The Bright Future of Irrigation around the world

Mike Harrington, President of HARCO Fittings, is the new President of the Irrigation Association

During the Irrigation Show 2009 in San Antonio, Texas, there were as usual many new products, emerging companies and a lot of papers and information about water and irrigation. New Ag International Editor Patricio Trebilcock went around exhibition stands, conferences and papers.

TOWARDS NEW ETHICS OF WATER USE

Sandra Postel, the Director of the Global Water Policy Project is very well known in the world of water management and the author of very popular books such as Pillars of Sand: Can the Irrigation Miracle Last? , that was launched during the IA Show nine years ago. In San Antonio, she gave an outstanding lecture.

"The last time I was here, says Postel, I had a very dark vision of the future of our society and of water. And today, although many of these problems such as water scarcity, drought, pollution and environmental systems health have worsened, I feel much more optimistic", she told the global irrigation industry.

Let's talk about optimism. "Water scarcity" is now a common phrase among world business men and politicians. During the last World Economic Forum in Davos, many of the main players talked about water scarcity and agreed that "we cannot manage water as we used to because if we continue the way we have been acting our economic system will collapse". And that is already a great step forward.

However, on the other hand, it seems that the main leaders have not understood the negative effects that all of the water policies that do not take the environmental services of the fresh water ecosystems have done to the planet.

SOCIETY HAS TO DOUBLE WATER PRODUCTIVITY

In order to satisfy our growing population and to maintain a significant proportion of our ecological infrastructure intact we have to double water productivity. Water has two characteristics that make it unique: its is finite and it cannot be substituted. Up until now we have only thought about how to expand the supply, now we have to start thinking about how to increase water productivity. Some countries are going in that direction, such as Australia and South Africa.

IIRRIGATION CENSUS IN USA: 2.4 MILLION ACRES MORE OF IRRIGATED LAND

Irrigation has a big role to play. Irrigated agriculture is extremely important: it provides 30% of the world´s food although it only uses 18% of the irrigated land. But it uses 70% of the World fresh water and its productivity is low. If only irrigation were to use 10% less water, that amount would be enough to satisfy the other sectors' future needs. Global irrigated land is not expanding as strongly as it used to do (currently at 0, 6% per year). Now enhancing water productivity is the name of the game. We have to double irrigation productivity and an intelligent combination of new irrigation technologies and information technologies can achieve that.

The "Farm and Ranch Irrigation Survey 2008" is part of the 2007 Census of Agriculture conducted by the US Department of Agriculture. The survey shows that American farmers are irrigating more land and they have changed their irrigation systems.

During 2008, 54.9 million acres were irrigated in USA. This is a great leap from the 52.5 million acres that were irrigated 5 years before. Sprinkler is by far the fastest growing irrigation system. Irrigated land under sprinkler systems jumped to 30.9 million acres, while gravity irrigation decreased 5%.

The main "irrigator" States are Nebraska,

Table 1: Irrigation Systems Used in USA

	Irrigated Acres	Gravity Systems		Sprinkler Systems		Drip and Microsprinklers	
		Farms	Irrigated Acres	Farms	Irrigated Acres	Farms	Irrigated Acres
2008	54.929.915	89.646	22.017.757	114.348	30.877.057	43.368	3.756.134
2003	52.492.687	100.626	23.106.280	103.154	26.888.528	41.802	2.963.742

California, Texas, Arkansas and Idaho. Applied water also increased between 2003 and 2008. The total amount of water used in agriculture grew 5% but average applied water remained stable. On farm surface water and ground water from wells use increased while the water brought from off-farm suppliers decreased. Another interesting fact is that wells with water meters increased by 76%, reaching 107.384 wells. Wells are deeper now. In 2008 the average well is 243 feet, 5 feet deeper than in 2003.

