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IRRIGATION MANAGEMENT SERIES

Subsurface Drip Irrigation Systems (SDI) Water Quality Assessment Guidelines

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Introduction

Water quality can have a significant effect on subsurface drip irrigation (SDI) system performance and longevity. In some instances, poor water quality, such as high salinity, can cause soil quality and crop growth problems. However, with proper treatment and management, water with high mineral loading, nutrient enrichment, or high salinity can be used successfully in SDI systems. However, no system should be designed and installed without assessing the quality of the proposed irrigation water supply.

Sampling Requirements

Water samples should be collected in clean triple-rinsed plastic bottles. Water samples from wells should be collected after the well has been operating for at least 15 minutes. Surface water samples should be collected below the water surface. If the quality varies throughout the pumping season, choose the worst case sample or sample multiple times.

About a half gallon of water is needed to perform the chemical analysis. The samples need to be analyzed within 3 hours. If this is not practical, the samples can be frozen or held below 40 degrees Fahrenheit. Check with the lab for specific collection and handling instructions. Be certain to let them know the types of tests you need. These tests are discussed below.

Water Quality Analysis Recommendations

Prevention of clogging is the key to SDI system longevity. Prevention requires an understanding of the potential problems associated with a particular water source. Water quality information should be obtained and made available to the designer and irrigation manager in the early stages of the planning so suitable system components — especially the filtration system — and management and maintenance plans can be selected. Recommended water quality tests include:

1. *Electrical Conductivity (EC)* — measured in ds/m or mmho/cm - a measure of total salinity or total dissolved solids
2. *pH* — a measure of acidity -1 is very acid, 14 is very alkaline, and 7 is neutral
3. *Cations* — measured in meq/L, (milliequivalent/liter), includes; Calcium (Ca), Magnesium (Mg), and Sodium (Na)
4. *Anions* — measured in meq/L, includes: Chloride (Cl), Sulfate (SO_4), Carbonate (CO_3) and Bicarbonate (HCO_3)
5. *Sodium Absorption Ratio (SAR)* — a measure of the potential for sodium in the water to develop sodicity, deterioration in soil permeability, and toxicity to crops. SAR is sometimes reported as Adjusted (Adj) SAR. The Adj. SAR value accounts for the effect of the HCO_3 concentration and salinity in the water and the subsequent potential sodium damage.
6. *Nitrate nitrogen (NO_3-N)* — measured in mg/L (milligram/liter)
7. *Iron (Fe), Manganese (Mn), and Hydrogen Sulfide (H_2S)* — measured in mg/L
8. *Total suspended solids* — measured in mg/L of particles in suspension
9. *Bacterial population* — a measure or count of bacterial presence in #/ml
10. *Boron** - measured in mg/L
11. *Presence of oil***

* *The boron test would be for crop toxicity concern.*

** *Oil in water would be concern for excessive filter clogging. It may not be a test option at some labs and could be considered an optional analysis.*

The measurement units for reporting concentrations is often milligrams per liter (mg/l). Milligrams per liter, when considering irrigation water, is essentially equivalent to parts per million (ppm). Concentrations may also be reported in milliequivalent per liter (meq/l). Conversion factors are needed to convert from mg/l to meq/l and vice versa. Table 1 lists the conversion factors for common constituents.

Tests 1 through 7 will likely be test results included in a standard irrigation water quality test package. Tests 8 through 11 are generally offered by water labs as individuals tests. The test for presence of oil may be a test to consider in oil producing areas or if the well to be used for SDI has experienced surging that may have introduced oil into the pumped water. The fee schedule for tests 1 through 11 will vary from lab to lab. The total cost for all recommended tests may be a few hundred dollars. This is still a minor investment compared to the value of determining the proper design and operation of the SDI system.

Water testing can be done by a number of laboratories in the state. Be sure to use a certified lab. Before collecting any sample, remember to check with the lab for the specific collection procedures, test kits, or the handling requirements of the sample that is needed to ensure quality test results. Table 2 summarizes the water quality guidelines for clogging potential. These guidelines help interpret water quality test results.

