Stream Depletion Due to Irrigation Wells along Bates Creek, Natrona County

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A finite-difference ground water flow model of the Bates Creek alluvial aquifer by Glover (1983) showed how stream flow responds to different irrigation pumping scenarios (e.g., pumpage of 1,983 or 3,481 acre-feet per year). The current analysis was undertaken to illustrate the relative impacts of existing (2006) irrigation wells on flow in Bates Creek.

Minimal hydrologic data is available for the Bates Creek alluvial aquifer. Glover (1983) estimated hydraulic conductivity (K) from lithologic information and obtained a range of 190 to 900 ft/day. Transmissivity (T) is the hydraulic conductivity multiplied by the saturated thickness. For saturated thicknesses of 9 to 80 feet, transmissivities range from 1,710 to 15,200 ft^2/d (13,000 to 113,700 gal/d-ft) for K=190 ft/d and from 8,100 to 72,000 ft^2/d (60,600 to 539,000 gal/d-ft) for K=900 ft/d. Glover (1983) assumed a specific yield (S_y) of .23 by analogy with the North Platte valley-fill aquifer (Crist, 1975). For a stream bed thickness of 1 foot, stream bed hydraulic conductivity was estimated as 1.65×10^{-5} ft/s and 2.43×10^{-5} ft/s at two locations (2×10^{-5} ft/s was used in the model). Calibration of the flow model to observed water levels resulted in the assignment of modified hydraulic conductivities for each grid square in the model (with minimum dimensions of 750 feet). These modified values are not known. Calibration was not sensitive to specific yield in the range .20 to .25.

Due to the limited amount and unreliable nature of the hydrologic data, only the simplest analytic model is used here to estimate relative well impacts. To calculate the amount of stream depletion due to a pumping well, the Glover-Balmer model (Glover and Balmer, 1954; Jenkins, 1968) requires transmissivity (T), specific yield (S_y), the distance from the well to the stream (L), the duration of pumping (t), and the discharge of the pumping well (Q). As reported here, the stream depletion (q_s) is the stream flow that is captured from the stream and discharged by the well. Transmissivities were calculated by multiplying the reported saturated thicknesses (well depth or bottom of perforations minus the depth to static water level) by 190 ft/d, specific yield was assumed to be .24, and distances were measured on 1:24,000 topographic maps.

The following assumptions were made in order to derive the Glover-Balmer equation mathematically:
1. The aquifer is semi-infinite, homogeneous, and isotropic.
2. The potentiometric surface is initially horizontal.
3. Flow in the aquifer is horizontal and drawdown is negligible compared to the saturated thickness (Dupuit approximation).
4. The pumping well is open to the entire thickness of the aquifer.
5. The pumping rate is steady and water is released instantaneously from storage.
6. Water pumped from the well comes only from storage in the aquifer and from the stream; as pumping time approaches infinity all the well discharge comes from the stream.
7. The temperature of the water in the stream and aquifer are the same and are constant.
8. Stream stage remains constant.
9. The aquifer is bounded on one side by an infinitely long, straight stream which cuts through the entire thickness of the aquifer; the stream bed coincides with the confining bed at the bottom of the aquifer and water flows between stream and aquifer through the stream bank.

Some of these assumptions are clearly unrealistic. Comparisons of the Glover-Balmer model with more appropriate models show that the Glover-Balmer equation tends to overestimate stream depletions. This tendency is partly compensated by using the lowest reasonable hydraulic conductivity in the calculations here. Although the results presented here are probably not very accurate, the general magnitude of the calculated stream depletions is probably correct and the relative stream depletions are probably reliable.

Three ways to compare the impacts of pumping wells on flows in Bates Creek are presented here: how long it takes the well's cone of depression to reach the creek, instantaneous rate of stream depletion after a given duration of pumping, and volumetric stream depletion after a given duration of pumping. The durations of pumping necessary to cause a .25 ft drawdown at Bates Creek are listed in Table1. Because the Theis equation does not account for vertical flow in the aquifer, pumping durations short enough to be affected by delayed yield effects could be inaccurate. This appears to be the case for well 28878, for which a pumping duration of 20 seconds (.0002 day) would be sufficient to cause more than .25 ft of drawdown at the creek based on the Neuman equation. In either case, well 28878 has the most rapid impact on Bates Creek.

