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GROUND-WATER RECHARGE ON THE SOUTHERN HIGH PLAINS, EAST-CENTRAL NEW MEXICO

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INTRODUCTION

The Southern High Plains extend into eastern New Mexico in three separate areas (Fig. 1). One of these lies in east-central New Mexico. It covers most of Curry County and the southwestern part of Quay County.

Although the High Plains cover only a small portion of New Mexico, they consitute an important agricultural area. According to estimates of acreage cultivated during the period 1973–1978 (Lansford et al., 1979), approximately 200,000 acres of irrigated cropland and 368,000 acres of dry cropland were in production in Curry County, whereas 53,000 acres of irrigated cropland and approximately 238,000 acres of dry cropland were under cultivation in Quay County.

The irrigated portion of this farmland owes its existence to ground water pumped from the Ogallala Formation. This aquifer not only provides water for irrigation, but also for municipalities and rural homes. Since extensive pumping for irrigation began in the 1930's, water levels have dropped substantially. Local declines of 7–9 m during 3–5-year periods have been common (Reeder et al., 1959; Hudson, 1978). Such declines occur because withdrawal rates exceed recharge rates. Safe yield (rate of withdrawal at which undesired results are not produced) may have been reached in Curry and Roosevelt Counties as early as the 1930's (Theis, 1932). Water levels continue to decline, and irrigation has been abandoned in some areas because of excessive lifts and fuel costs.

The rate of ground-water recharge is essential for assessing the life of the ground-water supply. However, recharge data are often not available, and the various chemical and physical methods of determining recharge in common use are complex, time-consuming and expensive. An alternative chemical method, based on chloride content of soil or vadose water, is simple and relatively inexpensive.

In 1983, the chloride method was applied to three settings in Curry County to obtain representative recharge rates and evaluate the variation of recharge with landscape setting on the High Plains of New Mexico (Stone, 1984a). The purposes of this paper are: (1) to modify the local or point recharge rates obtained in that study based on a new measurement of chloride content of local precipitation, (2) to convert these local recharge values to a regional recharge volume for Curry County and (3) to extend these recharge values to similar terrain in southwestern Quay County (the rest of the Southern High Plains in east-central New Mexico).

The region studied includes Curry County and southwestern Quay County (Fig. 1). Throughout this region, thin Quaternary deposits overlie the Ogallala Formation (Miocene and Pliocene). The Ogallala consists of up to 107 m of alluvial, eolian and lacustrine deposits (Hawley, 1984). The major Quaternary unit overlying the Ogallala is the Blackwater Draw Formation (Pleistocene), formerly mapped as windblown cover sand (Texas Bureau of Economic Geology, 1977). This unit consists of eolian sand occurring in a broad blanket generally less than 8 m in thickness. Locally, lacustrine and fluvial materials of Quaternary age also lie at the surface. An excellent summary of the geology and hydrology of the region has been given by Galloway (1982).

The climate of the region is semiarid. Annual precipitation averages approximately 400 mm, and potential evapotranspiration generally exceeds 1000 mm (Gabin and Lesperance, 1977). Most precipitation occurs in the period May through October. Net water-balance deficits of 760 mm or more are common.

THE CHLORIDE METHOD

In the chloride method, recharge is determined by the relationship $R = Clp/Clsw \cdot P$, where R = recharge (mm/yr), Clp = annual chloride input from precipitation (mg/L), Clsw = average chloride concentration in the soil or vadose water (mg/L) and P = average annual precipitation (mm/yr). Clp and P are either obtained from the literature or are measured in the study area. Clsw is determined from plots of chloride vs. depth. Analytical procedures were described by Stone (1984a, b, c). These procedures were evaluated by McGurk and Stone (1985).

For the present study, a value of 385 mm was used for P, based on data for Melrose, the closest rain gage to the sample sites (Gabin and Lesperance, 1977). A value of 2.38 mg/L was used for Clp, based on analyses of rainwater samples from the Agricultural Experiment Station north of Clovis. Preliminary local recharge values reported by Stone (1984a) were based on a precipitation value for Clovis (444 mm/yr) and a Clp value for Amarillo, Texas (0.59 mg/L). The adjusted local recharge rates determined in this study are believed to be more realistic because the precipitation is more representative of the sample sites and the Clp used includes some input from windblown dust (as does the ground surface), inasmuch as rainwater samples were collected in an ordinary rain gage. The Amarillo Clp used previously is somewhat low, because it was based on samples collected so as to eliminate dust.

