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EFFECTS OF PUMPING COLLECTOR WELLS ON RIVER-AQUIFER INTERACTION AT PLATTE RIVER ISLAND NEAR ASHLAND, NEBRASKA, 1998

The city of Lincoln, Nebraska, owns and operates two large collector wells-W90-1H and W90-2H-on the Platte River Island near Ashland, Nebraska (fig. 1). Wells W90-1H and W90-2H augment water supplies from the city's primary well fields on the west bank of the Platte River. In 1998, the U.S. Geological Survey (USGS) and the city of Lincoln entered a cooperative agreement to study the interaction of the Platte River with the underlying alluvial aquifer during various pumping scenarios for the collector wells. Description of the river-aquifer interaction at the Platte River Island while the collector wells are pumping will enable water managers to regulate the relative amounts of river water and ground water withdrawn by the collector wells. Results also will contribute to improved understanding of surface-water/ground-water relations in similar alluvial settings.

Background

The Platte River and the adjacent alluvial aquifer are essential sources of water to municipal, agricultural, and domestic wells. Near Ashland, (fig. 1) recharge to the alluvial aquifer predominantly comes from precipitation, inflow from hydraulically connected sand and gravel aquifers, and inflow from the Platte River. Recharge from the Platte River can affect the quality and quantity of the ground water quickly, either favorably or adversely.

Verstraeten and others (1995; 1999) determined a lag time of several days for the transportation of herbicides in the Platte River to the collector wells. Analysis of relative herbicide concentrations in the Platte River and water from the collector wells indicated that a large part of the water yielded by the collector wells originated from the Platte River (Verstraeten and others, 1999).

The objective of this study was to determine the extent to which management of the collector well laterals could be used to regulate relative amounts of well yield derived from river water and ground water. This study used three different pumping scenarios, estimating the mix of river water and ground water for each scenario. This report describes the results of evaluating these three scenarios.

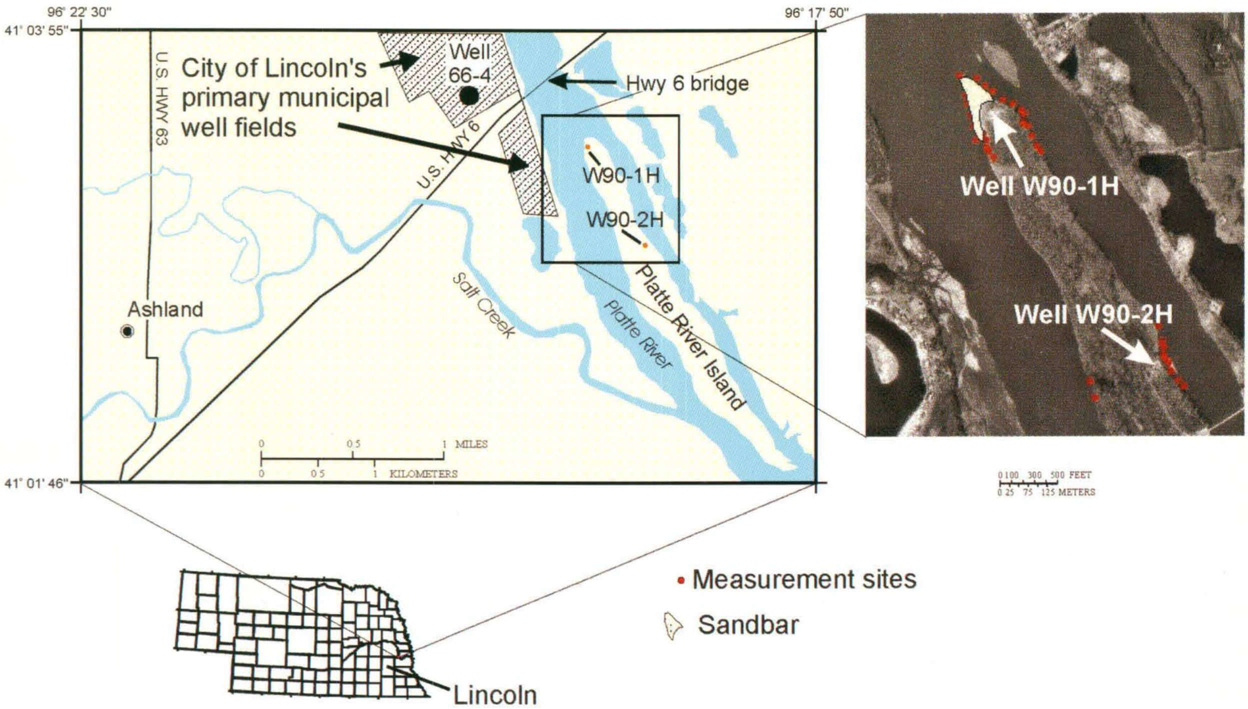

Figure 1. Location of study area and measurement sites, eastern Nebraska, 1998.

