9.0 LX BAR SUB-AREA MODEL

The LX Bar sub-area model was constructed primarily to evaluate the potential issues associated with extensive use of infiltration impoundments rather than direct discharge to handle CBM produced water. This type of impact analysis is more reasonably conducted at a smaller scale than the regional model. As with the regional model, the VMODFLOW program (v.3.0) was used to complete pre-processing, modeling, and post-processing, including zone water budgets.

Impoundments have seen increased use as a method of water handling in areas where direct discharge into creeks is discouraged, mainly as a result of concerns with the quality of CBM produced water that may affect downstream use for irrigation. Impoundments are used extensively for CBM discharges in the sub-watersheds of the Powder, Little Powder, and Tongue Rivers. Infiltration impoundments provide water for livestock and wildlife use and for artificial recharge of groundwater. Infiltration impoundments are designed to accommodate all the CBM produced water by infiltration to groundwater or evaporation with little or no discharge to surface waters. Some infiltration impoundments may be designed to allow surface discharge during storm water runoff events, however.

The major concerns regarding the use of infiltration impoundments are release of water that leaks from these impoundments into adjacent creeks, increasing flows in creeks that are downgradient of impoundments. This leakage could occur as seeps above low-permeability subsurface geologic units that may cause perched groundwater conditions. Alternatively, infiltration may increase shallow groundwater levels that may, in turn, cause increased discharge to adjacent creeks. The shallow groundwater table in ephemeral drainages is typically below the bottom of the creek bed, so that groundwater does not discharge to the creek and, in fact, creek flows recharge the groundwater.

The LX Bar drainage basin is an ephemeral system that is tributary to the Powder River in Townships 56 and 57 North and Ranges 75, 76 and 77 West. The area has not been extensively developed for coal bed methane, but CBM operators in the area likely would not be allowed to discharge to LX Bar Creek because of concerns that involve water quality. This area was selected for modeling because it is typical of a drainage basin that will likely see complete CBM development (assumed 80-acre spacing for two coal seams) and will use infiltration impoundments as its primary water handling method.

9.1 Leakage Rates for Infiltration Impoundments

The rate of leakage from an impoundment is largely controlled by the permeability of the soils and shallow geologic materials that directly underlie the impoundment, and by the amount of head in the impoundment. The proportion of water that infiltrates versus the proportion that evaporates is site-specific and varies seasonally. It is expected that most impoundments would be constructed in fine-textured soils ranging from clay loam to sandy loam. Infiltration impoundments would not be constructed on shale or clay soils where clay content is greater than 40 percent and infiltration rates would be low. Most infiltration impoundments would be constructed in upland areas that are not within alluvial deposits, within headwater drainages, and on valley terraces. Some infiltration impoundments may, however, be constructed in valley bottoms where the depths to groundwater are shallow.

Infiltration rates have been estimated at two impoundments within the PRB using water balance considerations.

The BLM completed a water balance study of Brown Reservoir (Meyer 2000b), which is located within the Dry Fork of Willow Creek. The water balance was performed between April 1 and July 31, 2000. The study found that infiltration rates during this 4-month period were essentially constant and averaged 0.077 feet per day (ft/day) or 27.6 feet per year (ft/yr). Evaporation increased from April through July, with an equivalent rate of approximately 0.015 ft/day or 5.5 ft/yr. Infiltration represented 84 percent of water loss from the reservoir during the study period, while evaporation accounted for 16 percent. Since this average is somewhat larger than estimates of annual lake evaporation rates in the vicinity, it is thought that the actual infiltration rate would average more than 84 percent over an entire year.

A seepage rate of 26.5 feet per year has been estimated for the K-Bar closed basin, located in Section 25, T44N R74W, based on water balance measurements taken over a 10-month period from January 1 through October 31, 1999 (NPDES Permit WY0037435). The water balance over this period indicates 90 percent seepage loss and 10 percent evaporation loss. The soils at the K-Bar closed basin are classified as an Ulm clay loam. The K-Bar seepage estimates were confirmed using a one-dimensional unsaturated flow model for a clay loam soil. The unsaturated flow parameters for the clay loam soil were obtained from the U.S. Soil Salinity Laboratory, Rosetta database. The results of the model projected that a steady-state seepage rate of 33 to 34 ft/yr could be sustained in a typical clay loam soil with a surface impoundment head of 4.92 feet.