Table 2: Irrigated area by crop groups

CROP GROUP	ACRES 2003	ACRES 2008
Grains and oil seeds	18.783.000	23.131.333
Tobacco	39.605	18.997
Cotton	4.583.003	3.935.982
Sugar Cane	8.286.484	8.503.112
Vegetables and melons	4.577.012	4.380.147
Fruit trees and nut trees	4.776.906	4.148.071
Ranch Cattle	7.669.461	7.125.661
Feedlots	1.451.473	934.093
Dairy	1.387.219	1.704.817
Other animals	938.335	1.047.722

Table 3: Irrigation scheduling methods

Method	Farms 2008	Farms 2003
Any Method	206.834	210.106
Crop condition	160.636	166.858
Soil tact	88.080	73.154
Soil moisture measuring device	17.874	14.233
Plant moisture measuring device	3.553	3.078
Irrigation scheduling service - private or governmental	16.625	13.461
Daily ET reports	18.862	15.177
Programmed by the water district	24.233	26.200
Personal scheduling	51.986	40.644
Computer models	2.859	1.201
When neighbours irrigate	14.231	14.048

SPRINKLERS: EXPLOSIVE GROWTH OF CENTRAL PIVOTS

Central pivots usage increased from 21.2 million acres in 2003 to 25.5 millions in 2008. Only in Nebraska there are 6.7 million acres under central pivots. In Texas there are at least 4 millions acres under this system. Linear pivots stayed stable at almost 400.000 acres, while solid set decreased from 277.000 to 195.000 acres. Side Rolls keep being important (1.8 million acres), big guns increased from 624 to 696,000 acres. Manual sprinkler systems decreased 33%.

DRIP AND MICROSPRINKLERS: 800.000 ACRES MORE

There are 43.368 farms in USA equipped with drip and microsprinklers. This is 3.7 million acres, almost 800.000 acres more than in 2003. California is by far the most important State for these technologies with 2.3 million acres. Florida ranks second with 549.000 acres. Superficial drip irrigation is the most important with 1.7 million acres (1.4 millions in 2003). Subsurface drip irrigation also increased: from 400.000 to 640.00 acres, a technique that is mostly used in California and Texas. Microsprinklers are used in 1.4 million acres.

FERTIGATION KEEPS GROWING

The use of fertigation grows on every single crop. In maize, for example, of the 12 million irrigated acres, almost 3 million are fertigated. This is a great increase because in 2003 only 2 million acres of maize were fertigated. Potatoes follow a similar trend with 579.985 fertigated acres out of 974.000 acres under irrigation. In fruit crops: of the 3.8 million acres under irrigation 1.25 million are fertigated and in 600.000 acres pesticides are also applied through the irrigation systems.

The irrigation survey is a very complete study and in its 180 pages readers can find detailed statistics sorted by State, irrigation system, energy use, etc... To conclude, there is a very interesting chapter named "Other uses of water" which shows many novel uses of water: in 1.6 million acres, farmers do frost control with sprinklers and in a similar area they use their equipments to cool orchards and even to delay blooming or budding.

Next year's show dates have been announced: December 5th to 7th in Phoenix, Arizona.

New Ag International will be there! ■

Applying biological effluent with drip or sprinkler irrigation:

Many advantages and some

Todd P Trooien

Water is a limited resource. Irrigation is the largest consumptive use of water in many parts of the world. Biological effluent can be used instead of fresh water to irrigate crops in areas where that effluent is available. Biological effluent, or just effluent, in this context includes resources such as treated municipal wastewater, runoff or other water from animal operations, and water from some food processing operations. Biological effluent is sometimes called wastewater but it should be viewed as a resource to be managed and not just a waste product fit only for disposal at the least cost! Sprinkler and drip irrigation have both been used successfully to irrigate with effluent. There are many advantages to irrigating with effluent but care must be exercised to avoid environmental degradation or economic loss. So, drip irrigation or sprinkler irrigation? Which one is best? There is no definite answer. Each technology has its advantages and drawbacks! Todd P Trooien, Natural Resources Engineer and Professor, at South Dakota State University in the USA and a respected expert on the topic, has the story for New Ag International.