Table 1. *Conversion factors: parts per million and milliequivalents per liter (Hanson et al. 1997)*

Constituent	Convert ppm to meq/l multiply by	Convert meq/l to ppm multiply by
Na (sodium)	0.043	23
CA (calcium)	0.050	20
Mg (magnesium)	0.083	12
Cl (chloride)	0.029	35
SO_4 (sulfate)	0.021	48
CO_3 (carbonate)	0.033	30
HCO_3 (bicarbonate)	0.016	61

Example: Convert 10 meq/l of SO_4 to ppm: ppm = 48 x 10 meq/l = 480 ppm

Clogging Hazards

Most surface water and groundwater supplies in Kansas are fairly hard, meaning they have a high mineral content. In addition, many wells, especially older wells, may produce sand when pumping. These two clogging hazards are classified as chemical and physical

Table 2. *Water Quality Guidelines for Microirrigation Systems*

Constituent		Level of Concern	
Clogging Potential	**Low**	**Moderate**	**High**
pH	< 7.0	7 - 8	> 8.0
Iron (Fe) mg/L	< 0.2	0.2 - 1.5	> 1.5
Manganese (M_n) mg/L	< 0.1	0.1 - 1.5	> 1.5
Hydrogen Sulfide (H_2S) mg/L	< 0.2	0.2 - 2.0	> 2.0
Total Dissolved solids (TDS) mg/l	< 500	500 - 2000	> 2000
Suspended Solids mg/L	< 50	50 - 100	> 100
Bacteria Count (# / mL)	< 10,000	10,000 - 50,000	> 50,000
Crop Effect		**Level of Concern**	
Potential	**Low**	**Moderate**	**High**
EC - mmho/cm	< 0.75	0.75 - 3.0	> 3.0
NO_3 - mg/L	< 5	5 - 30	> 30
Specific Ion		**Level of Concern**	
Toxicity	**Low**	**Moderate**	**High**
Boron - mg/L	< 0.7	0.7 - 3.0	> 3.0
Chloride - meq/L	< 4	4 - 10	> 10.0
Chloride - mg/L	< 142	142 - 355	> 355
Sodium (Adj SAR)	< 3.0	3 - 9	> 9

Adapted from Hanson et. al, 1994 and Hassan, 1998.

Table 3. *Example size of various particles.*

Particle	Diameter, mm
Coarse sand	0.50 to 1.00
Fine sand	0.10 to 0.25
Silt	0.002 to 0.05
Clay	<0.002
Bacteria	0.0004 to 0.002
Virus	<0.0004

hazards, respectively. The third clogging hazard is biological, which could be slimes produced by bacterial or algal growth.

As a general rule, filtration requirements are sized to remove particles 1/10 the size of the smallest emitter opening. Individual silt and clay particles and bacteria can generally pass through the filtration system and even through the drip irrigation emitters. However, conglomeration of multiple particles is possible, particularly with bonding "glues" provided by biological activity and clogging may result. It is impractical to filter out all the smaller particles, so considerations must be given to periodic flushing. Typical particle sizes are shown in Table 3.

Clogging hazards are discussed in more detail in *Filtration and Maintenance Considerations for Subsurface Drip Irrigation (SDI) Systems*, MF-2361.

Example: A grower wishes to use household bleach (NaOC at 5.25 percent active chlorine) to achieve a 15 ppm chlorine level at the injection point. The flow rate of the irrigation system is 700 gpm.

At what rate should the NaOC be injected?

IR = 700 gpm × 15 ppm × 0.006 ÷ 5.25 = 12 gallons per hour

At an irrigation flow rate of 700 gpm, the grower is pumping 700 × 60 = 42,000 gph. The goal is to inject 12 gallons of bleach into 42,000 gallons of water each hour that injection occurs.