The chloride method assumes (1) precipitation is the only source of chloride, (2) recharge is by piston flow, (3) precipitation has been constant through time and (4) chloride in precipitation has been constant through time. Because these are not always valid, results are considered to be estimates of recharge. However, recharge results from the chloride method compare favorably with those of other methods applied to the same site and to other similar areas. For example, a plot of recharge based on the chloride method vs. recharge from tritium in an Australian study gave a straight line (Allison and Hughes, 1978). Also, recharge estimates from the chloride method in Curry County compared favorably with those from various other studies of the High Plains in New Mexico and Texas (Stone, 1984a, table 2).

RECHARGE DETERMINATIONS

Recharge may be viewed in terms of three different scales: local, areal and regional. Local recharge is that occurring at a point in a given landscape setting. Such settings are unique combinations of geology, soils, vegetation, topography and land use or land-use history. Local or point recharge is expressed as a linear flux with the dimensions length per unit time (e.g., mm/yr). Areal recharge is that occurring over the entire extent of a given landscape setting and is expressed as a volumetric flux with the dimensions volume per unit time (e.g., m^3/yr). Regional recharge is that occurring in all areas of a study region and is also expressed as a volumetric flux.

These three recharge values are obtained in different ways. Local recharge is the value calculated from Clp, Clsw and P using the relationship defined above. Areal recharge is obtained by multiplying the local recharge rate (m/yr) by the area over which it applies (m^2). The result is an annual flux for that setting (m^3/yr). Regional recharge is simply the sum of all the areal values in the study region.

Curry County

This study of Southern High Plains recharge began in Curry County. Three landscape settings were determined to represent upland recharge

