Australian tests of PAM, sediment, nutrients, and pesticide reductions exceeded levels achieved by traditional conservation farming methods (Waters et al., 1999a,b).

Australia's irrigated agriculture is largely furrow and flood irrigated; sprinklers still account for a minor percentage of the irrigated area nationally. Many production and environmental problems in Australia's irrigated agriculture relate to the movement of suspended silt and clay during surface irrigation. These fine suspended mineral solids are transported within and sometimes away from irrigated fields. Some fines are redeposited on the soil surface during infiltration, forming surface seals that impair infiltration. The fine solids carry nutrients and pesticides and, when transported off fields, they become the dominant mechanism for contamination of riparian surface waters or waters delivered to users downstream. For this reason, much potential exists in Australia for substantial environmental and agricultural benefit from PAM use. However, the low product cost and low per hectare application rates, while good news for farmers and conservationists interested in buying PAM and using PAM-based erosion and water quality protection strategies, also result in a small product sales volume and profit margin. Successful technology development and transfer, therefore, will need to come largely from public agricultural, environmental, and water resource infrastructures.

PAM used for erosion control is a large (12-15 megagrams per mole) water soluble (non-crosslinked) anionic molecule, containing <0.05% acrylamide monomer. In a series of controlled field studies *in the United States, PAM eliminated 94% (80-99% range) of sediment loss in field runoff from furrow irrigation, with 15-50% relative infiltration increases* compared to untreated controls on medium to fine textured soils. Similar but less dramatic results have been seen with sprinkler irrigation. Infiltration into sandy soils is often unchanged by PAM or can even be slightly reduced. Results are achieved with per irrigation field PAM application rates of about 1 kg ha^{-1} for furrow irrigation and about 4 kg ha^{-1} for sprinkler irrigation. Often only fractions of these rates are required on subsequent irrigations (if the ground has not been disturbed between irrigations) to maintain efficacy. *Seasonal application totals typically vary from 3 to 7 kg per hectare*. In the United States farmer field sediment control has generally been about 80% or more of test plot results. Similar magnitudes of erosion and infiltration effects have been seen in the instances where PAM has been used successfully in controlled settings in Australia. *Cost of PAM in Australia's farm chemical market is approximately Au$15 kg*$^{-1}$.

U.S. research has shown no adverse effects on soil microbial populations. PAM effects on crop yields have only been sparsely documented. Initial studies, focused mostly on erosion and runoff water quality effects, conducted largely in field beans or maize, showed little effect on yields, probably because all treatments were supplied adequate water. Some evidence exists for PAM-related yield increases where infiltration was crop-limiting, especially in field portions having irregular slopes, where erosion prevention eliminated deep furrow cutting that deprives shallow roots of adequate water delivery. PAM's ability to increase lateral spread of water during infiltration is particularly useful for early season water conservation. Only small amounts of water are needed to germinate seed or sustain small seedlings in the early weeks after planting. This is accomplished by not having to completely fill the soil profile because wetting patterns of PAM-treated furrow streams spread further laterally for a given volume of water applied. High effectiveness and low cost of PAM for erosion control and infiltration management, coupled with relative ease of application compared to traditional conservation measures, has resulted in *rapid technology acceptance in the US, with about 400,000 ha of irrigated land currently employing PAM for erosion and/or infiltration management.*

A number of issues and conditions will deserve specific attention to successfully develop and transfer PAM technology for Australian needs. These include, but may not be limited to, problems relating to: irrigation scheme scale, irrigation operational systematics and PAM application method needs; quality of irrigation water affecting PAM efficacy (especially sodium adsorption ratio and electrical conductivity– SAR and EC); effect of clay size fraction, clay mineralogy, and iron or other variable charge coatings on clay particles or soil aggregates; the need to impart surface sealing before initiating flocculation enhancement in rice paddies; evaluation of the interaction of intermittent rainfall with PAM-treatment. *Specific PAM applications could benefit Australian agriculture and the environment:* Pasture establishment may benefit from PAM prevention of soil- and seed-washing (i.e. migration) in the first few irrigations after planting. In some instances PAM may be the best means to prevent migration of coliform bacteria and other organisms from pastures into return flows or riparian waters. PAM's microorganism- and seed-immobilizing properties may have phyto-sanitation and weed management benefits for a variety of agricultural and environmental applications. PAM may help in a variety of infiltration-enhancing applications to reduce irrigation durations, water application amounts, pumping, seal alleviating surface cultivation and/or deep tillage etc. and improve salt leaching. PAM's flocculating properties may help with clarification of turbidity in rice paddies, but this will need to be coupled with development of specific application strategies to preserve surface sealing (e.g. via spitting the filling operation to first form a seal, followed by filling with PAM-clarified water). There may be water retention benefits of PAM in center pivot-, drip-, and microspray- irrigated sandy soils related to PAM's effect on apparent water viscosity in confined pores. It may be possible, through use of PAM-enhanced flocculation basins, to deliver sediment-free water to sediment-threatened riparian, estuarian, or marine environments. PAM may benefit mine site reclamation by accelerating vegetative cover of reconstructed surfaces, where erosion often disrupts stand establishment of seeded ground covers.

NOTE : Web posting of the report with photos from the Australian survey is planned by year's end at <http://kimberly.ars.usda.gov/pampage/shtml>

KEYWORDS : Irrigation, Water quality, Erosion, Polymer, Pollution, Surface seal, Infiltration

1 *Key Processes and considerations in PAM Use*

The terms *polyacrylamide* and the shorthand acronym *"PAM"* are generic chemistry vocabulary, referring to a broad class of compounds. There are hundreds of specific PAM formulations, depending on polymer chain length and the number and kinds of functional group substitutions along the chain. In erosion polyacrylamides, the PAM homopolymer is copolymerized. Some of the spliced chain segments replace PAM amide functional groups with ones containing sodium ions or protons that freely dissociate in water, providing negative charge sites (Fig. 1). Typically one in five chain segments provide a charged site in this manner. PAM formulations for irrigated agriculture are water soluble (linear, not gel-forming, not cross-linked super water absorbent) anionic polymers with typical molecular weights of 12 to 15 Mg mole^{-1} (over 150,000 monomer units per molecule). These PAMs are currently available industrial flocculent polymers used extensively to accelerate separation of solids from aqueous suspensions in sewage sludge dewatering, mining, paper manufacture, food processing and as a thickening agent in animal feed preparations.

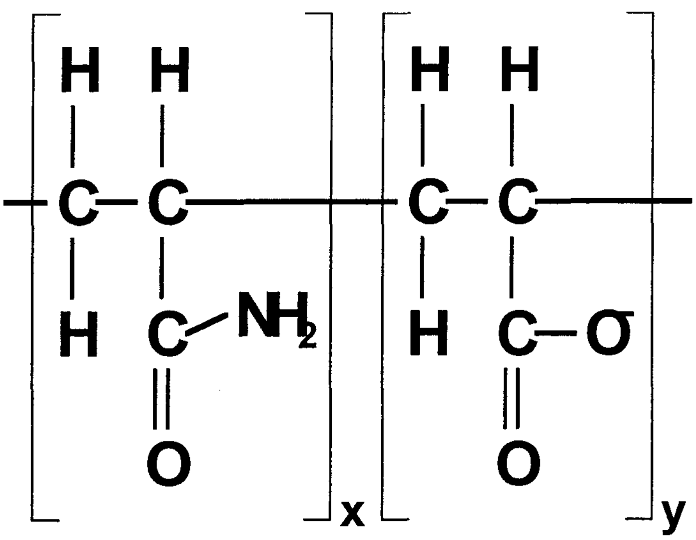

Figure 1 PAM Copolymer

PAM is attracted to soil particles via coulombic and Van der Waals forces (Orts et al., 1999, 2000). These surface attractions stabilize soil structure by enhancing particle cohesion, thus increasing resistance to shear-induced detachment and preventing transport in runoff. The few particles that detach, are quickly flocculated by PAM, settling them out of the transport stream. Minute amounts of Ca^{++} in the water shrink the electrical double layer surrounding soil particles and bridge the anionic surfaces of soil particles and PAM molecules, enabling flocculation (Wallace and Wallace, 1996).