If the injector is set for a 300:1 ratio, it will inject 42,000 ÷ 300 or 140 gallons per hour. Then, 12 gallons of bleach should be added to 140 gallons of water in the stock solution. Be careful to use the same time units (hours) when calculating the injection rate.

Well Chlorination

Bacteria do not normally live in groundwater until a well allows their introduction, an air exchange, and, in some cases, a source of nutrients. Bacteria can live on iron, manganese, or sulphur. Their growth process produces a slime that can build up on the well screens and cause well yield declines. A bacteria-contaminated well will introduce bacteria to the SDI system, which can result in clogging of the filtration system and dripline emitters. Chlorination of an irrigation well to kill bacteria should be at least an annual practice. Treat the well with a shock treatment of 500 ppm to

Table 4. *Notes on Chemical Clogging Hazards*

1. Bicarbonate concentrations exceeding about 2 meq/L and pH exceeding about 7.5 can cause calcium carbonate precipitation.
2. Calcium concentrations exceeding 2 to 3 meq/L can cause precipitates to form during injection of some phosphate fertilizers. Special procedures are necessary for the injection of phosphate fertilizers, and careful injection should be attempted only by experienced personnel.
3. High concentrations of sulfide ions can cause iron and manganese precipitation. Iron and manganese sulfides are very insoluble, even in acid solutions. In this case, frequent acidification or the use of a settling basin for separating iron and manganese precipitants is advisable.
4. Irrigation water containing more than 0.1 ppm sulfides may encourage growth of sulfur bacteria within the irrigation system. Regular chlorination may be needed.
5. Chlorination when manganese is present should be used with caution, as a reaction time delay may occur between chlorination and the development of the precipitate. This may cause the manganese precipitate to form downstream of the filter and cause emitter clogging.

2000 ppm. Details for shock chlorination of wells are discussed in *Shock Chlorination Treatment for Irrigation Wells*, MF-2589, or contact your local well service provider. A well that has been shock chlorinated should be pumped to waste until the water clears. This water should never be sent through the SDI system because there will be large amounts of dislodged chemical and biological material from the well casing and screen. A simple Excel template to calculate the chlorine rate for chlorination of deep wells can be found at *www.oznet.ksu.edu/sdi/Software/SDISoftware.htm*.

SDI System Chlorination

Chlorination of the SDI system is also a practice that would be a routine maintenance procedure, because chlorine will oxidize biological material. Bacterial growth in driplines can be troublesome due to small clay particles in the water that are smaller than the required level of filtration. The sticky slime growth may cause these small particles to stick together and clog emitters.

Chlorine can be injected to kill bacteria either continuously with a low dosage base (0.5-1.5 ppm) or periodically at a high dose of 5 to 20 ppm. Periodic dosage is more common in Kansas systems. The dosage level should be sufficient that a concentration of 0.5 to 1 ppm of free chlorine should be measured at the end of the system. Chlorine is more effective in acid waters. High pH or alkaline waters should be acidified to a pH of 6.5 for effective chlorine treatment. Acid treatment also can be effective in controlling bacterial growth.

Chlorine Injection Rate Formula

The general formula for calculating the amount of chlorine to inject in liquid form (sodium hypochlorite, NaOC) is:

$IR = Q \times C \times 0.006 \div S$

where:

IR= Chlorine injection rate (gal/hour)
Q = Irrigation system flow rate (gal/min)
C = Desired chlorine concentration (ppm)
S = Strength of NaOC solution used (percent)

Common household bleach is generally a 5.25 to 7.5 percent solution. Stronger concentrations of chlorine solutions are available from irrigation dealers and industrial suppliers.

The injected chlorine must travel through the entire system during the injection period. The propagation time should be calculated or obtained from the installer. Alternatively, water from the flushline can be tested to see if a free chlorine residual is detected, which would indicate sufficient injection time has elapsed.