Table 1. Duration of Pumping to Cause .25 ft Drawdown at Closest Point of Bates Creek, Based on Theis Equation with Transmissivity Calculated for Hydraulic Conductivity of 190 ft/day

Well	Discharge (gal/min)	Saturated Thickness (ft)	Duration of Pumping (d)	Transmissivity (ft^2/d)	Specific Yield	Distance to Stream (ft)
26060	950	80	1.8	15,200	0.24	640
28878^	925	50	0.22#	9,500	0.24	200
36222	875	76	0.75	14,440	0.24	400
38042	1100	81	12	15,390	0.24	1,740
38043	650	94	31	17,860	0.24	2,360
38044	1300	73	4.1	13,870	0.24	1,040
10363	55	9	145*	1,710	0.24	1,500
10364	1200	63	22	11,970	0.24	2,280
10365	1550	56	23	10,640	0.24	2,400
111933	650	50	75	9,500	0.24	3,360
111934	1550	67	33	12,730	0.24	3,000
402G	700	51	60	9,690	0.24	3,100
89273	150	67	160	12,730	0.24	2,360
95131	52	62	1100	11,780	0.24	1,800
9775	1175	64	43	12,160	0.24	3,160
111471	500	50	23	9,500	0.24	1,700
111472	425	45	35	8,550	0.24	1,960
62305	375	17	42*	3,230	0.24	1,700
104250	700	12	will capture North Platte before affecting Bates Cr.			7,240
104492	300	48	will capture North Platte before affecting Bates Cr.			4,140
27606	950	47	will capture North Platte before affecting Bates Cr.			4,360

*Well cannot pump for the duration indicated as drawdown in the well would exceed the saturated thickness.
#Delayed yield effect is significant; Theis equation probably overestimates duration.
^Effects of well 28878 are calculated for Corral Creek, not Bates Creek.

Wells 104250, 104492, and 27606 are not considered in subsequent analyses because their impacts on the North Platte River would invalidate the calculated effects on Bates Creek. Results for wells 62305, 111471, and 111472 are similarly suspect but they are included in the following tables because these wells could impact Bates Creek before impacting the North Platte and could have significant effects in addition to depletions of the North Platte. Calculated Bates Creek depletions for these wells are almost certainly overestimates.

The instantaneous stream depletion is the amount of water, expressed as a flow rate, produced from the well that would otherwise have flowed down the stream. This includes both water flowing from the stream to the well and water flowing to the well from elsewhere in the alluvial aquifer that would otherwise have flowed to the stream. Instantaneous stream depletions using the Glover-Balmer model have been calculated for hydraulic conductivities of 190 and 900 ft/d and for a constant transmissivity of 16,000 ft^2/d, which falls between the transmissivity ranges for the constant conductivities.

Table 2. Instantaneous Stream Depletion from Bates Creek after 10 Days of Pumping, for Specific Yield of .24 and Various Transmissivities

		For K = 190 ft/d		**For K = 900 ft/d**		**For constant T**	
Well	**Discharge (gal/min)**	**T (ft^2/d)**	**Stream Depletion (gal/min)**	**T (ft^2/d)**	**Stream Depletion (gal/min)**	**T (ft^2/d)**	**Stream Depletion (gal/min)**
28878	925	9,500	760	45,000	849	16,000	798
36222	875	14,440	626	68,400	759	16,000	638
26060	950	15,200	541	72,000	754	16,000	550
38044	1,300	13,870	433	65,700	854	16,000	478
38042	1,100	15,390	137	72,900	528	16,000	145
38043	650	17,860	34	84,600	243	16,000	27
111471	500	9,500	28	45,000	190	16,000	70
10364	1,200	11,970	27	56,700	353	16,000	58
10365	1,550	10,640	17	50,400	374	16,000	58
111472	425	8,550	9	40,500	122	16,000	38
111934	1,550	12,730	6	60,300	280	16,000	15
95131	52	11,780	4	55,800	21	16,000	6
89273	150	12,730	3	60,300	44	16,000	6
9775	1,175	12,160	2	57,600	175	16,000	7
62305	375	3,230	0.4	15,300	50	16,000	53
402G	700	9,690	0.4	45,900	79	16,000	5
111933	650	9,500	0.1	45,000	54	16,000	2
10363	55	1,710	0.004	8,100	4	16,000	11
	Total Stream Depletion:		**5.9 cfs**		**12.8 cfs**		**6.6 cfs**

Table 2 is sorted from highest to lowest stream depletion for K = 190 ft/d. Changes in calculated stream depletion are relatively minor for the wells at the top of the list but can be large for other wells. Wells in the lower part of the list are farther from Bates Creek so it takes longer for the effects of pumping to impact the creek. Raising the transmissivity speeds up the effects, particularly for high-discharge wells like 9775. The delay of stream depletion with distance is illustrated in Figure 1. This can also be seen in Figures 2 through 4, which show the changes in instantaneous depletion for each well during and after 10 days of pumping.

