Table 17.
Relative nitrogen uptake efficiencies achieved using different fertilizer placement methods in conjunction with typical irrigation systems. These estimates assume that nitrogen is supplied from soluble fertilizer materials and at rates which are not excessive.

Irrigation Method	Nitrogen Uptake Efficiency: Low (<25%)	Moderate (25-50%)	High (>50%)
Furrow	• water run before midseason • preplant broadcast and incorporated on sandy soils	• water run after midseason • preplant injection banding • Preplant broadcast and incorporate on heavier soils • sidedressing at seeding stage	• sidedressing at midseason
Basin/Sprinkler	• preplant broadcast and incorporated on sandy soils • fertigation preplant or at seedling stages	• fertigation or broadcast application followed by irrigation before midseason • preplant broadcast and incorporated on heavier soils	• preplant injection banding • fertigation or broadcast application followed by irrigation after midseason
Drip	• all other application methods		• injection through drip system • placement directly below emitters

GP 3.2 Incorporate nitrogen fertilizers which are applied to the soil surface.

All nitrogen fertilizers applied to the soil surface should be incorporated as soon after application as possible to reduce losses by volatilization and/or runoff. A discussion of ammonia volatilization is found on p. 6 with a listing of estimated nitrogen losses from surface broadcast applications for different fertilizer materials and application methods presented in Table 3.

GP 3.3 Apply nitrification inhibitors in combination with ammoniacal (NH^+_4) fertilizer formulations (See GP 1.6).

BMP 4. Application of irrigation water to meet crop needs shall be managed to minimize nitrogen loss by leaching and runoff.

Providing adequate irrigation water for the evaporative use of the crop, leaching of excess salts, promotion of seed germination and/or crop protection must all be considered in achieving this BMP. Nine Guidance Practices are included under this BMP to either improve the ability of an operator to know how much irrigation water to apply or facilitate more precise and/or uniform application of water to croplands.

The amount of irrigation water needed annually to leach excess salts is referred to as the "leaching requirement" (LR). The LR is defined as the fraction of irrigation water applied which passes below the root zone in order to maintain the salt content in the root zone within the tolerance of the crop being grown.

$$LR = \frac{EC_w}{5(EC_e) - EC_w} \qquad \text{Eq. 8}$$

where: LR = leaching requirement expressed as a fraction

EC_w = salinity of the irrigation water in mmhos/cm or dS/m

EC_e = soil salinity level tolerated by the crop in mmhos/cm or dS/m in a saturated paste extract

(after Ayers and Westcot, 1985. *Water Quality for Agriculture*, FAO, United Nations)

Nitrate present in the soil at the time of leaching irrigations will be subject to loss to the same extent as other soluble salts which are present. For this reason it is best to conduct leaching events when soil nitrate levels are low and when further nitrate depletion will not restrict crop growth.

The salinity tolerance levels (EC_e) for most of the important crops grown in Arizona are listed in Table 18.

Furthermore, the total annual depth of water needed to supply for both crop demand and the LR can be estimated as follows:

$$AW = \frac{ET}{1\text{-}LR} + SE + CP \qquad \text{Eq. 9}$$

where: AW = total annual water requirement (inches)

ET = annual crop water demand (inches)

Table 18.
Estimated salinity tolerance of selected crops expressed as electrical conductivity in a saturated paste extract (EC_e). (after Ayers and Westcot, 1985. Water Quality for Agriculture, FAO, United Nations).

