Appendix C: Ground-Water Pumping/Stream-Depletion Modeling

Numerical Modeling of Potential Stream-flow Depletion

The numerical model MODFLOW (McDonald and Harbaugh, 1988) is used to simulate the potential spatial and temporal effects on stream flows caused by pumping from proposed wells in the Smith River basin. Information on the geometry of aquifers in the Smith River basin is limited to general geologic maps (e.g. Groff, 1965) and few credible estimates of their hydraulic properties are available. Consequently, a simple single-layer model consisting of 1,178 active cells measuring 500 meters by 500 meters each is used (Figure C-1). The layer is designated as unconfined based on the interpretation that clay layers do not constitute continuous confining layers in the Smith River basin. Two zones of differing hydraulic conductivity are defined based on interpretations of well logs and relative well yields (Figure C-2). Hydraulic conductivities for each zone are estimated from limited pumping test results and typical values listed in textbooks, and ground-water flow boundaries are based on general geologic boundaries. The initial hydraulic gradient, and all sources of recharge and discharge to the model are set to zero following a method described by Johnson and Cosgrove (1999). The effect of pumping from each prospective well is modeled separately in transient and steady-state simulations using drains to represent river reaches and no-flow cells to represent bedrock boundaries. Well pumping rates are set to positive values to activate drain boundaries and streambed hydraulic conductivities are set to 10 percent of aquifer hydraulic conductivity.

Model Input Values:

Hydraulic Conductivity (K_1) = 100 feet/day
Hydraulic Conductivity (K_2) = 10 feet/day
Aquifer Thickness = 200 feet
Specific Yield (S_y) = 0.20
Drain Hydraulic Conductivity (K) = 10 feet/day
Drain Thickness = 3 feet
Drain Width = 30 feet

Drain flow rates for different stream reaches are divided by total pumping rates for each well to calculate response ratios. Response ratios are dimensionless values that are used to represent the relative amount of depletion from different stream reaches resulting from pumping for an infinite time period from wells that are hydraulically connected to surface water (Johnson and Cosgrove, 1999). Potential rates of depletion are calculated monthly for one hundred years of pumping in separate transient simulations. Pumping rates in transient simulations are set equal to the requested volumes of water for each application divided over a five-month long irrigation season during each year. Ranges of potential stream-depletion rates are calculated using ranges of model input to consider the effect of uncertain model input.

Several assumptions are made in designing ground-water flow models used to consider the potential for stream depletion from ground-water pumping in the Smith River basin. Most importantly, ground water and surface water in the Smith River basin are assumed to be hydraulically connected in a closed system where water pumped from wells eventually is offset by reduced inflow of ground water to streams or induced infiltration from streams to ground water. The potential for pumping to induce ground-water recharge from sources other than surface water, or to capture ground water consumed or otherwise lost to the system are not considered. Irrigation return flow and transpiration by riparian vegetation also are not considered in calculating potential stream-depletion rates. Last, model geometry, aquifer properties, and streambed properties input to ground-water flow models are estimated from sparse data or are based on professional judgment.

The values of aquifer properties input to the various models have varying effects on calculated potential rates of stream depletion. Tables C-1 and C-2 list the expected monthly peak rates of stream depletion and the residual rates of stream depletion prior to subsequent irrigation seasons for each proposed new well for different values of aquifer and streambed hydraulic conductivity, respectively. These values indicate the peak rate of stream depletion from all proposed new wells, taking into account uncertainty in the respective properties, is expected to be between 43 percent and 63 percent of the combined pumping rates.

Table C-1. Peak and residual potential stream depletion rates for proposed new wells in the Smith River basin for different values of aquifer hydraulic conductivity (K).