1.1 Erosion

In three years of furrow irrigation studies in Idaho, PAM used according to the Natural Resources Conservation Service (NRCS) application standard (Anonymous, 1995), reduced sediment in runoff 94% (Lentz and Sojka, 1994). The 1995 NRCS standard calls for dissolving 10 kg ML^{-1} (10 ppm or 10 g m^{-3}) PAM in furrow inflow water as it first crosses a field (water advance -- typically the first 10 to 25% of an irrigation duration). PAM dosing is halted when runoff begins. The PAM applied during advance generally prevents erosion throughout a 24 hr irrigation. Application amounts under the NRCS standard have typically been 1-2 kg ha^{-1}. For freshly formed furrows, Lentz and Sojka (1999) reported that effectiveness of applying PAM at a uniformly dosed inflow concentration varied with inflow-rate, PAM concentration, duration of furrow exposure, and amount of PAM applied. On 1 to 2% slopes erosion control was similar among three application methods in which PAM was applied to furrows in water brought to a known concentration before it entered the furrow: 1) the NRCS 10 kg ML^{-1} standard, 2) application of 5 kg ML^{-1} during advance, followed by 5 to 10 minutes of 5 kg ML^{-1} re-application every few hours, or 3) continuous application of 1 to 2 kg ML^{-1}. Constant application of 0.25 kg ML^{-1} was a third less effective at controlling erosion.

PAM treatment is recommended whenever soil is disturbed (loose and highly erodible) before an irrigation. For the NRCS standard method (dosing the advance flow), if soil is undisturbed between irrigations and PAM is not re-applied, erosion control typically is reduced by half. Following initial PAM-treatment, erosion in subsequent irrigations can usually be controlled with much less than 10 kg ML^{-1} (1 to 5 kg ML^{-1} PAM) if the soil has not been disturbed between irrigations.

An application strategy popular with American farmers is the "patch" application method. This involves spreading a measured amount of dry PAM granules (determined on an area-equivalent basis-- furrow spacing x length at a 1 kg ha^{-1} field application rate) placed in the first 1 to 2 m of furrow below the inflow. When water flows over this "patch" of dry granules, a thin gel-like mat forms that slowly dissolves during the irrigation. Erosion and infiltration effects of the patch method are comparable to the NRCS standard approach (Sojka and Lentz, unpublished data). Erosion control in subsequent non-treated irrigations is often better with patch application than for dissolving PAM in the water supply. This is because small areas of the patch are often still intact at the end of the treated irrigation; these areas provide small amounts of PAM in subsequent re-irrigations. There are advantages and disadvantages of each application method depending on specific field conditions and system requirements (Sojka et al., 1998c). The patch method works well in most circumstances, but has sometimes been found by farmers to be unreliable on very steep slopes (greater than about 3%) or where inflow rates are very high (greater than about 50 $Lmin^{-1}$). These conditions can result in breakup and transport of the patch down the furrow, or burying of the patch by the initial sediment load scoured at or near the water inflow point. Under these conditions PAM pre-dissolved in the inflow performs more reliably. When soil is damp (from dew, or a light rainfall, or canopy shading) the patch method or use of a continuous low dosage seems to control erosion more reliably. The reason for this effect is not fully understood, but a possible explanation for this may be that the initial wetness of the surface soil interferes with the adsorption of PAM, perhaps because of a reduced potential gradient. This is thought to result in a weaker imbibition of PAM-bearing water. Thus, delivering a constant small dose of PAM is needed to compensate for weaker initial stabilization of the soil.

Farmers and NRCS in the US Pacific Northwest report about 80% seasonal erosion control on farm fields, where irrigation of disturbed soil is PAM-treated at 10 kg ML^{-1} in the advance or using the patch method, followed by irrigations of undisturbed soil that are either untreated or treated at lower rates. Farmers typically report seasonal PAM application amounts of 3 to 5 kg ha^{-1} depending on field conditions and crop (thus, number of cultivations and irrigations).

1.2 Infiltration

The advance of furrow irrigation streams usually slows when PAM is in the water, especially for the initial irrigation on freshly formed or cultivated furrows (Sojka et al., 1998a,b). This occurs because the infiltration rate of PAM-treated furrows on medium to fine textured soil is usually higher compared to untreated furrows. Surface seals form on untreated furrow bottoms due to the destruction of soil aggregates with rapid wetting, and the detachment, transport and redeposition of fine sediments in the furrow stream. The seal formation process blocks a large fraction of pores at the soil surface, reducing pathways for water entry into the soil, thereby reducing the infiltration rate. Net infiltration on freshly formed PAM-treated furrows in silt loam soils is typically 15% more, compared to untreated water. For clay soils, comparative infiltration increases can reach 50% (Sojka et al., 1998a). Pore continuity is better maintained when aggregates are stabilized by PAM. Sojka et al. (1998a) reported that infiltration at 40 mm tension varied among irrigations over the range 12.9 to 31.8 mm hr^{-1} for controls and 26.7 to 52.2 mm hr^{-1} for PAM-treated furrows and that infiltration at 100 mm tension varied from 12.3 to 29.1 mm hr^{-1} for controls and 22.3 to 42.4 mm hr^{-1} for PAM-treated furrows.

Bjorneberg (1998) reported that in tube diameters >10 mm, PAM solution macro-scale effects on viscosity are negligible at 15 and 30° C water temperatures. Macro pore viscosity does not rise sharply until PAM concentration is >400 kg ML^{-1}. However, in small soil pores, "apparent viscosity" increases are significant, even for the dilute PAM concentrations used for erosion control (Malik and Letey, 1992).

PAM infiltration effects are a balance between prevention of surface sealing and apparent viscosity increases in soil pores. In medium to fine textured soils, the more significant effect is the maintenance of pore continuity achieved by aggregate stabilization. In coarse textured soils, where little pore continuity enhancement is achieved with PAM, there have been reports of no infiltration effect or even slight infiltration decreases with PAM, particularly at PAM concentrations above 20 kg ML^{-1} (Sojka et al., 1998a).

Infiltration increase is more transitory for furrows formed on wheel-tracks than on non-wheel track furrows (Sojka et al., 1998b). It is thought that reduced surface sealing with PAM improves infiltration only until repeated wetting and drying begin to disrupt subsurface aggregates and/or deliver enough surface-derived fines to seal the few remaining subsurface pores which have already been partially reduced by compaction. Because PAM prevents erosion of furrow bottoms and sealing of the wetted perimeter, lateral water movement increases about 25% in silt loam soils compared to non-treated furrows (Lentz et al., 1992; Lentz and Sojka, 1994). This can be a significant water conserving effect for early irrigations.

Furrow irrigation farmers should take advantage of PAM's erosion prevention to improve field infiltration uniformity. This can be done by increasing inflow rates two to three fold (compared to normal practices), thereby reducing infiltration opportunity time differences between inflow and outflow ends of furrows (Sojka and Lentz, 1997; Sojka et al, 1998b). Once runoff begins, the higher initial inflows must be reduced to a flow rate that just sustains the furrow stream at the outflow end of the field. Initial observations suggest that coupling PAM with surge flow irrigation can be a beneficial irrigation practice (Bjorneberg and Sojka, unpublished data). Even with PAM in the water, there is enough reconsolidation of the furrow surface that surges still accelerate advance. However, the upper-field scouring associated with doubled flows (as is typical when surge valves are used) does not occur.

1.3 Sprinklers

Spinkler-applied PAM has been studied in soil trays and boxes (Ben Hur et al., 1989; Levy et al., 1992). U.S. farmers have been interested in PAM for sprinkler irrigation as a means to prevent runoff/runon problems and ponding effects on stand establishment and irrigation uniformity. Water and chemical application precision are improved if infiltration occurs where water drops hit the soil. In soil box studies, PAM application rates of 2 to 4 kg ha^{-1} reduced runoff 70% and soil loss 75% compared to controls (Aase et al., 1998). Effectiveness of sprinkler-applied PAM is more variable than for furrow irrigation because of application strategies and system variables that affect water drop energy, the rate of water and PAM delivery, and possible application timing scenarios (Aase et al., 1998; Levin et al., 1991; Smith et al., 1990). Ben Hur and Keren (1997), Levin et al. (1991), Aase et al., (1998) and Smith et al.(1990) all reported improved aggregate stability from sprinkler-applied PAM, leading to decreased runoff and erosion, but results varied with droplet size and energy and with the size of aggregates. Flanagan et al. (1997a,b) reported increased sprinkler infiltration when water contained 10 kg ML^{-1} PAM, which they attributed to reduced surface sealing. Water drop impact and splash affect aggregate breakdown and surface sealing on 100% of sprinkler-irrigated soil surfaces (vs. about 25% with furrow irrigation). Thus, PAM effects under sprinkler irrigation have been more transitory, less predictable and have usually needed higher seasonal field application totals for efficacy. However, farmers in the United States with sprinkler infiltration uniformity problems stemming from runoff or runon of applied water, e.g. with center pivots on steep or variable slopes, have begun to use PAM. Farmer testimonials claim improved stands because of reduced ponding, crusting and damping off as a result of PAM-use. Research is ongoing to attempt to substantiate these kinds of on-farm observations.