9.2 Model Grid and Layering

The area of the LX Bar model is shown in Figure 9-1. A summary of the model setup and assumptions is provided in Table 9-1. The model grid consists of 146 cells in the north-south direction (rows) and 177 cells in the east-west direction (columns), for a total of 25,842 cells per layer. The grid spacing is uniform throughout the model and is 500 feet in both north-south and east-west directions within the active area of the model. The model grid was set up in the NAD27 UTM Zone 13 meters coordinate system. The active model area is shown in Figure 9-2.

Figure 9-1 Location of LX Bar Model Study Area

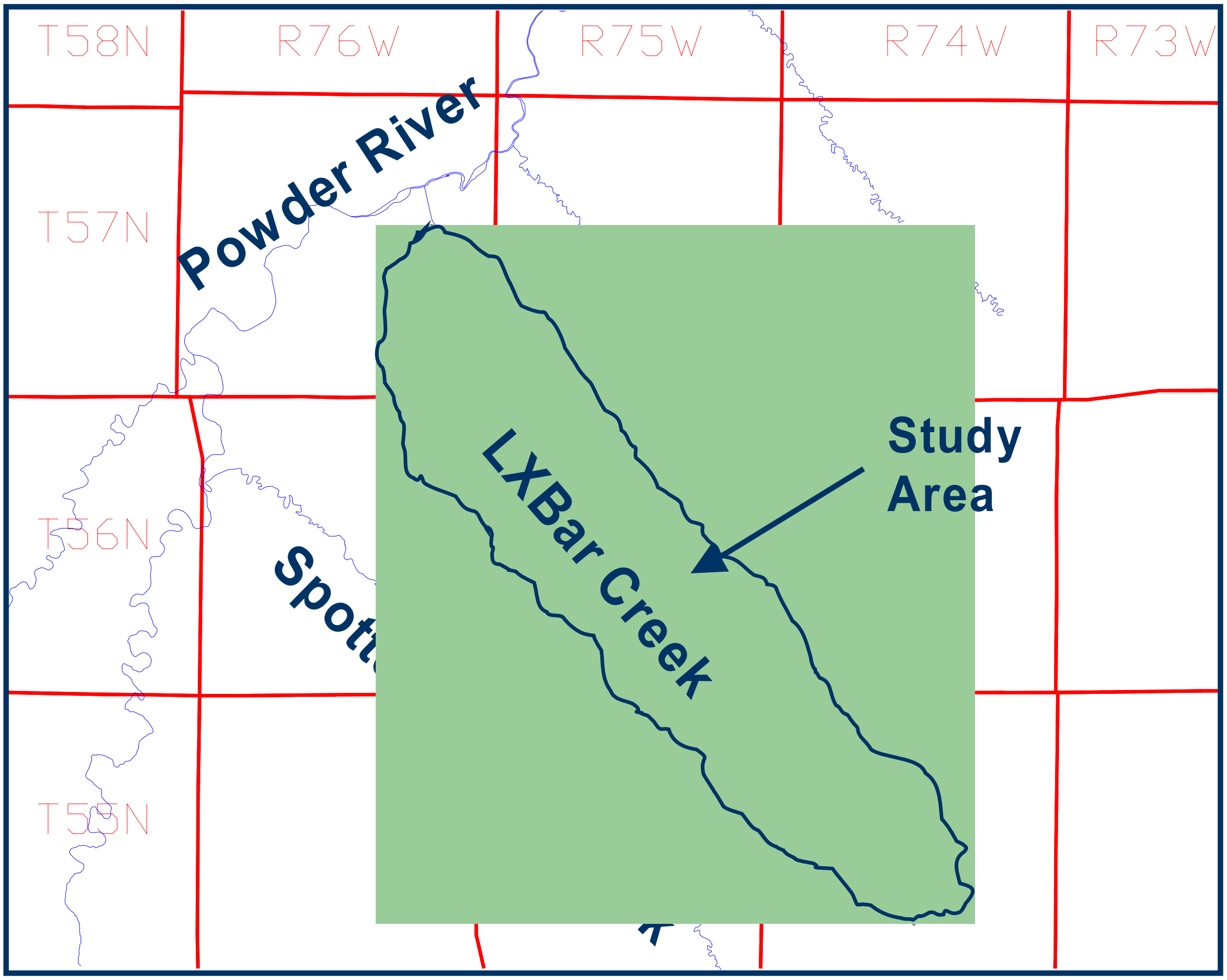


Table 9-1
Summary of LX Bar Model Setup and Assumptions

Project	Powder River Basin (PRB) Oil& Gas Environmental Impact Statement (EIS) - Powder River Basin Groundwater Impacts
Area	LX Bar Drainage Basin, Powder River Basin in northeast Wyoming
Code	MODFLOW-96. Pre- and post-processor: VMODFLOW v.3.0
Time modeled	Steady State: (Pre-development); Transient State: 40 years
Dimensions	X = 140,000 ft, Y = 120,000 ft (602.6 sq. miles)
X coords	0 – 140,000 ft
Y coords	0 – 120,000 ft
Coordinates	North American Datum (NAD)27 Universal Transverse Mercator (UTM) Zone 13, meters
Rows, columns	No. of rows: 177 No. of columns: 146 (25,842 cells/layer)
Grid spacing	500 ft x 500 ft (~0.1 mile x 0.1 mile) within the active area of the model
Layers/type	No. of layers: 13. Layer 1: Unconfined: Layers 2-13 Variable T, S
Surfaces	**Coal surfaces and isopachs:** Forney, 2001; Goolsby, Finley, and Assoc. 2001; WOGCC: 2001; Olive, 1957. **Surface topography:** U.S. Geological Survey (USGS) Digital Elevation Models (DEMs)
Geology	**Coal Units:** Forney 2001; Goolsby, Finley, and Associates (2001); Olive, 1957. **Surface Geology:** USGS: "National Coal Resource Assessment, 1999 Resource Assessment of Selected Tertiary Coal Beds and Zones in the Northern Rocky Mountains and Great Plains Region" (USGS 1999a)
