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Fate and Transport of Water in the Unsaturated Zone in Four Agricultural Areas of the United States, 2004

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Introduction

The movement of water through the unsaturated zone (UZ) at four agricultural settings in the United States (Fig. 1) was investigated under the National Water Quality Assessment (NAWQA) program. Objectives of the study were to calculate budgets, travel times, advective velocities, and specific fluxes for water within the UZ for each site. This information is essential to understanding the fate and transport of agricultural chemicals within agricultural ecosystems. Comparison of results from different settings provides some indication of how site specific hydrogeology, climate, and agricultural management practices influence the movement of water within the unsaturated zone.

Figure 1

Table 1 Study Site Description.

	Indiana (IN)	Maryland (MD)	California (CA)	Washington (WA)
Crop	Soybeans	Soybeans	Almonds	Corn
Irrigation (% of Input)	None	None	Sprinkler (82)	Rill (80)
Soil Texture	Silty Clay Loam to Silt Loam	Fine Sandy Loam to Medium Sand	Medium Sand	Silty Clay to Medium Sand
K_{SAT} (cm/s)	~5E-8	~6E-4	~3E-5	~3E-4
Tile Drains	Throughout Field	None	None	End of Rills Only
Avg. UZ Thickness (m)	1.1	10.6	7.2	4.4

Materials and Methods

- Soil volumetric moisture content (VMC) was measured in-situ at all study sites with water content reflectometers (Campbell Scientific Model CS616-L). Soil matric potential was measured with heat-dissipation probes (Campbell Scientific Model 29-L). These instruments were installed at 3 or 4 depths within the unsaturated zone at each study site.

- Ground-water levels were measured in, and water samples obtained from, wells that were screened just below the water table. Ground-water levels within the wells were monitored and recorded with a Solinst Levelogger pressure transducer.

- On-site weather stations recorded hourly precipitation volumes, with the exception of some data gaps that were filled with nearby weather station data. The weather stations also recorded climatic condition and soil parameters used to estimate the site-specific energy balance for determination of evapotranspiration (ET).

- Samples of UZ water were obtained with soil-suction lysimeters, which were installed at up to four depths in the UZ. Pan lysimeters, designed to collect only free-draining water, were also used to collect samples of UZ water.

- Recharge (drainage) to the ground water was estimated from continuous water level records using the Water-Table Fluctuation Method (Healy and Cook, 2002). The method assumes that an increase in the ground-water elevation of an unconfined aquifer is due to recharge water reaching the water table.

- ET was calculated with the Priestley-Taylor and FAO 56 Penman-Montieth models for IN and MD, with the Kimberly-Penman model for WA, and with a combination of the Penman-Montieth model and a modified version of the Penman model for CA.

- Soil water travel time, advective velocity, and specific water flux were estimated from applied conservative tracer studies using a bromide (Br) salt.

Healy, R. W. and P. G. Cook (2002). "Using groundwater levels to estimate recharge." Hydrogeology Journal 10: 91-109.

Water Budget

The water budget equation used is:

INPUT = DRAINAGE + EVAPOTRANSPIRATION + CHANGE IN SOIL STORAGE + RUNOFF

Runoff was not measured, and was calculated as the remainder after subtracting independent estimates of drainage, evapotranspiration, and change in soil storage from the total water input. Error in the calculation is also included in the remainder.

Table 2 Water Budget Components for 2004, in centimeters

	Indiana	Maryland	California	Washington
Precipitation	90.6	98.1	27.0	18.7
Irrigation	—	—	120	74.4
Drainage	51.2	55.7	54.1	11.9
Evapotranspiration				
Priestley-Taylor	58.0	51.7	—	—
Penman-Montieth	50.3	52.5	89.9	—
Kimberly-Penman	—	—	—	83.7
Change in Storage	0.1	-0.1	1.3	0.0
Remainder	-10.9	-10.1	1.7	-2.6

