



Groundwater Recharge from Agricultural Areas in the Flatwoods Region of South Florida¹

Sanjay Shukla and Fouad H. Jaber²

Introduction

Groundwater provides freshwater for drinking, agricultural production, and recharge to lakes, rivers, and streams. Groundwater is stored beneath earth's surface in aquifers that exist between saturated soil and rock. More than 90% of Florida's population relies on groundwater for its drinking water supply. Of the total water withdrawn in Florida for purposes such as drinking and agricultural irrigation, 62% comes from groundwater. Continued supply of groundwater relies on a natural recharge process, which replenishes the aquifers from the surface. Groundwater recharge is affected by a variety of factors, including land use. Changes in land use (e.g., agricultural to urban due to continued population growth in south Florida) can affect the extent and distribution of groundwater recharge from rainfall. The objective of this fact sheet is to: 1) define recharge and discuss factors affecting it and methods to estimate it, and 2) discuss the results from a study that investigated recharge from an agricultural area in south Florida.

Groundwater Recharge

Groundwater recharge occurs when a portion of the water falling on the ground surface percolates through the soil and reaches the water table. Recharge can be defined as any water that moves from the land surface to the water table. Water reaching the water table can move out of the groundwater to surface water through a process known as discharge, that is, the opposite of recharge. An example of groundwater discharge is water produced from springs. The travel time from recharge to discharge can range from less than 1 day to more than 1 million years.

Recharge is affected by factors such as weather, soil type, surface cover (e.g., vegetation, impervious pavements), slope, and water table depth. Usually, recharge studies consider only rainfall-driven recharge. In addition to rainfall, irrigation and wastewater can also provide recharge. Recharge occurs on a wide variety of scales, from small (localized) to large (distributed). Although recharge from agricultural and natural landscapes is mostly distributed, urban settings tend to result in more localized recharge.

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 2. Sanjay Shukla, assistant professor, and Fouad H. Jaber, post-doctoral associate, Department of Agricultural and Biological Engineering, Institute of Food and Agricultural Sciences, University of Florida, Gainesville, FL 32611.

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For sustainable use of groundwater resources, it is important that the quantity of water withdrawn from an aquifer for a variety of consumptive uses is returned back through recharge. Land covers differ in their ability to provide recharge. While a large fraction of rainfall falling on agricultural or natural areas can move through the soil and reach the shallow water table, localized impervious surfaces (e.g., roads and parking lots) in the urban landscape limit recharge ability because only a small fraction of rainfall can pass through a paved surface.

In most of Florida's agricultural areas, a portion of the water pumped from an aquifer for irrigation returns to the water table to help recharge it. Excessive recharge from irrigation can have adverse impacts on groundwater quality because the recharge water may contain leached nutrients or other agrichemicals. In some places, groundwater withdrawals in excess of long-term recharge have caused saltwater intrusion from the coast to inland areas. Long-term groundwater withdrawals in the southern part of the Southwest Florida Water Management District (SWFWMD) during the past few decades have caused saltwater intrusion from the Gulf of Mexico. This condition led to the establishment of the Southern Water Use Caution Area (SWUCA), an area covering parts or all of eight counties. To reduce further drawdown of the water table, the SWFWMD has restricted groundwater withdrawals in this area. Continued groundwater withdrawal in other parts of south Florida, especially in response to increased water demand in the urban coastal region, could potentially cause saltwater intrusion and reduce water levels in waterbodies and wetlands.

Quantifying recharge from agricultural areas is important to sustain long-term groundwater use, make intelligent groundwater allocation decisions, and develop on-farm water management strategies. Although quantifying recharge is important in managing worldwide water resources, it is especially important for high water table regions like south Florida, where the interaction between the unsaturated zone and both surface and groundwater is high.

Most crops in the flatwoods region of south Florida are grown on highly conductive sandy soils with the water table only 8 to 50 inches deep throughout the year. These conditions result in extensive soil water-groundwater exchange. This exchange is enhanced by the seepage irrigation practice that is widely used to produce row crops like sugarcane and vegetables (Figure 1). Seepage irrigation applies water to surface ditches, which move water laterally, causing the water table to rise high enough to provide optimum soil moisture in the root zone through upflux (Figure 1). Downward water movement from rainfall or irrigation results in groundwater recharge, while upward movement (upflux) provides water for plant uptake and also evaporates.