No-flow Boundaries	The LX Bar Creek drainage basin, and a two-mile reach of the Powder River opposite the confluence with LX Bar Creek, is the active area for the model
General Head	Regional groundwater flow to discharge areas beyond the model boundaries, such as the Yellowstone River, were simulated using general head nodes in layers 7, 11, and 13 at the northern "no-flow" boundary.
Recharge	Basin-wide infiltration: 0.04 inches per year LX Bar Creek infiltration: 0.6 inches per year Infiltration Impoundments: 72 inches per year for 10 yrs (max. life of CBM well)
Rivers (drain nodes)	Discharge of groundwater to the Powder River and the main channel of LX Bar Creek; Rivers were simulated by drain nodes with an elevation of the surface elevation minus about 5ft.
CBM Wells (drains)	**CBM Wells:** Input as drain nodes in the Canyon Coal (Layer 7). Projected CBM wells based on 80-acre spacing. Full development over the entire drainage area.
Solver	Steady-state: WHS (Waterloo hydrologic solver); Transient-state: WHS.

Table 9-2
LX Bar Model Layers

Model Layer	Geologic Formation/Member	Geologic Unit	Predominant Lithologies
1	Wasatch Formation	Upper Wasatch Formation	Sandstone, siltstone, claystone
2		Confining unit at base of Wasatch Formation	Siltstone, claystone
3	Fort Union Formation	Anderson Coal	Coal
4		Confining unit between coal units	Siltstone, claystone
5		Fort Union Sandstone	Sandstone, siltstone
6		Confining unit between coal units	Siltstone, claystone
7		Canyon Coal	Coal
8		Confining unit between coal units	Siltstone, claystone
9		Fort Union Sandstone	Sandstone, siltstone
10		Confining unit between coal units	Siltstone, claystone
11		Cook Coal	Coal
12		Confining unit between coal units	Siltstone, claystone
13		Wall Coal	Sandstone, siltstone

