The 40-Year, 28-Percent Stream Depletion

Lines for the COHYST Area

West of Elm Creek, Nebraska

(August 2004 version)

COHYST Technical Committee

September 2004

COoperative HYdrology STudy

COHYST

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Introduction

In July, 2004, the Nebraska Department of Natural Resources, one of the Cooperative Hydrology Study (COHYST) Sponsors, asked the COHYST Technical Committee to determine the locations of lines depicting 40-year, 28 percent depletion to flow of the Platte River and its tributaries, for the area west of U.S. Highway 183 near Elm Creek, Nebraska. These depletions would be due to any new well pumping groundwater over a period of 40 years.

This document describes how the COHYST groundwater flow models were used to draw 40-year, 28-percent depletion lines. Key assumptions made for calculating the location of these lines are described. A map showing the location of the lines is included. The document also examines the effect of changes in model inputs and assumptions on calculated stream depletion at selected locations.

Stream depletion is defined as either direct capture of streamflow from the Platte River and its tributaries, or capture of groundwater by pumping that could become streamflow in the Platte River and its tributaries if such capture had not occurred. In either case, the result is a reduction in streamflow in the Platte basin. Stream depletion does not imply that a particle of water moves from the stream to the well. In fact, in the COHYST area, this is seldom the case.

Due to the methods used, the COHYST models could not differentiate which tributary or even which river basin would be depleted by a pumping well. In Gosper and Phelps Counties, depletions occurred to both the Platte and Republication Rivers and their tributaries. The COHYST models could not differentiate the basin in which these depletions occurred. More detailed methods will need to be developed so that only the depletions to the Platte River and its tributaries can be determined.

Procedures

The COHYST groundwater flow models are regional models than can be used to measure stream depletions from a single pumping well over a 40-year period. There are three overlapping models that cover the entire COHYST area. The models are similar in the area of overlap. These models incorporate the spatial heterogeneity of the aquifer to the extent that it can be mapped at a regional level. Although these models are still in the calibration process, the models used in this analysis are thought to reasonably represent the groundwater flow system.

The versions of the models used to draw the lines are indicated in the Assumptions section of this document. The models were used to calculate total stream depletion due to continuous pumping at many nodes within each model. A model was first run for a 40-year period using average May 1, 1995, through April 30, 1998, recharge and groundwater pumping conditions (base case). This simulation produced a volumetric water budget for the 40-year period, which included total streamflow as one component. The model was then run for the same 40-year period with the same conditions, but with the addition of a single new hypothetical well pumping at a constant rate (test case). This simulation also produced a volumetric water budget, which included total streamflow.

The difference between streamflow volumes for the base-case and test-case water budgets was used to determine the volume of streamflow depletion due to pumping groundwater from the hypothetical well. The volume of streamflow depletion, divided by the volume groundwater pumped from the hypothetical well over the 40-year period, represents the stream depletion volume as a percentage of the volume pumped for the model node where the hypothetical well was placed. Stream depletion due to the hypothetical well in this report is expressed as a percent of the volume pumped.

This process was then repeated with the hypothetical well placed at a different model node. All model nodes west of Elm Creek, Nebraska, in the vicinity of the 40-year, 28-percent lines were tested.

Because stream depletion at model nodes is generally not exactly 28 percent in 40 years, depletion values were interpolated to determine points of 28-percent stream depletion in 40 years. The interpolated points were connected using a smooth line.

Assumptions

The COHYST groundwater models were still under development at the time the August 2004 version of the stream depletion lines were needed, so the latest versions of the models were used to determine the location of the lines. The groundwater flow models that were used in July and August of 2004 to draw the 28-percent, 40-year lines is as follows:

> Eastern Model Unit – 1-mile grid, multi-layer, transient model with uniform ET CropSim pumpage[1]. This model is the June 29, 2004 version of the EMU model, and precedes conversion to the ½-mile grid model.
>
> Central Model Unit – 1-mile grid, single layer, transient model with NebGuide pumpage[2]. This model is the July 7, 2004, version of the CMU model and precedes conversion to the multi-layer model.
>
> Western Model Unit – 1-mile grid, single layer, transient model with uniform ET CropSim pumpage[1]. This model is the April 16, 2004, version of the WMU model and precedes conversion to the ½-mile grid model.