Description of Study Area

The study area lies in the Platte River Valley near Ashland (fig. 1). In this area, the Platte River is a wide, braided, sand-bed stream. Alluvial clays, sands, and gravels of Quaternary age comprise the Platte River alluvial aquifer (herein referred to as the alluvial aquifer) that overlies limestone bedrock of Pennsylvanian age. The Platte River Island (herein referred to as the island) is about 0.5 mile downstream of the Highway 6 bridge (fig. 1) and extends nearly 2 miles. Locally, the banks of the island rise to more than 6 ft (feet) above the riverbed. Well W90-1H is near the northern tip of the island and well W90-2H is near the eastern bank midway on the island (fig. 1).

Flow in the Platte River near Ashland includes runoff from about 84,200 square miles of drainage area upstream from the study area and contributions from ground water. The flow also is affected by man-made factors, such as reservoir storage and release, and withdrawals and diversions for water use. Mean daily flow at the Platte River gage near Ashland for water year 1998 (October 1997 through September 1998) was 9,739 ft^3/s (cubic feet per second) (Boohar, 1999). Flow generally is highest in the spring and lowest in mid to late summer. During times of low river stage, flow in the Platte River is more channelized than it is during moderate or high river stage. If flow is extremely low (such as less than 2,000 ft^3/s) zero-flow conditions can occur on either side of the island.

Flow in the alluvial aquifer predominantly is to the south-southeast. Bedrock formations that crop out on the eastern and western sides of the study area generally constricts down-gradient flow to the alluvial aquifer. Depth to water on the island under nonpumping conditions generally is less than 10 ft. Aquifer test data from a well in the city's primary well fields indicate that the general hydraulic conductivity of the alluvial aquifer is about 480 ft per day (Ted Zorich and Associates, Inc., 1989, p. 27). Evaluation of historic river-stage and ground-water-level data suggests that water moves from the alluvial aquifer to the Platte River or from the Platte River to the alluvial aquifer. Under natural conditions, such movement—river water to ground water or ground water to river water—largely is controlled by local and regional ground-water flow systems (Winter and others, 1998). During unnatural conditions such as ground-water withdrawals, the relative movement of ground water to river water can reverse locally.

Methods Used to Determine River-Aquifer Interaction

Pumping of wells W90-1H and W90-2H (fig. 1) was conducted under three specified pumping scenarios. Each pumping scenario involved pumping both wells 24 hours a day for 7 consecutive days. The first scenario involved pumping each collector well with all seven laterals open (A); the second scenario involved pumping each collector well with the four easternmost laterals open (E), and the third scenario involved pumping each collector well with the four westernmost laterals open (W). All measurements were collected as described by Verstraeten and others (1999). Flows at the Platte River gage near Ashland were 6,090 ft^3/s on August 19, 1998 (scenario A), 4,160 ft^3/s on September 2, 1998 (scenario E), and 3,840 ft^3/s on September 16, 1998 (scenario W).

Differences in hydraulic head (elevation of the water surface) between the Platte River and the alluvial aquifer were determined through a series of potentiomanometer (fig. 2) measurements at 34 stations (fig. 1). Potentiomanometer measurements were collected using modifications of methods described by Winter and others (1988). Positive hydraulic-head differences indicated water was moving from the Platte River to the alluvial aquifer; negative differences indicated water was moving from the alluvial aquifer to the river. The existence of a large sandbar prevented measurements from being obtained at the tip of the island. Therefore, measurements were obtained at the sandbar/water's edge. Analysis of the potentiomanometer tests involved comparing each pumping scenario to the other two. The west side of the island nearest well W90-2H was considered to be too far from the well for accurate determination of hydraulic-head differences caused by pumping. Therefore, only two measurements per scenario