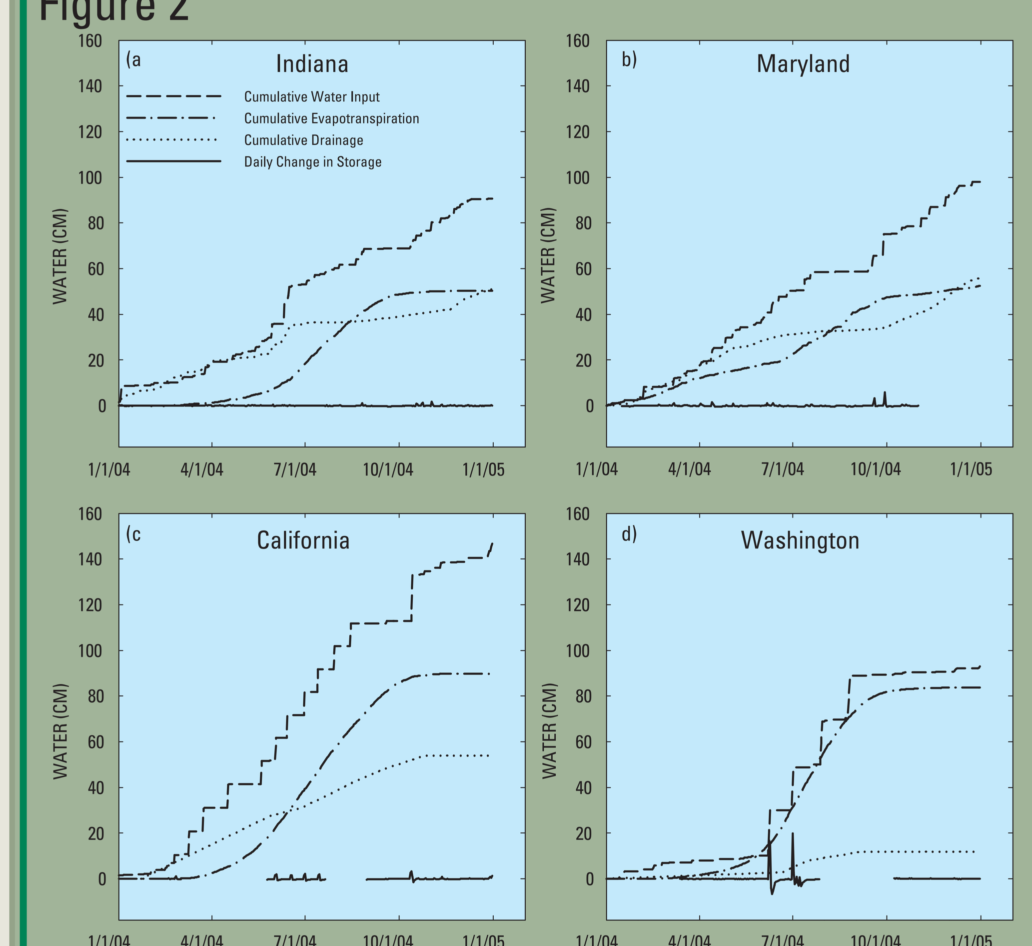


Figure 2

- While precipitation was the only water input at IN and MD for 2004, CA and WA added 82% and 80% irrigation water, respectively, to meet crop needs (Table 2).

- Water draining (recharging) from the soil surface to the ground water (Fig. 2) was seen at all study sites in 2004. Drainage estimated for WA was ~20% of the drainage estimates of the other study sites (Table 2).

- Recharge in CA and WA increased during irrigation events corresponding to increases in soil VMC and ground-water elevation (Fig. 2). This indicates that while recharge can occur in response to precipitation, irrigation events during the growing season contributed the majority of the recharge at these study sites.

- Recharge decreased in IN and MD (Fig. 2) as ET increased with crop growth. This was followed by an increase in drainage water after ET dropped off at the end of the growing season. This suggests that the majority of the recharge in IN and MD occurred during the months outside the growing season when ET has minimal impact on the water balance.

- The IN site has tile drains ~1 m deep. Recharge estimates for this site incorporate both water moving to the tile drains as well as to the water table.

- Crop water requirements in IN and MD (ET) were lower than CA and WA due to the difference in climate as well as crops (Table 1). ET in WA tracks cumulative irrigation input closely.

- Changes in VMC in IN and MD (Fig. 3 b and e) are not as dramatic in response to water input as in CA and WA, but do show decreases during dry periods.