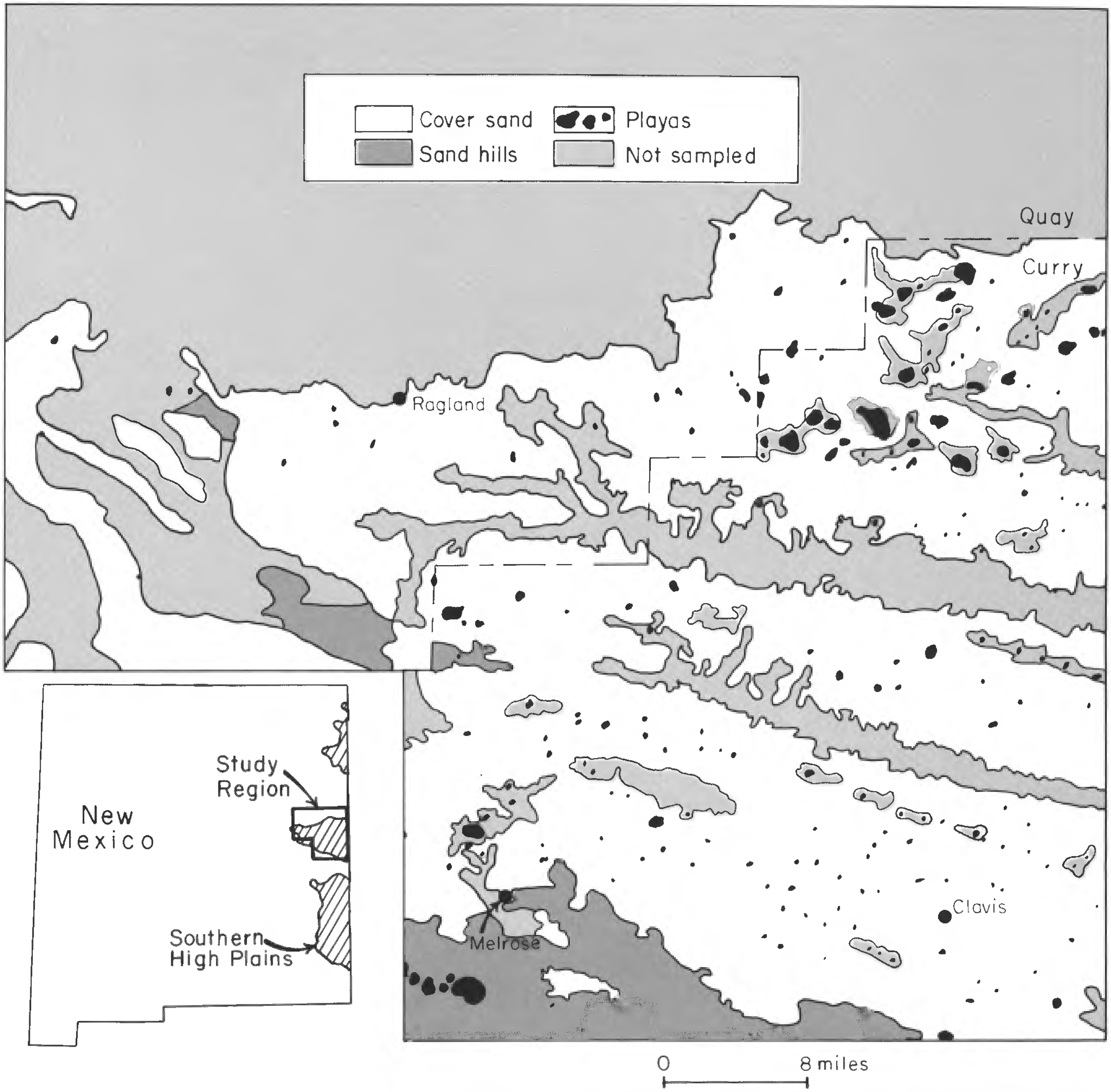

FIGURE 1. Generalized map of landscape settings studied (modified from soil maps by Buchanan et al., 1958, and Buchanan et al., 1960; extent of Southern High Plains on index map from Hawley, 1981). See text for soil series characterizing settings in each county.

areas based on geologic maps and field observations: cover sand, sand hills and playas. The cover-sand setting corresponds to the area occupied by the Blackwater Draw Formation (Pleistocene). The sand-hill setting includes areas of young eolian dunes (Holocene). Playas are the numerous shallow depressions where runoff periodically ponds and that provide the major relief on the High Plains surface. Recharge in valleys was not addressed.

In Curry County, a local recharge value of 0.75 mm/yr was determined for cover sand, 4.36 mm/yr was calculated for sand hills and 12.22 mm/yr was obtained for playas (modified from Stone, 1984a). Areal and regional recharge values are based on these point fluxes.

Areal recharge values were derived by (1) identifying the soils corresponding to the landscape settings sampled on soil maps, (2) determining areas covered by these soils from acreages given in the soil report and (3) multiplying each area by its corresponding local recharge value to obtain a volumetric recharge flux. The cover sand was found to be characterized by the Amarillo, Clovis and Pullman soils. The soils used to determine acreage for the sand hills include the Arch, Brownfield, Drake, Springer and Tivoli soils. Playas correspond to areas of playa floors as mapped in the county soil survey.

Areal and regional recharge values for Curry County are given in Table 1. Cover sand extends over nearly 675,500 acres and accounts for 1689 acre-ft of recharge per year or 54% of all upland recharge in the county. Sand hills cover approximately 81,400 acres and are responsible for 37% of the upland recharge. Although playas occupy only 0.8% of the area of upland settings sampled, they provide 9% of the upland recharge. A total upland recharge value for Curry County of approximately 3100 acre-ft/yr is indicated by this study. Recharge amounts to 0.3% of precipitation in Curry County (Table 2).

Southwestern Quay County

In order to determine the regional upland recharge for the Southern High Plains in east-central New Mexico, the local recharge values obtained for Curry County were applied to corresponding landscape

TABLE 1. Areal and regional upland recharge based on soil maps. Acreage in parentheses after county name refers to area of soils covered by soil survey; difference between it and total areal-extent value is area covered by soils not sampled (mainly valleys).

