Groundwater Loss From Playa Lakes in the Estancia Basin, Central New Mexico

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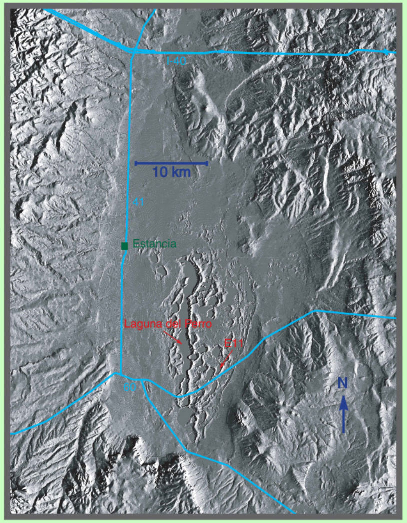
Abstract

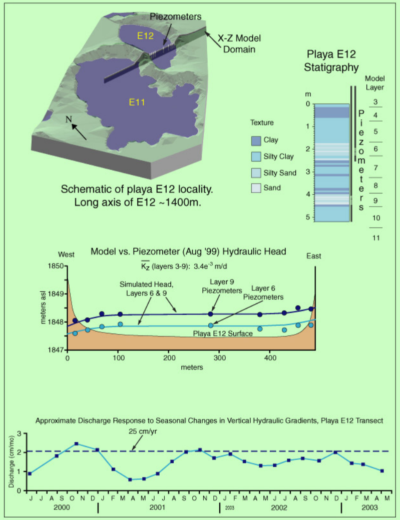
The 5000 km^2 topographically closed Estancia basin contains a complex of more than 80 groundwater-discharge playas that expose approximately 50 km^2 of the basin floor to direct loss of groundwater by evaporation. Hydrologic and meteorologic measurements collected at study sites since 2000 provide model estimates of evaporation loss from the playas. Multi-depth piezometers at study sites reveal increasing hydraulic head with depth at shallow levels beneath the playas. At playa E12 on the southeastern margin of the playa complex vertical hydraulic gradients are on the order of 0.2 (upward gradient) and estimated values for hydraulic conductivity (10^{-2} to 10^{-3} m/day) suggest less than 25 cm/yr of groundwater is being discharged as a result of the upward gradient. Near-surface meteorologic measurements at Laguna del Perro on the western side of the playa complex indicate that evaporation is strongly dependent on playa wetness, with dry periods and accompanying precipitation of salts associated with increased albedo and less energy for evaporation. During winter months, when daily net radiation is at a minimum, groundwater discharge alone is insufficient to maintain standing water on the playas. This observation and meteorological measurements during cool-dry periods at Laguna del Perro suggest groundwater discharge rates of less than 2-3 cm/month, similar to estimates based on hydraulic measurements at playa E12. These estimates of discharge, when integrated over the entire playa complex, imply a net evaporation loss of groundwater of less than 15 million m^3/yr (<12,000 acre ft/yr), significantly less than the ~30,000 acre ft/yr generally quoted as the amount of basinwide recharge to the groundwater system. Leakage from the basin under Holocene conditions is thought to be minimal, and some of this apparent difference between recharge and evaporation discharge may be attributable to anthropogenic groundwater withdrawals.



Hydrologic Estimates of Groundwater Loss

Methods

Estimates of groundwater discharge for locality E12, along the SE margin of the playa complex, use Darcy's law and water level measurements obtained from piezometers installed along an east-west transect across the playa. A two-dimensional (x-z) flow model was used to calibrate estimated values for hydraulic conductivity, based on sediment texture, with observed hydraulic gradients. The model grid contains 11 layers and 97 columns, and extends ~2000 m east-to-west. Model layers coincide with textural changes in lacustrine sediment that underlie the playa. Sediment textures and thicknesses of beds in the underlying lacustrine sequence are laterally persistent, suggesting that flow rates deduced from point measurements are representative of the entire playa.



Schematic of playa E12 locality. Long axis of E12 ~1400m.