Historic estimates of pumpage and recharge from May 1, 1995, through April 30, 1998, were averaged and used to simulate pumpage and recharge through April 30, 2038. Three

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[1] Uniform ET CropSim pumpage refers to pumpage estimated using net irrigation demand based on the CropSim model (Dr. Martin, University of Nebraska) with daily potential ET averaged across the COHYST area.

[2] NebGuide pumpage refers to pumpage estimated using net irrigation demand based on table I in NebGuide G90-992-A (Evapotranspiration (ET) or Crop Water Use).

years (May 1995 – April 1998) were used to determine the average so that climatic conditions in a single anomalous year for an area would not overly influence the results. The formula used to compute the average was

$$(S95*153+W96*213+S96*153+W97*212+S97*153+W98*212)/1096$$

where S95 represents the average daily pumpage or recharge for the summer of 1995 (May 1 through September 30), W96 represents the average daily pumpage or recharge for the winter of 1996 (October 1, 1995, through April 30, 1996), and so on. There are 153 days in the summer, 212 or 213 days in the winter period, and 1096 days in the 3-year period.

The hypothetical well was simulated to withdraw water at a constant rate of 1 cubic foot per second (449 gallons per minute or 724 acre-feet per year). In some areas where the aquifer could not sustain that rate, the hypothetical well was simulated as an injection well. The constant pumping rate used for the hypothetical well is part of the definition of the 28-percent depletion line[3], and the effect of this definition will be discussed in the Sensitivity section. Likewise, the difference between withdrawal and injection will be discussed in the Sensitivity section.

The 40-year time period modeled to establish the stream depletion lines is May 1, 1998, through April 30, 2038, a total of 14,610 days, including leap days. Pumpage and recharge were held constant throughout this period. A single stress period was used and the time steps ranged from about 15 to 100 days, depending on the model unit.

The hypothetical well in the Eastern Model Unit was placed in the model layer that represents the dominant water-producing layer. This was generally COHYST Hydrostratigraphic Unit 2 (coarse alluvial deposits) or COHYST Hydrostratigraphic Unit 5 (coarse Ogallala deposits). The effect of this assumption is discussed in the Sensitivity section. The other two model units (CMU and WMU) are simulated as single-layer aquifers.

Shallow water table evapotranspiration (ET) was simulated where it was thought to occur. The estimated annual ET rate from groundwater was calculated as the difference between lake evaporation and precipitation multiplied by a factor based on U.S. Geological Survey ET studies (Matt Landon, personal commun., July 2004) along the Platte River near Gothenburg and Odessa, Nebraska. Annual ET from groundwater was estimated to be 14 inches west of central Morrill County and 13 inches east of central Morrill County through Dawson County. The ET rate was reduced to zero when the simulated water table declined to a certain extinction depth. This depth varied from 7 feet below land surface in riparian forest areas to 3 feet below land surface in shallow water table cropland areas. Simulations in each model unit indicated that ET reduction due to pumping the hypothetical well substantially mitigated stream depletions in some areas.

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[3] See page 9 of Missouri Basin States Association, 1982, Missouri River Basin Hydrology Study: Technical Paper, Ground Water Depletion, Omaha, Neb., 94 p.

Lines

The 40-year, 28-percent depletion lines west of U.S. Highway 183 are shown on Figure 1. The area within the lines includes all of the tributaries to the North Platte, South Platte, and Platte Rivers that were perennial in 1997, with the exception of some tributaries on the north side of the Platte River in Dawson County. The lines tend to encompass the tributaries because the hypothetical well tends to deplete the tributaries. The line is about 20 miles north of the North Platte River in Sioux County near the Stateline because of a long perennial tributary to the north in this area. The line on the north side of the North Platte River in Sioux, Scotts Bluff, and Morrill Counties follows a bedrock high where the aquifer is poor to non-existent. The line on the south side of the North Platte River in Garden County is close to the river because a bedrock high near the river restricts flow from the south to the river. The island of less than 28-percent depletion in 40 years north of the river in Garden County also is due to a bedrock high. The line swings far north of the North Platte River in Lincoln and McPherson Counties because the hypothetical well tends to deplete tributaries in this area. In Dawson and Buffalo Counties, the line on the north side of the Platte River is close to the river because ET reduction in this area reduces the amount of stream depletion that the hypothetical well causes. Pumpkin Creek in Morrill County and Lodgepole Creek in Deuel County had only short perennial reaches near their mouths in 1997, so the line does not extend very far upstream in the Pumpkin Creek and Lodgepole Creek valleys.