1.4 PAM Formulations

The choice of large anionic PAM conformations is largely for environmental and safety considerations (discussed below). Lentz et al. (2000a) reported that these properties also favoured erosion control. They compared molecular weights of 4 to 7, 12 to 15, and 14 to 17 Mg mol^{-1} , neutral, positive and negative charges, and charge densities of 8, 19, and 35 %. The order of erosion control effectiveness was anionic > neutral > cationic PAMs and efficacy increased with charge density and molecular weight. Infiltration was greater for lower molecular weights and medium to high charge density. Neutral and anionic PAMs tended to favor infiltration over cationic PAMs. Charged PAMs increased infiltration of freshly formed furrows, but slightly decreased infiltration on re-irrigated furrows later in the season; neutral PAMs did not display late season infiltration decrease on re-irrigated furrows.

Commercial anionic moderate molecular weight PAM products for erosion control are usually of two types. The most commonly used product is a fine granular form of PAM. The granules are dissolved in water inflows or sprinkled in a dry patch on the ground near furrow inlets before water is let down the furrow. The second most common category of product formulation is concentrated liquid emulsions of PAM and mineral spirits. These also include "inverse emulsions" that contain a surfactant to help disperse the PAM when mixed with water. Emulsions are more commonly used with sprinkler PAM application than in furrow irrigation. Both granular materials and emulsified concentrates require substantial turbulence or agitation and high flow rate at the point of addition to water in order to dissolve PAM to reach a desired concentration. Detailed considerations for PAM use are available in several publications on the website <http://kimberly.ars.usda.gov/pampage/shtml>.

1.5 Environment and Safety

Environmental and safety considerations of anionic PAMs have been thoroughly reviewed (Barvenik, 1994; Bologna et al., 1999; Seybold, 1994). The single most significant result of PAM use in the environment is its huge capacity to prevent erosion and improve surface water quality by reducing pollution of surface waters with sediment and other contaminants washed from eroding fields. PAM greatly reduces nutrients, pesticides, and biological oxygen demand of irrigation return flows (Agassi et al., 1995; Lentz et al., 1998). There are some specific environmental issues related to PAM charge type and PAM purity.

Cationic and neutral PAMs have toxicities warranting caution or preclusion from sensitive environmental uses, whereas anionic PAMs are safe when used at prescribed rates. Anionic PAMs are specified by NRCS for controlling irrigation-induced erosion. Anionic PAMs are used extensively in the US for potable water treatment, for dewatering of sewage sludge, washing and lye pealing of fruits and vegetables, clarification of sugar juice and liquor, in adhesives and paper in contact with food, as thickeners and suspending agents in animal feeds, in cosmetics, for paper manufacturing, for various mining and drilling applications and various other sensitive uses. Significant negative impacts have not been documented for aquatic macrofauna, edaphic microorganisms, or crop species for the anionic PAMs used for erosion control when applied at recommended concentrations and rates (Kay-Shoemake, 1998a,b).

Even at very high concentrations, when PAMs are introduced into waters containing sediments, humic acids or other impurities, PAM effects on biota are greatly buffered due to adsorption and deactivation associated with the suspended impurities (Buchholz, 1992; Goodrich et al., 1991). Loss of PAM into runoff and return flows was studied by Lentz et al. (1996). They developed a sensitive assay for PAM in irrigation water and determined that, because of PAM's high affinity for suspended sediments and soil in waste ditch streams, only 3-5% of the PAM applied left fields in runoff; furthermore, lost PAM only travelled 100 to 500 meters in waste ditches before being completely adsorbed on sediments in the flow or onto ditch surfaces (Lentz and Sojka, 1996). Ferguson (1997) reported on a watershed scale test of PAM, where over 1,600 ha were irrigated using PAM-treated water for a two week period. On any given day, about half of the 40 farms in the study were contributing runoff to the watershed's drainage, which collected in Conway Gulch, a tributary of the Boise River. Waste water from the fields and the drain was analyzed for P, sediment, and PAM. About half of the water in the drain consisted of field runoff. PAM was not found detrimental to the drain's water quality. PAM was detected in drain water samples only twice (< 0.8 kg ML^{-1}) during the entire monitoring exercise. PAM was found to be an effective sediment control practice that was well adopted by farmers and did not negatively impact the drain.

Recent findings have shown that other than mineral solids are sequestered on fields using PAM in irrigation water to prevent erosion. Broad categories of microorganisms carried across and among furrow-irrigated fields by furrow streams, runoff and return flows are also reduced by PAM in irrigation water (Sojka and Entry, 1999, 2000; Entry and Sojka, 1999). Similar reductions occur for weed seed in runoff (Sojka and Morishita, unpublished data). These new findings further underscore the enormous potential for directly improving water quality of irrigation return flows and point to potential management improvements via PAM-use that may ultimately help reduce pesticide use. Promising new research has begun to investigate new classes of polymers synthesized from organic byproducts of crop agriculture and shell fish food processing which may supplement PAM for certain uses where enhanced biodegradability is needed or where bio-based chemistry is perceived to be an environmental benefit (Orts et al., 1999, 2000).

Another important environmental and applicator safety consideration is the need to use PAMs that contain <0.05% acrylamide monomer (AMD). AMD is a neurotoxin, but PAMs below these AMD contents are safe, when used as directed at low concentrations. In soil, PAM degrades at rates of at least 10% per year as a result of physical, chemical, biological and photochemical processes and reactions (Tolstikh, et al. 1992; Wallace et al. 1986; Azzam et al. 1983). PAM does not revert to AMD upon degradation (Mac Williams, 1978). Furthermore, AMD is easily metabolized by microorganisms in soil and biologically active waters, with a half life in tens of hours (Lande et al, 1979; Shanker et al., 1990). Bologna et al. (1999) showed that AMD is not absorbed by plant tissues, and apparently breaks down rapidly even when injected directly into living plant tissue. While the anionic PAMs used to control erosion are not toxic, prolonged overexposure can result in skin irritation and inflamation of mucus membranes. Users should read label cautions and take reasonable care not to breathe PAM dust and to avoid exposure to eyes and other mucus membranes. Another caution is that PAM spills become very slippery if wet. PAM application onto roadways should be avoided and PAM spills should be thoroughly cleaned with a dry absorbent and removed before attempting to wash down with water. Practical user considerations are numerous. Labels, website information and available extension information should be consulted before embarking upon large scale use of PAM.

2 *PAM Use in and outside the United States*

Soil stabilizing polymers were used in World War II to hasten construction under sub-optimal conditions (Wilson and Crisp, 1975). The idea was adapted for agriculture in the early 1950s (Weeks and Colter, 1952). The literature of polymeric soil amendments is extensive. Early use of PAM and other conditioners improved plant growth by reducing soil physical problems by stabilizing aggregates in the entire 30 to 40 cm tilled soil depth. This approach applied hundreds of kilograms per hectare of PAM via multiple spray and tillage operations. Material and application costs limited PAM-use to high value crops, nursery operations, etc. By the 1980s polymer costs, formulations and purity had improved. Reduced sediment in runoff, when irrigating furrows after pretreatment with PAM, were noted by Paganyas (1975) and Mitchell (1986). Lentz et al. (1992) reported a practical economical low-rate strategy for PAM-use to control furrow irrigation erosion. Malik et al. (1991b) found that PAM applied via infiltrating water is irreversibly adsorbed in the top few millimeters of soil. Thus, PAM delivery via furrow streams is very efficient, because it needs only stabilize the thin veneer of soil directly active in the erosion process. Furrow irrigation application of PAM treats only about 25% of the field surface area to a few millimeters depth. Thus, high efficacy is achieved with no more than 1-2 kg ha^{-1} of PAM per irrigation.

