# APPENDIX 19

## Models of Potential Impacts to Groundwater

# Models of Potential Impacts to Groundwater

## Prediction of Drawdown

Drawdown impacts in the Wasatch Formation aquifer in the PAPA due to drilling water extractions are modeled for a relatively dense drilling pattern, using very conservative assumptions about aquifer parameters. There is little hydraulic information available for the Wasatch Formation in the PAPA, and drilling locations, extraction rates and such variables are not closely specified, but some bounds may be placed on the extent and amount of drawdown using a semi-analytical method. This consists of developing a theoretical drawdown cone for a single pumping well, summing a number of cones in a section, and sketching the drawdown about a cluster of contiguous sections with active drilling at one time. The particular array of drilling rigs (or water supply usage) is based on a concentrated group of drilling rigs and serves as a representation of a possible concentration of groundwater use.

Sandstones of the Wasatch Formation were laid down by meandering rivers, and represent channel and oxbow fill deposits with some overbank flood sheets. These features are typically narrower than drill hole spacing, and cannot be individually correlated between holes, so that a geological model is statistical rather than precise. This assumes an extensive, uniform aquifer with average hydraulic properties is the most practical approach to predicting drawdown responses to groundwater extractions from the Wasatch Formation, until such times as more intensive data is available and a there is a need for greater local precision. This model may be simplistic but any more sophisticated model would have to be supported by additional data, real or assumed.

The drawdown cone in time for a single Wasatch Formation pumping well (half of it, in cross-section) is shown in Figure 1, with assumed hydraulic parameters noted on the plot. Each curve shows the drawdown in head after steady pumping for a certain time. The basis for the cone is the Theis equation for drawdown at time t and distance r due to pumping an extensive, approximately homogeneous aquifer with transmissivity T and storage coefficient S. The equation would be mathematically exact if the assumptions held. The Wasatch Formation is believed to have T between 300 and 2,000 sq.feet/day, and storage coefficient (“storativity”) is likely to be between 0.001 and 0.0001. Figure 1 is based on T = 300 and S = 0.001. Pumping rate is taken to be the higher Proponent estimates of usage, as if steady, namely 10 gallons per minute.

At a radius of 2,000 feet (almost half a section width) from a model pumping well, the drawdown (T = 300, S = 0.001) is about 2 feet after a year of pumping at 10 gpm, and about 3 feet in 5 years. Adding the effects of more wells scattered in a section multiplies these values by the number of wells; for instance, five wells close together would give an average of 10 feet drawdown at the section boundaries after 1 year, and 15 feet in 5 years; spreading the wells apart spreads the drawdown (flatter and wider cone). Moving the pumping points with gas drilling (that is, pumping new water supply wells at each new well pad) gives periods of respite in which water levels recover somewhat, but if the moves are short in time and distance the averaging approach is approximately valid for a cluster of active sections.

