BENEFICIAL USES OF TREATED DRAINAGE WATER

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ABSTRACT

The United States Bureau of Reclamation has a legal requirement to provide drainage services to the San Luis Unit of the Central Valley Project (CVP) in Southern California. A number of options are being investigated by Reclamation, but the current favored option includes a number of approaches to water reduction and treatment, including a spiral reverse osmosis plant. A different membrane system to recover higher proportions of saline drainage water, containing saturated levels of calcium sulfate, was tested in early 2004 at a drainage collection point in Panoche Water District. Results from that work suggest it may be possible to recover over 90% of saline drainage water for unrestricted reuse as fresh irrigation water at a cost less than or equal to the cost of producing sea water by reverse osmosis. If the equivalent amount of CVP water could be sold to urban areas at a price close to the cost of treating Sea Water by Reverse Osmosis this approach could provide an environmentally friendly and negligible cost solution to the problem of drainage water in the San Luis Unit.

The Drainage Problem in the San Luis Unit of the Central Valley

The disposal of irrigation water in the San Luis Unit of the federal Central Valley Project in California has been a problem from the inception of water deliveries by the United States Bureau of Reclamation (Reclamation) in the 1960's. The San Luis Unit encompasses 700,000 acres of prime farmland in the San Joaquin Valley. In about one half this area, the local geology includes a low permeability clay lined bowl under the fields that restricts drainage into the deep water table Consequently, over 300,000 acres of irrigated lands within the San Luis Unit have had to contend with rising water levels under the productive farmland over the last 40 years. In many places, saline water is now threatening the root zone area of the crops.

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It was originally intended that Reclamation would fulfill its contractual obligation to provide drainage service to both the northern Grassland section and the southern Tulare Lake Basin section of the San Luis Unit by constructing and operating a 250-mile master drain that would empty into the San Francisco Bay-Delta. This facility, called the San Luis Drain, was partially constructed in the 1970's and began transferring agricultural drainwater from Tulare Lake Basin north to Kesterson Reservoir in Merced County. The completion of the drain to the Bay-Delta was halted, and is now generally regarded as environmentally infeasible, after the selenium in the drainwater was attributed to adverse wildlife impacts at Kesterson Reservoir in the early 1980's.

Since 1995, certain drainage-impaired lands in the Grassland Area in the northern portion of the San Luis Unit have been permitted to dispose of their drainage water under an agreement with federal and state agencies and other interested parties. Under this interim arrangement, which expires at the end of 2009, drainage water from the 97,000 acres Grassland Drainage Area is discharged into a part of the San Luis Drain and then transferred to the San Joaquin River via a 7-mile natural channel which passes through Kesterson National Wildlife Refuge. This agreement requires a year by year reduction to the amount of selenium discharged into the San Joaquin River. By 2010, the Grassland Area dischargers must have in place an alternative discharge or an alternative method for eliminating their drainage flows.

No drainage outlet has been provided to the 200,000 acres of drainage-impaired farmland in the Tulare Lake Basin section of the San Luis Unit since closure of the San Luis Drain in 1986. Maintaining the arability of this drainage-impaired land is becoming increasingly problematic each year with some land already retired as unsuitable for agricultural production.

Salts are brought into the area by irrigation water supplied from the Delta-Mendota Canal and the California Aqueduct segment of the Central Valley Project, and sulfate salts, boron and selenium are leached from the soil. With boron and salt levels too high for many crops grown in the area, reuse of the water is restricted. The high selenium level in the drainwater presents environmental challenges for the use of evaporation ponds. Projected drainage water quality ranges are presented in **Table 1** below.

Since implementation of the Grassland Bypass Project in 1995, Panoche Drainage District, and other water/drainage districts in the Grasslands Area in the northern section of the San Luis Unit, have undertaken measures to improve water use efficiency at both the farm and district level, and have implemented drainwater recycling to the extent practical in order to meet their interim selenium reduction targets under the Grassland Bypass Project. In addition, Panoche is developing a regional drainwater re-use project on behalf of all the lands within the Grassland Drainage Area in which untreated drainwater is used to irrigate salt tolerant crops on dedicated fields. These measures have reduced by approximately 50% the amount of drainage water and salts that needs to be drained from the area, but the problem is not fully resolved through these practices.