On the south side of the Platte River in Gosper and Phelps counties, the lines do not close because depletions to the Republican River tributaries dominate stream depletion before steam depletion to the Platte basin becomes less than 28 percent in 40 years. The location of the line that defines 40-year, 28-percent depletion to the Platte River in this area is indeterminate because the procedure used cannot separate depletion by basin.

The 40-year, 28-percent depletion lines have been misinterpreted by some people as meaning that a well beyond the line does not affect the river. That is not the case because a well beyond that line may still cause stream depletion, but the depletion is less than 28 percent in 40 years. Figure 2 shows two transects that illustrate stream depletion as a continuum, ranging from much more than 28 percent in 40 years near the river to much less than 28 percent far from the river.

Sensitivity

The sensitivity of calculated stream depletion to the above assumptions and model inputs was investigated at eight locations (Figure 3). The locations were selected to represent typical conditions within the area and areas with unusual local conditions were purposely avoided. The locations were selected to be in areas close to the 40-year, 28-percent stream depletion line.

Five cases of hypothetical well was pumping rate were tested at each location (Table 1). For the normal condition, the hypothetical well withdrawal rate was 1.0 cubic foot per second (449 gallons per minute). In case 1, the hypothetical well withdrawal rate was 0.1 cubic feet per second (45 gallons per minute). In case 2, the hypothetical well withdrawal

