

Direct Measurement of Infiltration through a Playa Wetland Using Automated Double Ring Infiltrimeters

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Abstract

Freshwater playas are the predominant hydro-geomorphic landforms in the Southern High Plains (SHP). These shallow ephemeral lake basins act as precipitation runoff catchments within closed watersheds and provide a focal point for Ogallala aquifer recharge. Because of the gradual depletion of the Ogallala aquifer and the importance of playas to aquifer recharge, accurate estimates of infiltration rates through playas are needed. We measured three-day infiltration rates through a playa lakebed using mesoscale double ring infiltrimeters installed within a cropland playa. Results were compared to estimates made in earlier studies. Steady state infiltration averaged $0.008 \text{ cm} \cdot \text{min}^{-1}$ for double ring infiltrimeters as compared to $0.058 \text{ cm} \cdot \text{min}^{-1}$ for a simulated single ring. Mesoscale single-ring infiltrimeters and small double-ring infiltrimeters used in earlier studies considerably overestimated steady state infiltration rates.

Keywords

Playas, Playa Wetland, Hydrology, Infiltration, Automated Double Ring Infiltrimeters

1. Introduction

Freshwater playas, shallow ephemeral circular wetlands, are the most common hydro-geomorphic landforms on the Southern High Plains (SHP) of western Texas and eastern New Mexico. There are about 20,000 playa wetlands on the SHP which

have been estimated to occupy 3% - 5% of the land area [1] [2]. Playa wetlands are centers of biological diversity and provide functionally important ecosystem services [3] [4]. Playas have also been modified and exploited for anthropogenic purposes, though they are often viewed as marginally productive land.

The SHP playas are economically important because of their role in Ogallala aquifer recharge. Hydrologically, SHP freshwater playas are shallow flat-bottomed basins embedded in topographically closed watersheds. After precipitation events of sufficient duration and intensity, playas partially fill with runoff from the surrounding watershed. Neglecting additional precipitation and runoff events, the length of the hydroperiod is dependent on the rate of water loss through evaporation, transpiration, and infiltration. Infiltration into and through playa basin floors occurs through initial rapid piston flow and subsequent micropore infiltration, the latter being a much slower process [5]. It is through such processes that playas are generally thought to focus Ogallala aquifer recharge in the SHP. Aquifer recharge is critical to maintaining a productive irrigated agricultural system on the Texas High Plains [6]. Estimated recharge rates through playas are uncertain and may vary appreciably across the SHP region. However, there is no doubt that aquifer withdrawal rates greatly exceed recharge rates [7] [8]. Estimation of infiltration losses from playas through the vadose zone is usually obtained using indirect approaches.

The objectives of this experiment were to 1) directly measure the long-term infiltration rate of a playa using a meso-scale double ring infiltrometer, and 2) compare the results to previous studies in the same playa.

2. Methods

Briefly, mesoscale double ring infiltrometers were installed in the basin of a SHP playa. Water was added to maintain a constant head. The rate at which water was added was measured and logged for calculation of long-term infiltration rates. Results were compared to those reported from previous studies in the same playa.

2.1. Site Selection and Description

The playa wetland was located near Shallowater, TX (33.656 Lat., -102.0358 Long.). This site was chosen based upon proximity, landholder permission, and because previous studies had been conducted at this location (e.g., [5] [9]-[11]). This particular playa wetland was embedded within and proximal to an irrigated cotton cropping system surrounding the east and south and southwest portion of the playa (**Figure 1**). The west and north sides of the playa were surrounded by terraced Conservation Reserve Program (CRP) grassland. The playa basin is predominately a Randall Clay (very-fine, smectitic, thermic Ustic Epiaquerts), though soil composition was likely changing as a result of transport by surface runoff from land used for row cropping [12]. The soil proximal to the annulus is a Lofton clay loam (fine mixed Vertic Argusol). Farther upland the soil is an Amarillo fine sandy

loam (fine-loamy, mixed, superactive, thermic Aridic Paleustalfs). Instrumentation was installed at the deepest point within the playa basin. The deepest part of the basin was approximated by referencing U.S.G.S. topographic data and precisely located with a high-resolution global positioning system (GPS) consisting of a Trimble R-6 GNSS base and a rover with a Pacific Crest HPD-450 radio link Trimble TSC2 survey controller (Sunnyvale, CA), mounted on an all-terrain vehicle to collect real-time kinematic data of continuous topographic points at fixed 4.5 m intervals. GPS data were analyzed using Golden Software Surfer 11 (Golden, CO) to locate the lowest region of the playa. Four meso-scale double ring infiltrometers were installed in a cluster to minimize potential effects of soil and vegetation variability but separated by what was subjectively judged to be a distance that would minimize if not to eliminate the effects of one installation upon another. The individual infiltrometers were separated by about 50 m.