Figure 9-2 LX Bar Model Area and Grid

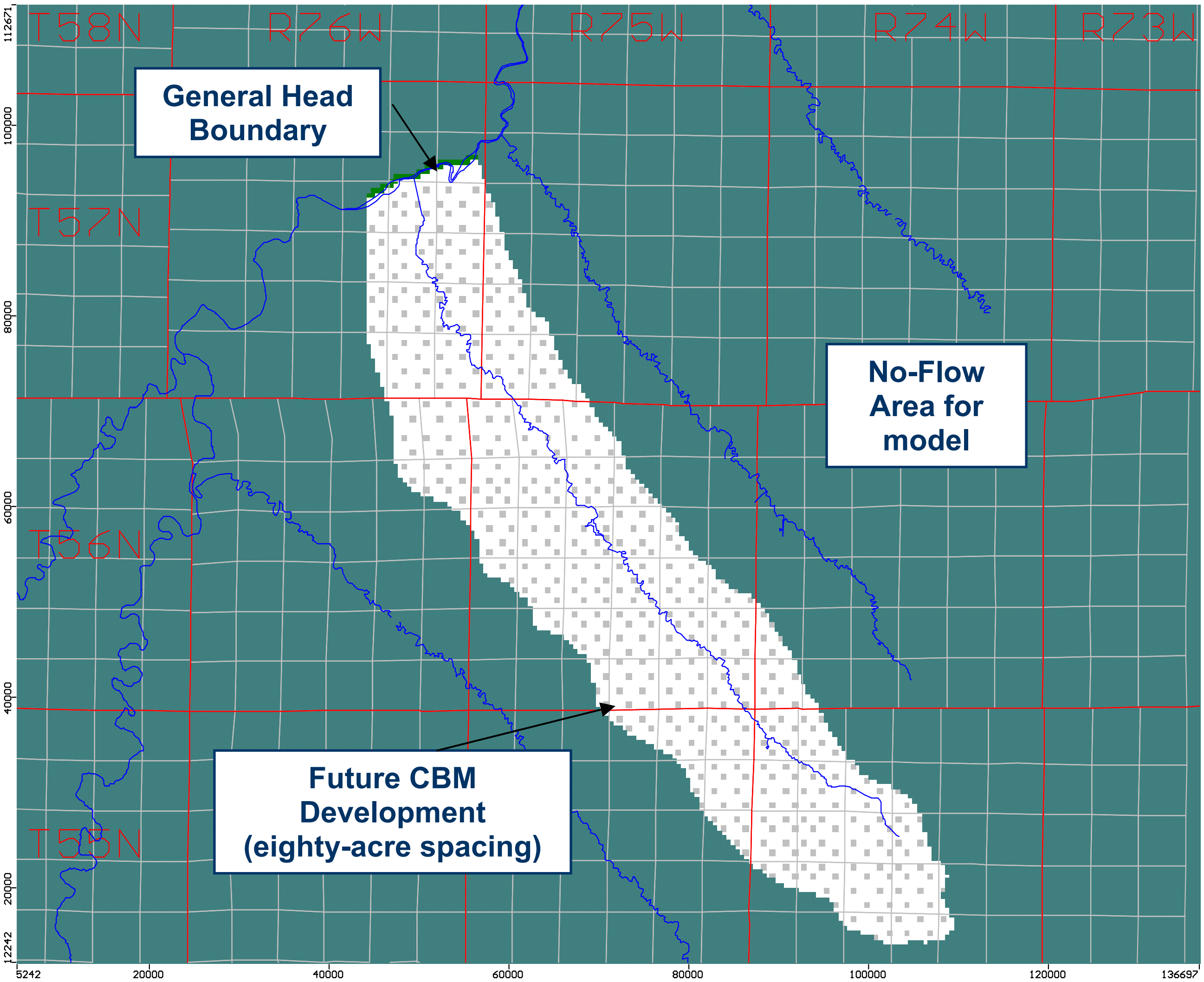
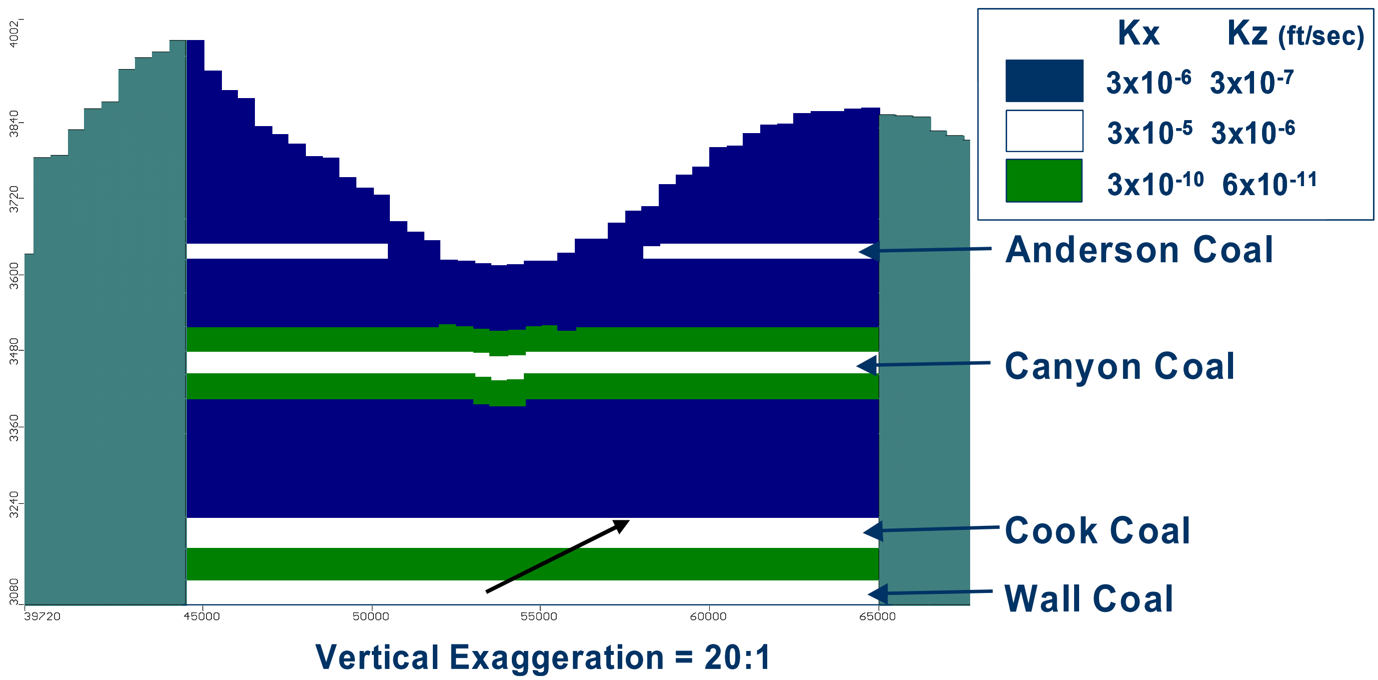