In the 1990s water soluble polyacrylamide (PAM) was identified as an environmentally safe and highly effective erosion-preventing and infiltration-enhancing polymer, applied at rates of 1 to 10 kg ML^{-1} (10 ppm or 10 g m^{-1}) in furrow irrigation water (Lentz et al., 1992; Lentz and Sojka, 1994; McCutchan et al., 1994; Trout et al., 1995; Sojka and Lentz, 1997; Sojka et al., 1998a,b). PAM achieves this result by stabilizing soil surface structure and pore continuity. In 1995 the United States' Natural Resource Conservation Service (NRCS) published a PAM-use conservation practice standard (Anonymous, 1995) that will be available in revised form by 2000. The standard gives considerations and methodologies for PAM-use. PAMs were first sold commercially for erosion control in the US in 1995. *By 1999 about 400,000 ha were PAM-treated in the U.S. The U.S. market is expected to continue to grow as water quality improvements are mandated by new Federal legislation and court action, and since PAM use is one of the most effective and economical technologies recently identified that accomplishes the needed water quality improvement. PAM-use has also branched into soil stabilization of* *construction sites and road cuts, with statewide standards for these uses having been formalized in Wisconsin and several southern states. Interest in PAM has also occurred outside the U.S., in places as diverse as Australia, Canada, Central America, Africa, Spain, Portugal, France, and Israel.*

3 Current PAM-use in Australia

PAM already is being used extensively for erosion control and infiltration enhancement in the Emerald River and Ord River irrigation areas (perhaps a fourth of the hectares in the Emerald area and half in the Ord area). Large scale trials have been preformed in the cotton growing areas of Queensland from Moree to St. George, although issues of operational scale and "culture" remain to be adequately addressed before continued adoption of the technology is assured in the cotton growing areas. Several large PAM trials have been conducted in the predominantly sugarcane area of the Burdekin River, however, continued adoption of PAM has been hampered by compounded problems of soil and water sodium levels. Local users were unaware of the need for calcium in the water and unfamiliar with the "patch" application method, two considerations that would likely improve adoption in that area. In South Australia, on the sandy soils from Loxton to Mildura, adoption of PAM under center pivots for row crops and with drip irrigation of high value horticultural crops, especially grapes and citrus, has a strong foothold, primarily because of perceptions of improved water retention and wetting patterns (no research has yet verified this, but numerous growers have asserted that their on-farm comparisons bear out large economic improvements).

4 Potential for PAM-use in Australia / Envionmental and production considerations

In some regions in Australia a rapid expansion of irrigated agriculture is taking place, although irrigation diversions have been capped within the Murray-Darling Basin, where most of the Australia's irrigated agriculture takes place. This expansion is happening both through development of publicly funded local and regional surface water schemes and through private development of on-farm water supplies. The on-farm water supplies include seasonal diversion and/or impoundment of all or parts of streams, diversions from flowing rivers, and pumping from wells (bores). In some regions, water is often stored in large shallow on-farm reservoirs ("ring tanks"). A significant portion of the total water supply in some areas is the contribution of tile drain water, used separately or used conjunctively with well- or surface-water (i.e. blended or "shandied" water). These systems are meant both to sequester runoff water and carried pollutants from riparian waters and to conserve water for irrigation. While the practice is being discouraged and largely curtailed, tail water from some irrigation systems, is still sometimes returned to rivers, carrying sediments, nutrients, dissolved organic matter, pesticides, microorganisms and weed seeds. Tail water and tile drain water reuse systems also add to the salt and sodium loads of water being reapplied to the soil surface. Throughout Australia, several aspects of erosion/sediment-transport prevention, clarification of turbid water and better infiltration management bear strong potential for effective and economical improvement through adaptation of PAM technology.

In essentially all of Australia's major irrigated areas, some growing season rainfall occurs in most years. In nearly every year, one or more of these rainfalls, in most areas, are sufficiently intense and/or sustained or voluminous to exceed the on-farm storage capacity and result in spilling of some excess water from storage. When on-farm storage capacity is exceeded, there can also be runoff losses directly from fields into riparian waters. The resulting pollution of riparian waters has alarmed environmental groups and non-agricultural water users. If nutrients and pesticides were retained on fields, the contamination of riparian waters from direct field runoff or from overflow of contaminated water from storage basins would be greatly reduced. Ensuring on-field soil retention best prevents pollution of surface waters with nutrients and pesticides.

Among the approximately forty farmers interviewed for this report, erosion per se was seldom regarded as a direct production-threatening issue. This perception was due primarily to farmer assessments (usually based upon annual earth moving and channel shaping expenses) that relatively small masses of soil were being transported within or from fields. Even where field soil loss was occurring, most of the sediment was usually thought to be captured in closed-loop on-farm or district-wide water management schemes, and being held in on-farm reservoirs or being returned to fields in irrigation water without loss to riparian waters. However, nearly all the farmers interviewed recognized the turbidity of supplied water or reused water as a cause of surface sealing of soil and reduction of infiltration rates. Farmers across Australia complained about the turbidity of water supplied to their farms from public irrigation schemes, or as water withdrawn from open rivers or from their own on-farm water impoundments. Even in the Toolangi strawberry growing area in Victoria, where soil structure was relatively good and water sources relatively free of sodium or suspended sediment, farmers were very keen to develop an economical alternative to repeated cultivation and deep ripping to preserve infiltration rates. In this case, elimination of one or more tillage operations and/or a single irrigation per season were regarded as sufficiently valuable in terms of time savings, pumping or labor costs, and reduced compaction-inducing traffic to consider using PAM, applied through sprinklers, to reduce surface sealing and improve infiltration. In the cotton growing areas of Moree, St. George and Emerald, there was concern over the endosulfan entrained and transported to riparian surface waters via sediments in runoff. Sediment in runoff was also viewed as a disease vectoring threat for soil borne diseases like fusarium. Soil-dispersion and water-turbidity, causing light penetration and temperature problems, were recognized by New South Wales rice growers as a threat to stand establishment and a cause of delayed maturity, capable of causing severe yield losses.

Increasing salinity and sodicity of recycled or downstream waters are direct threats to plants and to soil structure and hydrology. Elevated irrigation water SAR also increases erosion in furrow irrigated systems, through increased dispersion of clays leading to greater disruption of aggregates (Lentz et al., 1996). Ultimately this increases the transport and deposition of fine materials in furrows, causing the surface sealing that reduces infiltration. Sugarcane growers in the Burdekin River area rely heavily on the use of gypsum to lower the exchangeable sodium percentage (ESP) of sodic soils and improve infiltration. As noted by Nadler (2000), however, this practice may not be sustainable in all instances. Where sodicity is high but salinity is low, gypsum is usually effective for improving soil chemical and physical properties. However, gypsum is not always successful, depending on the mineral composition of the soil profile and soil solution. Gypsum addition leads to an increase in salinity (Electrical Conductivity– EC) which can benefit soil physical properties, until extreme salinity levels are attained, threatening plant performance directly. One of the main rationales for using gypsum is to reduce surface sealing and improve infiltration. Where the main aim in gypsum use is to prevent surface sealing, and not profile sodium displacement, PAM has the potential to help prevent surface sealing and improve infiltration in sodium-affected systems while helping reduce the amount of salt loading inherent in continual use of gypsum. The usefulness of PAM for improving water intake and salt removal from shrink-swell soils has already been demonstrated (Malik et al., 1991a).

Reduced infiltration rate has several cascading consequences for irrigation farmers. More water must be supplied (often pumped) or irrigation duration must be extended to achieve adequate infiltration to meet crop water requirements and runoff is increased. If runoff is occurring– even in water reuse systems– this leads to added energy consumption and labor costs to provide an adequate amount of water per irrigation to the soil profile and adds to the potential for off-site pollution via runoff contaminants. Unrecognized, reduced infiltration rates can lead to yield and/or quality reducing crop stresses. If infiltration rate-reduction is sufficient, it may lead to one or more added irrigation events being necessary during the growing season, with their associated additional water, fuel, and labor costs. Where reduced infiltration rates are associated with prolonged ponding of water on the soil surface, the extra ponding time can lead to crop aeration stress, and greater predisposition to disease or insect damage. Aeration restriction can induce physiological root pruning that can then lead to water stress between irrigations and/or result in greater irrigation frequency to avoid stress. Discrepancies in infiltration opportunity time from field inlet end to outlet end, and variations in field soil hydraulic properties can lead to nutrient and agrichemical leaching into groundwater, or losses of nitrogen via denitrification.