Table 1. Projected Drainwater Flows and Quality from the Northern and Southern Areas of the San Luis Unit before reduction/reuse[i]

Year	Drainage Volume (AF)	TDS Mg/l	Selenium mg/l	Boron mg/l
Northern Area SLU				
1	10.6 – 17.8	6,549 – 3,929	0.16 – 0.1	12.82 – 7.69
50	10.6 – 17.8	3,600 – 2,160	0.09 – 0.05	7.05 – 4.23
Southern Area, Zones A, B and C				
1	1.9 - 3.15	20,250 – 11,250	0.37 – 0.03	12.6 – 7.56
50	67.5 – 82.5	4,860 – 1,620	0.09 – 0.01	3.02 – 1.81

In response to a 2001 court order, Reclamation is currently evaluating alternatives for providing drainage service to its San Luis Unit water contractors. These options include reexamining completion of the San Luis Drain to the San Francisco Bay-Delta . A Pacific Ocean Discharge option was recently abandoned as being too expensive and environmentally infeasible. Land Retirement is also being considered for some of the farmland with high soil salinity levels in the southern Tulare Lake Basin Area.

As of mid 2004, the drainage service option that Reclamation considers to be most feasible is termed "In Valley Disposal". This option can be summarized by using a variety of on-farm, in-district, and regional drainwater volume reduction strategies, including the use of membrane processes for water recovery, to address the three key contaminants in the drainwater; salt, Boron and Selenium. The level of calcium sulfate in the drainage water is at or near saturation levels creating more challenges for membrane water-recovery processes. Reclamation's preliminary capital cost estimate for building the facilities necessary for implementing the In-Valley Disposal Option for all 260,000 acres in the San Luis Unit requiring drainage service is over $700 million[ii], for 100 AF drainage flows.

<u>Cross Flow Membrane Technology for drainage water treatment</u>

Reverse Osmosis technology uses a very "tight" semi-permeable membrane through which, in an ideal case, only water will pass, provided that the pressure exerted on one side of the membrane exceeds the natural osmotic pressure of the fluid itself. The technology is applied frequently for the treatment of saline waters. Reverse Osmosis membranes have the ability to retain dissolved salts and other solutes, while allowing water to pass through the semi-permeable membrane layer. Clearly the higher the level of salts in the fluid the higher the natural osmotic pressure and hence the higher the pressure that needs to be applied to the "raw water" side of the membrane before non-saline filtrate or "permeate" can pass thorough the membrane. Equation 1 below gives the filtration rate per unit membrane area through the membrane, J, in terms of π_0, the natural osmotic pressure of the fluid, π, the pressure applied across the membrane and k, an empirical constant derived from membrane performance.

$$J = k(\pi - \pi_0) \qquad \text{(Equation 1)}$$

For a typical reverse osmosis membrane, the concentration of sodium chloride salt seen on the permeate side of the membrane will be less than 1% of the concentration seen on the "feed" side of the membrane, giving the membrane a "retention" > 99% NaCl.

Nanofiltration technology uses similar membrane materials, but by making the semi-permeable membrane more open, allows a greater passage of salts. Further, the driving force or pressure required to pass filtrate through the membrane is lower. Nanofiltration membranes allow the majority of monovalent salts to pass through the membrane while retaining the larger proportion of the divalent salts. The energy required for nanofiltration is lower because the membrane area is smaller and/or the applied pressure is lower. The filtrate, however, will contain a higher proportion of salts than water that has passed through an RO membrane. In cross-flow membrane filtration there is a continual flow of the feed fluid at pressure across the membrane surface, while the permeate passes through the membrane at 90° to the feed's direction of flow. Cross flow filtration reduces the concentration of the retained fractions at the membrane surface through disturbance of the fluid at and near the membrane surface. If particulates are present in the feed material, these particulates will also be kept moving across the membrane surface instead of blocking the filter area. (Figure 1)

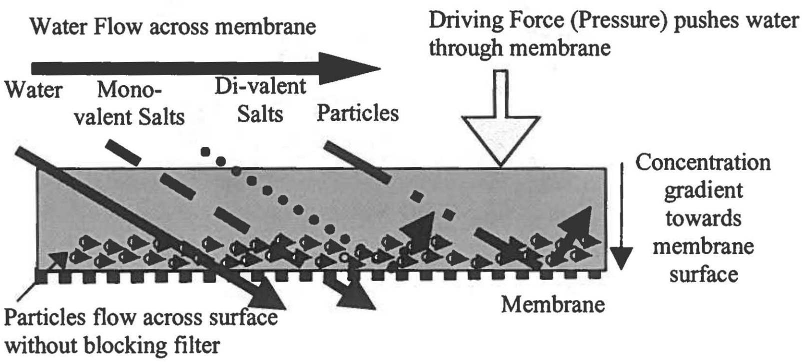

Figure 1. Cross Flow Nanofiltration Separation

Cross flow membranes can be configured in a number of ways, but for reverse osmosis there are two common forms. A spiral wound configuration **(Figure 2)** uses double layers of membrane supported on a substrate as leaves wrapped around a central "product" tube. The distance between the membrane layers is usually around 30 micron, restricting the ability to handle suspended solids.

