

DROUGHT TIP

Use of Shallow Groundwater for Crop Production

Shallow groundwater found within about 6 feet of the land surface can be a significant source of water for agricultural production, especially during drought periods. The fraction of the crop water demand that can be met by shallow water tables depends on the crops grown, irrigation and drainage management, the soil type, the depth to the water table, and the shallow groundwater salinity (Ayars et al. 2006). Several decades ago, research focused on the upward flow possibilities of groundwater from shallow water tables in terms of root zone hydraulic characteristics and soil salinization and the need for subsurface drainage. Due in part to the greater capillary rise (fringe heights; see Grismer 1986) in finer-textured soils, greater rates of upward flow have been found in loamy soils than in sandy soils with small capillary rise or in clayey soils with very slow permeability.

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Although such observations have been made for moderately salt-tolerant perennial crops such as alfalfa hay, vine and tree crops have a larger potential for in-situ water use from shallow groundwater than do annual crops because of their well-developed, established root systems after the first growing season. Following the original studies by Namken et al. (1969), Wallender et al. (1979), and Grimes and Henderson (1984), more recent studies with a renewed focus on improving water use efficiency through integrated irrigation and drainage management have found that shallow groundwater can satisfy up to half of the crop water requirement (Ayars and Schoneman 1986; Ayars and Hutmacher 1994; Hutmacher et al. 1996), thereby reducing irrigation demands. The obvious complexity of these interactions (see fig. 1) precludes investigations that consider irrigation, soils, plants, and water table depth simultaneously (Ayars et al. 2006); however, several multiple-aspect studies have been completed to suggest that this water resource should be used during drought periods.

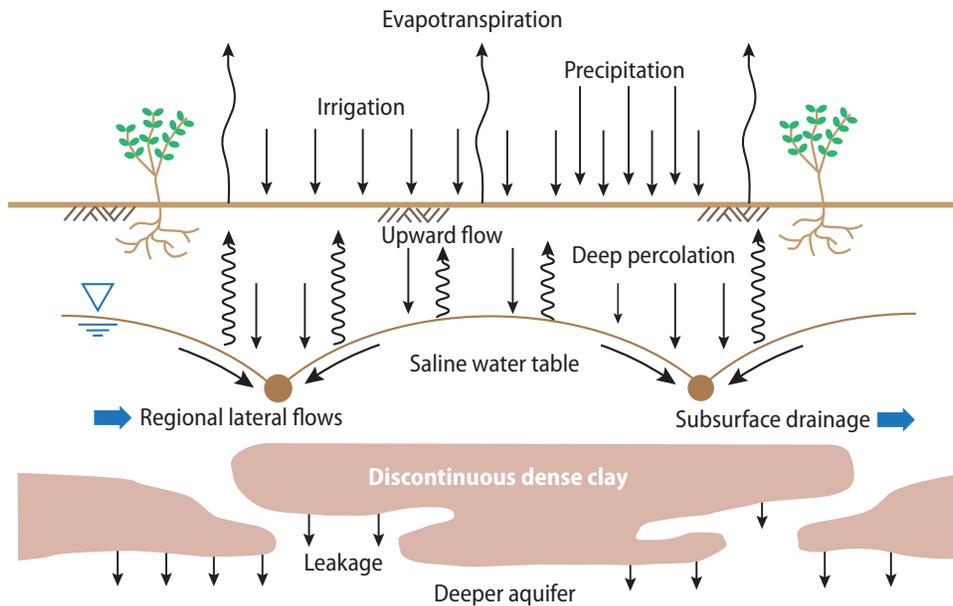


Figure 1. Shallow water table processes and interaction with irrigation-drainage systems. Source: After Grismer et al. 1988.

We consider each of these aspects below, followed by basic guidelines that should enable the use of shallow groundwater for a few years. While persistent use of saline shallow groundwater to meet crop water demands is likely not sustainable in the long term, studies indicate that when well-managed, shallow groundwater use by crops may be possible if sufficient root zone leaching by rain or preirrigation occurs.

Upward Flow of Soil-Water

For shallow groundwater to be available for crop water needs, the water must flow upward into the crop root zone. The rate at which this occurs depends on the distance between the water table and root zone base, as well as the soil type. This flow rate is determined from the soil hydraulic conductivity (which depends on soil moisture) and the upward driving force controlled by the water table depth and near-surface evapotranspiration rates. The smaller the distance between the water table and root zone, and the drier the root zone soils, the greater the upward flow rates from the water table, assuming

all other factors are equal. Similarly, the finer (more clayey) the soil texture, the smaller the hydraulic conductivities and the smaller the upward flow rates into the root zone. This upward flow rate is also affected by the water table salinity: increased shallow groundwater salinity decreases the upward flow, due to plant preference for lower-salinity water.