Erosion control and surface seal prevention with PAM will require attention to irrigation water SAR and EC. Even on a calcium-dominated soil (containing free calcium carbonate) in the US, mean sediment concentration of runoff and total sediment removed during furrow irrigation doubled and infiltration decreased 20% when irrigation water EC was decreased from 2 to 0.6 dS m^{-1} and SAR increased from 0.7 to 12 [m mol_c L^{-1}]$^{0.5}$ (Lentz et al. 1996). Wallace and Wallace (1996) noted the need for calcium electrolytes in irrigation water when using anionic PAM for infiltration and erosion control. Lentz and Sojka (1996) noted that when irrigation water SAR was increased from 0.7 to 9.0 [m mol_c L^{-1}]$^{0.5}$ that PAM's infiltration enhancement over control water was greatly diminished. In the areas visited in Australia, SAR of surface waters was generally below 5 [m mol_c L^{-1}]$^{0.5}$ (where farmers or conservationists knew the values). However, subsurface drain waters, and irrigation waters, resulting from blending of surface sources and subsurface drain water, were often much higher. In at least one instance, variation in PAM efficacy on a farm, whose owner (Mike Brosnan– Emerald, Queensland) was experienced with and committed to PAM use, seemed related to SAR differences among treated fields. A field irrigated with canal water having an SAR of 0.74 [m mol_c L^{-1}]$^{0.5}$ and EC of 0.22 dS m^{-1} consistently had good erosion control and infiltration when PAM was used, whereas an adjacent field, irrigated with water having an SAR of 4.3 [m mol_c $L^{-1}]^{0.5}$ and EC of 1.24 dS m^{-1}, often showed poor performance with PAM treatment. While this observation cannot be regarded as conclusive, it fits known data and principles and suggests an area for investigation of application criteria that may need to involve blending of PAM with a ready calcium source for use in high SAR waters.

Using PAM to control turbidity of rice irrigation water poses a significant potential that will depend on a challenging combination of surface seal and flocculation management that can conceivably be attained with a bimodal water application strategy and timing of PAM delivery. In all likelihood, this will require separating the initial flooding of rice paddies into two phases. The first phase of paddy flooding would apply just enough water to slake and seal the soil surface. The second phase would involve use of PAM (possibly PAM and a calcium source, depending on water SAR) to clarify the water flooded onto the sealed paddy. The clarified water would benefit stand establishment and early growth. The interruption between the two flooding phases, as surge irrigation technology has taught us, would only need to be for a fraction of an hour– only long enough for any free-standing water to enter the profile. The seal structure is quickly consolidated even at very slight water tensions. Once no free-standing water remains, paddy flooding could be resumed with PAM/Ca-clarified water without affecting the infiltration properties of the seal.

Establishment of flood-irrigated pastures in Victoria and Queensland has often been impaired by erratic and nonuniform seed emergence and sward growth. These non-uniformities are thought to be the result of high water flow rates at inflow ends of the pasture scouring and washing seed and soil. The washed areas often remain bare for prolonged periods and/or become weedy. Use of PAM in irrigation water during pasture establishment could prevent the scouring and washing away of seed and thereby promote more uniform emergence.

Another issue relevant to pasture management and other confined animal feeding operations (CAFOs), such as dairies or feedlots, is the need to insure on-field retention of coliform bacteria and other fecal microorganisms. Runoff from pastures and CAFOs are recognized sources of surface water contamination that threaten surface water quality and public health in systems with direct or indirect exposure of humans to the contaminated water. Recent studies in the US (Sojka and Entry, 1999, 2000; Entry and Sojka, 1999) have shown that PAM can greatly reduce nutrients and microorganism amounts in treated runoff. Ongoing work in Idaho (US) and in the Toowoomba, (Queensland) Australia area has shown that the sequestration effectiveness of the PAM is dependent on several management factors, including inflow rates and PAM application method (J.A. Entry, personal communication, 2000). The use of PAM in animal waste lagoon waters to accelerate settling of solids and partially sequester microorganisms and nutrients is also the subject of ongoing work in Idaho (Entry and Sojka, unpublished data) that may have relevance to Australian conditions, particularly where lagoon waters are applied to pastures and can runoff into open surface waters or return flow systems.

Horticultural farmers in the sandy areas from Loxton (South Australia) to Mildura (Victoria) are interested in a unique application of PAM for which there is little previous research to guide them. This stems from PAM's *reduction* of infiltration in sandy soils caused by the increased apparent viscosity of PAM solutions within soil pores (Malik and Letey, 1992 and Bjorneberg, 1998). In sands, surface sealing and water entry are not problems, but water retention and pass through time can be. On sandy soils, center pivots systems are hard pressed to apply adequate amounts of water and make a full circle fast enough to avoid crop water stresses in high evapotranspiration (ET) environments, especially where advective components are also high. If water viscosity is slightly increased in sandy soil, water infiltration is not substantially impaired, but water retention might be significantly increased. If water retention in the range of plant available water were increased as little as 10% in a 1 m profile, the available water saved would be equivalent to nearly a full day's ET. In the growing season of a typical crop this could greatly reduce the amount of water application needed, reducing water application amount, pumping cost, energy and leaching losses of nutrients and agrichemicals to groundwater. Although this concept has not been scientifically tested, several Australian center pivot irrigators growing potatoes in the Loxton area have begun using PAM at 1 kg ML^{-1} following this rationale. They offer testimonial endorsement of the strategy, convinced that stand establishment, plant stress-reduction, nutrient uptake, crop quality and yield have all benefitted from the practice. In the horticultural areas near Loxton, Mildura and Kerang, PAM has been used for up to three years by some farmers in drip irrigation systems for table and wine grapes, citrus, avocados, stone fruits and apples. In these drip irrigated crops, farmers have cited effects that they also explain in terms of water retention and wetting patterns. Drip irrigators report that using 1 kg ML^{-1} PAM in their irrigation water promotes a wider wetting pattern. They explain this result as "mounding" of water in the profile in to a broader "onion-shaped" water column.

They explain this as the result of reduced water and nutrient stress, because of water contact with a larger portion of the root zone, slower water and nutrient "pass-through" time and, thus, better water and nutrient absorption. As a side benefit, they note that drip lines run cleaner and without the need for periodic acid-treatment to flush out scale. Again, although these were testimonials and not replicated scientific observations, these were among the most meticulous managers encountered in interviews for this report; they were very familiar with their operations. They know what the wetting patterns had been without PAM, and closely followed plant and soil water indicators to maintain crop quality and yield in crops whose market value are very quality-dependent.

The estuaries, beaches and coral reefs of the western coast of Australia are valuable natural, fishing, and tourist resources. Some of these areas are being severely threatened by sediments carried seaward by rivers servicing inland agriculture. Retention of sediments on farm fields should be an especially high priority to protect these marine environments. The use of PAM as an erosion-mitigating technology in the fluvial systems affecting these waters should be a high priority. Several specific field crop uses of PAM mentioned above in sections of this report could play an important role in reducing fluvial sediment, nutrient and pesticide contamination, especially in Kununara (Western Australia) and Burdekin (Queensland) cane growing areas where there are substantial return flows directly from crop fields to surface riparian waters. In addition there may be areas where PAM could play a role in water clarification in wetlands or settling basins to reduce the amounts of suspended solids leaving the land for marine habitats.