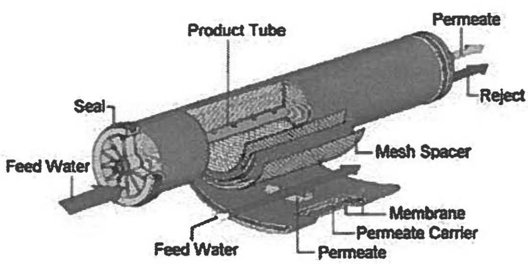

Figure 2. - Spiral Membrane Element

Where suspended material is present, a tubular membrane configuration may be used. In this version the membrane is coated on the inside wall of a pipe and filtrate passes through the pipe wall into a collection "shroud". Tube diameters are typically around ½'. (See Figure 3.)

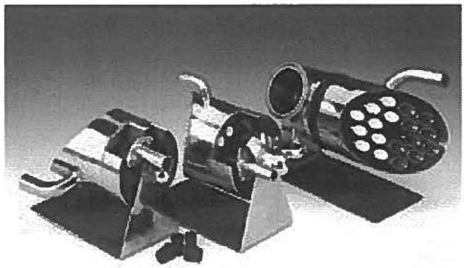

Figure 3. Tubular Membrane Module

Spiral and tubular devices are typically constructed to allow applied pressures up to 70 bar/1000 psi. With reverse osmosis, this allows dewatering up to a concentration of a saline solution until the natural osmotic pressure of the concentrate equals the applied pressure tending to limit the final concentrated water to 60,000 – 70,000 mg/l, as seen in seawater desalination membrane plant.

Application of Membrane Technologies to Drainage Water

Reverse Osmosis technology gives an opportunity to produce a good quality filtrate stream for irrigation, and a smaller volume of more highly saline "reject". The presence of calcium sulfate in the drainwater, at or near saturation levels, limits the recovery of water available in a spiral RO system. As the feed water is dewatered, the calcium salts begin to precipitate out as the concentration of salts in the retained portion rises. Crystals form on the membrane surface reducing filtration rates blocking the feed channels. Precipitation can be inhibited by the addition of "anti-scalants" but still only 50% recovery at most can be achieved.

In addition to concentration of the salts, RO will also retain almost all the Selenium, but only 50% of the boron. The high level of Boron in the filtered water would require removal by further treatment or dilution with sufficient fresh irrigation water before the filtrate could be reused for unrestricted irrigation purposes. Since water districts in the Grassland Area already dilute their fresh irrigation water supplies with recycled untreated drainwater to the point of their tolerance of boron, a boron-removal step after the membrane process will probably be required to achieve a higher in-district recycling rate.

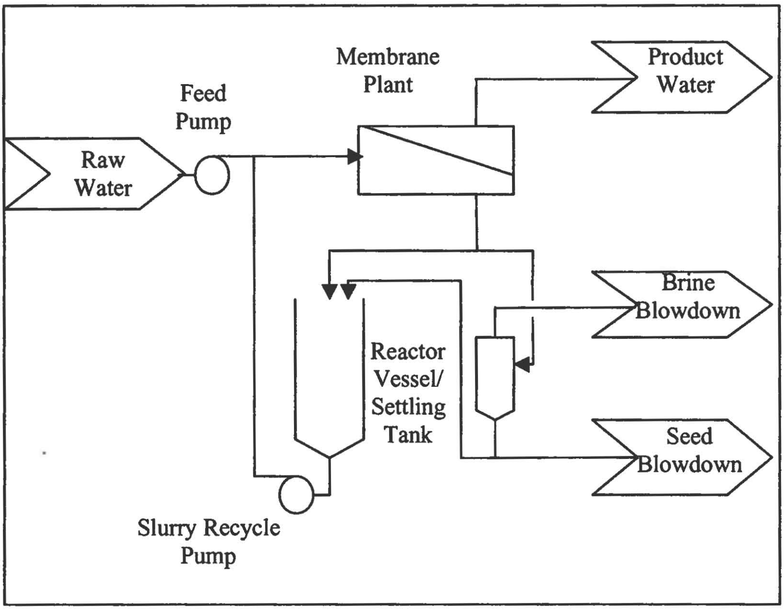

Figure 4. Simplified Seeded RO System Diagram

To overcome the calcium sulfate precipitation problem (though not applied to drainage water), a "seeded" reverse osmosis system was developed by Resources Conservation Corporation (now Ionics, Inc.) in the early 1980's. However, RCC/Ionics never advanced this process to commercial use[iii]. In the 1990's, Dr. Graham Juby et al. took RCC's work and developed a seeded RO system to treat mine drainage water in South Africa[iv] . In this approach calcium sulfate crystals are added to the incoming feed water and become the sites on which the dissolved calcium sulfate precipitate out, rather than on the membrane surface. Tubular membranes can handle the level of suspended solids present in the water caused by the crystals. The high level of Total Dissolved Solids gives the drainage water a naturally high osmotic pressure therefore requiring the reverse osmosis system to be run at high pressures generating low flux rates.

