THE USE OF A COUPLED GROUNDWATER SIMULATION AND OPTIMIZATION MODEL TO GUIDE GROUNDWATER MANAGEMENT IN THE UPPER KLAMATH BASIN, OREGON AND CALIFORNIA

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Abstract Demand for groundwater in the upper Klamath Basin has increased in recent years due to drought and changes in surface-water management aimed at improving habitat for fish listed under the Endangered Species Act. State and Federal water management agencies are concerned about the possible reductions in streamflow and excessive drawdowns resulting from the increased consumptive use of groundwater. Consequently, water and environmental managers in the basin need methods to determine groundwater withdrawal patterns that support water demand while simultaneously avoiding detrimental impacts of pumping on stream flows and groundwater levels. Here we present a groundwater-management decision model for the upper Klamath Basin that couples groundwater simulation with optimization. The simulation–optimization groundwater management model evaluates a complex array of water management options to identify strategies that best meet the resource allocation goals of the basin.

The upper Klamath Basin has a groundwater flow system that discharges to streams throughout the basin and provides the majority of late-summer stream flows needed to support critical wildlife habitat. An extensive data set of groundwater flux measurements reveals that decadal-scale climate cycles are an important factor controlling groundwater discharge to streams. Although groundwater has the potential to supplement surface water resources, groundwater pumping could negatively impact stream flow. The effects of groundwater pumping on stream discharge, however, have not been directly measured, and there is uncertainty regarding the timing, distribution, and magnitude of the effects of sustained groundwater development on surface water resources. Increased groundwater pumping will also impact groundwater levels. The use of groundwater increased significantly starting in 2001 as a result of drought and changes in surface-water management in the basin. The impact of this pumping on groundwater levels was marked in areas of increased pumping, with water levels showing both short- and long-term effects.

A numerical groundwater simulation model for the upper Klamath Basin has been developed to quantitatively evaluate the connection between groundwater pumping and groundwater discharge to surface water, and to assess the impact of pumping on groundwater levels. The model can be used to explore the response of the groundwater/surface water system to the combined effects of pumping and climate variability. When linked with techniques of optimization, the simulation model can identify groundwater management practices that meet the complex set of goals and constraints associated with groundwater use in the basin. First, the simulation-optimization groundwater management model is able to determine groundwater withdrawal patterns that support the spatially and temporally varying water demands for wildlife habitat. The groundwater management model evaluates groundwater/surface water interactions for streams and lakes throughout the basin, and

ensures that the impacts of managed pumping on surface water resources are within acceptable limits. Second, the groundwater management model evaluates the acute, seasonal, and long-term impacts of pumping on groundwater levels and designs groundwater pumping strategies to ensure that drawdown due to managed pumping does not exceed that allowed by Oregon water law. Third, the groundwater management model evaluates and compares alternative pumping strategies to identify those strategies that best support the water demands for irrigation. Fourth, the groundwater management model can evaluate the influence of the decadal-scale climate variability that is known to affect both groundwater discharge to streams and groundwater levels. The management model can identify the impact of climate variability on groundwater availability, including the necessity, timing, and extent of pumping restrictions during extended drought cycles.

The groundwater management model formulated for this study has an extensive set of constraints. These include constraints that limit the reduction in groundwater discharge to streams and lakes; control acute, seasonal, and long-term drawdown; limit the impact of pumping on irrigation drain flow; and impose geographic and seasonal demands on groundwater pumping. By applying techniques of sensitivity analysis to the groundwater management model, we have developed an array of optimal solutions for a broad and varied set of design considerations. Groundwater management alternatives for the basin will be described in terms of trade-offs among groundwater pumping decisions, constraints on the reduction of groundwater discharge to surface water, drawdown constraints, water demand constraints, and climate variability.