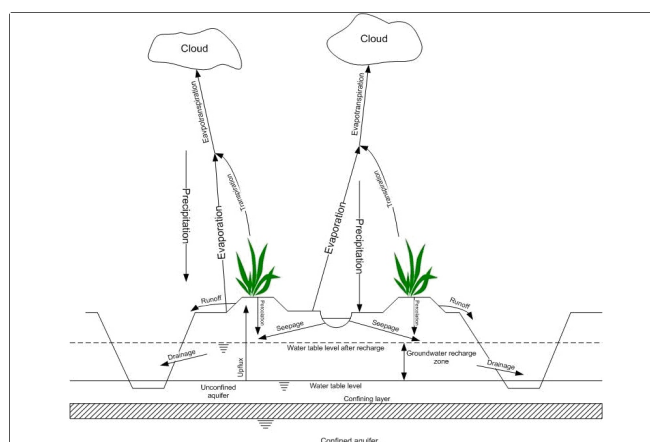


Figure 1. Hydrologic cycle for a row crop area with shallow water table in south Florida (not to scale).

Farmland provides extensive opportunities for groundwater recharge from rainfall and to some extent, irrigation water. As rain falls on a farm, part of it moves through the soil of the cropped areas and reaches the water table. If the rainfall brings the water table close to the root zone, the cropped areas are drained through farm ditches (Figure 1). Water from drainage and runoff is conveyed to a larger ditch or canal and is then pumped into a stormwater impoundment (reservoir). Pumped drainage/runoff is temporarily stored there until it reaches the impoundment's storage capacity. Once capacity is reached, water leaves the impoundment through outfall structures to adjacent water bodies.

As runoff and drainage water moves on its journey from field ditches to the impoundment, recharge occurs through the pervious ditch wall and

bottom. Recharge from cropped areas accounts for a large fraction of the total recharge from the farm. A variety of techniques ranging from simple to complex can be used to estimate groundwater recharge from cropped areas.

Estimating Recharge

Estimating groundwater recharge is not as easy and straightforward as identifying the factors that affect recharge. A variety of techniques including physical and chemical methods are available to estimate recharge. An example of a physical method is a water balance approach, while use of tracers is a chemical method of estimating recharge. A common method of estimating recharge is by constructing a gross water budget for an area of interest where recharge can be estimated as the difference between the input (rainfall and irrigation) and output (runoff and evapotranspiration). Another common method of estimating recharge is by using the changes in the groundwater level and multiplying it by apparent specific yield (S_{ya}).

Lysimeters have been successful in quantifying recharge by directly measuring drainage from the plant root zone. A lysimeter is a device that is used to measure the quantity and quality of water that moves through the soil. Lysimeters have closed sides and bottoms, allowing accurate measurement of the amount of water moving through the soil (Figure 2). Depending on the soil and hydrologic conditions to be represented, lysimeters are used with or without a water table. For shallow water table conditions (12 to 36 inches) in the flatwoods region of south Florida, lysimeters can be used to quantify the amount of water reaching the water table. Results from a study undertaken to quantify the groundwater recharge from southwest Florida row crop fields using large drainage lysimeters are presented in the next section.

Recharge from Row Crop Production Systems in South Florida

Five drainage lysimeters--16 ft long, 12 ft wide, and 4.5 ft deep--were built in the interior of a 1.7-acre vegetable field near Immokalee, Florida. The soil at this location is Immokalee fine sand, which

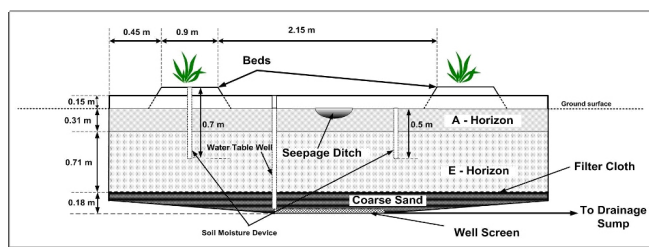


Figure 2. Schematic of the lysimeter and soil profile at the Southwest Florida Research and Education Center, UF/IFAS, Immokalee, FL (1 m = 3.33 ft = 39.96 in).

commonly occurs in the flatwoods region of south Florida.