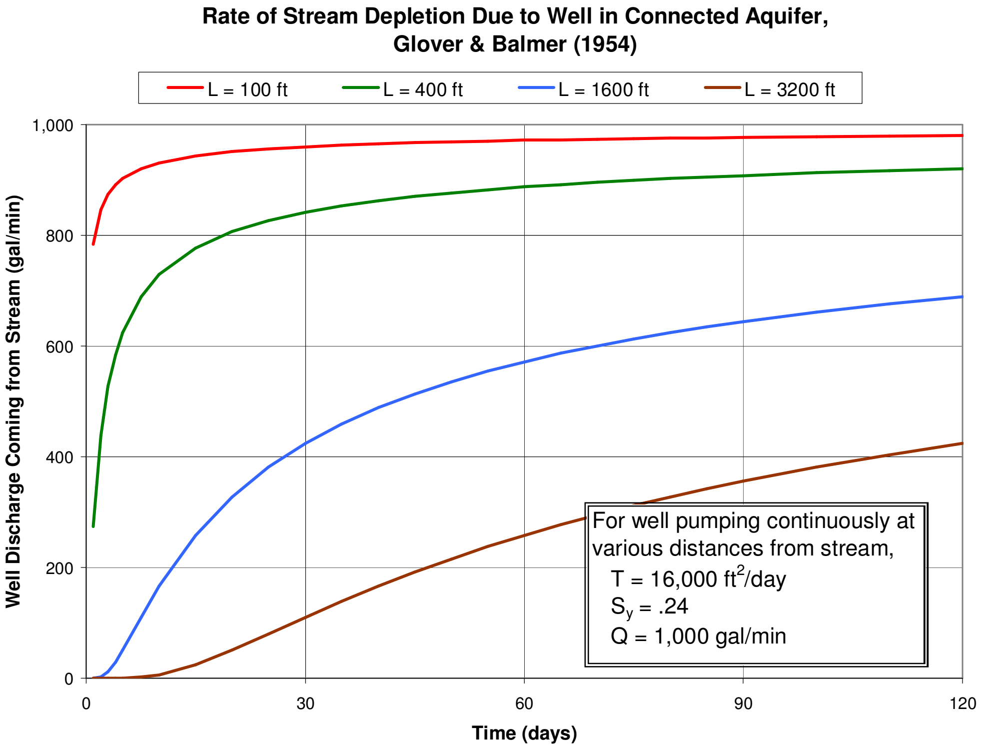

Figure 1. Instantaneous Stream Depletion with Continuous Pumping of Wells at Four Different Distances from a Stream