Mine spoil reclamation and erosion prevention is a research area that has been pursued for two or three years in Australia with mixed success (Vacher, 1999; Raine and Allen, 1998). The challenge for achieving mine spoil reclamation is largely to prevent erosion on reconstructed landscapes long enough for successful revegetation to occur. Preventing erosion on reconstructed landscapes at mine sites is often expensive and complicated by lack of organic cover and poor physical and chemical properties of stockpiled soil materials. Often soils are highly dispersible because high sodium content. Structure may have been degraded during the mining, stockpiling and reconstruction process. Water for irrigation is often unavailable, and when rainfall comes it can often occur on nearly bare ground that is highly erosion susceptible. The challenges in adapting a PAM-based erosion abatement strategy come from the difficulty of dosing the water causing the erosion (rainfall– often widely separated high-energy high-accumulation events). Furthermore, in a mine setting, the tendency is to look for solutions that allow management with large scale mining-oriented equipment. Once reconstruction has been accomplished (i.e. planted), the tendency an expectation for the ecosystem to recover "on its own", with little or no further intervention by the mine. In laboratory simulations, PAM has been shown effective at reducing erosion of Australian mine spoils and reconstructed soils. There have been difficulties in successfully extending the technology to field scale applications. Cost is less of a factor in these reclamation scenarios than for on-farm erosion control. Nonetheless, remoteness, convenience and site-conditions play large roles in adapting the technology. The use of higher application rates of PAM, applied via hydromulching equipment or aerial application deserve field scale testing. Success may require combination of PAM application with calcium sources to combat the high sodium content of many reconstructed soils. Application methods, timing, geometry and rates will likely all need to be investigated if the key to successful performance at Australian mine sites is to be discovered. The benefits, however could be significant, potentially greatly reducing the time required for mature revegetation of reconstructed mine sites.

Finally, PAM efficacy is impacted by various environmental factors. One of these is PAM degradation via ultraviolet light (UV). The UV levels encountered in Australia can be double or more the conditions in the United States where most of the initial PAM field research was done. The duration of PAM effects in the field may be shorter in Australia than in the US because of the higher UV energy levels. This could pose packaging, storage, handling and usage considerations related to UV effects that are specific, or at least more important for Australian conditions than for the northern hemisphere.

5 Recommended PAM research and development requirements for Australia

Below are ten topic areas that emerged as researchable questions from this survey of Australian irrigated agriculture. The topics vary in their degree of basic v.s. applied focus. Significant progress toward optimizing PAM technology for Australian conditions could be made in two to three years through pursuit of these investigation areas.

1. Optimize use of PAM for erosion and surface seal reduction in furrow irrigation. This

work must focus on impacts of specific Australian soil properties (e.g. mineralogy, clay size fractions, soil EC and ESP and water EC and SAR etc.) and the production system requirements of the large scale of water application systems on many Australian surface-irrigated farms.

2. Develop strategies for use of PAM to improved uniformity of pasture establishment.

3. Develop strategies for use of PAM to sequester microorganisms in irrigated animal production systems to protect water quality of return flows.

4. Develop use of PAM in furrow and sprinkler irrigation systems to improve infiltration in easily surface-sealed soils, with a particular aim to reduce the water application amount or frequency required for adequate infiltration and crop water availability. This thrust will likely find greatest application on heavier textured and/or sodic soils and evaluation should include investigation of PAM on gypsum application needs and soil profile salinity and sodicity changes as affected by leaching differences with and without PAM.

5. Verify the vectoring reduction potential of PAM in furrow irrigation systems for improved crop disease prevention and weed infestation reduction, both within individual fields and among fields where runoff is collected and used elsewhere.

6. Develop practical strategies for use of PAM to clarify turbidity of rice paddy irrigation water. This will likely require a bimodal water application strategy to insure surface sealing before PAM is introduced for water clarification.

7. Verify the effects of PAM on soil water retention properties in sprinkler- and drip-irrigated coarse textured (sandy) soils and investigate possible related effects on plant stress reduction and improved nutrient availability and reduced leaching.

8. Development of construction site, canal bank and mine site soil surface reconstruction strategies that take advantage of PAM's erosion preventing potential. These strategies will need to include consideration of anionic PAM's need for calcium ion to guarantee effective soil cohesion and retention, and will need to be developed using application

technologies compatible with each application scenario. For example, hydromulching may be needed for PAM use on canal banks or construction sites and aerial application techniques may be needed for compatibility with mine site operations and equipment.

9. Evaluation of field-applied PAM efficacy loss over time under high UV loads common to Australian conditions during crop growing/irrigating seasons; this work could involve both field and laboratory qantification of UV effects.

10. Development of emergency sediment retention strategies via constructed sedimentation basins and/or in conjunction with constructed wetlands to accelerate removal of sediments in proximity to sensitive riparian, estuarian or marine environments.

6 *Policy frameworks for future use of PAMs*

Regarding the more applied questions, close liaison with commercial interests and farmers would be advisable to ensure that progress is directed at cost effective solution strategies. For effective transfer of technology, the public conservation and soil/water management sector of Australian national, regional and local administration will need to play a key role. One or more key research or extension person(s) in each of the major irrigated areas will need to become intimately familiar with current PAM literature and applied technology from outside Australia, and become involved with local R&D efforts, as well as devote a significant amount of time transferring the technology to users. Once learned, the PAM technology is highly effective, however, it has a steep learning curve that is sometimes counter-intuitive in the context of more familiar agrichemical application technology. This relates to some of the unusual chemical and physical properties of the polymer. Experience from visits during this survey of Australian farmers who have experimented with or adopted PAM use suggests that, as has been the case across the US, they are keen observers and innovative adaptors of technology, provided that the key information is properly explained and adequately emphasized in clear consistent communication. Because of the relatively low cost and profit margin of agricultural PAMs for erosion/infiltration/flocculation, the technology transfer will need to come largely from the public sector– there isn't a strong enough financial incentive for PAM distributors to spend a large amount of time and money promoting this class of products. However, because of the large potential for environmental (especially surface water quality) benefit that would otherwise be very costly to achieve through alternate technologies, the public sector should seriously consider the potential for widespread public good through well-targeted promotion of PAM technology. PAMs have very few potential negatives associated with their use, however, two formulation criteria that might deserve attention relate to purity and charge type. As explained above, PAMs with low AMD content and anionic charge are specified by regulation in most US states having soil amendment laws. The same criteria would be advisable for Australian products.

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Bob Sojka's full itinerary

As of 12/01/2000

18th Jan 2000 Delta Airlines Inc. **(Carrier Sky West)**
Flight: **DL3804**
Twin Falls Departs : **1230**
Salt Lake City Arrives : **1324** Terminal Unit 2
(Journey Time 54min)

18th Jan 2000 Delta Airlines Inc.
Flight : **DL1411**
Salt Lake City Departs : **1445** Terminal Unit 2
Los Angeles Arrives : **1538** Terminal 5
(Journey Time 1Hr 53min)

18th Jan 2000 Qantas Airways Ltd
Flight : **QF 100**
Los Angeles Departs : **2010** Bradley Intl Terminal
20th Jan 2000 **Melbourne** Arrives : **0900** International Terminal
(One Stop – Auckland New Zealand) (Journey Time 17Hr 50 min)

20th Jan 2000 Melbourne 9.00am picked up by car and drive to Tatura
(Approx. 2.5 Hr)

Tatura, Melb, VIC from 20th Jan 2000 - 30th Jan 2000

21st – 23rd Jan 2000 Settle in – Recover from flights

24th Jan 2000 Tour Goulburn Broken Catchment region (ISIA/GMW)
Visiting Toolangi area – Graham Wilkinson

27th Jan 2000 Preparation for Presentation (ISIA/GMW)

28th Jan 2000 Presentation – Is PAM a best practice management method to be adopted by the catchment? (ISIA/GMW)
Full day facilitated workshop

29th Jan 2000 Rest ready for QLD - Toowoomba

Sun 30th Jan	Tatura to Melbourne (Aravind) **QF618** Melbourne 11.05am Fly to Brisbane 12.10pm then drive with Col Schiller to Toowoomba QLD (Stay over Sun, Mon, Tues nights at Bridge Street Motor Inn (07) 46343713 / Fax (07) 4634 3060 ***(ISIA Full)***
Mon 31st Jan **Tues 1st Feb**	Workshop with Steve Raine, Rob Loch, David Waters Colin Schiller, Skip Webb and other locals and students

Possibly an evening presentation with Soil Sci Society and Agri Sci Society. (Joint Seminar)