Figure 9-3 LX Bar Model - Typical East-West Cross-Section



Model layers 1 and 2 represent the shallow geologic units that are in the Wasatch Formation in the southeast part of the model area but represent the upper part of the Fort Union Formation in the northwestern part of the area. This distinction occurs because the valleys of LX Bar Creek and the Powder River cut down into the Fort Union Formation to the northwest. The uppermost layer (layer 1) represents the surface geologic units that include claystone, siltstone, and sandstone. This layer was assigned a variable thickness that ranged from 30 feet to 150 feet. The hydrologic properties within this layer were varied to reflect the different characteristics of the geologic units within this layer (Table 9-3). The discontinuous nature of the sandstone units within this layer is difficult to accurately simulate in a model, even at a drainage basin scale. However, this simulation was attempted by assigning hydrologic parameters to these layers that are representative of mixed sandstones and siltstone/claystone.

Overlying the Fort Union coal zone is a layer (layer 2) that represents claystones that act as a confining unit between the coal zone and the shallower discontinuous sandstones. This layer was set at a uniform thickness of 40 feet above the top of the coal zone in the upper portion of the Fort Union Formation. The vertical permeability and thickness of this layer in any location reflect its ability to act as a confining unit and influence the rate of leakage from the shallow discontinuous sandstone units in layer 1.

The major coal seams in the Fort Union Formation in this area are the Anderson, Canyon, Cook, and Wall, represented by layers 3, 7, 11, and 13. The average thicknesses of these seams, based on examination of drilling logs in this area, are 25 feet for layer 3, 45 feet for layer 7, 50 feet for layer 11,and 40 feet for layer13 (Table 9-3). The appropriate layers were assigned these thicknesses and representative coal properties. Similarly, the thicknesses of the intervals between the coal seams were averaged, and the model layers that represent these intervals reflect these values. In some cases, the interval between two coals was represented by several model layers (Table 9-3).

9.3 Boundary Conditions

Boundary conditions used in the LX Bar model include no-flow, general head (model outflow), and drains (Powder River, LX Bar Creek, and CBM wells). No-flow cells were assigned to the model grid that was outside the area of the outcrop for the geologic units represented by each model layer. The no-flow cell configuration was identical for all layers. The extent of no-flow cells is shown in Figure 9-2.