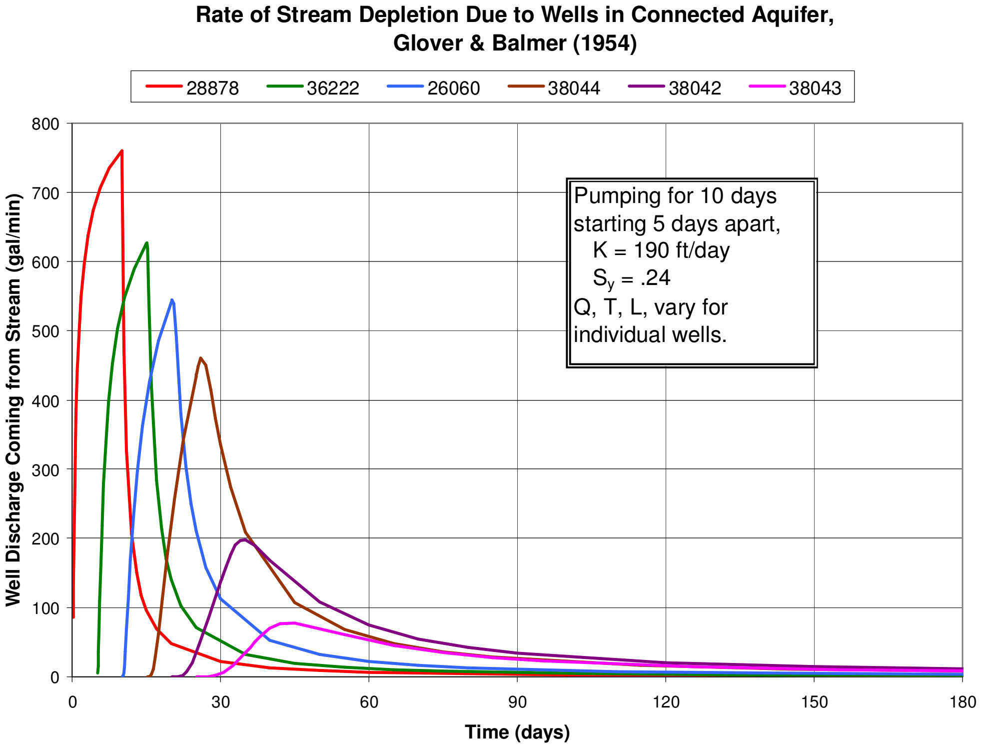

Figure 2. Instantaneous Stream Depletion for Relatively High-Impact Wells on Bates Creek

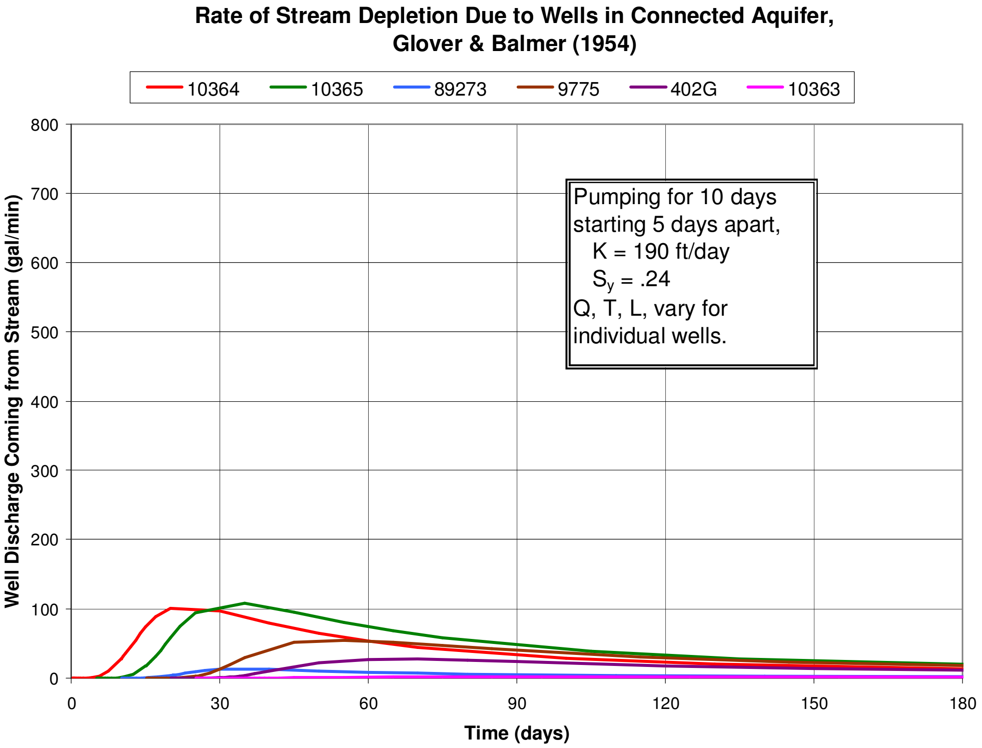

Figure 3. Instantaneous Stream Depletion for Relatively Moderate-Impact Wells on Bates Creek

