Optimal Surface Water-Groundwater Management: The Importance of Hydrology and Irrigation Technology

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Abstract

Across the western United States, surface and groundwater resources have historically been administered and managed independently, despite the fact that the two are highly interdependent in many areas. When a surface waterway and an aquifer are hydraulically connected, water moves from the surface into the aquifer as recharge, and from the aquifer back into surface waterways as discharge. A distinguishing characteristic of this type of system is that a decline in the groundwater table due to groundwater pumping reduces surface water flows. In recognition of this effect, a number of states have established systems of conjunctive surface water-groundwater management. Though the design of these systems varies widely state-to-state, they generally seek to jointly manage surface water and groundwater resources in order to maximize the availability and reliability of both.

The objectives of this paper are to define how hydraulic connectivity affects the optimal design of a system of conjunctive management and to estimate the gains associated with conjunctive management relative to independent management of surface water and groundwater resources. Though there is a large economic literature on optimal groundwater management, few studies have considered optimal management in a hydraulically connected system in which both surface water and groundwater are used for irrigation. When surface water is used in irrigation, the efficiency of irrigation technology becomes an important factor in the management problem. This is because applications of surface water in excess of consumptive use requirements provide incidental recharge to the aquifer, elevating the groundwater table. This has two benefits in a hydraulically connected system: It reduces the marginal cost of pumping groundwater and it increases aquifer discharge and surface water flows in the future. Accounting for incidental recharge therefore influences the optimal use of surface water under conjunctive management.

In this paper, I develop a dynamic model that describes the movement of water between surface waterways and an aquifer in hydraulically connected and disconnected systems. In a disconnected system, there is no discharge from the aquifer into surface waterways, and groundwater pumping cannot affect surface water availability. In addition to these two hydrologic scenarios, I consider two management scenarios. In the first, surface water and groundwater are managed optimally, but by independent social planners. In the second scenario, surface water and groundwater are managed conjunctively by a single social planner. I also

consider the cases in which surface water availability is a binding or a non-binding constraint on surface water diversions. The former is consistent with a surface water system that is fully or over-allocated in the majority of years.

The analytical model indicates that the gains to conjunctive management in a hydraulically disconnected system are driven entirely by the provision of additional incidental recharge to the aquifer. When the surface water constraint is non-binding, the conjunctive manager will increase surface water diversions to augment incidental recharge and elevate the groundwater table. When the surface water constraint is binding, however, the manager cannot increase surface water diversions and there is no benefit to conjunctive management. In a hydraulically connected system, the gains to conjunctive management are partially attributable to the provision of incidental recharge, but there is an additional benefit as the manager accounts for the effect of surface water diversions and groundwater pumping on discharge and surface water flows in the future.

To explore further the gains from conjunctive management as a function of hydrology, I develop a numerical simulation model that is parameterized to reflect conditions on the Eastern Snake River Plain of Idaho. In this region, hydraulic connectivity is particularly pronounced: annual inflows into the Snake River amount to approximately 4.75 million acre feet, which are augmented by an average of 7.21 million acre feet in discharge from the Eastern Snake Plain Aquifer. The results of the model indicate that conjunctive management increases irrigator welfare by 4.49 percent over independent surface and groundwater management. Were the region hydraulically disconnected, the benefits to conjunctive management amount to only 0.20 percent. In a connected regime, optimal conjunctive management results in a transfer in welfare from groundwater to surface water irrigators, whereas in a disconnected regime, conjunctive management benefits groundwater users.

As connectivity between the surface water and groundwater systems declines, so too do the gains associated with conjunctive management. However, the results of the model are relatively insensitive to changes over a large range of values for the connectivity parameter. In contrast, changes in irrigation efficiency have a large effect on the results. As irrigation efficiency increases, the gains associated with conjunctive management also increase. For example, a 10 percent increase in surface or groundwater irrigation efficiency increases the returns to conjunctive management by 8.4 percent.

This analysis indicates that hydraulic connectivity and irrigation efficiency play an important role in determining the gains associated with a system of conjunctive management. However, the complexity of hydraulically connected systems precludes a uniform approach to conjunctive management and highlights a need for flexibility in regional water management. Even so, the benefits to conjunctive management persist for a large range of values in connectivity, which implies that this approach is likely to be beneficial in many connected systems.