GP 4.8 Adjust irrigation run distance to maximize irrigation efficiency.

The selection of the proper furrow length must account for actual water infiltration rates. These rates are determined by soil texture and condition, slope and the rate that water is applied to the furrow. Greater water application uniformity combined with decreased percolation and runoff will all be achieved when suitable irrigation run lengths are selected.

Shortening irrigation run length should be considered when field gradients contribute to excessive runoff, when coarse textured soils result in high infiltration rates and when land leveling is not an acceptable alternative. A reduction in field length can be achieved by either using gated irrigation pipe or by the construction of new irrigation ditches. These options involve varying installation, maintenance and labor costs.

GP 4.9 Adjust basin size or distance between border dikes to maximize irrigation efficiency.

Basin size and irrigation water delivery rates should be matched with the infiltration characteristics of specific soils used in graded border basin and dead level basin irrigation systems. In general, smaller basins and/or higher water delivery rates are required on increasingly permeable soils. The length of a basin also has a controlling influence on irrigation efficiency. Short, wide basins are more efficient than long, narrow ones. Some on-site calibration of the effect of basin size and water application rate on irrigation uniformity and efficiency will be required.

BMP 5. The application of irrigation water shall be timed to minimize nitrogen loss by leaching and runoff.

Irrigation water is applied to crop lands to replenish soil moisture reserves, leach excess salts, promote seed germination and stabilize soil against wind erosion. Therefore, after stand establishment and leaching, irrigation water applications should be timed to coincide with soil moisture depletion and crop need. Both over and under application of water can result in reduced or unproductive crop growth, lower yields and ultimately in smaller profits. Over application of irrigation water and excessive nitrogen fertilizer rates are the two most critical factors which result in leaching of nitrates below the crop root zone and subsequent contamination of groundwater (RANN Report. 1979. Nitrate in Effluents from Irrigated Lands. University of California, Riverside).

Applications of irrigation water should be timed to avoid excessive soil moisture depletion. Allowable depletions vary from about 20% for some vegetables to over 60% for cotton (Table 19).

GP 5.1. Schedule irrigation applications based on crop need.

Timely measurement or estimation of soil moisture content and/or crop water stress are needed to effectively schedule when irrigation is needed. Various devices and techniques are available to assist in determining when, and in some cases, how much irrigation water is required (Table 22). Regardless of the irrigation scheduling method that is used, some on-site calibration will be required for specific soils.

BMP 6. The operator shall use tillage practices that maximize water and nitrogen uptake by crop plants.

Various tillage and soil management practices can be used to improve water delivery into the root zone or allow for efficient and uniform distribution of irrigation water to a farm field. Four guidance practices which improve irrigation efficiency are discussed under BMP 4. Four additional practices are presented here which can be used to facilitate water movement into the crop rooting zone.

Increased permeability of soils to the downward movement of irrigation water has the potential to result in accelerated leaching of solutes, including nitrates, if the amount and/or frequency of irrigation events is excessive. Conversely, if irrigations are scheduled correctly, appropriate tillage practices will tend to promote optimum growing conditions for crop plants. Under these conditions the uptake of nutrients and water will be maximized and the potential for nitrate leaching losses will be minimized.

GP 6.1 . Use land leveling to adjust field gradients (see GP 4.7).

Table 22.
Irrigation scheduling techniques and devices available to facilitate measurement or estimation of soil moisture, crop canopy stress and crop water use.

Irrigation Scheduling Tools	Information Supplied	
	When to irrigate	How much to irrigate
Soil Moisture Measurement		
Feel and appearance	X	X
Soil tensiometers	X	X
Neutron probe moisture tester	X	X
Resistance moisture tester (e.g. gypsum block)	X	X
Gravimetric moisture testing	X	X
Check Book Methods		
Computer models	X	X
Crop Canopy Stress*		
Crop Water Stress Index (CWSI) using infrared thermometry	X	
Leaf water potential using a pressure bomb	X	
Visual crop appearance	X	
Evaporative Loss Estimation*		
Reference evapotranspiration (ETo)	X	
AZMET**	X	
Evaporation pan	X	
Historical comsumptive use	X	

**These methods primarily determine when to irrigate. By periodic calibration to actual soil moisture content, how much water to apply may also be calculated.*

***Refers to the Arizona Meteorological Network of the University of Arizona.*

GP 6.2. Adjust irrigation run distance to maximize irrigation efficiency (see GP 4.8).

GP 6.3. Angle irrigation furrows to reduce furrow slope (see GP 4.5).