Chemical Precipitation

Chemical precipitation hazard guidelines, as shown in Table 1, give some indication of potential clogging hazards. SDI systems have an advantage over surface drip systems because the emitter level in the driplines are below ground and buffered from sunlight and temperature that could help drive both biological and chemical activity. Water pH and temperature also play a major role in many reactions.

Several of the references listed at the end of this publication noted several important chemical precipitation hazards. These are summarized in Table 4.

Calcium Carbonate

Calcium carbonate, commonly known as lime, can be a problem with high pH (>7.5) and high bicarbonate levels (> 2 meq/L). The symptom of calcium precipitant is a white film or plating on the dripline or around the emitters or white precipitants in the flush water of the dripline laterals.

The usual treatment for calcium precipitation is to acidify the water by lowering the pH to 7.0 or lower with continuous injection. Calcium becomes more soluble at low pH. When using a periodic injection treatment, pH may have to be lowered to 4.0 or less and allowed to sit in the system for up to 60 minutes. Temperature, pH, and the calcium concentration affect calcium solubility, so conditions will vary throughout the system. Litmus paper, colormetric kits, or a portable pH meter can measure the pH at the lower end of the system to determine if free chlorine exists.

Sulfuric acid or hydrochloric acid can be used to reduce pH. Muriatic acid (20 percent hydrochloric acid) may be the most commonly available acid from hardware or farm supply stores. Urea sulfuric acid, an acid with nitrogen fertilizer value, can also be used. This product is safer to use and is marketed as N-pHuric. Check with your irrigation or fertilizer dealer about its availability in your region. **Caution: Use extreme care in handling acids, and always add acid to water.** Be certain to flush and clean the injection system after an acid treatment because the acid may be corrosive to internal parts. Treatments need to be done before total emitter blockage occurs. Remediation, after total blockage, is difficult or impossible because the acid will not come into contact with precipitants in closed passages.

Iron and Manganese

Iron and manganese precipitation can become a problem with concentrations as low as 0.1 ppm. Most groundwater contains some iron

and manganese in a soluble state, but when exposed to air, they oxidize and precipitate as a solid. Irrigators with center pivots, especially center pivots using alluvial groundwater supplies, often see the structures turn red in a short time. These compounds also can be used as an energy source by bacteria. They form filamentous slime that can clog filters and emitters, and act as a glue to hold other contaminants together.

Symptoms of iron precipitation are reddish stains and rust particles in the flush water and reddish deposits in the orifices. Manganese would be similar, but darker or black. Bacterial slimes have a similar color as precipitants, but appear as filamentous sludge in flush water or collected on screens.

Aeration and Settling for Iron and Manganese Treatment

One effective option for removal of high concentrations of iron and manganese for high flow rate systems is the use of aeration and settling basins, especially for manganese. The oxidation rate of manganese is much slower than for iron, making manganese removal problematic with some of the other treatment methods.

Aeration of the source water occurs by spraying water into the air or running it over a series of baffles to enhance mixing with oxygen into the water. There must be sufficient aeration and reaction time; the soluble forms of manganese and iron will oxidize and precipitate. The disadvantage of this treatment is the need for a second pump. Total head requirements are not changed when using two pumps, so energy costs are not a major factor. Other disadvantages of a settling basin are the space requirement, construction costs, and long-term maintenance needs.