Wed 2nd Feb	Travel 280km to Moree (Northern NSW) to visit RMI co-operative Farm. Drive 120km to Colly. Stay over night at Colly farm.
Thur 3rd Feb	Visit Colly (Nth NSW) then travel 210km to St George (Sth QLD) where there is PAM's in action! Stay over night at Merino Inn (07) 4625-3333. Plus BBQ in evening with local growers, DPI, etc.
Frid 4th Feb	Travel with Col to Brisbane. Stay over night and Sat 5th Feb at Rydges (07) 3255-0822 / Fax (07) 3255 0899
Sun 6th Feb	Met with Skip Webb in Brisbane. **QF2404** Travel Brisbane 1.50pm to Emerald 3.50pm
Mon 7th Feb	Visit Emerald Irrigation area with Skip Webb (drive).
Tues 8th Feb	QF2314 Rockhampton 3.50pm to Townsville 5.55pm. Met with Col and Stay overnight Parkside Motel (07) 4783-1244/ fax (07) 4783 4769
Wed 9th Feb	Drive 100km to Burdekin Irrigation area Nth QLD meeting with Gary Ham and other BSES. Stay over night Parkside Motel (07) 4783-1244
Thurs 10th Feb	**QF2506** Townsville 4.30pm to 5.35pm Cairns then **QF944** Cairns 6.05pm to Darwin 9.20pm then Stay over night at Atrium Motel (08) 8941-0755/ Fax (08) 89819025.
Fri 11th Feb	**AN1313** Fly 8.00am Darwin to Kununarra 7.40am and Stay over at Mercure Inn (08) 91681455/ Fax (08) 9168 2622
Sat 12th Feb	**AN2392** Fly 4.35pm Kununarra to 7.00pm Darwin. Stay over night at Atrium Motel (08) 8941-0755
Sun 13th Feb	**AN158** Fly 12.00 noon Darwin to 4.35pm Adelaide. Stay over night at The Grosvnenor Hotel Adelaide (08) 8231 2961/ Fax (08) 8407 8860
Mon 14th Feb	Meeting with Andrew McHugh for guided tour of PAM work in SA. Arrive Barossa Junction Resort with Andrew on contact number

Tues 15th Feb	Elders Agronomy Conference (am) pm: Travel to Alawoona met with John Gladigau, Browns Well Ag. Bureau. Trial discussion - the role of PAM's in low rainfall cropping zones. Fertilizer vs Seed application methods. Getting trial objectives in place.
Wed 16th Feb	Citrus Field Day - Ingerson's Bookpurnong Fertigation with PAM's, suspension fertalizers, pruning systems pm: Fertigation with PAM's in the Loxton district, Century Orchards, Tom Quirke, Kingston Estate. Overnight in Loxton, BBQ native wildlife at their place.
Thurs 17th Feb	Travel to Mildura - PAM's in drip irrigation. Table grapes: Panuccio's and Cue enterprises. Mixing PAM's and fertalizers: T Opardo, Iraak and J Russell,Iraak. Dropped off in Swan Hill staying at Travellers Rest Motor Inn, 110 Curlewis St (03) 5032 9644
Friday 18th Feb	Picked up (7am) to Travel around Swan Hill with Stewert Rendall (03) 50329-255 (Rice and Gypsum application) Drive to Griffith to stay at The Kidman Wayside Inn, 58-72 Jondaryan Ave (02) 6964 5666 from Friday to Tuesday 22nd Feb morning.
Mon 21st Feb	Brett Tucker (LWRRDC) phone (02) 6964 1873. Possible – CSIRO seminar (Fiona Myers)
Tues 22nd Feb	Brett Tucker organise Bob back to Kerang in the late afternoon where he will be staying at a motel.
Wed 23rd Feb	Travel around the area with Bill Heslop then dropped back to Tatura ISIA.
23rd–27th Feb 2000	ISIA Tatura – Consulting and Report writing.
28th Feb 2000	**Tatura – Sodicity Conference Day One**
29th Feb 2000	**Tatura – Sodicity Conference Day Two**
1st March 2000	**Tatura – Sodicity Conference Day Three**
2nd March 2000	ISIA – Proposal work
15th March 2000	Tatura drive to Melbourne Airport (280km)

15th March 2000	Qantas Airlines Ltd	
		Flight : **QF 101**
	Melbourne	Departs : 1220 International Terminal
	Los Angeles	Arrives : **0730** Bradley Intl Terminal
	Non-Stop	(Journey Time 14Hr 10min)
15th March 2000	Delta Airlines Inc.	
		Flight : **DL 465**
	Los Angeles	Departs : **1040** Terminal 5
	Salt Lake City	Arrives : **1325** Terminal Unit 2
		(Journey Time 1Hr 45min)
15th March 2000	Delta Airlines Inc	**(Carrier Sky West)**
		Flight : **DL3805**
	Salt Lake City	Departs : **1505** Terminal Unit 2
	Twin Falls	Arrives : **1605**
		(Journey Time 1Hr)

NOTE : There were some minor changes to this itinerary due to some unforseen circumstances. Dr Bob Sojka had to depart earlier than expected due to his mother's ill health.

Appendix II– Focus group workshop notes

Focus Group Workshop Notes

Fiona Smolenaars
244 Mitchell Rd, Kialla Victoria 3631

Thursday 27th January, 2000
Goulburn Murray Water Training Centre, Tatura 3616

THE CONVERSION:
In America the flow of water is from:
Canal → Laterals → Ditches (return)

In Australia, the flow of water is from channel to delva and then back through a drainage network.
Farm channel (delva) ← Spur ← Channel
On farm drain → Community drain → Catchment (primary) drain→ Natural stream

TOMATO INDUSTRY:

(i) What are the problems relating to water use and irrigation management that your industry faces in the next 5 years?

- Was furrow irrigation but now (60-70%) drip
- Griffith likely to stay furrow
- Jerilderie reverted to furrow (1 grower)
- Expect 20-30% will stay furrow

- Erosion is not an issue
- Potential for PAM in infiltration with either furrow or drip
- Water shortages and irrigation efficiencies.

(ii) What do you see as the problems or questions about the use of PAM technology in your industry?

- blocking drip lines?
- Cost – may use more PAM during the season
- Will PAM alter water holding capacity of soils (mainly clay soils around here)?
- Problem: even emergence of seed
  Pesticide and nutrient runoff
- Water logging as a result of heavy rain
- Bio-degradation of PAM

DAIRY INDUSTRY:

(i) What are the problems relating to water use and irrigation management that your industry faces in the next 5 years?

- Freshly lasered ground – fall of 1:600 and irrigating every 7 days

  Soil loss, pasture establishments, nutrient loss
  Dairy Farmers use the most water, create the most nutrients, attaches to sediment when available.
- Sediment in drains (re-use)
- Possible Water Holding Capacity in soil profile
- Cracking soils
- Water quality – ground water, effluent (waste water), channel water, re-use water
  How does PAM relate to the above?

(ii) What do you see as the problems or questions about the use of PAM technology in your industry?

- Where are sediments coming from?
- Applying PAM with first irrigation on freshly lasered ground
  Need to know impact on mass balance of nutrients and sediments
  Effect on pasture establishment
- Combating sediments that are generated with the drainage networks
  Rain fall events, channel scouring
- Can we increase the Water Holding Capacity and this decrease the frequency of irrigation - effects of Water Use Efficiency.

MIXED CROPS:

(i) What are the problems relating to water use and irrigation management that your industry faces in the next 5 years?

- Economic viability - $/Ml
- Poor infiltration – red brown earth
- Access to water – there is movement away from mixed crops to higher return crops.
  $100/ML for mixed crops, $300/Ml from dairying and $1000/Ml from horticulture
- Nutrients and pesticides in run off
- Irrigation efficiencies
- Transportation of pesticides with sediments/dust
- Sodicity, pH, salinity , water table

(ii) What do you see as the problems or questions about the use of PAM technology in your industry?

- Effects of PAM in soil/water – sodicity, salinity and pH
- Change of irrigation practices

- Identifying soils where it will be effective
- Calcium levels in soils adequate??
- Cost and benefit analysis
- Does it effect micro nutrient availability
- Benefits to the environment – reduced nutrients in sediments
- Effect on environment – in relation to soil, fish, worms
- Breakdown products
- Organic farming certification – synthetic PAM

REGIONAL CHANNELS AND DRAINS:

(i) What are the problems relating to water use and irrigation management that your industry faces in the next 5 years?

- Erosion – sediments, nutrients, salinity, chemicals, agricultural run off, cost of re-building banks
- Seepage – water conservation, high water tables, ground water quality.

(ii) What do you see as the problems or questions about the use of PAM technology in your industry?

- Drains: entrance to wetlands
  Adding PAM to hydromulch?

- Channels: small distribution channels – up to 20Ml/day, high erosion rates
  Mix with channel bank material before construction?
  Or apply to batters?