In 2001, WaterTech Partners conceived a "double pass" seeded RO process which was further developed with PCI Membrane Systems for which a patent has been submitted. Nanofiltration membranes are used to concentrate and precipitate the calcium sulfate in the drainage water ahead of an RO system. With most of the calcium salts now removed, the filtrate goes to a spiral reverse osmosis operating without the fear of calcium sulfate precipitation occurring.

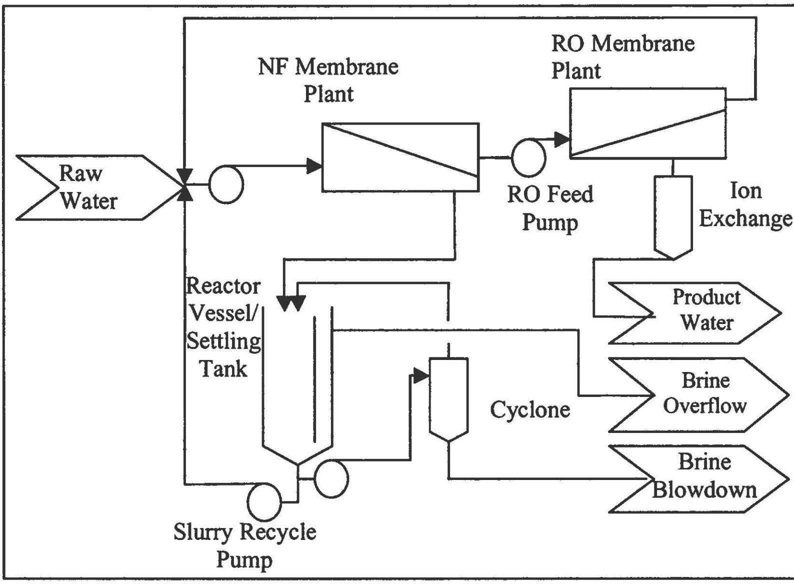

Figure 6. Simplified Schematic of DP3RO Process

The DP3RO process was first tested on actual San Luis Unit drainwater in December 2003 when a 5-gpm DP3RO pilot system was installed and placed in service at Discharge Point 25 (DP 25) in Panoche Drainage District. This system was operated for over 500 hours over a 4-month period under a grant from the Ecosystem Restoration Program of the California Bay-Delta Authority (previously known as CALFED). Preceding this pilot system project, WaterTech Partners had performed "proof of concept" bench-scale testing of the DP3RO process under a grant from the Public Interest Energy Research Program of the California Energy Commission.[5]

Feed, seeded with calcium sulfate crystals, is fed to the tubular nanofiltration plant. Filtrate from this process is filtered in a Reverse Osmosis system with its permeate passing through an Ion Exchange system to remove Boron. The reject from the RO is fed back to the front of the process to increase the overall recovery of the system. The reject from the nanofiltration system is partially returned to provide fresh seed crystals to the process, and a small volume is bled away as the

[5] This project was funded on the basis that the DP3RO process might desalinate low-TDS farm drainwater (3,000 to 5,000 mg/L) creating "new water" supplies for California with less energy per acre-foot of product water than desalinating seawater containing 36,000 mg/L TDS.

liquid reject from the plant. A liquid/solid separator removes the crystals created by the process.

Options for Use of Membrane Technology as Part of the In Valley Disposal Option for the San Luis Unit

Reclamation's In-Valley Disposal Option currently envisions using single-pass spiral RO membranes systems as part of its volume reduction strategy.

An initial volume reduction, would be achieved by transporting the drainwater produced on individual farms in the San Luis Unit service area to regional re-use sites where the 4,000 to 6,000 mg/L TDS farm drainwater will be used to grow salt-tolerant crops and to irrigate pasture. Such re-use sites are expected to achieve a 75% volume reduction in the farm drainwater. Subsurface tile-drain systems will be installed at the re-use sites to remove salts from these lands. The drainage water will be collected from these re-use areas and may be expected to have salinity levels in the 16,000 to 24,000 mg/L range. Selenium and Boron levels will also be at more concentrated levels in the "Re-Use Drainage water.