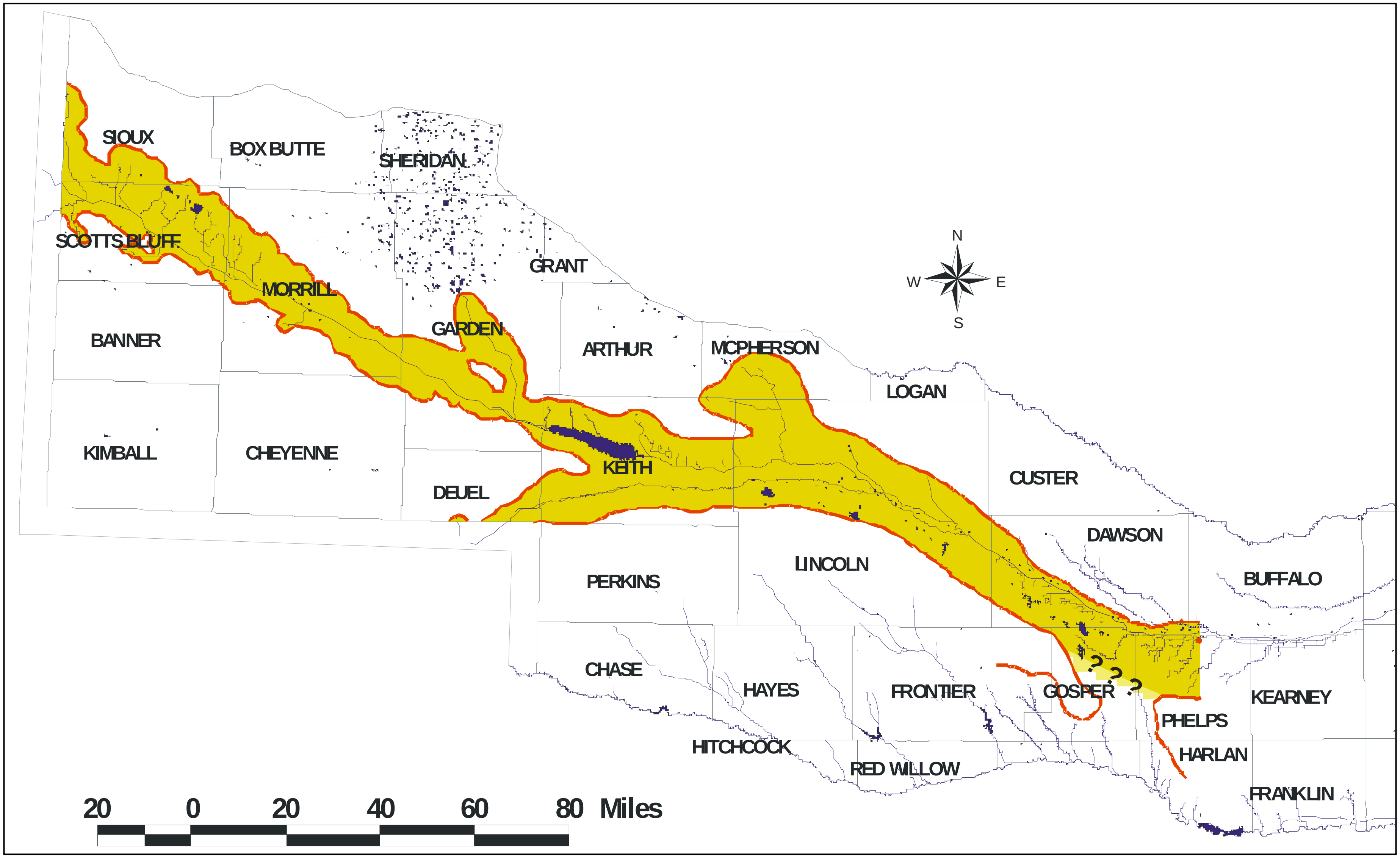

Figure 1. Lines of 40-year, 28-percent stream depletion in the Platte River basin west of Elm Creek, Nebraska.