GP 6.4. Install irrigation runs on the contour in fields with excessive slope (see GP 4.6).

GP 6.5. Rip soil in wheel row furrows.

Repeated equipment traffic through farm fields can result in serious compaction in wheel row furrows later in the season. This leads to reduced permeability in these areas and unequal water infiltration in traffic versus nontraffic rows. All soil types are subject to compaction, but particularly those soils which are high in silt and/or clay content. Wheel pressure on moist but not saturated soils will usually result in the greatest severity of compaction.

Mechanical disruption of soil compaction can be accomplished by inrow ripping. This involves inserting ripper shanks to the depth of the compacted soil and moving the shank horizontally along the length of the affected wheelrow. Inrow ripping is normally done in conjunction with other field operations such as cultivation or side dressing.

Care should be taken to avoid ripping to excessive depths. This practice may require excess energy and can impede the flow of irrigation water, damage root systems or cause excessive infiltration. In some crops, compaction of the furrow bottoms for the first several irrigations will actually improve irrigation efficiency. Under these conditions this practice is not recommended.

GP 6.6. Rip soils during land preparation to depths sufficient to disperse identified compaction zones.

Mechanical disruption of compacted surface and sub-soil horizons may be necessary for proper water infiltration and crop root development. Ripping, chiseling or deeper subsoiling can be used to disperse compaction resulting from previous equipment traffic. If uncorrected, soil compaction will result in poor water infiltration, inefficient water use and reduced crop productivity. Greater runoff from compacted soils can directly lead to an increased potential for groundwater contamination by nitrates if tailwater is not reused.

All soil types are subject to compaction, but particularly those soils which are high in silt and/or clay and low in organic matter content. Equipment traffic on moist but not saturated soils will usually result in the most severe compaction.

Preseason ripping should be done prior to furrowing and at right angles or diagonally to equipment traffic patterns in the previous season. The level of soil moisture is critical if subsoil ripping is to be effective. The soil should be moist enough to be workable but also dry enough to fracture and disperse compacted soil layers. *The need for soil ripping should be established by identifying compacted layers in the soil before performing the operation.* Unnecessary deep ripping will increase production costs for the expense of the tillage itself and for excessive amounts of water required for preplant irrigation. The application of soluble N fertilizers prior to deep ripping should be avoided if subsequent preplant irrigation will leach N below the expected depth of the root zone.

GP 6.7. Cultivate furrow irrigated crops.

The application of water to furrow irrigated fields will invariably lead to a slaking of soil aggregates and the formation of a surface crust within the furrow. This crusting forms a beneficial layer which helps reduce evaporation losses initially, but which also can dramatically reduce water infiltration rates in later irrigation events.

Cultivation is traditionally used for weed control. Cultivation just prior to an irrigation also mechanically mixes and aerates compacted or crusted soils in furrow irrigated fields. This practice will improve water infiltration and increase irrigation efficiency thereby reducing the potential for runoff and the associated leaching hazards of unused tailwater.

GP 6.8. Use preseason deep plowing.

The practice of mechanically inverting the surface 12 to 24 inches of soil can have several beneficial effects. First, it can redistribute nutrients which have been leached below the root zone of shallow rooted crops. Second, it can be used in place of shallow ripping or chiseling to disperse soil compaction occurring above the plow depth. Third, it can redistribute harmful concentrations of soluble salts or weed seeds which may have been present at the soil surface. And fourth, it could aid water movement by mixing stratified soil layers. Deep plowing can also stimulate early season microbial activity and the release of nutrients contained in organic residues previously incorporated.

Deep plowing of furrowed fields should be done after the furrows are disced down and when the soil contains enough moisture to be workable. Plow at right angles to previous equipment traffic patterns and at an angle to ripping patterns if the field was ripped prior to plowing.

Tractors with relatively high horsepower ratings are required for deep versus shallow plowing. The use of custom operators should be considered by growers who do not have equipment suitable for deep plowing.

Other Methods 7. Other methods to minimize nitrogen loss from leaching, runoff or backflow into irrigation wells.

Nine Guidance Practices are listed under Other Methods. Three are designed to limit seepage losses of irrigation waters, two protect well casings from contamination, one specifies cropping sequences to enhance recovery of soil nitrogen and two outline techniques for enhancing root zone aeration and crop uptake of water and nitrogen.

GP 7.1. Divert and confine irrigation runoff water into reuse systems.