Interaction between rivers and shallow Wasatch sands is simulated in the model by drain nodes along the reach of the Powder River that cuts through the northwest corner of the model and the main channel of LX Bar Creek. The head set in the drain nodes was based on the topographic elevation of the river at each node location. Drain nodes were also used to simulate CBM wells. These are described in Section 9.4.

General head nodes were designated along the western and northern boundaries of the model to allow regional groundwater flow to continue to the northwest if prevailing head gradients indicate that this flow would occur. General head elevations were set based on steady-state, pre-development conditions.

Table 9-3
Summary of Input Parameters for LX Bar Model

Formation	Model Layer	Thickness (ft)	$K_{x,y}$ (ft/s)	K_z (ft/s)	S_s (1/ft)	S_Y (unitless)
Wasatch Discontinuous sandstone	1	30 to 150	3×10^{-6}	3×10^{-7}	5×10^{-5}	0.1
Wasatch Discontinuous siltstone	1	30 to 150	3×10^{-7}	3×10^{-8}	5×10^{-5}	0.1
Wasatch Confining	2	40	3×10^{-10}	6×10^{-11}	3×10^{-6}	0.03
Upper Fort Union Anderson Coal	3	25	1×10^{-4}	3×10^{-6}	2×10^{-5}	0.005
Upper Fort Union Confining	4	55	3×10^{-10}	6×10^{-11}	3×10^{-6}	0.03
Upper Fort Union Discontinuous sandstone	5	50	3×10^{-6}	3×10^{-6}	5×10^{-5}	0.1
Upper Fort Union Confining	6	40	3×10^{-10}	6×10^{-11}	3×10^{-6}	0.03
Upper Fort Union Canyon Coal	7	35	1×10^{-4}	3×10^{-6}	2×10^{-5}	0.005
Upper Fort Union Confining	8	40	3×10^{-10}	6×10^{-11}	3×10^{-6}	0.03
Upper Fort Union Discontinuous sandstone	9,10	185	3×10^{-6}	3×10^{-6}	5×10^{-5}	0.1
Upper Fort Union Cook Coal	11	50	1×10^{-4}	3×10^{-6}	2×10^{-5}	0.005
Upper Fort Union Confining	12	50	3×10^{-10}	6×10^{-11}	3×10^{-6}	0.03
Upper Fort Union Wall Coal	13	40	1×10^{-4}	3×10^{-6}	2×10^{-5}	0.005

$K_{x,y}$ = hydraulic conductivity (horizontal)
K_z = hydraulic conductivity (vertical)
S_s = specific storage
S_y = specific yield

9.4 CBM Wells

Active CBM wells are simulated in the model by setting drain nodes at appropriate locations in the Canyon and Cook coal seams (layers 7 and 11). A CBM development scenario on an 80-acre spacing pattern was assumed for both coal seams (Figure 9-2). For simplicity, the CBM development was assumed to occur simultaneously and would last for 10 years. Groundwater will enter an active drain node from an adjacent node as long as the potentiometric level in the adjacent node is higher than the drain elevation.The water flow to the drain declines as the potentiometric head declines in the model nodes surrounding the drain to simulate the process that occurs in CBM production wells, where declines in production over time are typically observed.

Each drain node is activated for a 10-year period to simulate the period of active CBM operations. The water level in a drain node for an active CBM development area is set 16 feet above the top elevation of the highest coal unit being developed in that area. After all CBM production ceases in the node, the drain node is made inactive by setting the drain elevation above ground level, which allows the water level in the node to recover. The reported pumping rates of existing CBM wells over time were downloaded from the WOGCC database and were used to calibrate the drains that represent these wells in the model. The limited production data in this area suggest that the average pumping rate for a CBM well is equivalent to about 4 to 6 gpm.

9.5 Recharge

The LX Bar area receives between 10 and 12 inches of precipitation per year (USDC/NOAA 1979). The LX Bar drainage is naturally ephemeral. Groundwater aquifers recharge from infiltration of direct precipitation (rain and snowmelt), runoff in creek valleys, and standing water in playas, reservoirs, and stock ponds.

Precipitation provides a minimal source of recharge over most of the area because the climate and surface features restrict significant infiltration. Only a small percentage of the available precipitation infiltrates, while the majority runs off. Recharge during the short period when LX Bar Creek flows is probably significant but would be restricted to the area of the main creek channel. A value for infiltration of 0.6 inches per year was assigned to this restricted area. Area-wide recharge, which includes recharge in ponds and side tributaries to LX Bar Creek, expressed over the entire area, is expected to be less than 1 percent of the total precipitation, on average or equivalent to less than 0.12 inches per year. A value of 0.04 inches per year was assigned to this area. The assigned recharge value yielded a reasonable water table configuration when the model was run in steady state, reflecting conditions that existed before CBM development began.