Crop	Soil Salinity Threshold Above Which Yield Loss Will Occur	
	mmhos/cm or dS/m	ppm
Field Crops		
Barley	8.0	5120
Corn	1.7	1090
Cotton	7.7	4930
Sorghum	6.8	4350
Wheat, bread	6.0	3840
Wheat, durum	5.9	3780
Forage Crops		
Alfalfa	2.0	1280
Bermudagrass	6.9	4420
Sudan grass	2.8	1790
Fruits and Vegetables		
Apple	1.5	960
Asparagus	8.0	5120
Broccoli	2.8	1790
Cabbage	2.8	1790
Cantaloupe	2.2	1410
Cauliflower	1.8	1150
Citrus	1.7	1090
Corn, sweet	1.7	1090
Grape	1.5	960
Lettuce	1.3	830
Pecan	1.7	1090
Pistachio	1.7	1090
Potato	1.7	1090
Watermelon	2.2	1410

LR = leaching requirement expressed as a fraction

SE = water needed for stand establishment (inches)

CP = water needed for crop protection (inches)

In many cases the inherent inefficiencies in most irrigation systems are sufficient to satisfy the LR without the application of additional "leaching" water. The amounts of water needed for stand establishment and crop protection will depend on many factors and ultimately on the judgement of the grower.

GP 4.1 Apply the amount of irrigation water required to meet crop needs.

Following this GP requires that growers be able to accurately estimate crop water use. This may be done directly by taking plant measurements or soil measurements, and indirectly by estimation from weather data. Then, the grower must have the ability to precisely apply predetermined amounts of irrigation water to individual farm fields. The amount of soil water depletion that can be tolerated by crops varies considerably (Table 19). Any irrigation scheduling technique must recognize crop specific soil moisture depletion requirements.

Table 19.
Generalized maximum allowable soil depletion and available soil moistures for different soil types when crop use is 0.20-0.25 in./day (after Doorenbos and Pruitt. 1977. Guidelines for Predicting Crop Water Requirements. AO Irrigation and Drainage Paper No. 24).

Crop	Maximum Allowable Depletion*	Available Soil Moisture for Different Soil Types Fine	 Medium	 Coarse
		in./ft.		
Alfalfa	0.55	1.43	1.10	0.55
Barley	0.55	1.43	1.10	0.55
Broccoli	0.45	1.17	0.90	0.45
Cabbage	0.45	1.17	0.90	0.45
Carrots	0.35	0.91	0.70	0.35
Cauliflower	0.45	1.17	0.90	0.45
Citrus	0.50	1.30	1.00	0.50
Corn	0.60	1.56	1.20	0.60
Cotton	0.65	1.69	1.30	0.65
Decidious Orchards	0.50	1.30	1.00	0.50
Grapes	0.35	0.91	0.70	0.35
Grass	0.50	1.30	1.00	0.50
Lettuce	0.30	0.78	0.60	0.30
Melons	0.35	0.91	0.70	0.35
Onions	0.25	0.65	0.50	0.25
Peppers	0.25	0.65	0.50	0.25
Potatoes	0.25	0.65	0.50	0.25
Sorghum	0.55	1.43	1.10	0.55
Spinach	0.20	0.52	0.40	0.20
Wheat	0.55	1.43	1.10	0.55
Ripening	0.90	2.34	1.80	0.90
TOTAL AVAILABLE SOIL WATER		2.6	2.0	1.0

**When plant use is 0.10 in./day or less increase values by 30% or when plant use is 0.30 in./day or more reduce values by 30%.*

Soil moisture deficits can be measured *directly* using devices or techniques such as neutron probes, tensiometers, resistance blocks and gravimetric sampling. Even determining the moisture content of soil by hand using the "feel" method can be helpful in determining how much irrigation water is needed (Table 20). Other methods such as infrared thermometry or crop canopy reflectance measurements

Table 20.
Indicators of soil moisture content based on appearance, feel, and consistence for varying soil textures, The "Feel" Method (after Hohn, C.M. The Feel Test Tells When to Irrigate. New Mexico State University).