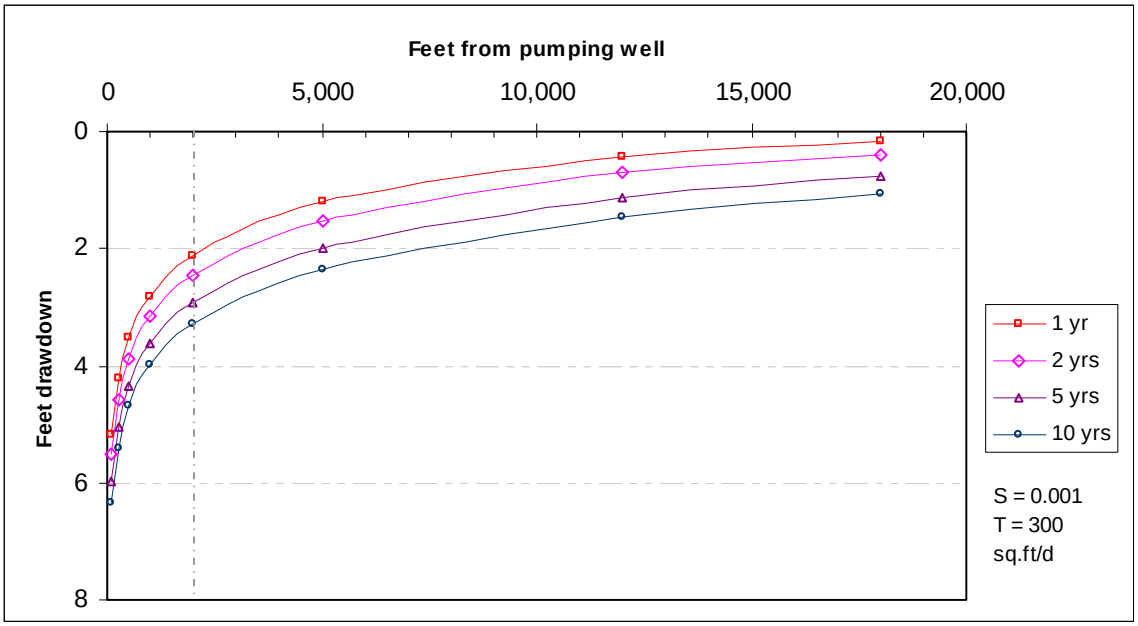


**Figure 1 Analytical model of drawdown in the Wasatch due to pumping a single well**

As an example, a cluster of actively drilling gas pads in one earlier scenario had the number of drilling rigs active by section (~ square mile) as:

| | | | |
|---|---|---|---|
| 4 | 6 | 3 | 2 |
| | | 1 | 1 |

If each of these natural gas rigs steadily used Wasatch Formation groundwater from supply wells located in the same section at 10 gpm per natural gas rig, and stayed within these sections for 5 years, the average drawdown at that time at the section perimeters (in feet), due to just the pumping within the particular section, would be:

| | | | |
|---|---|---|---|
| 12 | 18 | 9 | 6 |
| | | 3 | 3 |

Drawdown at any point can be estimated by summing all the contributions of each pumping well. For instance, the drawdown in the lower left section (0 wells pumping) equals the impacts of pumping of four wells at 1 mile (upper left), six wells at 1.4 miles, three wells at 2.2 miles, 8 wells at 3.2 miles, 4 wells at 2 miles, and 4 wells at 3 miles. Adding all the components of drawdown in each section due to pumping in that section *plus* all the effects of the other wells gives a matrix as below (the six sections with active pumping are outlined in the middle).

| | | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 2 | 2 | 3 | 3 | 4 | 5 | 5 | 5 | 5 | 5 | 4 | 4 | 3 | 2 | 2 | 1 |
| 2 | 3 | 3 | 4 | 5 | 6 | 7 | 7 | 7 | 7 | 6 | 5 | 4 | 3 | 2 | 2 |
| 2 | 3 | 4 | 6 | 7 | 8 | 9 | 10 | 10 | 9 | 8 | 7 | 5 | 4 | 3 | 2 |
| 3 | 4 | 5 | 7 | 9 | 11 | 13 | 14 | 14 | 13 | 11 | 8 | 6 | 5 | 4 | 3 |
| 3 | 4 | 6 | 8 | 11 | 14 | 18 | 19 | 19 | 17 | 14 | 10 | 8 | 6 | 4 | 3 |
| 3 | 5 | 7 | 9 | 13 | 18 | 24 | 27 | 26 | 28 | 17 | 12 | 9 | 6 | 4 | 3 |
| 4 | 5 | 7 | 10 | 14 | 20 | 41 | 52 | 40 | 24 | 17 | 12 | 9 | 6 | 4 | 3 |
| 3 | 5 | 7 | 9 | 13 | 18 | 24 | 28 | 30 | 25 | 16 | 12 | 8 | 6 | 4 | 3 |
| 3 | 4 | 6 | 8 | 11 | 15 | 18 | 20 | 19 | 17 | 13 | 10 | 8 | 6 | 4 | 3 |
| 3 | 4 | 5 | 7 | 9 | 11 | 13 | 14 | 14 | 13 | 11 | 8 | 6 | 5 | 4 | 3 |
| 2 | 3 | 4 | 6 | 7 | 8 | 10 | 10 | 10 | 9 | 8 | 7 | 5 | 4 | 3 | 2 |
| 2 | 3 | 3 | 4 | 5 | 6 | 7 | 7 | 7 | 7 | 6 | 5 | 4 | 3 | 2 | 2 |
| 2 | 2 | 3 | 3 | 4 | 5 | 5 | 5 | 5 | 5 | 4 | 4 | 3 | 2 | 2 | 1 |
| 1 | 2 | 2 | 2 | 3 | 3 | 4 | 4 | 4 | 3 | 3 | 3 | 2 | 2 | 1 | 1 |