Table 5. *Water treatments to prevent clogging in drip-irrigation systems*

Problem	Treatment Options
Carbonate precipitation (white precipitate) HCO_3 greater than 2.0 meq/l — pH greater than 7.5	1. Continuous injection: maintain pH between 5 and 7 2. Periodic injection: maintain pH at under 4 for 30 to 60 minutes daily
Iron precipitation (reddish precipitate) Iron concentrations greater than 0.1 ppm	1. Aeration and settling to oxidize iron. (Best treatment for high concentrations - 10 ppm or more). 2. Chlorine precipitation - injecting chlorine to precipitate iron: a. use an injection rate of 1 ppm of chlorine per 0.7 ppm of iron b. inject in front of the filter so that the precipitate is filtered out 3. Reduce pH to 4 or less for 30-60 minutes daily.
Manganese precipitation (black precipitate) Manganese concentrations greater than 0.1 ppm	1. Inject 1 ppm of chlorine per 1.3 ppm of manganese in front of the filter
Iron bacteria (reddish slime) Iron concentrations greater than 0.1 ppm	1. Inject chlorine at a rate of 1 ppm free chlorine continuously or 10 to 20 ppm for 30 to 60 minutes daily.
Sulfur bacteria (white cottony slime) sulfide concentrations greater than 0.1 ppm	1. Inject chlorine continuously at a rate of 1 ppm per 4 to 8 ppm of hydrogen sulfide, or 2. Inject chlorine intermittently at 1 ppm free chlorine for 30 to 60 minutes daily.
Bacterial slime and algae	1. Inject chlorine at a rate of 0.5 to 1 ppm continuously or 20 ppm for 20 minutes at the end of each irrigation cycle.
Iron sulfide (black sand-like material) Iron and sulfide concentrations greater than 0.1 ppm	1. Dissolve iron by injecting acid continuously to lower pH to between 5 and 7.

Chlorination to control algae and bacteria in the basin may be required.

Chlorination and Filtration for Iron and Manganese Treatment

Injection of chlorine into water will cause the dissolved iron to precipitate so it can be filtered out. The reaction occurs quickly, but injections need to be located upstream of the filter. This treatment method may be best suited for systems with sand media filters. Chlorine is injected at a rate of 1 ppm for each 0.7 ppm of iron. Additional chlorine may be required if other contaminants, such as iron bacteria, are present. This treatment requires continuous injection of chlorine. Successful treatment also requires complete mixing of the chlorine in the water.

This treatment method is not suited to manganese removal because of its slower oxidation rate. If manganese and free chlorine remain in the line after filtration, precipitation could occur and clog emitters.

pH Control

Iron is more soluble at lower pH, so acid can be used as a continuous or periodic treatment as described for calcium carbonate. In this case, the pH should be lowered to 2.0 or less for 30 to 60 minutes for a periodic or cleaning treatment. After a periodic treatment, the system must be flushed.

Iron and Manganese Sulfides

Dissolved iron and manganese, in the presence of sulfides, can form a black, sand-like insoluble precipitant. The recommended treatment for this combination of compounds is continuous acid injection that lowers pH to between 5 and 7.

Sulfur slime also can be produced by bacteria that can oxidize hydrogen sulfide and produce elemental sulfur. The symptoms of this condition are white, cottony masses of slime that either clog emitters directly or act as glue to collect small silt and clay particles that clump together and clog emitters.

Treatment Summary

The symptoms and treatments for the various clogging hazards are summarized in Table 5.

Table 6 gives water quality data from the analysis of two irrigation water samples. Examples 1 and 2 in Table 6 use the water quality data from Table 1 to evaluate the clogging potential of these irrigation waters.

Summary

Subsurface Drip Irrigation offers a number of agronomic production and water conservation advantages, but requires proper design, operation, and maintenance to be an efficient, effective, and long-lived irrigation system. One management change from the current irrigation systems is the need to understand the SDI system

Table 6. *Water quality analysis of two irrigation water samples (After Hanson et al. 1997)*

Water 1	**Water 2**
EC = 2.51 dS/m	EC = 0.87 dS/m
pH = 7.4	pH = 7.7
Ca = 306 ppm	Ca = 44 ppm
Mg = 121 ppm	Mg = 16 ppm
Na = 124 ppm	Na = 127 ppm
Cl = 158 ppm	Cl = 70 ppm
HCO3 = 317 ppm	HCO3 = 122 ppm
SO4 = 912 ppm	SO4 = 226 ppm
Mn = less than 0.1 ppm	Mn = 2.6 ppm
Fe = less than 0.1 ppm	Fe = 0.65 ppm

Example 1. The relatively high total dissolved salts (EC rating) indicates that *Water 1* has some clogging potential. This is verified by the relatively high bicarbonate concentration. The calcium concentration and the bicarbonate concentration together suggest that calcium carbonate could clog the emitters, particularly if the pH were to rise as a result of any chemical injection. The iron and manganese concentrations indicate little potential for clogging from precipitation of those elements.