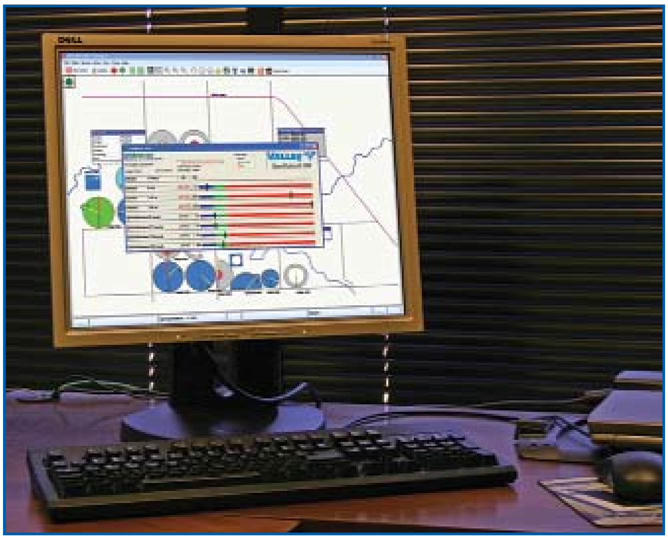
The composition of an effluent depends on its source. Generally, there are nutrients in the effluent. Nitrogen (N), phosphorus (P), and sometimes potassium (K) are of the greatest interest when irrigating with effluent because of the crop requirements for those nutrients. Concentrations of total N can range from minimal to 400 mg/L or more and concentrations of P can range from minimal to 50 mg/L or more. Most effluents contain some salts. Depending on the effluent source, the concern may be total salt concentration or concentrations of specific ions or both. There may be pathogens in the effluent, including bacteria, viruses, and protozoa. There may be organic matter in the effluent. Finally, there may be suspended solids in the effluent. Treated municipal effluents or household effluents tend to have lower concentrations of total suspended solids (TSS). Some values reported by research studies are between 5 and 30 mg/L but some effluents contain TSS concentrations as high as 300 mg/L. Effluent from animal operations contain higher concentrations of suspended solids, with TSS values commonly around 500 mg/L and sometimes as great as 1500 mg/L or more.

MANY ADVANTAGES BUT POTENTIAL HAZARDS AS WELL

Irrigating with biological effluent has many advantages. One obvious advantage is that potable water resources are conserved for other uses because irrigated crops do not require potable water. Second, the nutrients in the effluent can be used by the crop. The nutrients in the effluent may have value greater than the water itself in some cases. In particular, macronutrients such as nitrogen, phosphorus, and potassium are of value because most irrigated crops require these nutrients in relatively large amounts. Finally, the cost/benefit ratio of irrigating with effluent is favorable in some cases. Use of specific irrigation systems (drip irrigation or sprinkler irrigation) can also bring specific benefits that will be addressed below.

drawbacks!

But there are some potential hazards of irrigating with biological effluent. In particular, the constituents in the effluents sometimes pose specific dangers. The nutrients contained in effluent can be a valuable resource but if the nutrient content becomes excessive in the effluent or in the irrigated soil, some nutrients can cause problems. Second, the salinity of the effluent will require careful management. Salinity management in irrigation has been studied extensively in many areas of the world; the salinity management methods developed in those studies are appropriate for use when irrigating with effluent. Third, suspended solids in the effluent must be managed to prevent clogging of emitters or sprinkler nozzles or other irrigation system components. Fourth, care must be used to prevent human infection by any pathogens in the effluent. Various countries, states, and the World Health Organization (WHO) have developed guidelines for human exposure to those pathogens and some have developed guidelines for effluent use to avoid human exposure. These constituents can be present in varying concentrations in any effluent. The best way to know the concentrations in one effluent is to have a certified laboratory analyze a sample.



A NUMBER OF PREREQUISITES TO THE IMPLEMENTATION OF THE TECHNIQUE

Regardless of the irrigation system type, an appropriate irrigation objective from the irrigator's perspective is to maximize crop yield or profit. To maximize either requires uniform application. Good uniformity is even more important for any irrigation system used to apply effluent. Thus, good planning, design, and management practices for fresh water irrigation systems are often appropriate for effluent systems. One of the primary site considerations is the availability of effluent and fresh water in time and space. Ideally, the effluent source would be close to the irrigated field and generated during the peak irrigation season. Second, the soil must be permeable enough to allow good water movement and leaching but have adequate water holding capacity and exchange capacity to temporarily hold effluent constituents. The soil profile must be thick enough to provide an adequate root zone and storage and exchange volume for the effluent constituents. The climate must be adequate to allow crop growth and breakdown of organic matter added in the effluent.