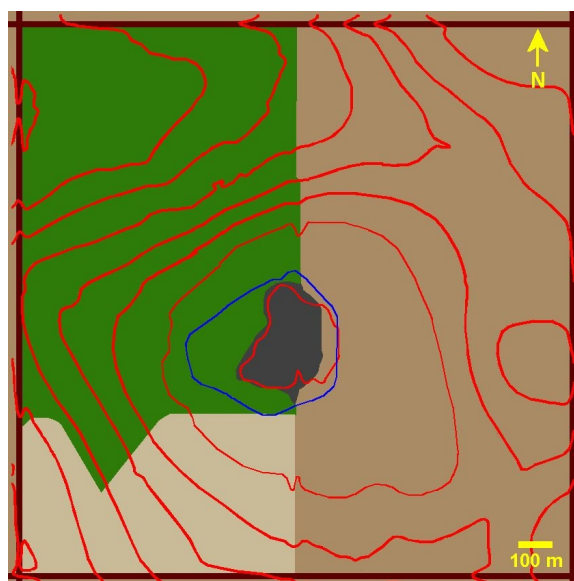


Figure 1. Playa embedded within 1.6 km (1 mile) square watershed bounded by roadways. Irrigated crop land (dark tan), dryland crop land (light tan), C.R.P. grassland (green) and clay playa basin bottom (dark gray) identified from aerial photography. Elevation lines (red) and basin edge (blue) are from U.S.G.S. topographic data.

2.2. Double Ring Infiltrimeters

Rings (**Figure 2**) were fabricated from rolls of 0.04 cm (30 ga.) thickness $\times$ 91 cm (36 inches) width galvanized sheet steel. The metal was cut to length, the ends overlapped, and the overlapped portion fastened with screws and sealed with a silicone sealant. The resulting inner and outer ring diameters were 120 cm and 200 cm, respectively. The infiltrometer was set to a depth of 40 cm. In an effort not to affect the soil hydraulic properties care was taken to leave the soil undisturbed while setting the rings. Precautions included using plywood forms to stand upon and work from. The forms served to more precisely guide manual trenching operations. Infiltrimeter rings were placed in the resulting trenches, and the ply-

wood forms carefully removed. Small spaces remaining on the inner sides of the trenches were filled with a slurry of sifted soil to prevent water from escaping under the rings. The remaining trench space on the outer surface was backfilled, but additional soil was mounded a few centimeters high to allow for settling. After installation of the rings in January of 2012, the soil was left undisturbed for five months until early summer.

Water was hauled from an irrigation well and fed into large holding tanks at the experimental site, and hose-fed into the infiltrometer rings from a portable generator-driven electric pump. Water was allowed to circulate back into the holding tanks through valves adjusted such that system pressure was maintained at 138 kPa (20 psi). The water depth within each ring was controlled with rugged inexpensive float valves of the type commonly used to maintain livestock water trough levels. The float valves were manually adjusted over the course of several hours during filling, and periodically throughout experimentation, so that no difference could be measured between the top edge of the inner ring and the surfaces of the water. Infiltrometer flow was forced through either a paddle wheel flow meter or a more sensitive low-flow turbine type flow meter. During initial filling the higher flow required to maintain a 20 cm head was passed through the paddlewheel meter. As flow decreased, water to the inner ring was passed through a filter and then through the high-resolution turbine flow meter. Flow to the outer ring was similarly measured. Flow meter outputs were summed over 15-minute intervals and recorded for later analysis.