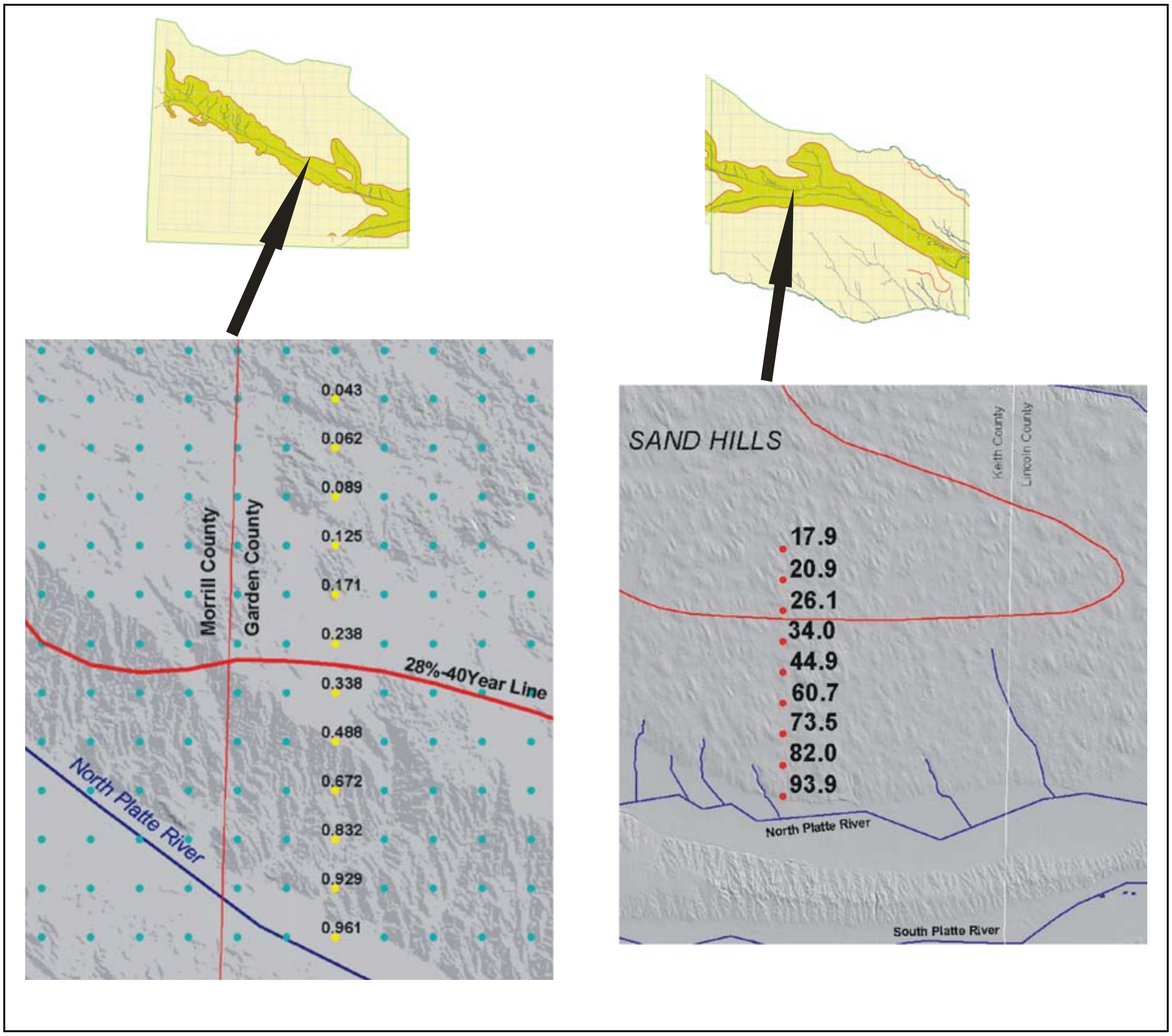

Figure 2. Stream depletion transects near Morrill-Garden County line and near Keith-Lincoln County line.

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rate was 10 cubic feet per second (4,490 gallons per minute). In case 3, the hypothetical well injected water into the aquifer at a rate of 1.0 cubic foot per second. In case 4, the hypothetical well was pumped for three months at 1.0 cubic foot per second and remained idle for the rest of the year. In case 5, the hypothetical well withdrew water from a minor model layer rather than the dominant model layer. This case required a multi-layer model and could only be tested in the Eastern Model Unit.

Four cases were tested relating to model parameters. Model parameters describe the physical condition of the aquifer. The range of parameter variation in each case represents the potential range of uncertainty in the average parameter value over a relatively large area. The ranges were based on a consensus of the modelers' experience as gained during the calibration process. Case 1 checked sensitivity of calculated stream depletion to variation in hydraulic conductivity, the parameter that describes how easily water is transmitted through the aquifer. Hydraulic conductivity was increased or decreased by 35 percent in case 1. Case 2 checked sensitivity of calculated stream depletion to variation in specific yield, the parameter that describes how much water is stored in a unit area of the aquifer. Specific yield was increased or decreased by 25 percent in case 2. Case 3 checked sensitivity of calculated stream depletion to variation in streambed conductance, the parameter that describes how easily water flows between the aquifer and a stream. Streambed conductance was increased or decreased by a factor of two in case 3. Case 4 checked sensitivity of calculated stream depletion to variation in anisotropy, the parameter that describes the ratio of horizontal to vertical hydraulic conductivity. This case required a multi-layer model and could only be tested in the Eastern Model Unit. Anisotropy was increased or decreased by a factor of five in case 4.

Four cases were tested relating to model stresses. Model stresses describe the exchange of water between the aquifer and the outside environment. As described in the Assumptions section of this document, model stresses were averaged over the period May 1, 1995, through April 30, 1998. The range of stress variation in each case represents the potential range of uncertainty in the average parameter value over a relatively large area. The ranges were based on a consensus of the modelers' experience as gained during the calibration process. Case 1 checked sensitivity of calculated stream depletion to variation in average May 1995 through April 1998 volume of groundwater pumped. The volume of groundwater pumped was increased or decreased by 20 percent in case 1. The volume of groundwater pumped from the hypothetical test well was not changed. Case 2 checked sensitivity of calculated stream depletion to variation in average May 1995 through April 1998 volume of recharge due to agricultural practices, excluding surface-water irrigation practices. Recharge due to agricultural practices was increased or decreased by 40 percent in case 2. Case 3 checked sensitivity of calculated stream depletion to variation in the average May 1995 through April 1998 volume of recharge from surface-water irrigation and power generation practices, including canal leakage and deep percolation of excess applied surface water. Recharge from surface-water practices was increased or decreased by 40 percent in case 3. Case 4 checked sensitivity of calculated stream depletion to variation in shallow water table ET by removing ET from the model. The assumed range of ET variation in case 4 is beyond the range of uncertainty of this stress, but was chosen because ET parameters were very poorly constrained during model calibration.