Appendix III – impressions from the Sodicity conference

Impressions from the Sodicity Conference

Dr BOB SOJKA
USDA/AGRICULTURAL RESEARCH SERVICE
NORTHWEST IRRIGATION AND SOILS RESEARCH LAB
3793N-3600E, KIMBERLY, ID 83341, USA
PH 208-423-6562, FAX 6555, e-mail: sojka@kimberly.ars.pn.usbr.gov
WEBSITE: http://kimberly.ars.usda.gov

In January of this year I arrived for a two month visit of Australia, on a mission to assess the nature and extent of irrigation-induced erosion, its impact on surface water quality and the feasibility of using chemical polymers to help alleviate these problems. My visit coincided with the Sodicity Conference held in Tatura, Victoria, from 28 February through 1 March, and since I was not a formal conference participant its organizer, Dr. Aravind Surapaneni, asked if I could offer comment from, what he termed "an objective and unbiased viewpoint." While being humbled by a suggestion to offer comment on the contributions of so many fine scientists in a field in which I have only had a small personal role, I was also eager for the chance to offer comment on a topic that, as my own fact finding trip confirmed, is so central to the future fate of Australian agriculture. Sodicity is especially important to Australia's irrigated agriculture and its surface water ecology and its terrestrial and riparian management.

"Awareness" may be the word that best sums up the issue of greatest public importance, and it did not take long to surface at the conference. Several speakers noted that many Australian land managers are still unaware of the extent and potential severity of their country's soil and water salinity and sodicity problems. This may be related to the fact that the ambitious development of large irrigated tracts has been a relatively new occurrence and that even on tracts established in the 1950s and 1960s it has taken several decades for sodicity and salinity problems to manifest themselves. The problem of awareness takes on an even greater urgency now as widespread conversion from rainfed pasture and grazing lands, following a market-driven decline of the sheep and wool industry, is prompting many landholders to convert their operations to irrigated cropping. Many of these "new farmers" are unfamiliar with basic "on farm" aspects of soil chemistry and soil physics– even to the extent of not distinguishing the difference between salinity and sodicity. Indeed, it is not merely a farmer problem, as water quality criteria in some water management schemes are based solely on salinity, i.e. electrical conductivity management.

Water blending ("conjunctive water use" in American terms, or "shandying" in Australian terms) was identified as another major issue. Perhaps the issue is better framed as blending vs separating of relatively high quality primary water sources and saline, sodic, or saline/sodic waters from field tile drains or deep wells. The rationale for blending is to increase the total volume of water available by diluting problem waters with relatively high quality waters. The rationale for segregating impaired water from high quality water is to limit the extent of soil salinization and sodification to a minor fraction of the total land area irrigated– and in so doing limit the extent of land that requires special and higher order management. The logic of each approach was explored by several speakers. The conference keynote speaker, Dr. James Oster challenged the conference to consider the desirability of creating a system of monetary incentives based on acceptance of impaired water, thereby encouraging segregation and limitation of the extent of salt impairment of primary agricultural lands.

A third unique, and certainly controversial idea, was the suggestion by Dr. Arie Nadler that the pervasive use of gypsum to combat sodicity may have become more widespread and frequent than is warranted by documented yield results. Further, he noted that solubility as influenced by common ion effects and evidence from mass balances in leaching studies suggests that not all calcium added via gypsum remains available in soil solution to affect the calcium/sodium balance of the soil exchange complex. His thesis, stemming from this caution against what he termed "gypsomania" was relatively simple: Gypsum is applied for two reasons, to reduce direct sodium impairment of plant growth and to improve infiltration– if there is no crop response to gypsum, then other infiltration-enhancing practices should be used and further gypsum additions might well be curtailed.

An issue whose importance is obvious to anyone who has looked down on Australian waters from an airplane is the role of sodicity in soil dispersion and runoff turbidity. The dispersive properties of sodium, related to the ion's hydrated radius and its relative inability to shrink the electrical double layer surrounding suspended clay particles plays a major role in soil erosion, infiltration impairment and transport and desorption of nutrients and pesticides from suspended soil into surface waters. Clarifying Australia's surface waters, estuaries or coastal waters and reducing their pesticide and nutrient contamination will be linked to managing soil and runoff water sodicity. This issue also has significant implications for rice production, which suffers severe stand reduction and maturity delay when water turbidity impairs photosynthetic light penetration and lowers temperature in paddy water.

These and many other technical issues were explored in the conference. The level of technical competence of the presenters and the quality of their work must be commended. I was gratified that more than one speaker noted that when studying salinity and sodicity one must keep in mind that outcomes and effects of treatments and management strategies are dependent on long lists of interactive and sometimes subtle but important factors—physico-chemical, biological, system architecture and operations related, societal, economic etc. In the soil alone, mineralogy, organic matter, iron chemistry, cropping system artifacts and climate all need to be appreciated and accounted for to understand or predict the influences of salinity and sodicity. Finding a normalization rationale to evaluate what has been learned from one set of circumstances for use in Australia is no small part of the challenge facing Australian soil scientists, agronomists and engineers.

If there were any aspect of the conference that may have been improved it might relate to this latter issue, which is really a statement of the need for "perspective." The Sodicity Conference provided a top-notch forum among sodicity experts-- soil scientists, water and agricultural engineers and even a few policy makers. Absent were influential farmers or representatives of the popular environmental community. It might have been better to have heard from the policy makers at the end of the conference, after they had had the benefit of the scientific presentations. And the scientific presentations might have had more impact if grounded by a questioning audience of other than, largely, scientists and engineers. These are small deficiencies for so well organized and so high quality a scientific conference, and are meant more as a reflection than a criticism.

Science seems to be losing some of its allure and emotional authority in this new world of ours, where toddlers are weened on gigahertz microprocessors. We are all so used to technology and take it so for granted that we forget that before technology comes knowledge. Certainly if we are to convince governments and other funding bodies of the need to do research and the need to transfer technology to users and to policy makers we need first to educate them and engage them in the dialogue (at the risk of being educated ourselves). Accomplishing this kind of interaction is a common oversight in scientific communities. It makes us uncomfortable and sometimes it takes a real effort to establish genuine cross communication among scientists and the public. I would argue, however, that in this "information age" (misinformation age?) the old traditional patterns of dealing with environmental problems from within the scientific infrastructure need some rethinking. The benefits of inclusivity are potentially considerable, and we as scientists will probably be surprised at how astute the lay public can be at assimilating the knowledge we present them, if it is indeed relevant to real problem solving. Perhaps the conference proceedings can be "translated" for broader dissemination to the public through a final act of "extension." And perhaps at the third sodicity conference, which I definitely want to attend, we can all enjoy presentations and panel participation aimed at and drawn from our customers in the farming and environmental communities, as well as from our colleagues at the bench.

All in all, I commend the conference organizers and sponsors on a job very well done. The topics explored and the technical challenges presented by conference participants will chart a path of scientific investigation lasting several years. One of the best indicators of a great conference is one that sends the participants home with more questions than answers. The sodicity conference met this test, and its organizers and sponsors are to be commended.

NOTE: This article is published in official newsletter of the Australian Society of Soil Science Inc (ASSSI), Profile – issue 122, April 2000.

Impressions from the Sodicity Conference

These impressions are written by Dr Bob Sojka from the USDA Agricultural Research Service, a visitor at the conference.

In January of this year I arrived for a two month visit of Australia, on a mission to assess the nature and extent of irrigation-induced erosion, its impact on surface water quality and the feasibility of using chemical polymers to help alleviate these problems. My visit coincided with the Sodicity Conference held in Tatura, Victoria, from 28 February through 1 March, and since I was not a formal conference participant its organizer, Dr. Aravind Surapaneni, asked if I could offer comment from, what he termed "an objective and unbiased viewpoint." While being humbled by a suggestion to offer comment on the contributions of so many fine scientists in a field in which I have only had a small personal role, I was also eager for the chance to offer comment on a topic that, as my own fact finding trip confirmed, is so central to the future fate of Australian agriculture. Sodicity is especially important to Australia's irrigated agriculture and its surface water ecology and its terrestrial and riparian management.

ABOVE: Peter Donlon from Goulburn Valley Water explains wastewater treatment processes during a conference field tour.

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"We are all so used to technology and take it so for granted...we forget that before technology comes knowledge"

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