Example 2. The analysis of *Water 2* reveals little potential for clogging from total dissolved salts (EC rating), but the pH and bircarbonate concentrations indicate that clogging might result from calcium carbonate precipitation. The levels of manganese and iron indicate a severe potential for clogging from manganese oxide precipitation and iron oxide precipitation.

sensitivity to clogging by physical, biological, or chemical agents.

Before designing or installing an SDI system, be certain a comprehensive water quality test is conducted on the source water supply. Once this assessment is complete, the manager should be aware of many of the potential problems that might be caused by the water supply. The adage "an ounce of prevention is worth a pound of cure" is very appropriate for SDI systems because early recognition of developing problems can prevent hardship. Developing problems can be easily handled as compared to remediation of a clogged system. While this may seem daunting at first, as with most new technology, managers will quickly become familiar with the system and its operational needs.

References

Burt, C.M. and S.W. Styles. 1994. *Drip and Microirrigation for Trees, Vines, and Row Crops* (with special sections on buried drip). Irrigation Training and Research Center, Cal Poly, San Luis Obispo, CA. 261 pgs.

Clark, G.A., W.J. Lamont Jr, C.W. Marr, and D. H. Rogers. 1996. *Maintaining Drip Irrigation Systems: Commercial Vegetable Production bulletin*. MF-2178. K-State Research and Extension. Manhattan, KS. 6 pgs.

Hanson, B., L. Schwankl, S.R. Grattan, and T. Prichard. *Drip Irrigation for Row Crops*. Water Management Series #93-05. University of California, Davis. Davis, CA. 175 pgs.

Hassan, F., 1998. *Micro-irrigation Management and Maintenance*. Agro Industrial Management. Fresno, CA. 233 pgs.

Hanson, B., Schwankl, L, Grattan, S., and Prichard, T. 1997. *Drip Irrigation for Row Crops*. Division of Agriculture and Natural Resources. Publication 3376. University of California, Davis. 238 pgs.

Rogers, D.H., F.R. Lamm, M. Alam and C.M. Powell. *Shock Chlorination treatment for Irrigation wells*. Water Quality Series Bulletin MF-2589. K-State Research and Extension. Manhattan, KS. 4 pgs.

Schwankl, L., B. Hanson, and T. Prichard. 1993. *Low-Volume Irrigation*. Water Management Series #93-03. University of California, Davis. Davis, CA. 116 pgs.

Van der Gulik, T.W. 1999. B.C. *Trickle Irrigation Manual*. B.C. Ministry of Agriculture and Food. Abbotsford, B.C., Canada. 321 pgs.

Additional Resources:

MF-2361, *Filtration and Maintenance Considerations for Subsurface Drip Irrigation (SDI) Systems*

MF-2242, *Economic Comparison of SDI and Center Pivots for Various Field Sizes*

MF-836, *Irrigation Capital Requirements and Energy Cost*

MF-2590, *Management Consideration for Operating a Subsurface Drip Irrigation System*

MF-2578, *Design Considerations for Subsurface Drip Irrigation (SDI) Systems*

MF-2576, *Subsurface Drip Irrigation (SDI) Components: Minimum Requirements*

Related K-State Research and Extension SDI Irrigation Web sites:

General Irrigation
www.oznet.ksu.edu/irrigate

Mobile Irrigation Lab
www.oznet.ksu.edu/mil

Subsurface Drip Irrigation
www.oznet.ksu.edu/sdi

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