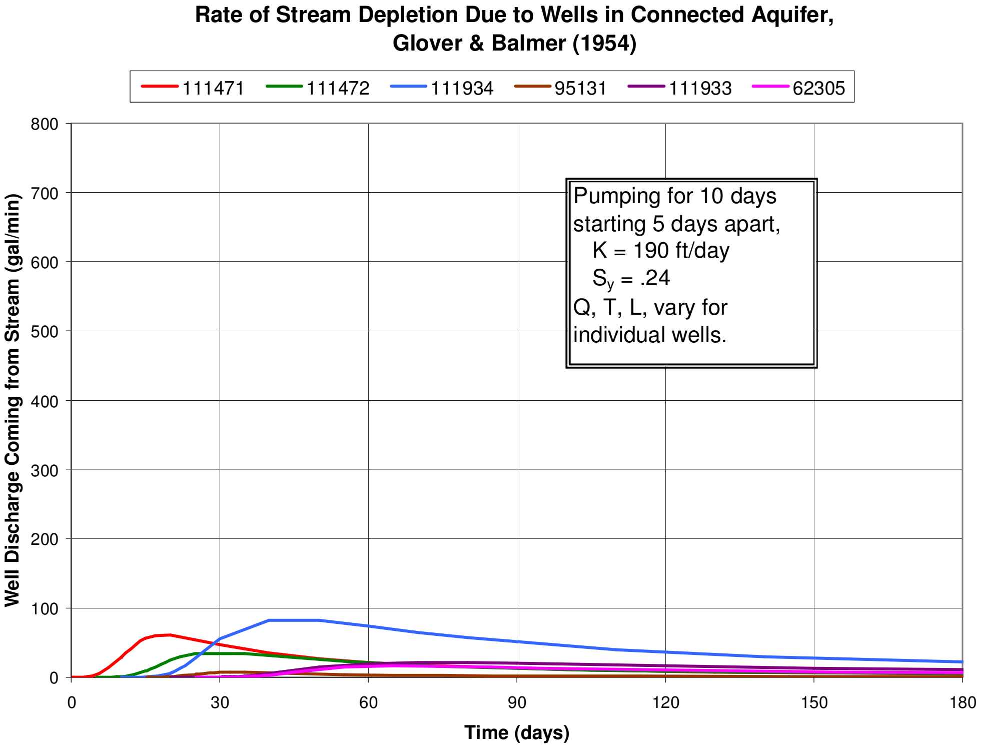

Figure 4. Instantaneous Stream Depletion for Relatively Low-Impact Wells on Bates Creek

The cumulative impact of many wells can be substantial and persist well after pumping stops even if the maximum stream depletion of any one well is only a small fraction of total stream flow. As shown in Figure 5, the total stream depletion due to the ten highest impact wells along Bates Creek is still about 300 gal/min (0.67 ft^3/s) at 60 days, or 50 days after pumping stopped.