Degree of Moisture	Percent Useful Soil Moisture Remaining	Soil Texture*			
		Coarse	Light	Medium	Heavy to Very Heavy
Dry	0	Dry, loose, single-grained, flows through fingers.	Dry, loose, flows through fingers.	Powdery, dry, sometimes slightly crusted but easily breaks down into powdery conditions.	Hard, baked, cracked, sometimes has loose crumbs on surface.
Low	50 or less	Still appears to be dry; will not form a ball with pressure.	Still appears to be dry; will not form a ball.	Somewhat crumbly, but will hold together from pressure.	Somewhat pliable; will ball under pressure.
Fair	50 to 75	Same as course tecture under 50 or less.	Tends to ball under pressure but seldom will hold together.	Forms a ball and is very pliable; slicks readily if relatively high in clay.	Easily ribbons out between fingers, has a slick feeling.
Excellent	75 to field capacity	Tends to stick together slightly; sometimes forms a very weak ball under pressure.	Forms weak ball breaks easily, will not stick.	Forms a ball and is very pliable; slicks readily if relatively high in clay.	Easily ribbons out between fingers, has a slick feeling.
Ideal	At field capacity	Upon squeezing, no free water appears on soil but wet outline of ball is left on hand.	Same as coarse.	Same as coarse.	Same as coarse.
Too wet	Above field capacity	Free water appears when soil is bounced in hand.	Free water will be released with kneading.	Can squeeze out free water.	Puddles and free water forms on surface.

**Coarse refers to sand and loamy sand, Light: sandy loam and loam; Medium: silt, silt loam and sandy clay loam; Heavy to Very Heavy: clay, sandy clay, silty clay, clay loam and silty clay loam.*

can be used to estimate plant water stress. Regardless of the method used, some on-site calibration is required for specific soils and plants.

Estimates of crop water use can also be approximated *indirectly* from historical evapotranspiration data (Erie et al., 1982. Consumptive Use of Water by Major Crops in the Southwestern United States. USDA-ARS Conservation Research Report No. 29.) or from near real-time weather data obtained through the Arizona Meteorological Network (AZMET) at the University of Arizona.

Irrigation water can be accurately measured onto a field using flumes, weirs, orifice plates or flow meters. The actual device used will depend on the type of irrigation delivery system and other site specific factors.

GP 4.2 Install trickle irrigation systems to improve water application efficiency and uniformity.

Trickle or drip irrigation is a water delivery system which utilizes a series of low pressure, low volume plastic pipes, tubing, emitters, sprayers, sprinklers or bubblers. Conveyance and emission of water can occur either above or below the soil surface.

The primary advantage of trickle systems with respect to nitrogen management is that precise amounts of nitrogen and irrigation water can be applied very uniformly over an entire field. Thus with careful operation, trickle systems can greatly reduce the potential for deep percolation or runoff from croplands, especially on soils that are very permeable or cannot be leveled.

To reduce the hazard of emitters plugging, only completely water soluble and compatible nitrogen solutions should be used. Clear solutions containing urea, ammonium nitrate and/or calcium nitrate are usually highly compatible with properly designed trickle systems. In contrast, fertilizer suspensions or materials which form colloids when added to water should not be used with trickle systems. Fertilizers should be injected near the end of the irrigation cycle with enough time included to flush all lines and emitters prior to turning off the system.

There are many agronomic, financial and logistical factors which will determine whether installation of a trickle irrigation system is advisable. It is advisable to obtain professional assistance when information on selecting, designing and maintaining a trickle irrigation system is needed.

GP 4.3 Apply furrow irrigations using surge flow techniques.

Surge flow irrigation is the application of irrigation water to a given furrow in a series of pulses rather than a single, uninterrupted irrigation set. This technique advances the flow of water to the end of a field with less surface storage and with reduced runoff. Thus, when properly applied, surge flow irrigation can increase water distribution uniformity and reduce deep percolation losses. Surge irrigation is best suited on fields with coarse textured soils and a slope greater than 1%. It can also work well on fine textured (clay) soils with severe cracking problems. Surge irrigation does not work well on noncracking fine textured soils or with level basins. This technique will require greater inputs of labor, capital equipment and maintenance in comparison with conventional furrow irrigation systems.

GP 4.4 Adjust irrigation application rate and set time for sprinkler irrigation systems, depending on soil and slope characteristics.