The land area required for an effluent irrigation system depends on the crop being irrigated, the climate, and the effluent. Although any constituent can be limiting, the limiting factor for crop production is often one of water, N, or P. It is rare that the crop needs of all three of these will be met with just effluent. For example, consider irrigated maize that uses 450 mm of water in addition to the annual rainfall, 340 kg N per ha, and 45 kg P per ha during the growing season. The effluent source is treated municipal wastewater with a total N concentration of 50 mg/L and P concentration of 7 mg/L. If we assume that all of the nutrients in the effluent are available to the crop, then 640 mm of effluent are needed to meet the N needs of the crop and 680 mm of effluent are needed to meet the P needs of the crop. Thus, the water needs of the crop are met before the N or P needs. Additional N and P fertilizers should be added to meet the needs of the crop and the irrigated area should be based on the expected volume of water available for irrigation annually. There are similar examples using other effluent sources where the N needs of the crop are met first (requiring additional irrigation water and P fertilization) or where the P needs of the crop are met first (requiring additional water and N fertilization).

MANY ADVANTAGES SPECIFIC TO THE USE OF DRIP IRRIGATION

There are many advantages specific to the use of drip irrigation with effluent. One advantage is the reduced human exposure to the effluent due to wind drift or overspray. This is especially important in populated areas. Another advantage is that damage to irrigated plants can be reduced because effluent is not applied directly to plant tissues. Further, small flow rates are usable and pressure requirements are low, making the irrigation system more flexible. Unusual field shapes and sizes can be accommodated. The ability to apply small irrigation amounts precisely allows the irrigation of shallow soil profiles and erodable soils. The effluent and its constituents are applied uniformly. Finally, much of the irrigation system is plastic rather than metal, reducing the potential for corrosion and associated problems.

There are additional advantages to applying effluent with SDI systems. Potential human contact is further reduced because the effluent is placed directly into the root zone, not on the soil surface. In some locations, setback (separation) distances are decreased. Runoff of effluent is minimized because the effluent is not placed on the soil surface. When the SDI system is designed and operated to keep the soil surface dry, weed germination and bacteria survival are reduced. Vandalism to the application system is reduced because it is underground. Odor caused by effluent application is reduced. Weather constraints such as strong winds or air temperatures near freezing are reduced or eliminated. Irrigation contributions to air humidity are reduced. Most crops and soils can be irrigated. Finally, septic tank effluent can be applied in some situations where conventional systems fail.

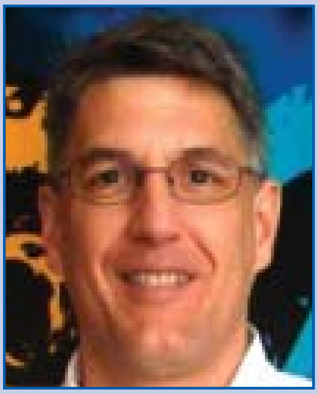
There are some potential drawbacks to applying effluent with drip irrigation systems. For example, clogging of the system, especially the emitters, could cause non uniformity of application or even system failure. Installation costs could be increased compared to other irrigation systems. Maintenance and (especially) monitoring requirements may be increased to keep the system operating as designed. The management of the drip irrigation system may require a higher level of expertise. In some areas, experience with drip irrigation systems is limited and that lack of experience could result in improper system design or management. For SDI systems in some areas and crops, root intrusion can cause emitter clogging. Finally, nutrient accumulation rates and land area requirements might be greater, especially when using SDI systems, because of the reduction of nutrient losses such as volatilization.

The leading cause of irrigation system performance degradation or failure in drip irrigation systems is emitter clogging. Irrigating with effluent presents an even greater challenge to preventing emitter clogging because of the higher concentrations of nutrients, salts, solids, and biological organisms. Design and management steps in the following five areas can reduce the danger of emitter clogging: (1)select the proper components, especially the emitters; (2) filter the effluent adequately; (3) suppress biological growth and chemical precipitation with appropriate treatment or chemical injection; (4) flush materials from the system when needed, and (5) monitor the system so small problems don't become large problems.