County, landscape setting, soils	Areal extent (acres)[1]	% of county or area	Areal recharge (acre-ft/yr)[2]	% of total upland recharge
CURRY COUNTY (897920)				
Cover Sand	(675471)	(75)	1689	54
Amarillo	369051	41		
Clovis	37004	4		
Pullman	269516	30		
Sand Hills	(81365)	(9.5)	1153	37
Arch	7697	1		
Brownfield	27946	3		
Drake	4630	0.5		
Springer	16232	2		
Tivoli	24860	3		
Playa floors	(6926)	(0.8)	277	9
	763761	85.3	3119	100
SOUTHWEST QUAY COUNTY (483235)				
Cover Sand	(323145)	(66)	808	72
Amarillo	30668	6		
Arvana	9467	2		
Clovis	20321	4		
Pullman	262689	54		
Sand Hills	(12351)	(2.7)	175	16
Arch	4533	1		
Drake	4499	1		
Springer	2827	0.6		
Tivoli	492	0.1		
Playa floors	(3281)	(0.7)	131	12
	338777	69.4	1114	100

[1] from county soil surveys; for m^2 multiply by 4047. Parentheses indicate subtotals.
[2] based on local recharge values given in text; for m^3/yr multiply by 1233.

settings in southwestern Quay County as well. Areal recharge values were determined in the same way as for Curry County. The areal extent of cover sand was assumed to be that associated with the Amarillo, Arvana, Clovis and Pullman soils. The area of sand hills was taken to be that covered by the Arch, Drake, Springer and Tivoli soils. Fewer playas occur in southwestern Quay County. In fact, no acreage was given for this landform. The acreage for playa floors was, therefore, determined by planimeter, using the detailed soil maps in the southwestern Quay County soil survey.

Areal and regional recharge values for southwestern Quay County are given in Table 1. Cover sand extends over roughly 323,100 acres and accounts for approximately 800 acre-ft of recharge per year or 72% of the upland recharge in this part of the county. Sand hills cover nearly 12,400 acres and contribute 175 acre-ft or approximately 16% of the upland recharge. Playas occupy nearly 3300 acres and are responsible for 131 acre-ft or approximately 12% of the upland recharge in southwestern Quay County. Total upland recharge is approximately 1100 acre-ft for southwestern Quay County. Recharge there amounts to approximately 0.2% of the annual precipitation (Table 2).

Southern High Plains

The total upland recharge on the Southern High Plains of east-central New Mexico is determined to be slightly greater than 5300 acre-ft (Table 1). Cover sand contributes 59% of the recharge, sand hills are responsible for 31% and playas produce 10% (Table 3).

In order to determine a net recharge (upland plus valley), that occurring along valley slopes and ephemeral-stream channels must also be evaluated. The chloride method is difficult to apply on steep slopes because drilling there is difficult. Similarly, the chloride method is not well suited to channel bottoms, where water and chloride input equals that associated with precipitation plus some unknown amount of stream flow. Thus, no such application was attempted in these settings. Of the two settings, however, recharge should be highest along channels due

TABLE 2. Recharge as a percentage of precipitation (precipitation from Gabin and Lesperance, 1977).

County	Precip. station	Ave. annual precipitation (mm/yr)	Ave. annual precipitation (acre-ft/yr)	Regional recharge (acre-ft/yr)	% of precipitation
Curry	Melrose	385	1053691	3118	0.3
Southwest Quay	Ragland	444	685033	1114	0.2
			1738724	4232	

to transmission loss during flow events. Because runoff is fairly rapid on the steep valley slopes, recharge should be minimal.

DISCUSSION

At first glance, the percentage of recharge contributed by the three different landscape settings is misleading (Table 3). For example, the large contribution by cover sand (59%) is more a matter of its regional extent than its recharge rate; this setting covers more than three-fourths of the study region. By contrast, sand hills cover less than 10% of the area, but contribute 31% of the upland recharge. Playas, interestingly, occupy less than 1% of the area, but provide 10% of the upland recharge.

The volumetric recharge rates given here are estimates. They are based on (1) estimated local recharge rates (modified from Stone, 1984a) and (2) areal extents of landscape settings as determined from soil maps for Curry and southwestern Quay Counties. Inasmuch as the detail of the soil mapping in the two areas differs, so does the accuracy of the estimates. Thorough field checking would be necessary to establish similarities and differences between the settings/soils in Curry County and those used in Quay County.

The local recharge rates given here should be applied to other areas only with considerable caution. Differences in texture of geologic and soil materials, annual precipitation, vegetation and land use or land-use history in such areas may significantly modify recharge rates. Areal and regional recharge values in distant areas would be best determined by sampling and calculating local recharge rates there.