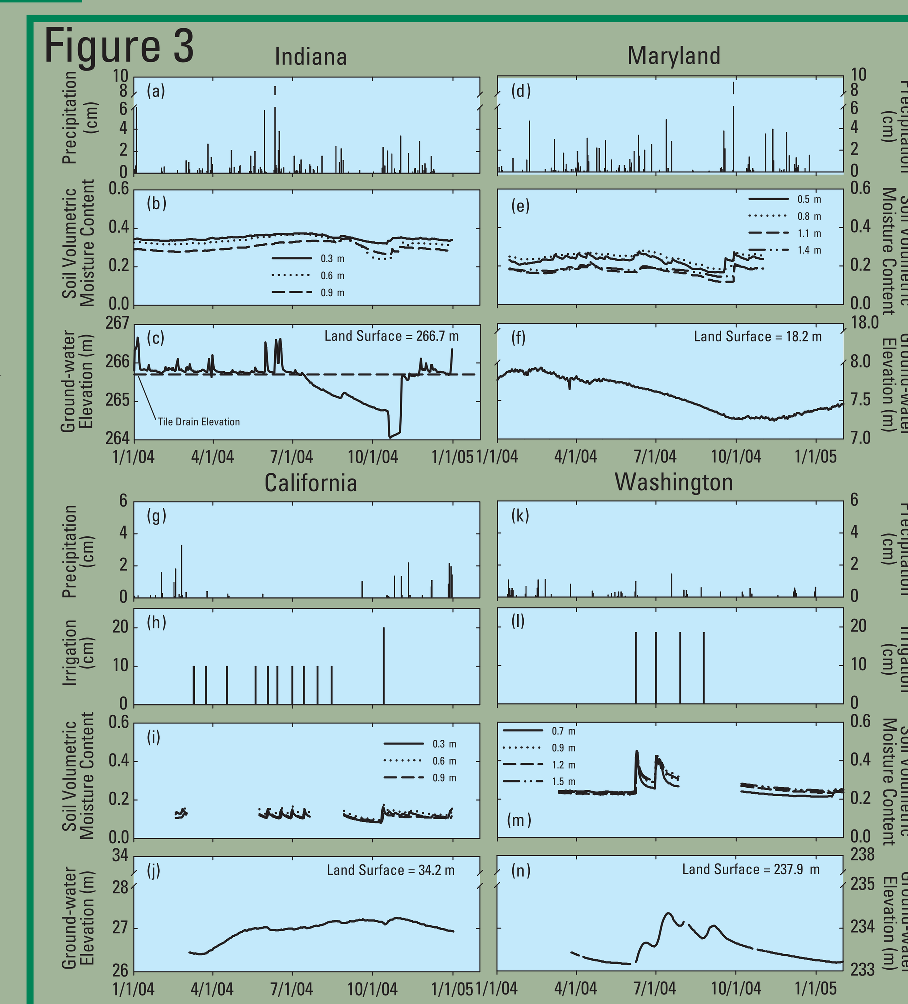
- Water ponds on the tight silty clay loam soil surface at IN during precipitation events, and the ground-water elevation (Fig. 3c) shows relatively quick increases in response to these events followed by a fairly rapid recession. The ground-water elevation at this site is controlled by tile drains located ~1 meter below land surface. However, during dry periods the water table dropped below the tile drain and experiences less response to water input.

- Changes in ground-water elevation in MD (Fig. 3f) show comparatively little response to individual precipitation events, and declines over the growing season as ET rates exceed input.

- The cumulative water input for CA and WA in Figures 2(c) and 2(d) show step-like increases in response to irrigation input (Fig. 3 h and l) that correspond with changes in VMC (Fig. 3 i and m) and ground-water elevation (Fig. j and n).

- The dramatic increase in VMC and ground-water elevation in response to irrigation input in WA – in contrast to CA – is likely due to (1) rill irrigation as opposed to sprinkler, (2) differences in irrigation volume per irrigation application, and (3) a finer soil texture (Table 1) in WA than CA.

Figure 3



Conservative Tracer Study

- Br sample collection lacked the resolution to confidently define breakthrough curves.

- Time of travel at all sites is likely greater than the longest time reported in Table 3 due to tailing of the conservative tracer.

- Br was transported in low concentrations below the root zone and tile drains within 7 days after application in IN (Fig. 4a).

- Br transport in MD appears to be associated with free-draining water (pan lysimeter) as opposed to water that is more tightly bound within the UZ matrix (suction lysimeter) (Fig. 4b).

- Relatively rapid transport of Br (8 days) to 0.9 m was seen at the CA site (Fig. 4c) likely due to the sandy soil texture (Table 1) and during the early growing season.

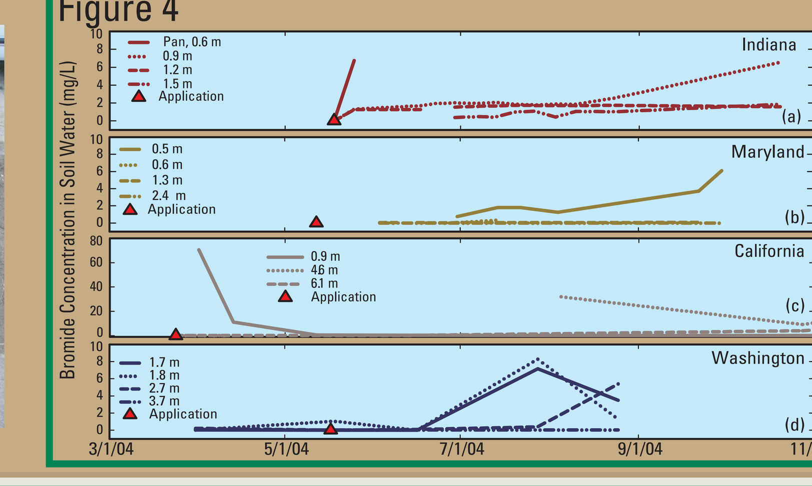
- Br was transported to 1.8 m within 1 day (~180 cm/day) in WA (Fig. 4d) likely due to preferential flow.