Irrigation of farm fields with appreciable slope often leads to the accumulation of ponded tailwater at the bottom end of the field. The collection, storage and reuse of this runoff water can greatly decrease the potential for uncontrolled leaching of nitrates (or other soluble chemicals) which could occur beneath ponded tailwater.

The entire reuse system will include a storage reservoir or sump, a suitable pump, and a pipe and ditch system capable of delivering captured tailwater onto adjacent croplands. Heavy duty earth moving equipment and engineering assistance may be required for the proper design and construction of a tailwater reuse system. This includes an assessment of whether a sump at a particular site should be lined or sealed to minimize seepage losses.

Appreciable capital costs are often associated with the construction, operation and maintenance of an onfarm reuse system. For this reason this practice may not be applicable when the farm operator is not the land owner.

GP. 7.2 Line irrigation delivery ditches to reduce water losses.

Seepage and weed growth along unlined earthen irrigation ditches can result in significant water loss. In addition, seepage can directly contribute to the potential for dissolved nitrates to enter and pollute groundwater supplies. Lining ditches with concrete, plastic or other impermeable materials can significantly increase irrigation efficiency and reduce seepage losses.

The decision to line irrigation ditches will incur considerable capital costs particularly if concrete is used. The practice of lining ditches is most effective on loamy to sandy textured soils and is most feasible when the operator is the land owner. The applicability of other water conveyance structures such as pipelines should also be considered (see GP 7.3). Water run applications of nitrogen fertilizers should be avoided in unlined irrigation ditches.

GP 7.3 Install pipelines to convey irrigation water.

The installation of pipelines to carry irrigation water instead of using open canals can improve irrigation water utilization by decreasing water losses from seepage and evaporation. Reducing seepage losses can significantly lower the potential for leaching of nitrates and other pollutants into groundwater sources.

Proper equipment, construction materials, design and layout, and engineering assistance are all essential for the installation of an effective and low maintenance pipeline distribution system. The implementation of this management practice should be considered when the farm operator owns the cropland, when excessive seepage losses will or do occur from unlined water delivery systems, and when other types of surface conveyance are inefficient or unsuitable.

GP 7.4 Upgrade well design or condition.

Wells can act as direct conduits for pollutants into the groundwater when they are not properly completed or maintained or when they contain perforated and/or damaged casing segments. Pollution can occur when cascading flows from areas of upper casing damage and/or perforation or preferential flow down the casings of uncompleted wells carry pollutants into lower portions of the aquifer.

All wells should be properly completed prior to operation and then inspected periodically for evidence of damage or cascading flows. Inspections and needed repairs should be scheduled during off-season periods when possible. If cascading flows from upper level perforations occur, water tests for nitrate or other possible pollutants should be made to determine the potential for groundwater contamination and the necessity for implementing this management practice.

Onsite visual or audio well inspections can identify most problems which are associated with unacceptable well design or condition. Contact a suitable pump and well maintenance company for assistance in determining the condition of existing well casings and whether additional improvements are needed.

GP 7.5 Equip closed irrigation systems having chemical injection capabilities with appropriate antisiphon check valves.

Closed or pressurized irrigation systems such as trickle or sprinkler systems are routinely equipped with chemical injectors to apply soluble fertilizer solutions or other agricultural chemicals in the irrigation water; a practice known as chemigation. However, if unprotected by a suitable antisiphon system including check and relief valves, chemical injectors can also provide a means for backflow of pumped irrigation water when the pump is shut down. This flow of water passes down through the well casing and ultimately can reenter and pollute groundwater supplies.

A properly designed system should include the following components (Figure 21):

1) a check valve, to prevent reverse flow, and a vacuum relief valve in the irrigation line;
2) an inspection port or other device which permits monitoring of the performance of the check valve in the irrigation line;
3) an automatic low pressure drain, located between the main check valve and the irrigation pump such that water will drain away from the well casing or the water source being used;
4) a check valve in the chemical injection line; and
5) an interlocking device between the power supply for the chemical injector(s) and that of the irrigation pumping plant to insure that both units will shut off simultaneously.

GP 7.6 Equip transfer hoses on fertilizer nurse rigs with valves to prevent spillage.