One design compromise for drip irrigation is to select low zone flow rates to minimize control hardware requirements while maintaining high emitter flow rates to minimize susceptibility to clogging.

THE VIEWPOINT OF

Waste water re-use through pivots: The Valmont viewpoint, by Jonathan Paetz, Valmont Water Management Group


Courtesy of Valmont

"Valmont Irrigation, known as the leader in mechanized move irrigation, and the manufacturer of the Valley brand of center pivots and linears, has led the world for more than 50 years in the development of energy and water efficient irrigation products and services for wastewater irrigation applications.

Our products, specifically designed for wastewater applications, include the Valley PolySpan® and Valley Slurry Manager. The PolySpan, a polyethylene liner, for center pivot and linear machines was introduced in 1992 to help resist the effects of acidic, alkaline, corrosive and saline wastewater as well as fresh water. PolySpan extends the life and investment of the irrigation system pipeline in all water conditions. The Valley Slurry Manager applies livestock manure, industrial wastewater and municipal effluent, containing up to 4% solids, through a series of sequenced end guns with less soil compaction and reduced energy requirements compared to tractor applicators.

The Valley BaseStation2-SM, a centralized irrigation management system, allows for remote monitoring and control of wastewater and fresh water applications through center pivots and linears. The Water Sentinel, a web based data management tool for wastewater land application systems, can be integrated with data from the BaseStation2-SM. This customized data management tool provides the end user with ongoing nutrient loading and crop irrigation information to meet regulatory permit and reporting requirements.

Land application of agricultural, industrial, municipal, food processing, mining and energy production wastewaters can reduce the need for commercial fertilizers, limited groundwater resources, and energy to mechanically treat wastewater and eliminate wastewater discharge to rivers and streams. This type of application will therefore increase in the future. At Valmont we are prepared to cope with such an increase".

This is especially true for irrigation with effluent because of the greater solids concentrations in most effluents.

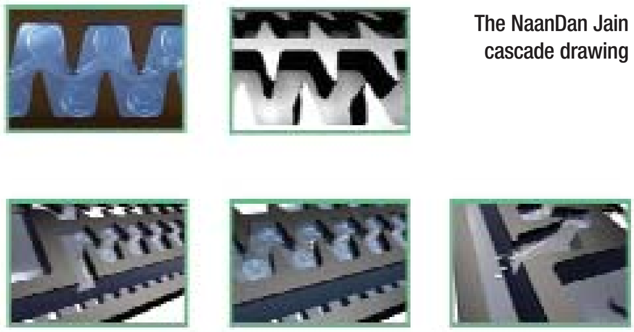
Filtration is required to reduce the solids concentration. Emitter and dripline manufacturers provide filtration recommendations of opening sizes for their products. These recommendations should be followed but there are a few different filtration technologies from which to choose to achieve the recommendation level of filtration. Sand media filters have been shown to be effective in multiple studies. Disc filters have been used successfully in some projects. Screen filtration can be successful but it is likely that additional filtration, such as screen filtration combined with media filtration, will result in better protection of the emitters (prevention of clogging). When pressure differential across the filter is greater than about 35 kPa, the filter should be flushed.

Injection of appropriate materials may be required to prevent biological emitter clogging. Chlorination is the most common method of suppression of biological growth. Chlorination can be continuous at lower concentrations or intermittent at higher concentrations. Injection of acid may be advantageous to reduce the pH and thereby increase the effectiveness of the chlorination. Alternatively, there are products designed for effluent irrigation in which the pipe is impregnated with anti-microbial materials to prevent biological emitter clogging. In some cases, injection may be required to prevent clogging by chemical precipitation, also. Injection to prevent chemical precipitation will depend on the specific hazard, if any, and should be designed based on laboratory analysis of an effluent sample. A biological control method that has shown promise in laboratory-scale testing was the injection of antagonistic bacteria to eliminate the clogging organisms (bacteria and fungi) and the emitter clogging was reversed.