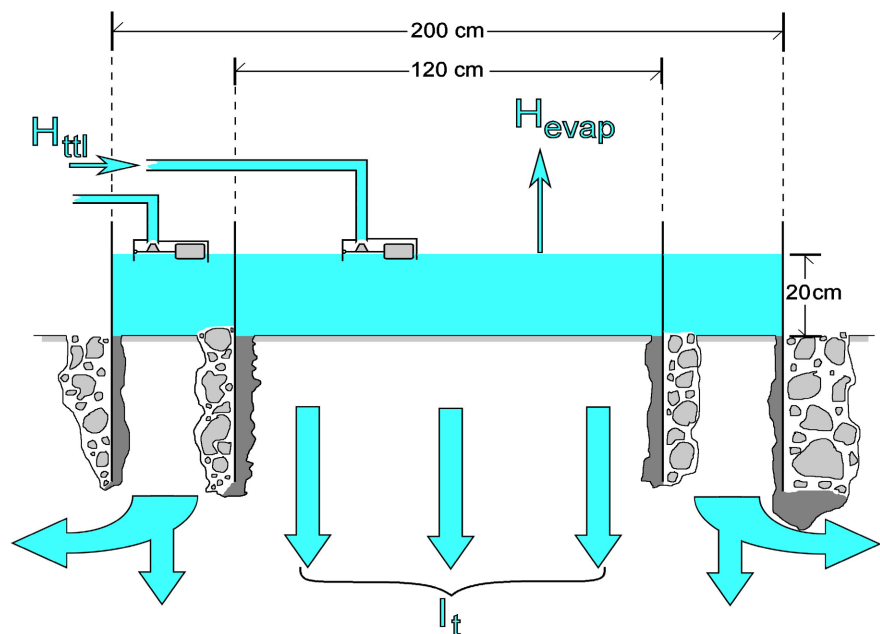


Figure 2. Cross-sectional diagram of meso-scale infiltrometer placed in playa bottom. Flow inlets to float valves are shown. Dimensions and head maintained throughout experiment are indicated. Infiltration (I_t), Evaporation (H_{evap}) and total flow (H_{ttl}) are indicated. Soil infiltration is indicated by large blue arrows.

There were originally five functional infiltrometers installed. During the filling of one of the devices, the contents unexpectedly drained into what appeared to be an animal burrow. Here we report results taken from the remaining devices. During installation of another infiltrometer, a textile tube drain was encountered. These were installed as part of an engineering scheme to harvest playa water and increase aquifer recharge [10]. The drain tube was simply severed where the infiltrometer walls were to be installed leaving the remainder in place. Drain tubes external to the outer wall were torn from the ground and discarded.

2.3. Data Inspection and Analysis

Flow rates ($\text{cm}^3 \cdot \text{min}^{-1}$) were converted to the apparent drop in head (H_{ttl} , $\text{cm} \cdot \text{min}^{-1}$) from the inner ring (Figure 2). It should be borne in mind that the “drop in head” is a rate calculated from flow; and that actual head, the distance from the soil to the water surface, was kept constant. The total head drop values (H_{ttl}) were corrected for evaporation (H_{evap}) using values from a “near Class-A” pan located at the USDA-Plant Stress and Water Conservation Laboratory at a distance of 14.5 km ESE (33.593849 Lat., -101.900978 Long.) from the study site [13]. Head loss from infiltration at any time was calculated as: $I_t = H_{\text{ttl}} - H_{\text{evap}}$. Data were plotted, inspected, and then fitted according to three models to evaluate infiltration: the “Green-Ampt” model [14], “Horton’s” infiltration model [15], and a simple hyperbolic decay model of the form $I = I_{\text{ss}} + (a \times b)/(b + t)$; where, I_{ss} = steady state apparent head drop, t = time (minutes), and both a and b are site specific coefficients introduced by iterative curve fitting. Infiltration estimates were made by iterative curve fitting using SigmaPlot v. 11 (Copyright© 2011, Systat Inc.). Infiltration through a single ring infiltrometer was numerically simulated by combining flows to both inner and outer rings and treating data as described above for inner rings of the double ring infiltrometers. For presentation, long term infiltration values, averages, and standard error were presented in tabular form.

3. Results

Infiltrometers

Six infiltrometers were originally installed. One was sacrificed to investigate infiltration patterns beneath and around the device (not presented). Another unexpectedly failed when the contents suddenly drained into what appeared to be the remains of an animal burrow. The results of the four remaining infiltrometers are shown.

Long term infiltration estimates are shown in Table 1 and Table 2 (below). Table 1 shows estimates made by each numerical modelling routine and the standard error of the estimates, for Horton’s and the hyperbolic decay models. The Green-Ampt model was calculated using a spreadsheet and errors about the mean were not calculated.

Because the three models yielded slightly different results, values for each device across models are presented as the averaged results of all models. That is, the long-

term estimates made using; Horton's, Green-Ampt, and the simple hyperbolic regression models averaged devices A through D in **Table 2**. The numerically simulated "single ring", or cylinder infiltrometer are presented likewise.

Table 1. Long term infiltration estimated by Horton's, Green-Ampt, and Hyperbolic with double ring infiltrometers methods. Standard error (S.E.) of estimate is shown in parentheses. Estimate error was not calculated for the individual Green-Ampt estimates.

Infiltrometer	Infiltration, cm·minute ⁻¹ (S.E.)		
	Horton	Hyperbolic	Green-Ampt
A	0.004 (0.008)	−0.002 (0.008)	0.013
B	0.007 (0.005)	0.002 (0.005)	0.010
C	0.013 (0.005)	0.009 (0.004)	0.011
D	0.014 (0.004)	0.008 (0.003)	0.011
Avg. (S.E.)	0.010 (0.006)	0.004 (0.003)	0.010 (0.001)

Table 2. Long term infiltration estimated with double and single ring infiltrometers. Results are averaged across modelling techniques.