A bell pepper crop was grown in the lysimeters and the surrounding field, with a planting date of September 17, 2003, and a harvest date of December 15, 2003. Raised beds (Figures 1 and 2) were planted with two rows of pepper plants. The plants were spaced 1 ft apart within the row, and the beds were 7 ft apart. Two of the five lysimeters were irrigated by seepage irrigation, which involved applying water through a v-ditch (Figure 2) to raise the water table to a depth that provided sufficient moisture to the crop root zone through upflux. Three lysimeters were irrigated by drip irrigation, which allowed water to be applied directly to the root zone within the bed rather than wetting the entire field. Water input (irrigation and rainfall), water output (runoff and drainage), water storage (soil moisture), and water table depth were measured for all lysimeters during the study period. The soil moisture in the lysimeter was measured in 4-inch-depth increments from the soil surface to a depth of 28 inches.

Recharge Calculations

A water balance approach was used to estimate daily water movement to and from the water table. For a lysimeter, the water budget (in depth units) can be expressed as (Equation 1):

$$\text{Rainfall (P) + Irrigation (I) = Runoff (R) + Drainage (D) + Evapotranspiration (ET) + Change in Soil Water Storage (\Delta S)}$$

If all water inputs and outputs plus the change in soil moisture are known, only ET in Equation 1 is unknown, so it can then be calculated. After calculating ET, recharge can be calculated. For the purpose of this study, recharge was defined as the water that entered the water table in the lysimeter from the unsaturated zone. A water balance for every

4-inch soil layer was calculated using ET and soil moisture data. ET, the only unknown component of the water budget in the lysimeter, was estimated from equation 1. Recharge was then calculated as the water percolating down from the deepest 4-inch layer in the unsaturated zone to the water table. The calculated recharge was divided by the corresponding water table increase to estimate the apparent specific yield (S_{ya}). The apparent specific yield is an estimate of the amount of water drained from the soil or aquifer material per unit horizontal area and per unit change in water table depth. The apparent specific yield (S_{ya}) was calculated as (Equation 2):

$$S_{ya} = \frac{\text{Recharge}}{\Delta WTC} \quad \text{where } \Delta WTC$$

is the water table depth change. The average S_{ya} calculated from all recharge days could be used to estimate future groundwater recharge in the flatwoods region of south Florida.

Results

Average water budget components for the drip- and seepage-irrigated lysimeters are shown in Table 1. Estimated total recharge for the drip lysimeters from September 17 to December 15, 2003, was 5.36 inches, which constituted 42% of the total water input (12.7 inches of rainfall plus irrigation). Runoff accounted for only 5% of the total input due to the highly conductive sandy soil that allowed infiltration of most of the rainfall. Crop water use (ET) was 60% of $P + I$. Such a high rate of recharge indicates the rapid water movement in Florida's highly conductive sandy soils. A large part of the rainfall was eventually drained.

The average recharge for the seepage-irrigated lysimeters from September 17 to December 15, 2003, was 5.95 inches, which constituted 41% of the total $P+I$ (14.5 inches). Runoff made up 5% of $P+I$ (Table 1).

To form the planting beds, seepage irrigation was applied to the drip lysimeters to raise the water table approximately 18 inches below the top of the bed. After plant establishment, irrigation water was applied solely by the drip system for the rest of the growing season. If the water table in the lysimeter came close to surface, the lysimeter was drained from

the bottom. Draining the lysimeter emulated practices followed in local agricultural fields with a shallow water table. Water is usually pumped from drainage canals surrounding the fields into a stormwater impoundment to lower the water table. Since the lysimeter was drained from the bottom, all drainage was considered as part of recharge in this study. Therefore, water unused by the plant amounted to recharge plus runoff minus upflux.

Although the percentage of applied water that is unused is less in seepage lysimeters than in drip lysimeters, this percentage represents a larger volume due to the higher irrigation rates in seepage lysimeters. Total recharge from the seepage irrigated system was 5.94 inches, while it was 5.37 inches for the drip-irrigated system.