It is assumed that infiltration impoundments would be used to accommodate the CBM produced water during the 10-year active life of the CBM development. Two infiltration impoundments per section, each with a surface area of 5.74 acres (500 feet by 500 feet) were assumed to be adequate to accommodate the average production from 16 CBM wells (8 wells per section in two coal seams). The impoundments were assumed to recharge the shallow groundwater at a rate of 72 inches per year over the entire 10-year period of CBM development. In addition to infiltration, evaporation from the impoundments would average about 42 inches per year. Neglecting storage within the reservoir, total infiltration and evaporation from each reservoir would be equivalent to about 34 gpm, or eight wells pumping an average of 4.2 gpm over the entire 10-year period of CBM development. In actuality, pumping rates from an individual well will probably be higher than the average at the beginning of its life cycle and will decline to rates much lower than the average after a few years of operation.

9.6 Hydrologic Parameters

A summary of the model input parameters assigned to the various geologic units in the model is shown in Table 9-3.Several lithologies or conditions may be represented within any layer. The range of permeability values used in the model was based primarily on typical values derived from pumping test data and the model calibration performed for the Caballo Creek area and the regional model (Appendix B).

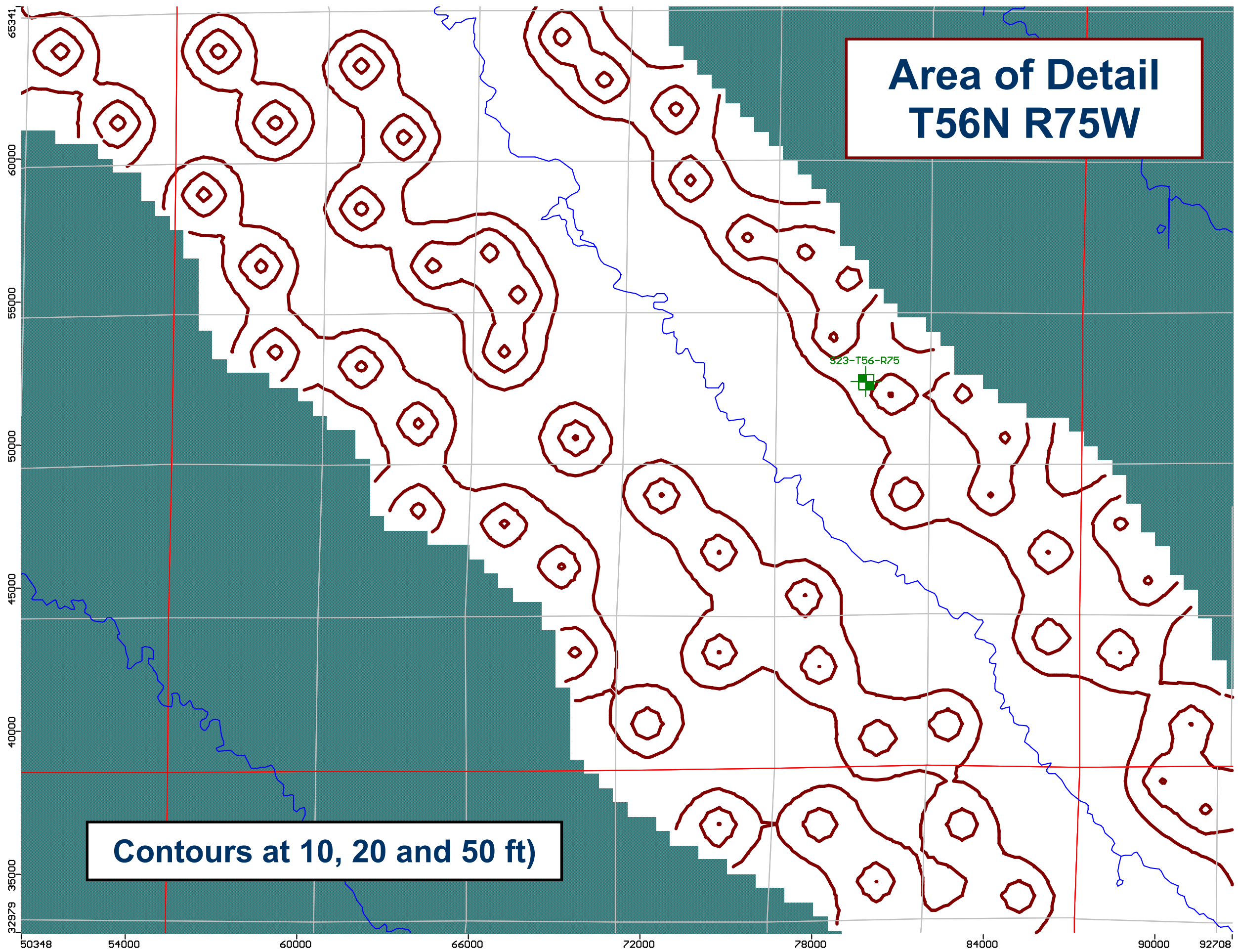
The values for storativity used for the various model layers are also summarized in Table 9-3. There are relatively few reliable data on storage coefficients in the PRB. Storage coefficient values vary considerably, depending on whether the unit tested is under confined or unconfined conditions. Most pumping tests conducted in the coal are considered to be under confined conditions. Storage coefficients derived from these pumping tests are in the range of 10^{-3} to 10^{-5}. The specific storage (S_s, equivalent to the storage coefficient divided by the thickness) used for the coal ranged between 2 x 10^{-5} ft^{-1} and 5 x 10^{-6} ft^{-1}. Pumping tests conducted in the Wasatch sands may be under confined or unconfined conditions. Storage coefficients derived from these pumping tests are in the range of 10^{-2} to 10^{-4}. The specific storage derived from Wasatch sand tests averages 1.8x10^{-4} ft^{-1}. The specific yield of the unconfined geologic units in the uppermost layer is assumed to be about 0.1, reflecting typical poorly consolidated sandstones and siltstones.