Flushing the driplines is required to remove the very small particles that are not removed by the filter and any biological growth within the dripline. Flushing velocity should be 0.3 m/sec or greater to adequately move the solids from the dripline although some have recommended velocities of 0.5 m/sec or greater. Flushing frequency may be as often as daily in some severe cases. More often, however, flushing every week or two weeks or even monthly has been found to be adequate. If flushing requirements are excessive, better filtration may reduce the flushing requirements.

Emitter clogging is a continuous incremental event; reversing any clogging early is easier than waiting until the clogging becomes severe. Thus, attentive monitoring of the irrigation system can prevent small problem from becoming catastrophic problems. Pressures and flow rates should be monitored, at a minimum. Appropriate pressure measurement locations include zone inlets and above and below any filters. Pressure measurements before and after each filter can be used to automate the filter backflushing.

Measurement of the flow rate for the entire system is minimal; flow rate for each zone may be appropriate in some situations. Advances in sensors and data communications are making monitoring systems easier to implement and use and better at handling data.



The NaanDan Jain cascade drawing

SPRINKLER IRRIGATION: A ROUTINELY USED TECHNOLOGY

Sprinkler irrigation is routinely used to apply biological effluent in areas such as the Great Plains of the USA. The vast majority of the irrigation systems in that area are center pivots.

There are many advantages to applying effluent with sprinkler irrigation. One is that sprinkler irrigation is a well-known technology in many regions; irrigators have high levels of expertise and comfort with the technology. The nozzles are larger than drip emitters and therefore less likely to clog (but clogging is still possible) and clogging remediation is easier because the nozzles are more easily accessible. The per-acre installation cost is less than drip irrigation in many cases. Some systems are portable so the nutrients and water can be spread over multiple fields, reducing the potential for excessive accumulation and potential environmental degradation. A well-designed and managed system can apply effluent and water quite uniformly. Finally, many sprinkler systems provide visual feedback-the irrigator can see the water being applied.

There are some potential disadvantages. Irrigating in windy conditions can result in wind drift and overspray of effluent to unintended areas. Nutrients and other compounds can volatilize and exacerbate air quality issues or nutrient losses. Contact of effluent with sensitive plant parts, especially leaves, can cause injury. Additionally, contact with effluent can cause contamination of fruits or other harvested plant parts. Finally, some effluents can cause corrosion if they come in contact with metal parts.

Wind drift and overspray concerns can be addressed by installing the nozzles on drops, so the effluent is applied within a meter (or less) of the soil surface. If the nozzle elevations are low enough, effluent contact with the crop leaves can be minimized, reducing any potential foliar injury. Using drops without reducing the nozzle size increases the instantaneous application rate; the soil infiltration rate must be great enough to allow adequate infiltration and thus prevent excessive runoff. Thus, nozzles on drops may not be appropriate for slowly permeable soils or steep slopes or other conditions that increase the probability of excessive runoff, unless measures such as special tillage are practiced. Finally, the sprinkler spacing must be appropriate so that pattern overlap is adequate and application uniformity is maximized. As the sprinklers are installed closer to the soil surface, the spacing between them must decrease to maintain adequate uniformity. Many different nozzle types are used successfully on center pivots used to apply effluent.

When effluent is applied via sprinkler irrigation to food crops, regulations are more stringent because of the potential for direct contact with the effluent, especially if the food is eaten uncooked. Effluent irrigation via sprinkler irrigation is often for feed crops (such as maize intended for animal feed) and the regulations are not as strict.

Some irrigation equipment manufacturers have addressed the corrosion issue by developing lined irrigation pipes. The liner prevents contact of the effluent with metal, extending the life of the pipe and the irrigation system.

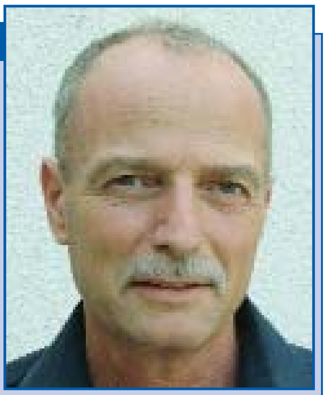
In some locations, application of effluent is limited based on the phosphorus concentration in the top few cm of the soil profile. This is done to reduce the potential for loss of phosphorus to surface water resources, where the added phosphorus can causes algal blooms. When applying phosphorus-rich effluent such as beef feedlot runoff, phosphorus can accumulate in the soil profile quickly. The mobility of sprinkler irrigation systems is valuable because the irrigation system can be moved and the effluent can be applied to another field while crops use the phosphorus in the original field.