**Figure 2 Drawdown in Wasatch Formation aquifer after 5 years pumping with 17 natural gas rigs in eight central sections (T 300 sq.feet/d, S 0.001)**
**Value in square (1-mile section) is the average drawdown (feet) over the section**

The sensitivity of the model to the hydraulic assumptions can be gauged by comparing drawdown cone profiles at different times with ranges of T and S parameters. In Figure 3, profiles are shown for transmissivity 300 and 1,500 sq.feet/day, and storativity 0.001 and 0.0001. Note the drawdown cones in Figure 3 for T 300, S 0.001, which are the basis of the Figure 2 model, are approximately in the middle of the range indicated for the possible parameter values. That is, the Figure 2 model drawdown is about what might be actually expected given reasonable parameter assumptions.

The Fort Union and Wasatch Formation strata are said to achieve a local maximum thickness in the PAPA area (Glover et al., 1996), and to be near 7,000 feet. No estimate of local sand percentages or transmissivities in the Wasatch Formation are available, but a 1,000 feet thickness of sands with hydraulic conductivity 0.3 feet/day would give the 300 sq.feet/day transmissivity assumed in Figure 2. If the Wasatch Formation sands were in fact thicker, coarser grained and more permeable, then transmissivity would be higher and the aquifer would yield more water with less drawdown.

It should be emphasized that this model represents an ideal, extensively continuous aquifer, which the Wasatch Formation aquifer is not. Because sand lenses in the Wasatch Formation are variably linked, sinuous channel deposits, the modeled drawdown is unlikely to be valid more than a mile from a pumped well or cluster of wells (it may be more and it may be less).