Table 3 Bromide Tracer Study Data.

	Indiana[1]	Maryland[2]	California[2]	Washington[4]
Application Date	5/19/2004	5/12/2004	3/24/2004	5/17/2004
Travel Time (days)	7 to > 56	49 to >141	8 to >20	1 to >100
Advective Velocity (cm/day)	<1.1 to 8.7	<0.4 to 1.1	<4.6 to 11.4	<1.8 to 183
Specific Water Flux[5] (cm/day)	<0.3 to 3.1	<0.1 to 0.3	<0.5 to 1.3	<0.5 to 47.3

[1]Bromide tracer data from 0.6 m depth.
[2]Bromide tracer data from 0.5 m depth.
[3]Bromide tracer data from 0.9 m depth.
[4]Bromide tracer data from 1.8 m depth.
[5]Specific water flux is per unit area.

Figure 4



Findings

- Water transport from land surface to the water table (recharge) occurred within 1 year at all sites (Table 2) although the hydrogeology, climate, and agricultural management practices observed at each site differ In some cases transport times were significantly less than 1 year. Thus, agricultural chemicals have the potential to be transported to the ground water within 1 year or less.

- Most recharge in CA and WA occurred during the growing season when irrigation input exceeded ET rates. However, nominal recharge occurred in response to precipitation events outside of the growing season when ET was minimal, more so in CA than in WA. The majority of the recharge in MD and IN takes place during wet periods outside of the growing season when ET is minimal, while a small amount occurred during the growing season when water input exceeded ET.

- Recharge estimates at the IN site incorporate both water moving to the tile drains as well as to the ground water. While reports suggest that tile drains may help protect ground-water quality by intercepting infiltrating water that may be carrying solutes, the conservative tracer was detected below the elevation of the tile drain. This suggests that water and solutes have the potential to move below the tile drains and eventually to the ground water at this site.

- The frequency and spatial distribution of irrigation in CA and WA causes recharge to vary in space and time. Because of this, site-specific recharge rates estimated for CA and WA may not be representative of recharge rates for other sites within the study area. Precipitation, the only water input for IN and MD, tends to be distributed relatively even spatially and somewhat temporally in comparison to irrigation methods. Thus, recharge rates for MD and IN may be more reflective of typical recharge rates for other locations within the study area.

Acknowledgments

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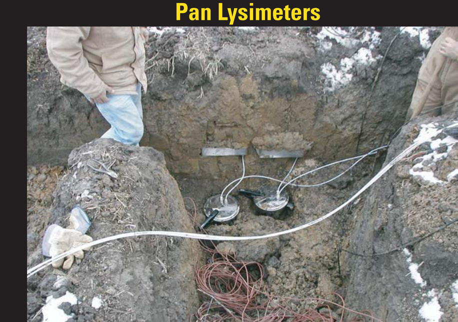
Installation of Heat-Dissipation Probe

Water Content Reflectometer Array

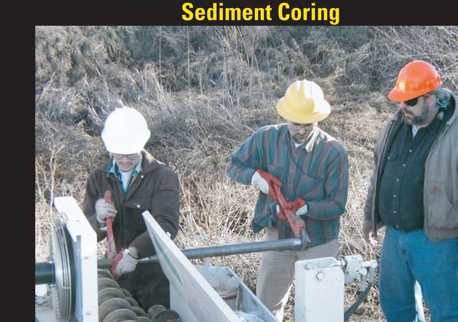
Suction Lysimeter

Pan Lysimeters



Well Drilling

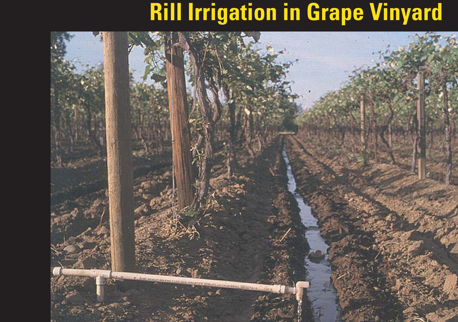
Sediment Coring



Head Ditch for Rill Irrigation

Weather Station

Rill Irrigation in Grape Vinyard



Hank's Diggin' It!

Soil Parameter Sensor In