Root Zone Conditions

Crop use of shallow groundwater will not be significant until the root system is adequately developed in the proximity of the water table, since the roots are the primary conduit between the water table and the crop. However, quantification of the root zone has been elusive, as little data is available about root development relative to crop growth stage, maximum rooting depth, and how these are affected by the presence of shallow groundwater of a particular salinity. Clearly, the more rapidly roots approach the water table, the greater the opportunity to extract shallow groundwater earlier in the growing season. The coarser the soil texture, the closer the roots will need to be to the water table to extract shallow groundwater because coarser soils can hold less water than finer-textured soils at the same soil-water suction (the same matric potential). While some research suggests that the top third of the root zone, where the root density is usually greatest, is the most important, research considering shallow groundwater extraction found that the smaller portion of the root zone closest to the water table capillary fringe was the origin of the greatest fraction of groundwater extracted (see Soppe and Ayars 2002).

Type of Crop

For a given field, crop selection is the key controllable management variable for maximizing plant use of shallow groundwater to meet evapotranspiration demand. While many plants can extract shallow groundwater, the agronomic plant characteristics that affect the contribution of shallow groundwater toward meeting crop water requirement include salt tolerance, length of growing season, and rooting characteristics. Plant salt tolerance is a dominant factor affecting crop water use, and shifting to salt-tolerant crops

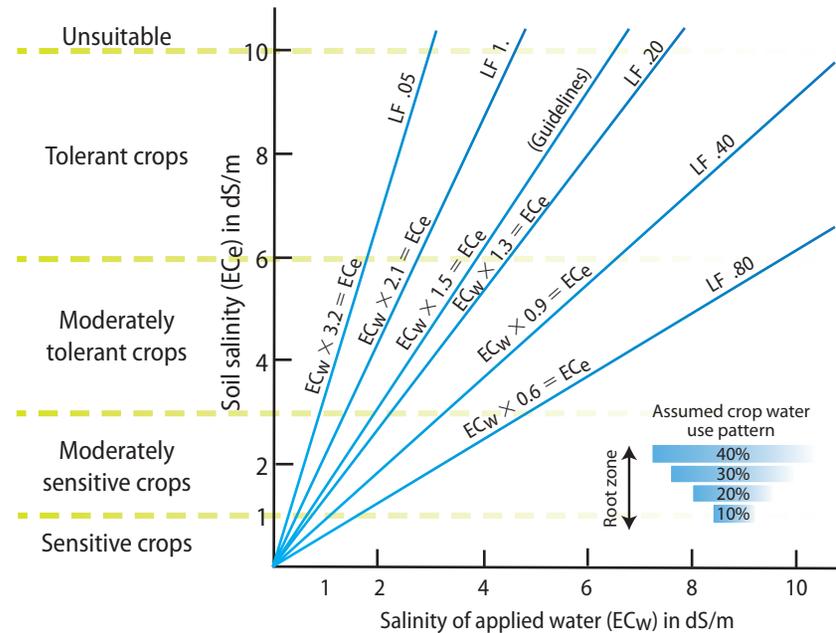


Figure 2. Effect of applied water salinity (EC_w) on root zone soil salinity (EC_e) at various leaching fractions (LF). *Source:* Ayers and Westcot 1985, fig. 7.

should be considered during drought periods. Maas and Hoffman (1977) and Maas (1986) characterized plant salt tolerance based on the loss of yield as a function of increased salinity in the root zone. Lysimeter and field studies have indicated that this salinity tolerance is, in practice, not a static value and that crops tend to become more salt tolerant as they mature, suggesting that the Maas-Hoffman salinity threshold value can be used as a starting point for consideration of saline shallow groundwater use (see figure 2).

A wide range of crops has been successfully grown that obtained a significant portion of the crop water requirement from shallow groundwater. The types of crops range from truck crops (peppers and carrots) to grain, hay, and some tree crops (e.g., date palms) that have salt tolerances from sensitive (lettuce) to tolerant (cotton). However, the majority of the crops that used shallow groundwater are deep rooted and moderately salt tolerant or are

salt-tolerant crops based on the Maas-Hoffman (1977) salinity tolerance thresholds. Ayars et al. (2006) summarize, for crops that have successfully used significant amounts of shallow groundwater, the soils in which they were grown, the water table depths and salinity, and the irrigation management and associated climate conditions (e.g., average rainfall). Additional studies not included in the table in Ayars et al. (2006) that have similar results as those tabulated include those for sudangrass and alfalfa hay crops (Bali et al. 2001a and 2001b; Grismer and Bali 2001; Grismer et al. 2001), as well as corn (Kang et al. 2001), winter wheat (Kang et al. 2001; Karimov et al. 2014), safflower (Gharmarnia et al. 2011), and date palm trees (Zeineldin 2010).