The local recharge value used for playas, based on samples taken by drilling in the center of a playa floor in Curry County, may not fully reflect playa recharge. Wood and Osterkamp (1984) concluded that most recharge on the Llano Estacado in Texas occurs through a permeable annular area adjacent to the playa floors. This was based on the observation by various workers that, after playas first became filled with runoff, the water level drops rapidly until a water depth of approximately 0.5 m is reached; then water level declines slowly (Wood and Petraitis, 1984). They attributed the slower decline to the presence of a clay layer on the playa floor. Further, they concluded that even the slower decline is accomplished by infiltration rather than evaporation, because waters do not increase in salinity over time. Wood and Petraitis (1984) believed the average recharge flux in annular areas was between 4 and 5 cm/yr.

In view of the work of Wood and Petraitis (1984), regional playa recharge is really the sum of two separate regional values: one for playa floors and one for the annuli surrounding them. Table 1 gives reasonable values for regional playa-floor recharge in east-central New Mexico. Regional playa-annulus recharge may be approximated by applying the lowest value for the recharge range given by Wood and Petraitis (1984) for such annulus areas (4 cm/yr) to the area covered by permeable playa-margin soils (Church and Lofton soils). The minimum annulus-recharge value is selected because the study region is more arid than the area Wood and Petraitis studied. Using this approach, regional recharge associated with playa annuli is an additional 1092 acre-ft, giving a total regional playa recharge of 1500 acre-ft/yr.

The local recharge value used for cover sand is the average of two values obtained for this setting in Curry County by Stone (1984a). In those calculations, Clsw was based on the lower (pre-irrigation) part of the profiles. Although irrigation has no doubt enhanced recharge in some areas, the pre-irrigation value is warranted because (1) not all of the cover-sand setting is irrigated and (2) the rate at which recharge is, and will be, occurring at the water table for some time is the lower, pre-irrigation rate.

The regional recharge values presented are somewhat conservative in view of the precipitation value used for local recharge calculations. The value used for P comes from Melrose: 385 mm. Although this value is valid for western Curry County and southwestern Quay County, precipitation is higher in the eastern part of Curry County (e.g., 444 mm at Clovis).

The average regional recharge rate determined from this study compares favorably with that reported for the Southern High Plains by other workers. An average regional recharge value may be obtained by dividing the total regional recharge volume (5332 acre-ft/yr; Table 3) by the total area covered (1,102,540 acres; Table 3). This gives 0.005 ft/yr, 0.06 inch/yr or 1.5 mm/yr. By comparison, the U.S. Geological Survey uses an average recharge rate of 2.5 mm/yr for the entire Southern High Plains (Wood and Petraitis, 1984, p. 1195). The New Mexico value is predictably lower because (1) valley recharge is not included and (2) the climate in New Mexico is more arid than that elsewhere on the Southern High Plains (Texas, for example).

Much of the recharge documented herein occurs through caliche developed at the top of the Ogallala Formation or associated with various Quaternary deposits. When well developed, caliche is quite dense and appears to be impervious to recharge. However, this study and others in Australia have shown that recharge through caliche does occur, largely through fractures and root tubes (Stone, in press).

Further recharge studies should include an evaluation of valley and channel recharge. Additionally, the playa-annulus recharge rate should be tested by the chloride method, preferably in conjunction with other

TABLE 3. Percentage of total upland recharge by landscape setting.

Setting	Area (acres)	Total areal upland recharge (acre-ft)	% of total regional upland recharge
Cover Sand	998616	2496	59
Sand Hills	93716	2428	31
Playas	10209	408	10
	1102540	5332	100

chemical and physical methods. Estimates of irrigation return flow should be possible using the chloride method in irrigated settings.

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Tucumcari Mountain. View is N55°W. Jurassic Entrada Sandstone (white) and underlying Triassic rocks are exposed in canyon heads about halfway up mountain; elsewhere these rocks are covered by thick colluvial deposits. Flat upper surface of mountain is underlain by Tertiary Ogallala Formation and Cretaceous Mesa Rica Sandstone. Camera station is in SE1/4 SE1/4 sec. 5, T10N, R31E. W. Lambert photograph No. 85L8. 5 April 1985, 3:11 p.m., MST.