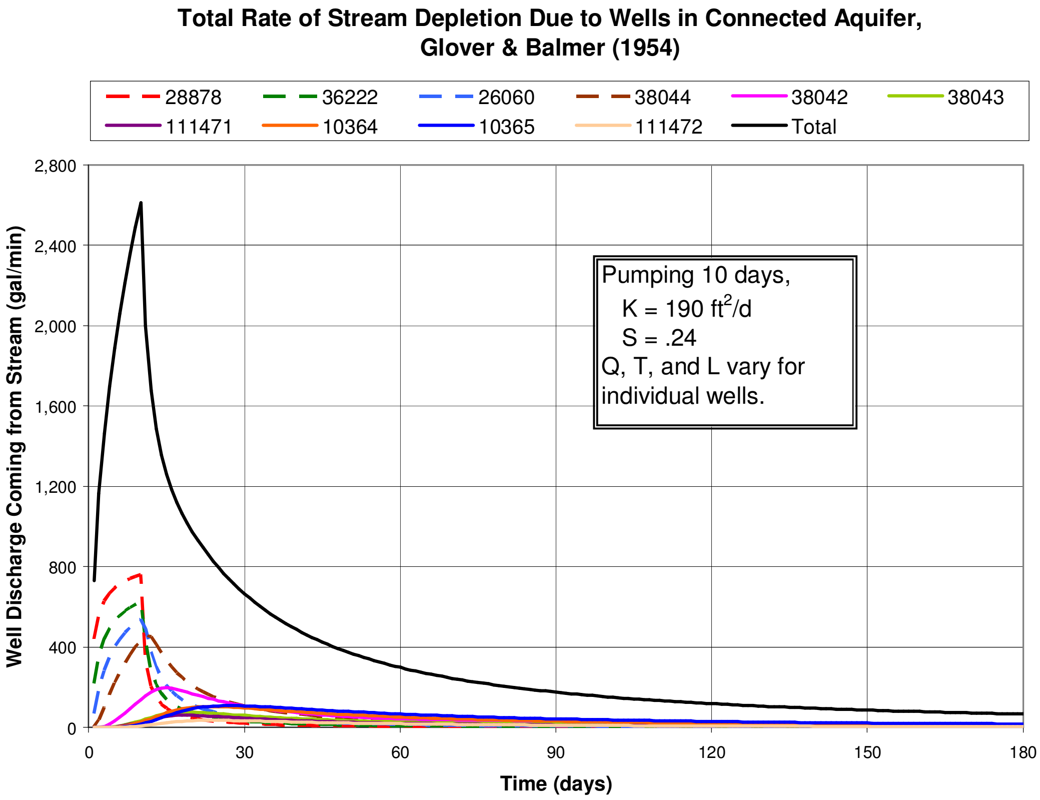

Figure 5. Total Instantaneous Stream Depletion Due to 10 Irrigation Wells along Bates Creek Pumping Simultaneously for 10 Days

For wells close to the stream, the instantaneous rate of stream depletion reaches a maximum quickly and falls off quickly. For distant wells, stream depletion increases gradually and tapers off slowly. In some cases, most of the impact occurs after the well has stopped pumping (e.g., Figures 3 and 4). For these wells, the stream depletion at the end of pumping is not a good measure of the impact of the well on the stream. The Glover-Balmer model allows the calculation of stream depletion volume in addition to instantaneous stream depletion rates. Figures 6 through 8 repeat Figures 2 through 4 with volume of stream depletion during and after 30 days of pumping rather than rate of stream depletion at the end of 10 days of pumping.

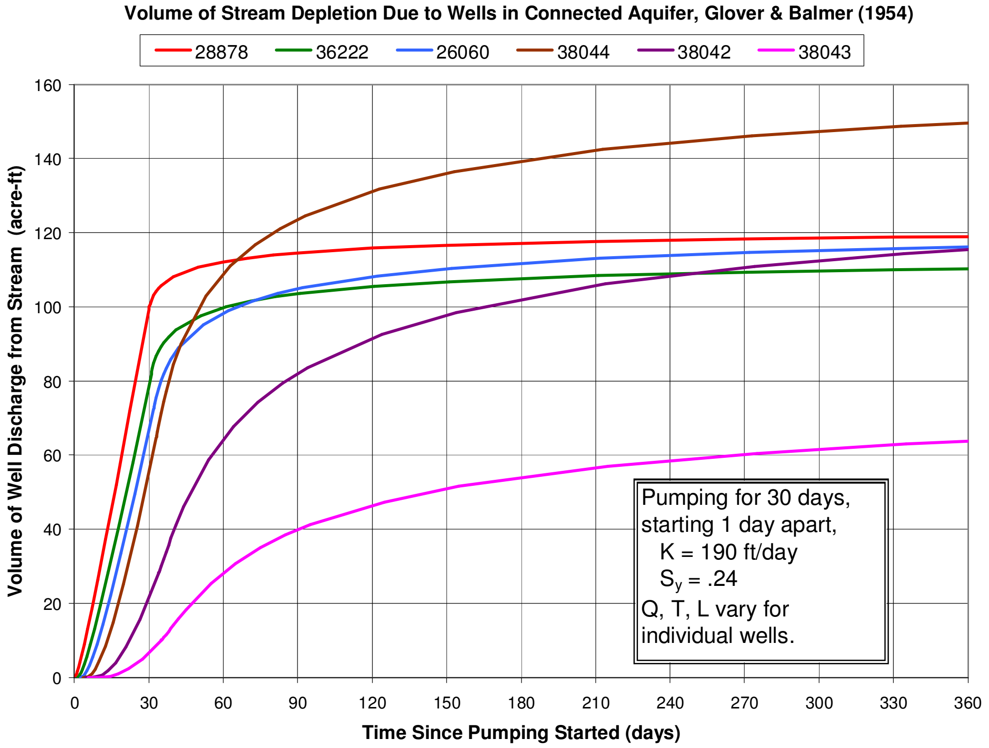

Figure 6. Volume of Stream Depletion for Relatively High-Impact Wells on Bates Creek