Estimating Groundwater Recharge from Water Table Fluctuations

Calculated daily recharge from the water balance was used to estimate S_{ya} for the flatwood sandy soils of south Florida. Average S_{ya} found from 35 observations of recharge in the lysimeters was 0.017. This value is relatively low compared with literature values for sandy soils of 0.04-0.06. This result is explained by the shallower water table (< 28 inches) used in this study compared with 80-120 inches for the literature values. The S_{ya} estimated here is the first of its kind in South Florida. It could be used for more accurate prediction of recharge under shallow water table conditions. An example of the use of S_{ya} estimated in this study follows.

Example

Consider that a 1-inch rainfall raised the ambient water table from 24 inches to 8 inches deep. What is groundwater recharge (Equation 3)?

$$\Delta WTC = 24 - 8 = 16 \text{ inches}$$

$$S_{ya} \text{ from this study} = 0.017$$

$$\text{From Equation 2, Estimated recharge} = S_{ya} \times \Delta WTC = 0.017 * 16 = 0.272 \text{ inches}$$

The recharge variance occurring between small and large scales would be due to differences in farm water management practices, soil characteristics, crop type, and water conveyance structures (drainage ditches, impoundments, etc). Nonetheless, estimation

of groundwater recharge from this study provides an assessment of groundwater recharge from row crop production areas in the flatwoods region of south Florida. It provides agricultural producers a means to evaluate their farm water budget and allows for better irrigation management, and will provide state agencies an estimate of recharge for water resource management.

Recharge and Watershed Water Resources Management

The extent of groundwater recharge within a watershed affects the hydrologic cycle, groundwater supply, and ecosystems. Recharge affects the groundwater depth under a variety of land uses in a watershed. Decreases in recharge and resulting groundwater depth can affect surface water flow to and from rivers and lakes. Lower groundwater levels can adversely affect the hydroperiod of wetlands and its ecosystem.

Agricultural and natural areas provide extensive opportunities for distributed recharge, while urban areas often limit the diffusive recharge areas from rainfall due to increased impervious surfaces. Currently, limited information exists on the groundwater recharge from urban areas in south Florida, as well as throughout the world. Some estimates from studies conducted in other parts of the United States suggest that there may be either no net change in the recharge or in some cases increased recharge. Increased recharge estimates in some urban areas are likely to stem from irrigation and other sources of water supply brought from outside the urban areas and leakage from water supply mains and sewers.

Most of south Florida's population is concentrated in coastal areas. With continued population growth in urban areas, some new growth is moving inland, replacing agricultural areas. With population growth comes increased demand for fresh water. For example, the water supply demand within the Lower West Coast of the South Florida Water Management District is expected to increase approximately 25% by 2020. As more agricultural areas are being converted to urban use, increased reliance on aquifers for water supply combined with

the potential changes in diffuse and localized recharge may result in decreased groundwater levels in some or large areas within a watershed. Lowering the groundwater in certain parts of south Florida watersheds may result in decreased flow from rivers and could adversely affect wetland ecosystems. Replenishing groundwater stored in aquifers through recharge is essential for agricultural production and ecosystem health of south Florida. Future land-use management should consider the impact of conversion of agricultural and/or natural forested areas on the extent and distribution of recharge for sustainable use of groundwater resources in the region.

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Table 1. Water budget components for the drip and seepage lysimeters (1 in = 25.4 mm). Recharge is estimated as the net water reaching the water table in the lysimeter, P is rainfall, I is irrigation applied, D is the drainage from the lysimeter, R is runoff, ET is the soil evaporation plus transpiration from plants, and S is the change in soil moisture in the lysimeter for individual recharge events. Data presented are mean values from three drip and two seepage lysimeters.

Lysimeter	Value	Recharge	P (mm)	I (mm)	P + I (mm)	D (mm)	R (mm)	ET (mm)	(S) mm
Drip	Mean	198.24 (3872)	204.30	118.09	322.39	119.62	15.30	193.33	- 5.87
	% P + I	42.26	63.37	36.63	100.00	37.10	4.75	59.97	- 1.82
Seepage	Mean	151.1	204.3	165.2	369.5	127.0	17.0	249.5	- 24.0
	% P + I	40.90	55.29	44.71	100.00	34.36	4.61	67.53	- 6.50