Infiltrometer	Infiltration, cm·minute ⁻¹ (S.E.)	
	Inner Ring (S.E.)	Single Ring (S.E.)
A	0.005 (0.004)	0.049 (0.016)
B	0.006 (0.002)	0.045 (0.003)
C	0.010 (0.001)	0.054 (0.028)
D	0.010 (0.002)	0.083 (0.010)
Avg.	0.008 (0.002)	0.058 (0.009)

4. Discussion

Playa ecology and hydrology is strongly influenced by the surrounding watersheds. The variability of historic and current land use patterns around playas contributes to playa variability. There are few, if any, wild natural playas in the region because ranching and cropping operations have altered the surrounding watersheds over the last century. For such reasons, and because of the finite number of playas in the Llano Estacado, it is difficult to identify "typical playas". Playas located in grassland settings that have not been extensively modified are thought to be relatively unchanged compared to those near cropland. But even grassland playas are affected by plant community changes resulting from fire suppression or continuous cattle grazing.

Freshwater playa wetlands are classically described as shallow dish shaped circular depressions about 100 m to 3000 m in diameter consisting of a flat basin of clayey soil within a relatively steep annular region that transitions to a gently sloping upland region. Anthropogenic land use increases sediment transport and deposition into such playas during runoff events. Sediment transport introduces sand

and silt into playas making the basins shallower and irregularly shaped [16] [17]. Such processes affect infiltration as well [5] [11].

The playa described here has been the subject of several studies over several decades ([5] [9]-[11]). The land surrounding this playa has undergone land use changes. Initially the playa was embedded entirely within row cropped dryland production. Land on the northwest quadrant was later terraced and, on the northeast, converted to irrigated cropping. The terraced land was planted into CRP grassland (**Figure 1**). This was the proximal land use pattern prior to and during the time of the present experiment. Soil sampling and analysis were not done. However, the possibility that sediment transport associated with anthropogenic activities surrounding the playa led to considerable changes in the soil hydrologic properties described elsewhere [11]. Row cropping invariably leads to sediment transport into playa basins [17] [18]. In this watershed terracing forced runoff water around the southern terrace ends and into a broad single channel that fed into the playa. The playa was irregularly shaped and had little of its flat pan like bottom remaining. The playa has since undergone more land use changes. The former CRP land and some of the farmland have been divided up into tracts for residential housing. Moreover, since development and sediment transport has continued since the study described here, soil sampling to relate potential changes in hydraulic conductance to particle size distribution would be speculative.

Long term infiltration estimates in previous studies at this playa vary widely. Estimates made with over one hundred small-scale double ring infiltrometers (12.8 cm diameter inner ring, 20.5 cm diameter outer ring allowed to infiltrate for 48 hours) were “highly variable” and ranged from zero to $66.4 \text{ cm}\cdot\text{min}^{-1}$ ([5] [9]). Cylinder infiltrometers of diameters 200 cm yielded infiltration rates between $0.042 - 0.084 \text{ cm}\cdot\text{min}^{-1}$ (1 and 2 inches/hr) but were assessed for only 130 minutes and constant head was not maintained. A single large scale 890 cm diameter cylinder infiltrometer experiment yielded a long-term infiltration rate of $0.007 \text{ cm}\cdot\text{min}^{-1}$ (0.16 inches/hr) after three days. Head was not maintained. Rates did not change markedly after three days. For such reasons the double ring infiltrometers used as described herein were maintained for 3 - 5 days [5] very close to our estimate of $0.008 \text{ cm}\cdot\text{min}^{-1}$ obtained using our system.

5. Conclusion

The mesoscale infiltrometers described were large enough to span cracks and other potential sources of variation using small scale double ring infiltrometers while providing an estimate similar to that of much larger nine-meter diameter cylinder infiltrometers which require an on-site water source. Our simulated single ring or cylinder infiltrometer values were of the same magnitude as those reported elsewhere, which calls into question the utility of such devices. While the method described herein is feasible for remote playas, yields similar results to much larger devices and requires less labor to install as compared to other approaches, this approach is still labor intensive and would benefit from improvements such as automation.

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Author Contributions

Conceptualization, CB, RZ, and DG; methodology, DG, and RZ; software, CB and DG; validation, DG, RZ, and CB.; formal analysis, DG, and JS; investigation, DG, RZ, and AW; data curation, CB, and DG; writing—original draft preparation, CB, DG; writing—review and editing, DG, JS, RZ, RL; visualization, JS, RL, and DG; supervision, DG; project administration, DG and RL; funding acquisition, RL. All authors have read and agreed to the published version of the manuscript.

Conflicts of Interest

The authors declare no conflicts of interest regarding the publication of this paper.

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