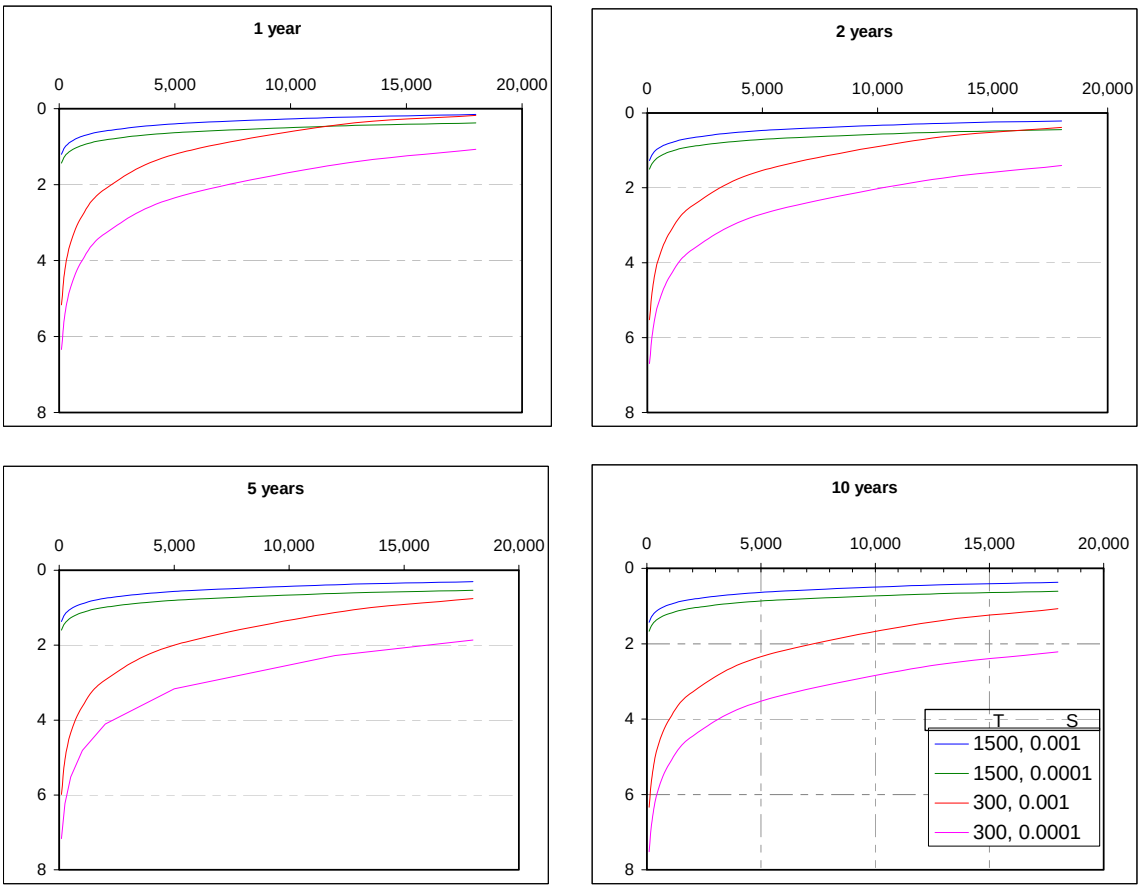


**Figure 3 Comparison of drawdown at 1, 2, 5 and 10 years for range of transmissivity, storativity**
**(as in Figure 1, drawdown is in feet on left axis, and distance from well on the top axis)**

This model assumes zero recharge during the period of pumping. If 1 percent of assumed surface infiltration (that is, 0.001 feet/yr) passes through the alluvial cover and reaches the Wasatch Formation, this would yield about 5 acre-feet/yr per section, or 10 bbl/day. This would shrink the drawdown surface in Figure 2 inward, so that the 10-foot contour would be 2 rather than 3 miles from the cluster.

Based on this analysis of potential drawdown impacts:

- up to 3 feet of drawdown may be observed within a distance of a mile of a single water supply well that has been steadily active for 5 years;
- Up to 30 feet drawdown may be observed within a mile of a dense cluster of active gas drilling pads (here, 17 wells in six sections). Greater drawdown may occur within dense pumping well clusters;
- Measurable drawdown (more than 2 feet) around a dense cluster of drilling activity and groundwater extraction could extend approximately 6 miles from the perimeter of the cluster after 5 years of pumping (though the spread of drawdown is limited by imperfect connection between sand lenses);
- Drawdown continues to deepen and spread as long as pumping continues in one place, but pumping points will follow drilling rig movement, and water level recovery begins immediately pumping desists;
- Recovery is expected to be rapid overall, although there will be variability where aquifer sandstones are locally poorly connected. Leakage from shale aquitards

(a completely unknown potential) would hasten recovery. In the analytical model (without leakage), drawdown doubles from 1 to 5 years in active pumping; if pumping ceases at 5 years, recovery is similarly half complete 1 year later, and ¾ complete 5 years after ceasing pumping.

It is emphasized that these predictions of drawdown assume no vertical recharge, and even very small infiltration would substantially reduce these impacts and the recovery time.

Drilling out production zones with produced water reduces the demands on Wasatch Formation water as much as 15 percent overall, which has not been taken into account in this model. The drawdown is a linear function of pumping withdrawals, so that a drawdown predicted at any location with re-use would be potentially 85 percent of that without re-use.

The total water use for drilling by all of the Operators is a small percentage of the water stored in the Wasatch Formation aquifer just beneath the PAPA. Annual usage by Operators is on the order of 100 acre-feet; Wasatch Formation aquifer storage must be in excess of 10,000 acre-feet under the PAPA (200,000 acre area, S > 0.0001, and initial head > 500 feet above base of aquifer makes storage >10,000 acre-feet).

A better model of probable hydrologic consequences in the Wasatch Formation aquifer might be constructed in the future, when the formation and its hydraulic properties are better known. BLM may acquire such data in the form of well logs, pumping tests, or overall drawdown observations. BLM will develop the monitoring plan to include acquisition of such data both for purposes of detection and mitigation of potential impacts and for a groundwater model basis. A refined model could allow more accurate prediction of aquifer responses over the life of the project, and assist determination of any necessary mitigation measures through an Adaptive Management approach supporting the SEIS record of decision (ROD) and regulatory constraints.

**Reference**

Glover, K., D. Naftz, and L. Martin. 1998. Geohydrology of Tertiary Rocks in the Upper Colorado River Basin in Colorado, Utah, and Wyoming Excluding the San Juan Basin. Water-Resources Investigations Report 96-4105.