Values of stream depletion in Table 1 are presented to the nearest tenth of a percent; however, this does not mean that calculated stream depletion is accurate to the nearest tenth of a percent. Even beyond the uncertainty of the model inputs, the groundwater flow models have a certain amount of numerical error in them due to how the groundwater flow equations are formulated and solved. The numerical errors in the models cause errors in the simulated volumetric water budgets. Although the large differences between numbers in Table 1 represent real differences, some of the small differences may be more representative of numerical errors. Differences of less than 2 percentage points were not considered significant in the discussion below.

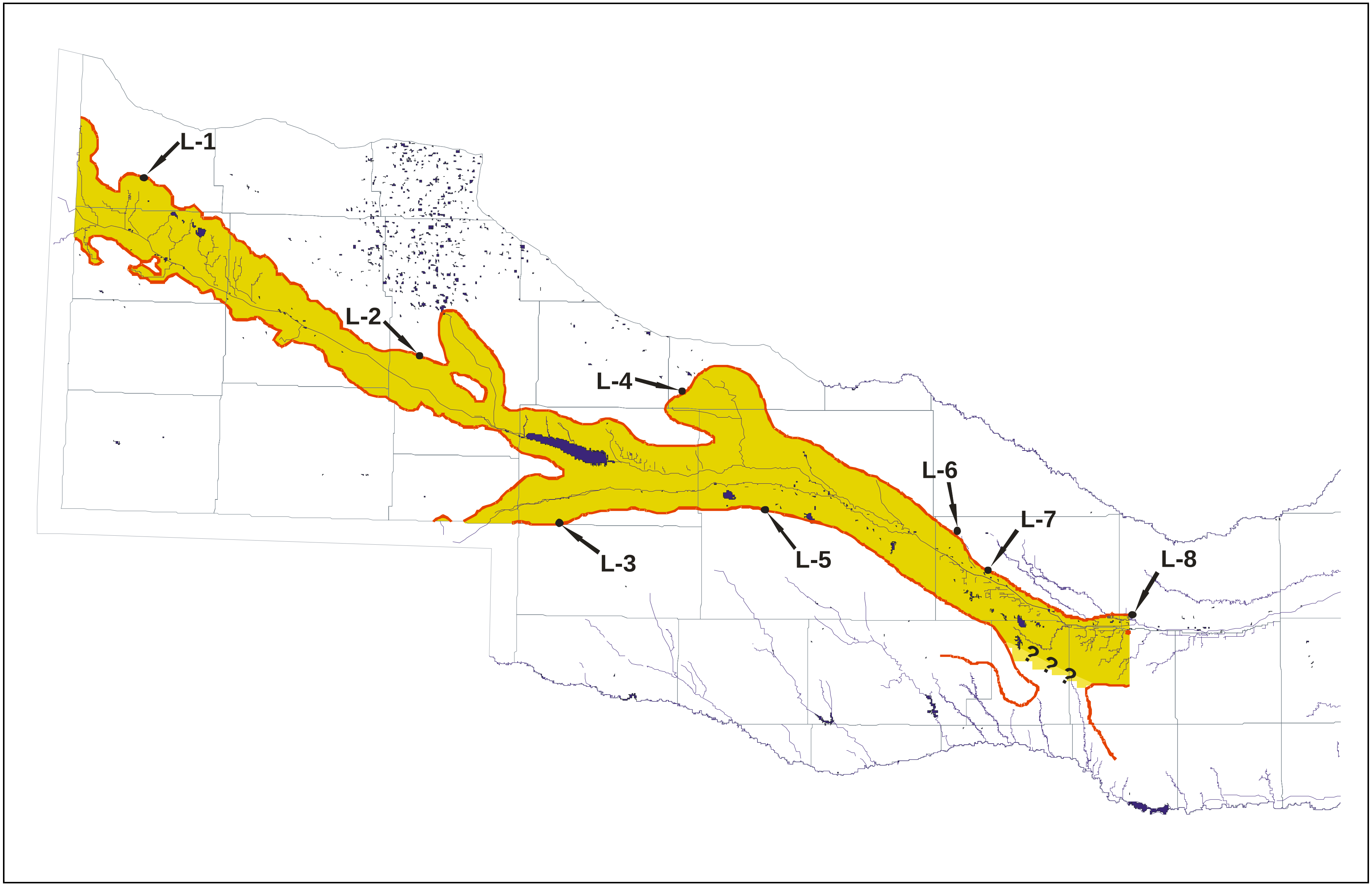

Figure 3. Locations used in sensitivity analyses.