Soils vary greatly in the rate at which water infiltration will occur; from about 2.0 inches/hour on a coarse sandy soil to 0.05 inches/hour on a clay soil (Table 21). Efficient sprinkler irrigation systems match water application rates with infiltration properties of the soil. High application of water can result in either surface runoff which could transport soluble nitrogen into receiving surface water, or in ponding and subsequent deep percolation of water and leaching losses of nitrogen. Conversely, low application rates or short set times can reduce application efficiency by increasing water losses due to evaporation.

Adjusting sprinkler application rates to correspond to specific soil and crop conditions can increase irrigation efficiency, lower water costs as well as reduce the potential for the contamination of surface and/or groundwater supplies. Soil survey reports for most of the irrigated soils in Arizona are available through the Soil Conservation Service.

GP 4.5 Angle irrigation furrows to reduce the furrow slope.

The orientation of irrigation furrows at angles other than 90° from the irrigation delivery ditch can reduce the slope for a furrow. Angling of furrows will be most effective when the slope in the field is perpendicular to the delivery ditch. This practice can increase irrigation efficiency while reducing tail end ponding and runoff. However, for optimum irrigation efficiency, both the rate and amount of water application must be properly designed. Angle furrowing can achieve many of the goals of land leveling but without the large capital cost.

Angle furrowing may result in some increased labor and machinery costs due to variable row length. The alignment of irrigation furrows may require preseason evaluation of slope values and slope direction in individual fields.

GP 4.6 Install irrigation runs on the contour in fields with excessive slope.

In fields where excessive slopes result in rapid runoff and severe erosion, land leveling or angled irrigation runs may not be feasible management alternatives. In these cases irrigation runs (i.e. furrows) can be arranged to conform with the surface contours of the field. When properly installed, this practice of contour furrowing can significantly reduce the potential for runoff and soil erosion from fields with variable or excessive slope. Reduced tail water ponding can also lower the potential for downward movement of soluble nutrients due to leaching.

The arrangement of contoured irrigation runs requires preseason planning and familiarity with the conditions in individual fields. This practice is most appropriate in narrow mountain valleys as opposed to the broad alluvial areas in southern Arizona.

GP 4.7 Use land leveling to adjust field gradients.

Land leveling can be used to physically adjust the gradients or slopes in farm fields. This practice is used to minimize or eliminate runoff while maximizing irrigation uniformity and efficiency. Leveling should be considered for fields where existing gradients either contribute to excessive runoff and deep percolation or are not uniform. The advisability of using land leveling will depend on such factors as soil depth, soil texture, water quality and quantity, topography, and crop selection. Suitable characteristics of the subsoil are necessary if deep cuts are to be made.

The economics of land leveling will depend on the existing gradients in the field and the amount of soil to be moved, the availability of suitable equipment and whether the farm operator owns the land. The USDA-Soil Conservation Service estimates that the payback period for land leveling costs is about five years for most areas in Arizona.

Those unfamiliar with land leveling practices should consult with a qualified professional to have specific fields evaluated for the applicability of this guidance practice.

Table 21.
Representative soil physical properties including infiltration rate and available moisture content (after Israelson and Hansen. 1965. Irrigation Principles and Practices. John Wiley and Sons, Inc. N.Y.)

Soil Texture	Infiltration Rate*		Total Available Moisture	
	Average	Normal Range	Average	Normal Range
	inches/hour		*inches/foot of soil*	
Sand	2	1 - 10	1.0	0.8 - 1.2
Sandy loam	1	0.5 - 3	1.4	1.1 - 1.8
Loam	0.5	0.3 - 0.8	2.0	1.7 - 2.3
Clay loam	0.3	0.1 - 0.6	2.3	2.0 - 2.6
Silty clay	0.1	0.01 - 0.2	2.5	2.2 - 2.8
Clay	0.2	0.05 - 0.4	2.7	2.4 - 3.0

**intake rates can vary greatly with soil structure and structural stability, even beyond the normal ranges shown.*

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).