Application #	**Pumping Rate (cfs)**	**Potential Rate of Stream Depletion (cfs)**		
		K_1 = 25 feet/day K_2 = 5 feet/day	**K_1 = 100 feet/day K_2 = 10 feet/day**	**K_1 = 500 feet/day K_2 = 50 feet/day**
11366700-41J	**0.66**	**0.25 / 0.25**	**0.27 / 0.27**	**0.28 / 0.27**
11508000-41J	**1.14**	**0.54 / 0.38**	**0.81 / 0.19**	**0.97 / 0.10**
11510000-41J	**0.30**	**0.11 / 0.14**	**0.12 / 0.13**	**0.12 / 0.12**
11778600-41J	**1.58**	**0.68 / 0.62**	**0.89 / 0.41**	**1.20 / 0.21**
11779100-41J	**1.63**	**0.64 / 0.64**	**0.68 / 0.66**	**0.75 / 0.61**
30000211-41J	**0.69**	**0.37 / 0.21**	**0.45 / 0.14**	**0.56 / 0.07**
30001310-41J	**0.69**	**0.28 / 0.28**	**0.29 / 0.28**	**0.31 / 0.26**
Combined	**6.69**	**2.87 / 2.52**	**3.48 / 2.08**	**4.19 / 1.64**

Table C-2. Potential depletion rates for proposed new wells in the Smith River basin for different values of streambed hydraulic conductivity (K).

Application #	**Pumping Rate (cfs)**	**Peak / Residual Depletion Rates (cfs)**		
		***K = 2.5 ft/day**	**K = 10 feet/day**	**K = 25 feet/day**
11366700-41J	**0.66**	**0.27 / 0.27**	**0.27 / 0.27**	**0.27 / 0.27**
11508000-41J	**1.14**	**0.71 / 0.26**	**0.81 / 0.19**	**0.83 / 0.18**
11510000-41J	**0.30**	**0.12 / 0.12**	**0.12 / 0.13**	**0.12 / 0.12**
11778600-41J	**1.58**	**0.81 / 0.48**	**0.89 / 0.41**	**0.92 / 0.40**
11779100-41J	**1.63**	**0.68 / 0.66**	**0.68 / 0.66**	**0.68 / 0.66**
30000211-41J	**0.69**	**0.41 / 0.17**	**0.45 / 0.14**	**0.46 / 0.14**
30001310-41J	**0.69**	**0.29 / 0.28**	**0.29 / 0.28**	**0.29 / 0.28**
Combined	**6.69**	**3.29 / 2.24**	**3.48 / 2.08**	**3.57 / 2.05**

Analytical Modeling of Irrigation Return Flow Factors

Estimates of return flows used in the surface water flow model for the upper Smith River basin are calculated using an analogy to a parallel drain analytical solution (Glover, 1977). In this method, a river is assumed to lie in the center of a valley, equidistant between two no-flow boundaries representing valley margins. Monthly return flow factors are calculated from analytical equations using estimates of aquifer hydraulic conductivity, depth from stream to impermeable barrier, specific yield, and valley width.

Irrigation return-flow factors for the Smith River basin are calculated using estimates of aquifer properties and valley width based on information available from well driller's logs and a geologic map by Groff (1965). Hydraulic conductivity values used range from 50 feet/day to 250 feet/day and depths from stream to impermeable barrier range from 50 to 200 feet. Valley width is set equal to twice the width of a valley on one side of a stream where a stream is not located in the center of a valley. Values of irrigation return-flow factors used in the surface water flow model are a composite of the factors for individual sub-basins.

Suggested Hydrogeology Data Acquisitions for the Smith River Basin

The DNRC acknowledges that many aspects of the hydrologic system of the Smith River basin will remain unquantified until the time that a long-term, properly-budgeted hydrologic study is mandated. Major hydrologic parameters that require quantification include credible estimates of the mass water balance of the Smith River hydrologic system, aquifer properties, aquifer geometry, and diminishment of surface-water availability from ground-water development. Comprehensive computer modeling of the Smith River hydrologic system will not occur until detailed, pertinent data are collected to credibly complete such an effort.

Figure C-1. Modeled area with grid used for estimating potential stream depletion from proposed new wells in the Smith River Basin.