The delivery end of all fertilizer nurse rig transfer hoses should be fitted with a suitable ball valve. The proper use of this valve will prevent spillage losses of about 3 to 5 gallons of fertilizer solution per transfer. In addition, a second in line ball valve should be installed on the nurse rig itself, between the tank and the point where the transfer hose is at-

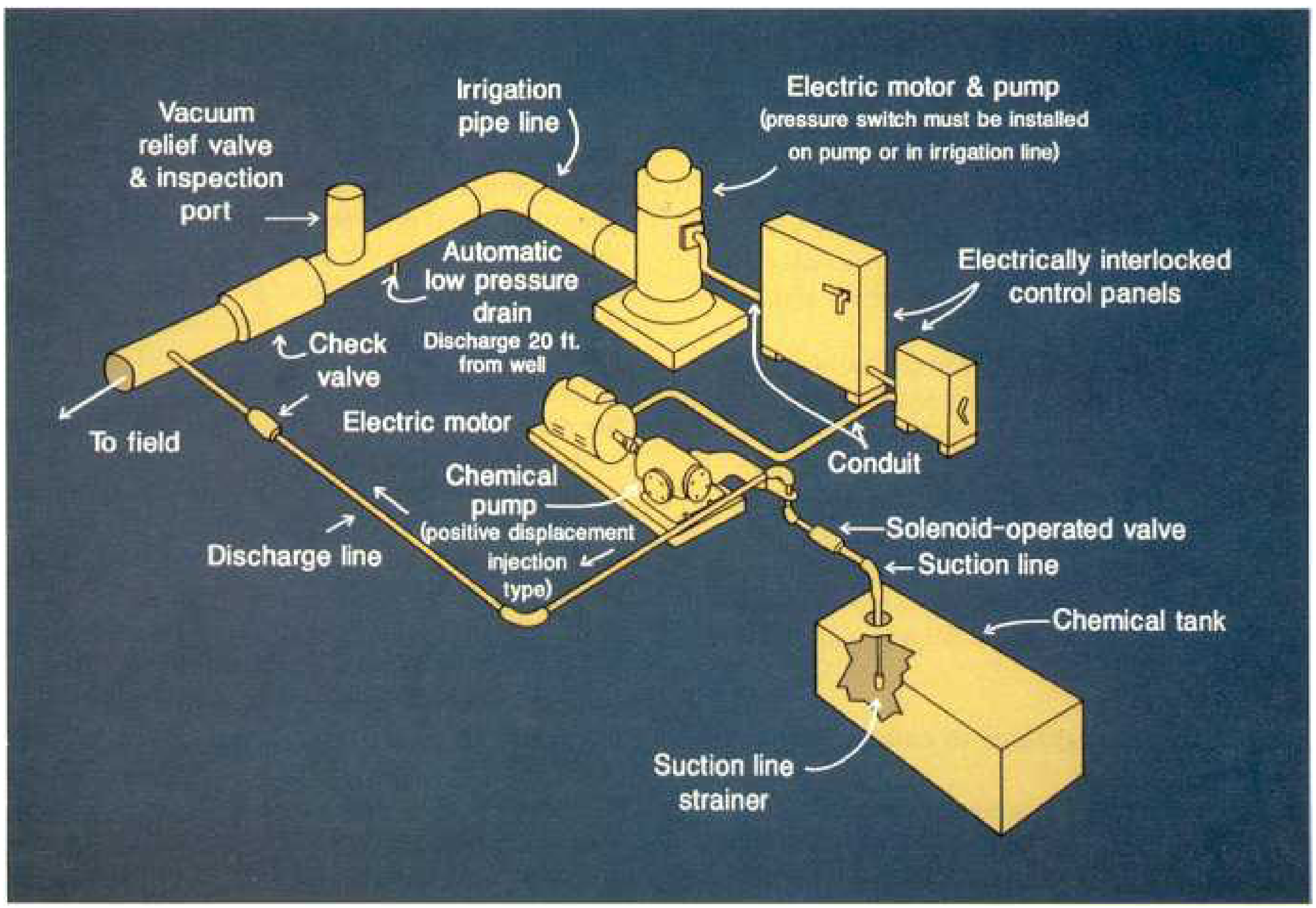

Figure 21.
An example of EPA-required antipollution devices and equipment arrangement for chemigation using a motor driven system (after: Doane's Agricultural Report. 1988. Chemigation Safety Requirements. Vol. 51, No. 19-6).

tached. Valves should be periodically checked for proper operation and/or leakage.

Contact your fertilizer or farm equipment dealer for assistance in obtaining suitable corrosion resistant ball valves for use with your fertilizer nurse rig. Fertilizer dealers who supply nurse rigs should equip them with the appropriate valves.

GP 7.7 Follow shallow rooted crops with deep rooted crops in crop rotation.