As noted above, the total amount of shallow groundwater used by the crops varies widely, depending on the salinity of the groundwater in relation to the crop salinity tolerance, the irrigation and drainage system management, the irrigation water quality, the soil type, and the water table depth. Crops drawing in excess of 50% of the crop water requirement from shallow groundwater had reasonable groundwater salinity (4 to 6 dS/m) relative to the crop salt tolerance, were deeper rooted, and were subject to low irrigation frequency of less than once per week. The fraction of shallow groundwater used by the crop decreases dramatically as the soil and shallow groundwater salinity increases, though the crop can still draw shallow groundwater at three to four times the threshold salinity.

The length of the crop growing season can significantly impact the crop water use of shallow groundwater: the longer the growing season, the greater the potential water use from shallow groundwater. Perennial crops with deeper root systems, or longer-growing annual crops that develop such root systems, have a greater opportunity to extract shallow groundwater when the plants are mature and more salt tolerant. For annual crops, the majority of the crop water use of shallow groundwater occurs between the last irrigation and crop harvest, when the root zone is at maximum development and the plant is most salt tolerant.

Irrigation and Drainage System Management

Integrated irrigation and drainage system management is directed at providing soil moisture (with associated acceptable salinity) and soil aeration conditions favorable for crop growth. Together with crop selection, the possibility of shallow water table manipulation combined with changing irrigation frequency can maximize exploitation of the shallow groundwater resource to meet crop water requirements.

In fields with subsurface (tile) drainage systems in which the field main collector drain outlet flows can be manipulated, the optimal water table control would involve maintaining the water table near the base of the crop root zone. As the crop matures and root zone depth increases, the water table depth would also ideally increase. The source of the local high water table is important to consider. If the high water table results from inefficient irrigation, improving the irrigation efficiency will reduce the deep percolation from the root zone, and the shallow water table may recede to depths beyond which root zone extraction is significant. On the other hand, if the field's shallow groundwater is sustained by regional (lateral) shallow groundwater flows (e.g., canal leakage, rain), there is a greater potential for sustained shallow groundwater use locally. If the regional shallow groundwater is saline, the potential for sustained groundwater use will be limited by the root zone salinity management, and preplant or fallow period leaching irrigations may be required.

Irrigation management, as described by the type of application system (e.g., flood, sprinkler, or drip), the associated application uniformity, application depths, and application frequency, has a direct effect on the potential for shallow groundwater use by the crop. In general, the better the application uniformity and the less frequent and smaller the application depth, the greater the opportunity for shallow groundwater to meet some of the crop water demand. While some crop coefficient values for saline water table depth have been developed (e.g., Ayars and Huttmacher 1994) for possible use in irrigation scheduling, development of general guidelines remains problematic due to the complexity of the system, as described above. Regular monitoring of the shallow groundwater

depth and salinity, root zone soil-water salinity, and the associated plant-water stress is required as part of the irrigation scheduling so as to have real-time information about the crop growing conditions. Such monitoring might occur bi-weekly for seasonal crops and monthly for perennial crops.

Summary

Shallow groundwater is a potentially valuable source of additional water supply to meet crop water requirements, especially during drought; however, developing this resource is site specific and requires an assessment of the projected cropping system, the soil and water resources, and the irrigation and drainage management available. Use of shallow groundwater will be limited by the water source supplying the groundwater and the associated salinity management of the soil profile. Shallow groundwater is likely a possible resource for a few years, but it is not likely to be sustainable over the much longer term unless the source of good-quality shallow groundwater is also sustainable over the longer term. Using recycled water for irrigation may be another alternative (see Platts and Grismer 2014a and 2014b; Weber et al. 2014).

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This publication was written and produced by the University of California Agriculture and Natural Resources under agreement with the California Department of Water Resources (DWR). It is an update of Drought Tip Number 92-27, which was part of a series developed as a cooperative effort by DWR; University of California; USDA Drought Response Office and Soil Conservation Service; and USDI Bureau of Reclamation, Mid-Pacific Region.

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Publication 8521

ISBN-13: 978-1-60107-915-2

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This publication has been anonymously peer reviewed for technical accuracy by University of California scientists and other qualified professionals. This review process was managed by ANR Associate Editor for Agronomy and Range Sciences Rachael Freeman Long.

pr-6/15-SB/CR