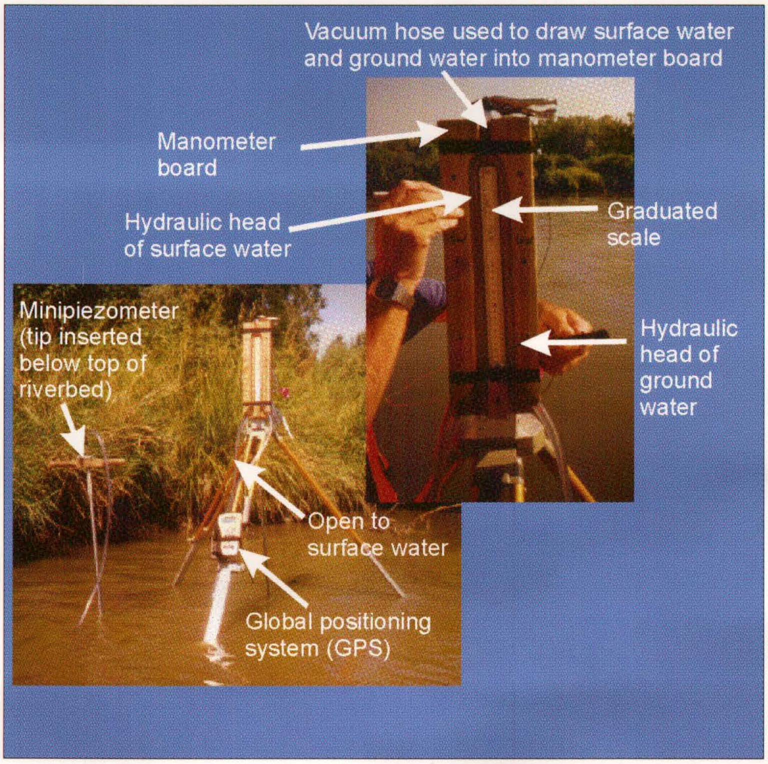

Figure 2. Potentiomanometer system used to measure differences in hydraulic head.

were made on the west side of the island nearest well W90-2H. Consequently, comparison of results for pumping scenarios E and W only were done using data collected near well W90-1H.

Chemical tracers such as major ions, trace elements, and isotopes were used to evaluate the relations between river water and ground water. Chemical tracers also were used to measure the percentage of water pumped from the well that was derived from the Platte River. During each pumping scenario, water-quality samples were collected from the Platte River (on the first day of pumping), and concurrently from the collector wells and a third municipal well (well 66-4) in one of Lincoln's primary well fields (on the fifth day of pumping). All water samples were analyzed for major ions, selected trace elements, and deuterium and oxygen isotopes.

The percentages of river water pumped by the wells were estimated by using the following formula:

$$P_m = \frac{(C_g - C_w)}{C_g - C_r} \times 100$$

where P_m is the percent of well yield coming from the river at time t,

C_g is the chemical composition of the ground water (assumed represented by water from well 66-4) at time t,

C_w is the chemical composition of well water at time t, and

C_r is the chemical composition of the Platte River of the assumed same aliquot of water (based on a 4-day lag time).

Evaluation of River-Aquifer Interaction based on Hydraulic Heads

Differences in the hydraulic heads between the Platte River and the alluvial aquifer varied by pumping scenario. However, during all three scenarios water predominantly moved from the Platte River to the alluvial aquifer, resulting in induced recharge. Analysis of potentiomanometer data collected around well W90-1H indicates that when all seven laterals were open (scenario A), the relative differences in hydraulic head between the river water and the ground water (herein after referred to as the difference in hydraulic head) were positive and fairly evenly distributed on both sides of the island (fig. 3). Varying which four of the seven laterals were open (scenario E or scenario W) produced similar results. When only the easternmost (E) or westernmost (W) laterals were open, the greatest differences in hydraulic head were always on the western side of the island (table 1; fig. 3). The complexities of the system preclude explanation as to why this is so. However, the magnitude of differences in the hydraulic head tended to increase depending on which laterals were open (greater values on a side when the same-side laterals were open in comparison to when the opposite-side laterals were open).