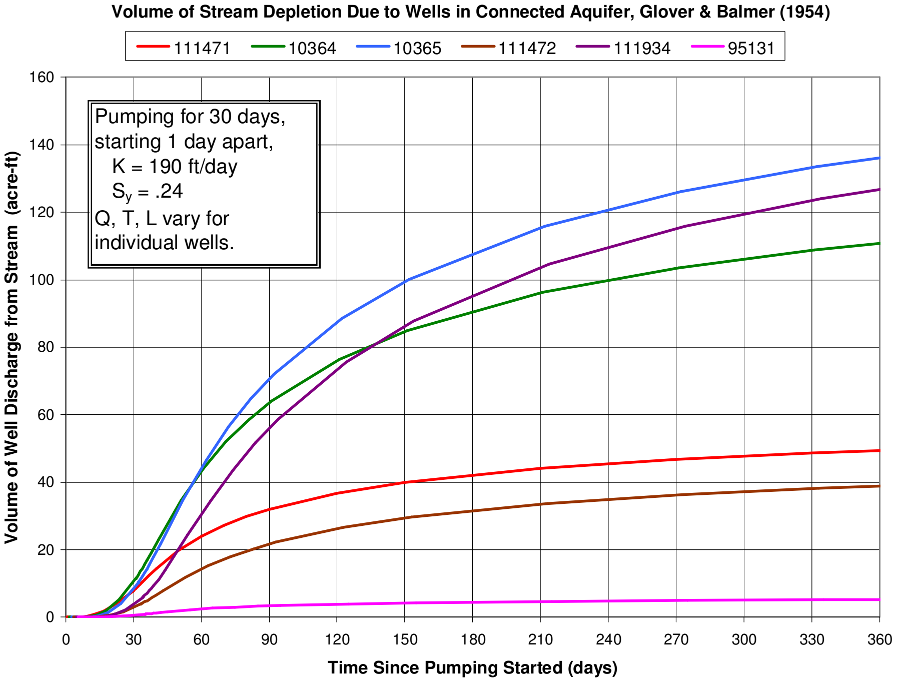

Figure 7. Volume of Stream Depletion for Relatively Moderate-Impact Wells on Bates Creek

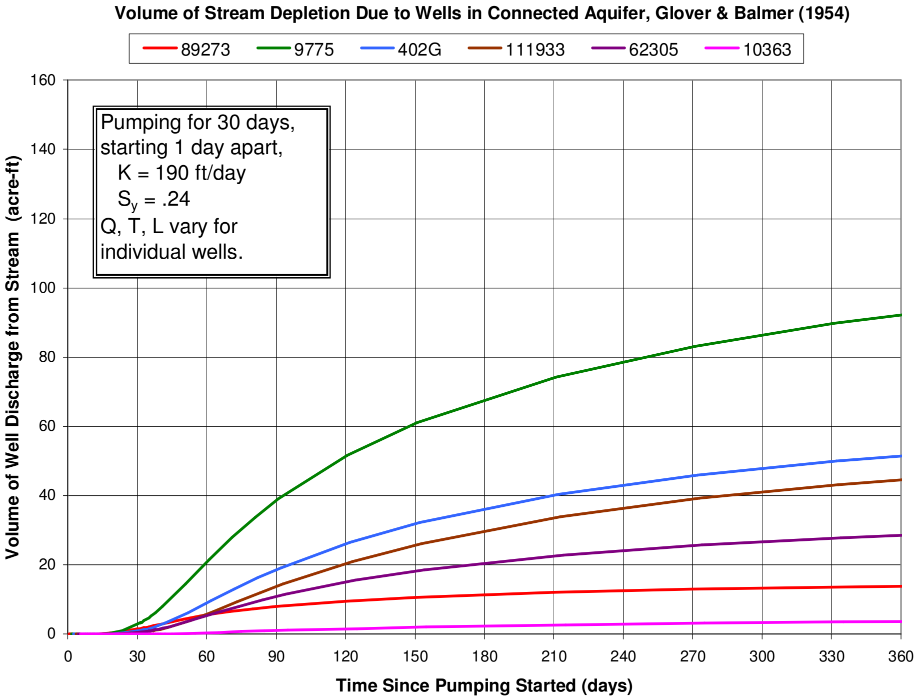

Figure 8. Volume of Stream Depletion for Relatively Low-Impact Wells on Bates Creek

For the wells close to Bates Creek, the volume depleted increases rapidly and then stops changing much about a month after the 30 days of pumping. For some wells far from the creek, the volume depleted is still increasing a year after pumping stopped. This is partly an artifact of the analytical method as it was assumed that the stream is the only source of water for the well (and never stops flowing). Withdrawal of water from storage within the bounds of a well's cone of depression allows the well to produce water without any immediate source but, after pumping stops, the stream continues to lose water to the cone of depression as it refills. One would expect the volume of depletion to cease once the aquifer is recharged seasonally by precipitation, ditch leakage, etc.