Table 1. Results of sensitivity analyses.

[NA – Not applicable to single-layer model; Dry – Cell went dry during test, so stream depletion was not calculated.]

Description (down) or location (across)	Simulated Stream Depletion, in Percent							
	L-1	L-2	L-3	L-4	L-5	L-6	L-7	L-8
Normal conditions	**24.9**	**29.3**	**27.1**	**26.4**	**27.4**	**30.6**	**25.5**	**29.1**
Rate case 1 (rate decreased 10 times)	15.6	29.7	27.1	25.4	27.6	30.6	25.3	27.9
Rate case 2 (rate increased 10 times)	Dry	28.6	Dry	26.7	26.8	29.6	31.3	40.9
Rate case 3 (injection instead of withdrawal)	30.0	29.4	27.4	26.5	27.7	30.6	25.8	25.4
Rate case 4 (cyclical withdrawal)	22.6	29.9	28.3	27.5	28.9	31.0	28.9	28.2
Rate case 5 (pump from minor layer)	NA	NA	NA	NA	NA	30.6	NA	29.1
Parameter case 1A (increase hydraulic conductivity 35%)	36.3	36.2	32.7	29.3	33.5	26.8	30.3	35.7
Parameter case 1A (decrease hydraulic conductivity 35%)	16.7	19.4	20.1	22.6	20.0	23.3	19.3	21.3
Parameter case 2A (increase specific yield 25%)	19.2	24.0	22.6	21.9	22.9	27.5	25.3	27.9
Parameter case 2B (decrease specific yield 25%)	33.4	36.6	32.6	32.2	33.8	34.6	25.8	30.6
Parameter case 3A (Increase streambed conductance 2 times)	24.6	31.4	28.9	34.2	28.2	30.6	31.6	31.7
Parameter case 3B (decrease streambed conductance 2 times)	25.2	27.8	22.8	19.1	27.8	30.0	24.4	25.5
Parameter case 4A (increase anisotropy 5 times)	NA	NA	NA	NA	NA	30.6	NA	28.5
Parameter case 4B (decrease anisotropy 5 times)	NA	NA	NA	NA	NA	30.6	NA	29.4
Stress case 1A (increase pumpage 20%)	25.4	29.1	27.5	26.9	26.8	28.3	25.8	29.4
Stress case 1B (decrease pumpage 20%)	24.9	29.0	28.1	26.5	28.3	30.9	25.4	23.0
Stress case 2A (increase recharge from agricultural practices 40%)	25.0	29.3	28.5	27.3	29.1	31.0	26.0	21.1
Stress case 2B (decrease recharge from agricultural practices 40%)	26.1	29.2	27.3	26.0	26.1	15.2	30.0	32.3
Stress case 3A (increase recharge from surface-water practices 40%)	26.0	30.1	27.4	26.4	29.1	34.6	26.1	17.5
Stress case 3B (decrease recharge from surface-water practices 40%)	26.8	29.2	28.9	26.4	26.3	18.4	25.6	31.9
Stress case 4 (removal of shallow water table ET from the model)	25.2	32.4	30.1	26.4	28.1	36.9	78.5	64.6

Rate Cases 1 Through 5

Stream depletion was relatively insensitive to the rate at which the hypothetical well was pumped, except where the aquifer was thin or where ET was high. For example, location L-1 was on a bedrock high that exists on north side of the North Platte River. The hypothetical well altered the local hydrology by changing saturated thickness and thus stream depletion was sensitive to a pumping well at this location. Locations L-1 and L-3 were in areas where the saturated thickness was not sufficient to support continuous pumping at 10 cubic feet per second (4,490 gallons per minute) for 40 years; therefore pumping at these locations caused model cells to dewater and stream depletion was not calculated. Locations L-7 and L-8 were in areas of considerable ET and thus were somewhat sensitive to the pumping rate. At the large pumping rate (rate case 2), ET reduction became limited and the hypothetical well got more of its water from stream depletion. At the small pumping rate (rate case 1) and with injection (rate case 3), ET reduction was not limited. Stream depletion was also relatively insensitive to cyclical pumpage (rate case 4) except at locations L-1 and L-7. Stream depletion was insensitive to the model layer in which the hypothetical well was placed (rate case 5) at the two locations where this was tested.