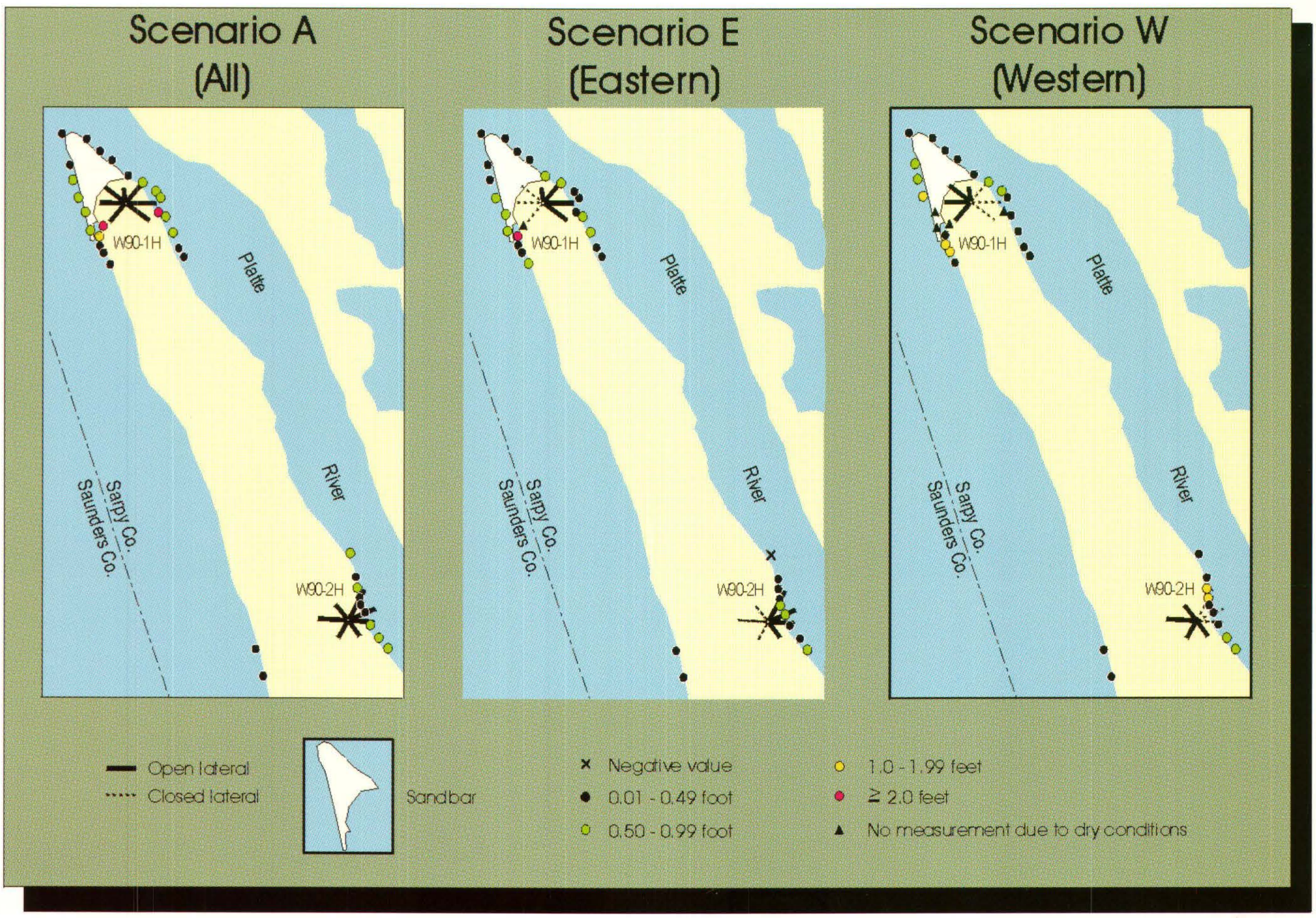

Figure 3. Differences in hydraulic head between the Platte River and the alluvial aquifer in the study area.

Verstraeten, I.M., Carr, J.D., Steele, G.V., Thurman, E.M., Bastian, K.C., and Dormedy, D.F., 1999, Surface water-ground water interaction; herbicide transport into municipal collector wells: Journal of Environmental Quality, v. 28, p. 1396-1405.

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WRIR 99-4161

Photo of USGS hydrologist using the potentiomanometer.

In terms of magnitude, differences in hydraulic heads, in most cases, were greatest in areas directly (or nearly so) overlying the laterals; the greatest differences in hydraulic head were 2.56 ft on the western side of the island and 2.53 ft on the eastern side of the island, scenario A (table 1). When only the easternmost laterals were open (scenario E), differences in hydraulic heads were as great as 2.16 ft near well W90-1H and 0.768 ft near well W90-2H. When only the westernmost laterals were open (scenario W), differences in hydraulic head were as great as 1.74 ft near well W90-1H and 1.85 near well W90-2H. Some areas that were wet during scenario A were dry during scenarios E and W. One station (western side) was dry when the eastern laterals were open, and four stations (one on the eastern side) were dry when the western laterals were open. In areas not directly overlying the laterals, the differences in hydraulic heads were typically less.

Evaluation of River-Aquifer Interaction based on Simple Mixing Calculations

Estimated percentages of water in the collector-well yield, from simple mixing calculations of field measurements, major ions, and selected isotopic data (table 2) indicated that during the summer, when river-water and ground-water temperatures are differing the most, water temperature appeared to be a reasonable indicator of mixing under the local conditions. The simple mixing calculations based on water temperature were confirmed by hydrogen or oxygen isotopic data from scenario E and by oxygen isotopic data from scenario W.