9.7 Effects of Infiltration Impoundments on Water Levels

A major focus of this modeling work was to assess the influence of continuous recharge from infiltration impoundments on groundwater levels in shallow Wasatch sands. Figure 9-4 shows the peak water level rise (build-up) in the shallow geologic units (layer 1) at the end of the 10-year development period. The recharge from the impoundments (at a rate of 6 ft/yr) results in a groundwater rise below ponds ranging from 20 to 50 feet for the case of impoundments that are built on sandy loam soils ($K_{x,y}$ = 3 x 10^{-6} ft/sec. K_z =3 x 10^{-7} ft/sec.). The storage within the pore spaces of the previously unsaturated geologic units accommodates much of the infiltrated water. However, the model results illustrate that infiltration impoundments that overlie Wasatch sands should preferably be sited in upland areas where the groundwater table is more than 50 feet below the land surface.

Higher recharge rates or lower vertical permeabilities could result in higher rises in the groundwater level. However, the recharge rate is linked to the permeability of the underlying soils, so that the rise in water level is self-limiting to some extent.

Figure 9-4 Projected Groundwater Rise in Shallow Wasatch Sands after 10 Years Caused by Recharge from Infiltration Impoundments



Notes:

Sandy Loam Soils ($K_{x,y} = 3 \times 10^{-6}$ ft/sec. $K_z = 3 \times 10^{-7}$ ft/sec.)
Recharge from Impoundments (infiltration rate = 6 ft/yr)
(groundwater rise in shallow Wasatch sands below ponds ranges from 20 to 50 feet.

9.8 Effects of Infiltration Impoundments on Surface Flows

A second objective of this modeling was to assess the influence of continuous recharge from infiltration impoundments on surface flows in LX Bar Creek and the Powder River. Figure 9-5 shows that the increase in groundwater discharge to total surface flows (Powder River and LX Bar Creek) will peak at 0.08 cfs, equivalent to about 36 gpm. This increase in surface flow is almost entirely attributable to projected increased flows in the upper part of the LX Bar drainage as a result of higher groundwater levels. The increase in surface flows would be negligible compared with total flows in the Powder River.

Groundwater levels would subside slowly after infiltration from the impoundments ceases. As a result, the increases to surface flows peak some years after the CBM development period and slowly subside, as shown in Figure 9-5.

Figure 9-5 Projected Changes in River Flows Caused by Recharge from Infiltration Impoundments