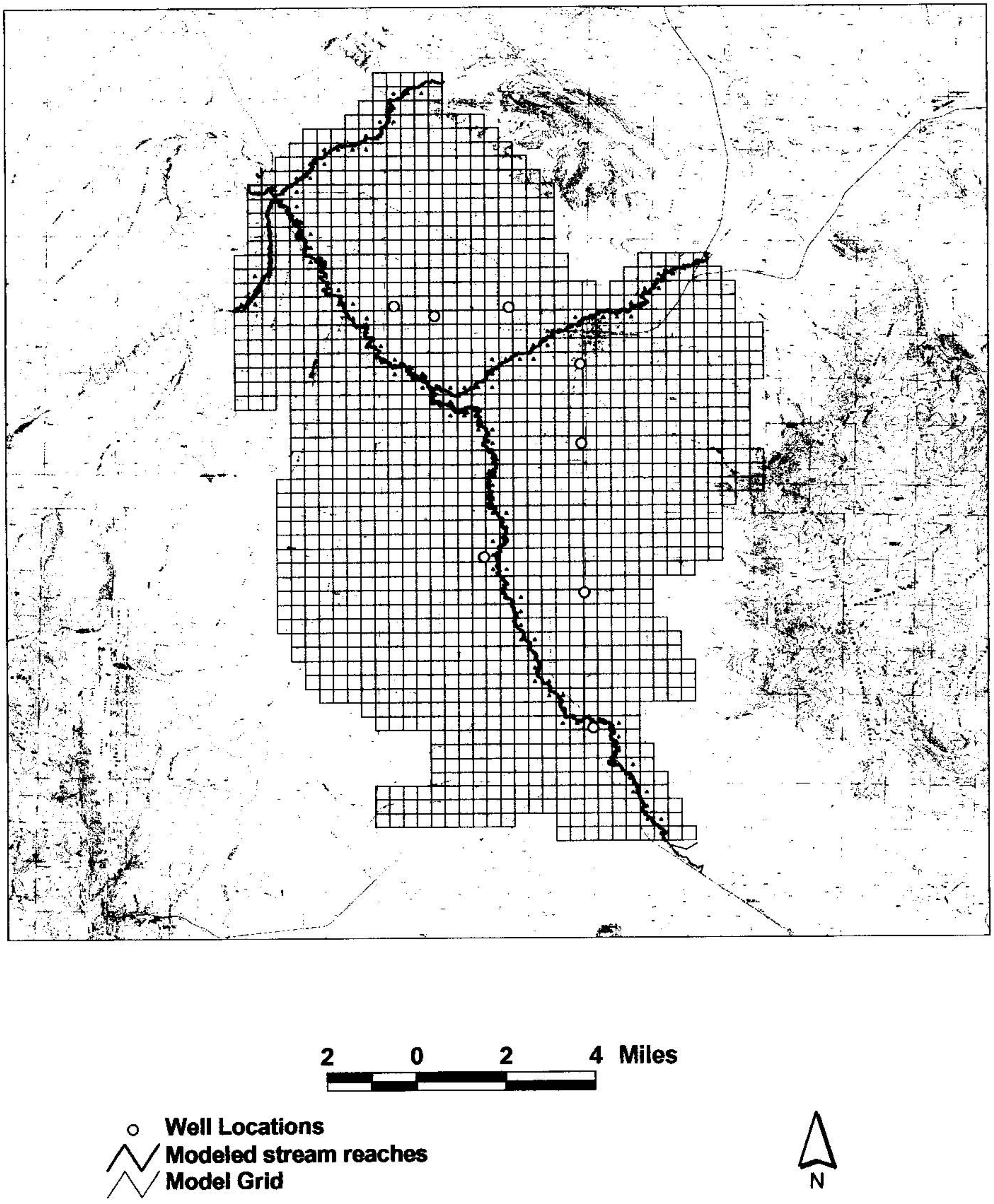

Figure C-2. Modeled area with hydraulic conductivity zones used for estimating potential stream depletion from proposed new wells in the Smith River Basin.