Many shallow rooted crops are high value vegetable and specialty crops which receive high rates of nitrogen fertilizer. Some of this nitrogen may be leached below their effective rooting zone but could still be utilized by succeeding crops with deeper root systems (see Table 16). The use of deep rooted crops following shallow rooted crops can increase nitrogen fertilizer use efficiency and reduce the potential for nitrate contamination of groundwater via leaching.

Rooting depth and nitrogen recovery are not the only factors affecting the choice of a cropping sequence or rotation. Other considerations including herbicide use restrictions, market demand and the availability of labor and farm equipment must also be evaluated.

GP 7.8 Practice soil aeration in turf areas.

Aeration is an indispensable turf management technique which can improve turf growth in many ways. Aeration reduces compaction in the surface soil layer thereby increasing oxygen availability to roots and improving water infiltration. Some aeration techniques can also mechanically reduce thatch accumulation. By improving the growing environment for turf, aeration can improve nitrogen fertilizer use efficiency and reduce the potential for ponding of irrigation water and subsequent leaching into groundwater supplies.

Various techniques are available to mechanically improve soil aeration in permanent turf plantings where more conventional tillage or cultivation is not possible. In general, soil aeration is accomplished by either slitting the soil surface or removing soil cores. Other management techniques such as topdressing with sand or soil amendments, mowing and dragging - together or separately, can be used in conjunction with aeration to further improve physical properties of the soil or to restore an aesthetically pleasing appearance to the turf surface. Aeration can be performed at any time during the year but greatest benefits are obtained in the spring and summer growing season.

GP 7.9 Apply amendments which contribute soluble calcium to sodic soils and irrigation water.

Soils in arid and semiarid regions commonly contain high concentrations of adsorbed sodium (Na). This results in poor soil structure, sealing of the soil surface when wetted, low water infiltration rates and low crop productivity. In addition, soils irrigated with high sodium water will also become increasingly sodic over time. A number of chemical and organic soil amendments can be used to remove unwanted sodium from sodic soils. Likewise, the application of various soluble chemicals to irrigation water can offset the adverse effects of high sodium levels they may contain. The proper use of soil and water amendments can significantly increase water infiltration and irrigation efficiency while lowering water costs and runoff from croplands. Improved conditions for crop growth and reduced runoff can increase nitrogen uptake efficiency and reduce the potential for nitrate contamination of groundwater by leaching.

- **Reclaiming Sodic Soils**

The first step in reclaiming a sodic soil is to measure the extent of sodium saturation using a soil test for exchangeable sodium percentage, or ESP. The recommended procedure is to measure the sodium, calcium and magnesium concentrations in a saturated paste extract and then calculate ESP using the following two equations (from Richards, 1954. Diagnosis and Improvement of Saline and Alkali Soils, USDA Agriculture Handbook 60):

Eq. 10

$$\text{Sodium Adsorption Ratio (SAR)} = [Na^{+}] / \sqrt{([Ca^{+2}] + [Mg^{+2}])/2}$$

NOTE: Na, Ca and Mg are expressed as milliequivalents per liter (meq/L).

$$ESP = \frac{100\,(-0.0126 + 0.01475\ SAR)}{1 + (-0.0126 + 0.01475\ SAR)} \qquad \text{Eq. 11}$$

The interpretation of ESP values depends on the soil texture and is summarized in Table 23.

Table 23.
Interpretation of exchangeable sodium percentage (ESP) values in soils of varying texture.

Soil Texture	Sodium Hazard in Soil		
	None	Moderate	Severe
	ESP (%)		
Sandy loam	0 - 12	13 - 20	>20
Silt loam	0 - 10	11 - 15	>15
Clay loam	0 - 7	8 - 12	>12

When a moderate to severe sodium hazard exists and water penetration is poor then an application of a soil amendment should be considered. Organic amendments such as animal manures or plant residues are helpful in improving the physical condition of soil for absorbing irrigation waters. Repeat applications of these materials over several years may be required to fully reclaim a sodic soil. However, these organic amendments are not effective if the soil is continually irrigated with high sodium water. The use of organic soil amendments is discussed under GP 1.3

In most cases, sodic soils are reclaimed by using chemical amendments which displace sodium from the surfaces of soil particles. The amendments most commonly used in Arizona are listed in Table 24. Soluble sodium compounds are then leached below the root zone with applications of supplemental irrigation water. The amendment used most in Arizona is gypsum ($CaSO_4 \cdot 2H_2O$). Gypsum directly supplies the soluble calcium which takes part in the sodium displacement reaction. Gypsum reacts with sodic soils as follows:

Eq. 12

$$\text{gypsum} + \text{sodic soil} \rightarrow \text{calcium soil} + \underset{\substack{\text{sodium sulfate}\\ \text{(leachable)}}}{Na_2SO_4}$$

Other commonly used amendments contain acidifying compounds which react with naturally occurring calcite ($CaCO_3$) or "free lime" in the soil to release soluble calcium. The most common such materials are elemental sulfur, sulfuric acid, ammonium polysulfide and calcium polysulfide (lime-sulfur). These compounds are effective only on sodic soils which contain calcite and react as follows:

- **Oxidation of sulfur**

Eq. 13

$$\underset{\text{sulfur}}{S} + \underset{\text{oxygen}}{\tfrac{3}{2}O_2} + \underset{\text{water}}{H_2O} \xrightarrow{\text{microbes}} \underset{\text{sulfuric acid}}{H_2SO_4}$$

- **Neutralization of sulfuric acid**

Eq. 14

$$\underset{\text{sulfuric acid}}{H_2SO_4} + \underset{\text{calcite}}{CaCO_3} \rightarrow \underset{\text{gypsum}}{CaSO_4} + \underset{\text{carbon dioxide}}{CO_2} + \underset{\text{water}}{H_2O}$$

Table 24.
Commonly used soil amendments and their chemically equivalent values.

Amendment	Chemical Formula	Rate Equivalent to 1 Ton of Pure Gypsum
Gypsum	$CaSO_4 \cdot 2H_2O$	2000 lbs.
Ammonium polysulfide	NH_4S_x	950 lbs.* 98 gal.*
Sulfuric acid	H_2SO_4	1220 lbs.
Sulfur	S	380 lbs.
Lime sulfur (22% S)	CaS_x	1360 lbs.

**reflects S content only*

Sulfuric acid reacts with the soil immediately while the microbial oxidation of sulfur takes several weeks or even months to occur. The fineness of soil applied sulfur materials is critical and products with individual particle sizes of <100 mesh are recommended. Materials with coarser particles will react much more slowly with the soil. Finally, the gypsum formed when sulfuric acid reacts with calcite reclaims a sodic soil in the same manner shown in Equation 12.

The rate of material needed depends on the specific amendment that is used, the degree of sodium saturation in the soil and the purity of the amendment. A typical application rate is 1 to 2 tons of gypsum per acre or equivalent amounts of the

Table 25.
Expected restriction in the rate of irrigation water infiltration based on salinity and the sodium adsorption ratio of various water sources. (after Ayers and Westcot, 1985. Water Quality for Agriculture, FAO, United Nations).

Irrigation Water Quality		Degree of Infiltration Restriction		
Salinity	(EC_w*	None	Moderate	Severe
dS/m*	ppm	SAR		
0 - 0.5	0 - 320	—**	0 - 6	> 6
0.5 - 1	320 - 640	0 - 3	3 - 12	> 12
1 - 2	640 - 1280	0 - 7	7 - 17	> 17
> 2	> 1280	0 - 15	15 - 25	> 25

**electrical conductivity of the water.*

***very low electrolyte water may cause reduced infiltration in soils as a result of removing beneficial calcium and magnesium salts from the surface and causing dispersal of surface soil particles and crusting.*

other amendments listed in Table 24. Greater rates for highly sodic soils and lower maintenance application rates under marginally sodic conditions may also be warranted.

- **Treating Sodic Water**

Irrigation water which is high in sodium or very low in total salt content may exhibit low infiltration rates into cultivated soils. The expected restriction in water infiltration is related to the salinity level and SAR of the water as summarized in Table 25.

The addition of soluble calcium compounds to sodic or very low salinity water can effectively increase water infiltration rates, particularly on heavier textured soils. Gypsum, calcium nitrate and calcium chloride are all effective materials when properly applied. The rate of material to apply will depend on the quality of the water. An initial water test for salinity, calcium, magnesium and sodium is required to calculate the proper rate of water amendment to use. Typical rates are about 100 to 300 lbs. of pure gypsum per acre-foot of water.

In most cases specialized equipment is required to accurately inject or meter soluble calcium solutions into irrigation water. Contact your Cooperative Extension agent, soils specialist, agricultural fieldman/consultant or amendment distributor for assistance in selecting appropriate amendments, rates and methods of application for your specific soil and water conditions. A computer program entitled *WATERTST* interprets water analysis data for many water quality properties including gypsum requirement. The program is available from The University of Arizona, Cooperative Extension.