Results

Groundwater discharge estimates using reasonably large values for hydraulic conductivity (mean kz 10^{-2} to 10^{-3} m/day) indicate that annual discharge rates on the order of 25 cm may be attained at playa E12. Observed seasonal fluctuations in hydraulic gradients and smaller estimates of hydraulic conductivities for shallow confining beds suggest that actual annual discharge and may be somewhat less.

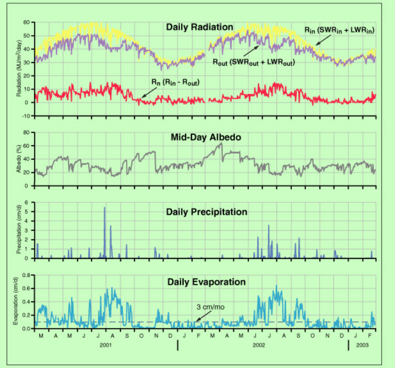
Meteorologic Estimates of Groundwater Loss

Methods

Estimates of groundwater discharge from Laguna del Perro are based on the energy balance near the ground-air interface:

$$R_n = H + \rho\lambda E + G$$

where R_n is the net radiant energy flux (sum of incoming and outgoing shortwave (SWR_{in}, SWR_{out}) and longwave (LWR_{in}, LWR_{out}) radiation), H is the sensible heat flux into the air, $\rho\lambda E$ is the latent heat flux (ρ is density and λ is heat of vaporization of water; E in units of L T^{-1}), and G is the heat flux into the ground. R_n and G are measured directly. A number of models may be used to evaluate the terms H and E in the energy balance equation, depending on available field measurements (detailed discussion of methods are presented in standard micrometeorological texts). The Penman-Monteith formulation uses the energy-balance equation to calculate evaporation from a free-water surface. For a drier surface the flux-gradient equations can be used in combination with the energy balance to evaluate the term H and solve for E. The Penman-Monteith and energy balance/flux-gradient methods require sufficient upwind fetch relative to measurement height to minimize the effect of horizontal discontinuities on vertical gradients (local advection effects). At Laguna del Perro meteorologic measurements are collected ~100 m east of the western margin of the playa, and atmospheric measurements (e.g. air temperature, water vapor pressure, wind speed) are measured within 1m of the surface. Meteorologic measurements are made every 30 seconds and model estimates of evaporation are calculated using one hour averages.



Results

Temporal changes in surface albedo (SWR_{out} / SWR_{in}) are especially large on the playas. Mid-day albedo values range from ~20% when the playa is covered with water, to 50% or more when the surface is coated with salts. Thus, the energy available for evaporation is significantly reduced as salts are precipitated, regardless of how saturated the surface may be. This observation highlights the problem of using common empirical formulations, such as pan coefficients or air temperature/evaporation relations, to estimate evaporation is this setting.

Evaporation estimates using the Penman-Monteith and energy balance/flux-gradient models produce similar results when integrated over daily periods. Penman-Monteith provides the larger estimates- on the order of 5-10% higher than the flux-gradient method. Reasonable agreement is also obtained between model estimates of evaporation and measured drawdown of standing water on the playa. For example, drawdown of 4.11 cm during the period 23-31 July '02 was measured using a sonic distance sensor deployed over the water surface. Model estimates of evaporation for the 9-day period were 4.41cm (Penman-Monteith) and 4.16cm (energy balance/flux-gradient).

Model evaporation rates following wet periods are comparable to estimates of free-water evaporation for the region. For extended periods with no precipitation, evaporation is limited by the rate of groundwater discharge to the playa surface. For the period March '01 - February '03 evaporation during dry episodes has been less than 3 cm/month on average.

Conclusions

Current estimates of groundwater loss from the Estancia playas, based on hydrologic and meteorologic investigations at two study sites, suggest less than 2-3 cm of groundwater is removed by evaporation per month, on average. These values are significantly less than previous estimates of evaporation loss from the playas.

Integrated over the area of the playa complex, these estimates suggest less than 12,000 acre ft/yr is presently being discharged to the playas and removed by evaporation.

If recharge to the groundwater basin is ~30,000 acre ft/yr, as presently thought, and assuming negligible leakage from the basin, estimates of evaporation loss presented here suggest that 2/3 or more of basin recharge is being captured by pumping of water wells in the basin.

Pertinent References

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