The total volume of water lost by the stream to the 13 highest-impact wells after 30 days is shown in figure 9. This suggests that a stream would continue to lose water through most of the winter after the irrigation season ends. Refilling the cones of depression is a slow process. If the stream dries up or flows at a lower rate for part of the year, then the cones of depression would take even longer to refill. This would be particularly important if the alluvial aquifer fails to recharge completely from year to year. In that case, stream depletion would continue year-round.

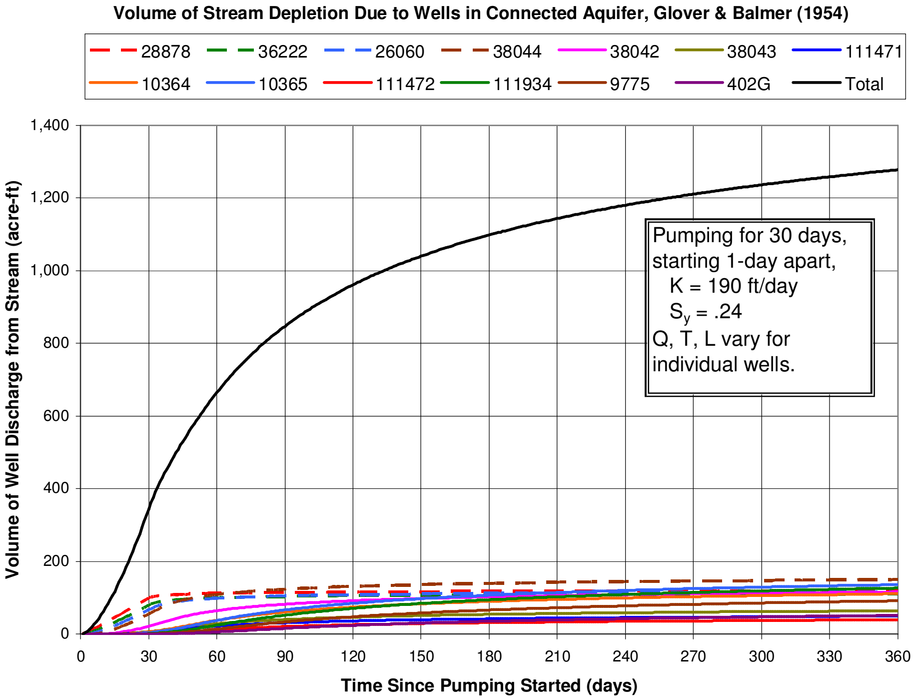

Figure 9. Total Volume of Stream Depletion Due to 13 Irrigation Wells along Bates Creek Pumping Simultaneously for 30 Days

Although the results presented above cannot be relied upon in detail, they do demonstrate that for reasonable choices of aquifer parameters the existing irrigation wells on Bates Creek have a major impact on stream flows after only a few days of continuous pumping. Depletions persist long after the pumps are turned off. Instantaneous stream depletion rates due to the different wells range over a factor of 100 depending primarily on pumping rate and distance from the creek. The 5 highest-impact wells account for 65% (K=900 ft/d) to 95% (K=190 ft/d) of the cumulative instantaneous stream depletion at the end of 10 days of pumping. For wells relatively distant from the stream, the maximum instantaneous depletion may occur after the well has stopped pumping. Due to the lag effect of distance, the volumes of stream depletion for distant high-discharge wells may take weeks or months to surpass the volume depletions of closer, lower discharge wells.

References

Crist, M.A., 1975, Hydrologic analysis of the valley-fill aquifer North Platte River valley, Goshen County, Wyoming: U.S. Geological Survey, Water-Resources Investigations Report 75-3, 60 p.

Glover, K.C., 1983, Digital model of the Bates Creek alluvial aquifer near Casper, Wyoming: U.S. Geological Survey, Water-Resources Investigations Report 82-4068, 45 p.

Glover, R.E. and Balmer, G.G., 1954, River depletion resulting from pumping a well near a stream: American Geophysical Union, Transactions, v. 35(3), p. 468-470.

Jenkins, C.T., 1968, Techniques for computing rate and volume of stream depletion by wells: Ground Water, v. 6(2), p. 37-46.