Parameter Cases 1 Through 4

Stream depletion was sensitive to hydraulic conductivity (parameter case 1). This was not surprising because model parameters define the basic structure of the flow system, and it was the structure of the flow system that most dominantly controlled stream depletion. In general, as hydraulic conductivity increased, stream depletion also increased because water could more easily move through the flow system. Location L-6 was the exception to this, although the reason for this was not well understood. At location L-6, ET increased with increased hydraulic conductivity, so the hypothetical well could get more water from ET reduction and needed less water from stream depletion. Likewise, as hydraulic conductivity decreased, stream depletion also decreased because water had more difficulty moving through the flow system.

Stream depletion was also sensitive to specific yield (parameter case 2). As specific yield increased, stream depletion decreased because the hypothetical well could get more water from storage and did not need as much water from stream depletion. Conversely, as specific yield decreased, stream depletion increased because the hypothetical well could get less water from storage and needed more water from stream depletion.

Stream depletion was sensitive to streambed conductance (parameter case 3) at some locations evaluated and relatively insensitive to it at other locations. When the hypothetical well was at location L-4, stream depletion was particularly sensitive to streambed conductance because the value of this parameter limited streamflow gain to nearby Birdwood and West Birdwood Creeks. Pumping a hypothetical well at location L-1 was curious in that increasing streambed conductance decreased stream depletion and decreasing streambed conductance increased stream depletion. This was the opposite of what would normally be expected. However, location L-1 was in an area of little saturated thickness, and decreasing streambed conductance may have increased saturated thickness, increased flow through the area around the location, and increased stream depletion.

Anisotropy (parameter case 4) could only be tested for the Eastern Model Unit because the eastern model was the only multilayer model used in these analyses. Stream depletion was not sensitive to this parameter at the two locations tested. This was not surprising because of the 40-year time frame of the analyses and the distance of the locations from the Platte River. Stream depletion probably would be more sensitive to anisotropy for relatively short periods very near the river.

Stress Cases 1 Through 4

Stream depletion was generally insensitive to the average May 1995 through April 1998 volume of groundwater pumped (stress case 1). The only exceptions were for stress case 1A at location L-6 and stress case 1B at location L-8. At location L-6, increasing pumpage decreased ET, so less ET was available for ET reduction by the hypothetical well; therefore, the hypothetical well needed more water from stream depletion. At location L-8, decreasing pumpage increased ET, so more ET was available for ET reduction by the hypothetical well; therefore, the hypothetical well needed less water from stream depletion because reduced ET mitigated stream depletion. These areas also had large average May 1995 through April 1998 pumpage relative to other areas.

Stream depletion was sensitive to average May 1995 through April 1998 agricultural recharge (stress case 2) at locations L-6 and L-8, was somewhat sensitive at location L-7, and was insensitive at the remainder of the locations checked. In areas where stream depletion was sensitive to changes in agricultural recharge, both ET and average May 1995 through April 1998 agricultural recharge tended to be higher than in other areas. At locations L-7 and L-8, increasing average May 1995 through April 1998 agricultural recharge increased ET, so more ET was available for ET reduction by the hypothetical wells and the wells needed less water from stream depletion because reduced ET mitigated stream depletion. However, this does not explain the results at location L-6; these results were not understood.

Stream depletion was sensitive to average May 1995 through April 1998 recharge from surface-water practices (stress case 3) when the hypothetical well was at locations L-6 and L-8 and was insensitive when the hypothetical well was at the remainder of the locations studied. At locations L-6 and L-8, increasing average May 1995 through April 1998 recharge from surface-water practices increased ET, so more ET was available for ET reduction by the hypothetical wells and the wells needed less water from stream depletion because reduced ET mitigated stream depletion.

Stream depletion was very sensitive to the removal of shallow water table ET (stress case 4) when the hypothetical well was at locations L-7 and L-8, and was somewhat sensitive when the hypothetical well was at locations L-2, L-3, and L-6. Areas around locations L-6, L-7, and L-8 had a large amount of ET relative to much of the COHYST area and ET reduction was an important source of water to the hypothetical well. As a result, the hypothetical well needed to get less water from stream depletion.