AMMONIA VOLATILIZATION: LESS WITH SDI

As outlined above, sprinkler and drip irrigation are both being used successfully to irrigate with effluent. A direct comparison of effluent irrigation with subsurface drip irrigation (SDI) and simulated low-elevation precision appli-

THE VIEWPOINT OF

Making Drippers Suitable for Reclaimed Water: The viewpoint of Kobi Shilo, Chief Agronomist at NaanDanJain (Israel)



Courtesy of NaanDanJain

Adapting Irrigation Systems for the use of reclaimed water

Manufacturers of irrigation solutions developing products to be used for reclaimed water require in-depth knowledge of the special features and behavior of such water.

Three main subjects need to be considered: (1) The chemical effect on the dripper's component and the long effect on the soil, the crops and/or the trees; (2) The physical effect of higher levels of organic materials that can increase clogging of the narrow water passages in the dripper. In certain soil textures, this might cause different water movements; (3) Environmental and health effects.

Reclaimed water contains a number of substances that can affect irrigation equipment and is featured by different qualities than potable water: Large numbers of dirt particles of various types and sizes, as well as chemical substances that exist or are added to the water as part of the reclaiming process. And, last but not least, chlorine is commonly used to avoid development of micro-organisms such as algae or coli forms.

Specific Driplines

Following intense research and two years of field testing, we have implemented a number of changes mainly to the pressure-compensated drippers to adapt them to the specific conditions and make them suitable for long-term use with reclaimed water. First of all, we have improved materials: The specifications of silicon compound in drippers have been changed to make the products more resistant to chemicals. Special attention has been given to the diaphragm, which is the most sensitive part of the dripper.

Secondly, drippers have been redesigned to avoid clogging.

The Cascade Labyrinth - self-cleaning mechanism

A long methodical research in the understanding of the self - cleaning mechanism of water flow enabled us to achieve a new structure of the dripper water passages that effectively deals with the typical effluent water quality. A recently introduced product, the Lateral Flashing Valve is a dripline accessory that automatically flushes or drains the drip lateral lines at the start and the end of irrigation. Frequent and consistent flushing avoids dirt accumulation and protects drippers from clogging. This is part of the physical/technical treatment for irrigation with reclaimed water.

Planning Irrigation Solutions

Reclaimed water has a different distribution pattern than potable water, with less horizontal distribution. Irrigation planning thus requires either a denser drippers' spacing or higher flow rates for full coverage of the crops. Any planning department such as ours must be staffed with experienced agronomists aware of the special features of reclaimed water. These planners must also make sure that any peripheral equipment such as filters and pumps will be resistant to chemical corrosion.

cation (LEPA) was performed in the Great Plains of the USA. Maize yields were comparable under either irrigation system when enough effluent was applied to at least meet the crop N needs. However, the amount of N unrecovered after the two-year study differed between the two systems. Any N applied in the effluent and not harvested or stored in the soil profile (2.4 m deep) at the end of the study was considered unrecovered. When the amount of effluent applied was adequate to meet the crop N needs (490 kg/ha for the two years), no N was unrecovered under SDI (in fact, additional N was mineralized from the soil) and 156 kg/ha were unrecovered under LEPA. When effluent was applied to provide excessive N (840 kg/ha for the two years), 80 kg/ha were unrecovered under SDI and 320 kg/ha were unrecovered under LEPA. There was more N remaining in the soil profile under SDI at the end of the study. Possible losses include volatilization and leaching, although leaching was minimized with careful irrigation management. These results are consistent with other studies that have shown the potential for ammonia-N volatilization when applied via sprinkler irrigation.

In summary, irrigation with effluent can be successful with either drip or sprinkler irrigation. There are many advantages to irrigating with effluent but care must be exercised to avoid environmental degradation or economic loss. As is the case when irrigating with fresh water, either technology has its own advantages and drawbacks when it comes to using effluent! ■