The results of the simple mixing calculations indicate that the percent of collector-well yield derived from river water may vary between 52 to 97 percent. The results suggest that the percentage of collector-well yield derived from the Platte River depends at least partly upon the location of the collector well and which laterals were used during pumping, confirming the study of Verstraeten and others (1999). Independent of the pumping scenario, the relative amount derived from river water tends to be greater in water from well W90-1H than from well W90-2H (table 2). The simple mixing calculations also indicate that the percentage derived from river water in water from well W90-1H is greatest during scenario W and smallest during scenario A, whereas the percentage derived from river water in water from

Table 1. Potentiomanometer-determined differences between hydraulic heads in the Platte River and the alluvial aquifer

[All, all laterals open; eastern, four easternmost laterals open; western, four westernmost laterals open; --, dry; negative number indicates ground water discharging into the Platte River; all data in feet]

Station	Hydraulic-head differences			Station	Hydraulic-head differences		
	Scenario A (All)	Scenario E (Eastern)	Scenario W (Western)		Scenario A (All)	Scenario E (Eastern)	Scenario W (Western)
			Well W90-1H				
1	0.007	0.876	0.033	13	0.282	0.345	0.230
2	.043	.033	1.31	14	.197	.345	.331
3	.233	.072	1.08	15	.410	.653	.472
4	1.97	2.16	.338	16	.528	.742	.919
5	2.56	--	--	17	.617	.177	.571
6	.784	.974	--	18	.771	.466	.427
7	.863	.879	--	19	2.53	.384	--
8	.607	.591	1.74	20	.797	.768	.164
9	.505	.397	.764	21	.581	.666	.387
10	.135	.194	.614	22	.033	.289	.253
11	.013	.030	.023	23	.052	.276	.249
12	.016	.003	.043				
			Well W90-2H				
24	.558	-.010	.351	30	.715	.377	.167
25	.141	.105	.207	31	.915	.266	.768
26	.791	.469	1.03	32	.715	.715	.837
27	.043	.308	1.85	33	.082	.049	.033
28	.026	.682	.030	34	.082	.020	.010
29	.128	.768	.089				

Table 2. Percentage of water in the collector-well yield derived from the Platte River

[All, all laterals open; eastern, four eastern laterals open; western, four western laterals open; Hydrogen, hydrogen isotope; oxygen, oxygen isotope]

Collector well	Fraction of surface water, in percent					
	Scenario A (All)	Scenario E (Eastern)			Scenario W (Western)	
	Temperature	Temperature	Hydrogen	Oxygen	Temperature	Oxygen
W90-1H	72	85	90	69	96	97
W90-2H	52	74	81	60	63	67

well W90-2H is greatest during scenario E and smallest during scenario A. Each collector well induces the greatest amount of river water when the laterals that underlie the Platte River are open. On the other hand, it is likely that the amount derived from river water in yields from both collector wells is smallest during scenario A because ground water is obtained from a larger area.

Finally, analysis of the data indicates that the general composition of river water and ground water is similar in the alluvial valley. Nevertheless, water temperature may be a useful tool for distinguishing between ground-water and surface-water sources during hot summer days. Hydrogen and oxygen isotope data may be useful during rain events or spring melt when the signature of these isotopes in river water and ground water may differ the most.

Conclusion

River-aquifer interaction in the study area is influenced greatly by the pumping of the collector wells. Water withdrawals from wells W90-1H and W90-2H for municipal supplies can change the direction of the natural ground-water flow. At the northern tip of the island, locations nearest the laterals experienced the greatest differences in hydraulic head between the Platte River and the alluvial aquifer. Under natural conditions, river water can move to ground water or ground water can move to river water.

However, when wells W90-1H and W90-2H were operated, water predominantly moved from the Platte River to the alluvial aquifer, resulting in induced recharge.

Depending on the conditions of flow in the Platte River, water managers for the city of Lincoln can affect the degree of interaction between the Platte River and the alluvial aquifer by planning and adjusting which laterals are open. For example, if contaminants in the Platte River were to be observed in the eastern channel of the river, closing the easternmost laterals likely would reduce the amount of water drawn from the river on the eastern side of the island. Likewise, closing the westernmost laterals likely would reduce the amount of water drawn from the river on the western side of the island.

The data confirm that the water quality of the Platte River can have a significant effect on the quality of water from the collector wells within a matter of days. This can occur because, after 5 days of pumping, 50 to almost 100 percent of water yielded by the collector wells could be derived from the river. The percentage derived from the river could be reduced by varying which collector well and laterals are used.

—By G.V. Steele and I.M. Verstraeten

View of Platte River looking south from the Highway 6 bridge. Platte River Island is in background.

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