Reverse Osmosis systems would be installed at the re-use sites to achieve a 50% reduction in the volume of re-use site drainwater. The 50% filtered water stream at TDS below 600 mg/l will still contain levels of Boron well above the 0.7 mg/l limit for general irrigation use but the selenium and salts will be concentrated in the reject stream. Reclamation's plan is to add the desalinated and de-boronized RO filtrate water to its CVP supplies and credit the entities receiving drainage service with the value of this water at CVP water prices.

The reject from the RO plant, which might contain between 30,000 and 40,000 TDS and high levels of Selenium, would be sent to evaporation ponds. The environmental impact of the evaporation ponds would require mitigation through the construction of adjacent wetlands. The final residual from the evaporation ponds would be the dried salt requiring removal and disposal elsewhere.

Reclamation is continuing to investigate the feasibility of the above approach, including biological process to remove the Selenium from the RO reject, alongside other potential solutions. The unknown factors at this time are the sustainability of the arability of the re-use sites, the economics and volume-reduction capability of single-pass RO on the re-use drainwater, and the selenium-removal efficacy of biological processes on high TDS feedwater. Environmental concerns to this approach are focused on the large land areas required for the evaporation ponds, the environmental mitigation areas and the levels of Selenium present in standing water.

While Reclamation's proposed In-Valley Disposal Plan may be the least cost and lowest risk drainage service option currently available for San Luis Unit water contractors, a further increase in the volumetric reduction would have a number of advantages. Although the construction and operation of drainwater desalination/de-boronizing plants using the high recovery DP3RO process, as part of a drainage-service system for San Luis Unit water contractors, would in itself be more expensive than building and operating single-pass RO systems operating at a 50% water recovery rate, the higher water recovery rate would reduce the evaporation pond area by 80%, reduce the mitigation area and provide additional payback from the higher volume of recovered water. The higher levels of Selenium in the smaller volume reject water might however present an issue unless solar evaporators rather than evaporation ponds could be used. Current environmental legislation may make this difficult at the re-use sites.

If the DP3RO plants were located within the water districts, the districts could retain and use the desalinated/de-boronized product water from the DP3RO plants to displace their use of CVP water. This would make an equivalent amount of CVP water available for long-term sales to urban areas as contemplated and authorized under the Central Valley Project Improvement Act (CVPIA) enacted by Congress in 1992. With the additional income stream available to San Luis Unit contractors from selling water under CVPIA as part of a long-term drainage-service plan, application of the DP3RO process bears investigation to see if it presents a more economic and environmentally acceptable solution.

With this on farm approach, the reject stream could go to a solar evaporator. Current legislation in California enables small on farm solar evaporators to be constructed and operated under SB 1372 without having to perform an environmental impact analysis, provided certain statutory requirements and design and operating criteria that the approach is likely to achieve, are met.

Performance and Costs of DP25 Pilot

Drainwater with 8,300 mg/L TDS, 410 µg/l selenium, and 17mg/L boron was processed at 90% recovery into product water with 260 mg/L TDS, and "non detect" selenium and boron levels. The DP3RO pilot system was operated for over 500 hours and processed more than 100,000 gallons of DP#25 drainwater. While long term membrane fouling and membrane life predictions are difficult to make after only 500 hours of operation, no membrane failures occurred, calcium sulfate crystals did not block up the system, and the process was controllable in a manually operated system without difficulty.

A design and cost model for the DP3RO process shows that a 250gpm (= 1 acre-foot/day) on-farm plant operating at 90% water-recovery on 6,000 mg/L TDS feed drainwater will be able to produce recyclable high quality irrigation water (including de-boronization) at a cost under $900 per acre foot, including capital cost amortization. If $900/AF were the transfer value to urban water users of the displaced agricultural-use CVP water then this drainage-service option would become a "no cost" solution to the San Luis Unit water contractor's drainage problem. The overall cost of using this process as treatment in the re-use areas has not been calculated, but bears investigation against Reclamation's current favored plan.

Further optimization of the process is still required to assess how the process can be most effectively used as a part of the drainage solution. Nonetheless, the completed pilot project demonstrated the potential to employ the DP3RO membrane desalination/de-boronization process to achieve water-recovery rates of 85% to 90% as part of a drainage-service plan for Reclamation or the San Luis Unit water contractors.

REFERENCES

[i] US Bureau of Reclamation Mid Pacific Region. San Luis Drainage Feature Re-Evaluation Preliminary Alternatives Report December 2001

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