9.0 Model Based Responses to Six Initial Questions

Although the model builds directly on the fully-calibrated USGS Columbia Plateau Regional Groundwater Model, the hydrogeologic complexity of the Black Rock site, the limited hydrologic data for characterizing this complexity, and the time constraints on model development mean that the first five questions posed earlier can only be answered within a fairly broad range of possible outcomes.

The first two questions are addressed using results of the (early-time) LP version of the Black Rock model. The next three questions are addressed using results of the (late-time) GHP version of the model. The last question is answered based on knowledge gained during development and application of the model

1. How long will it take to fill Black Rock reservoir initially, given the expected water availability and expected reservoir seepage rates?

Based on monthly water availability at the Priest Rapids Dam Reservoir during an average water year (i.e. 1967), the LP model estimates that it will take approximately 380 days to initially fill the reservoir to the1,775-foot stage, assuming no reservoir withdrawals for irrigation during the first year.

2. What is the expected seepage rate from the Black Rock reservoir during initial filling?

Reservoir seepage is expected to increase from month to month as the reservoir initially fills. Based on two model runs that assume different hydraulic conductivity distributions but the same average value for specific-storage, the LP version of the model predicts that seepage would range between 1,160 and 4,390 acre-feet per month (14,100 and 53,400 acre-feet per year) after the first month of reservoir operation. After six months, the seepage rate could be expected to increase to between 4,850 and 6,370 acre-feet per month (58,980 and 77,480 acre-feet per year), and at the end of the first year, reservoir seepage rate is expected to range between 5,600 and 8,630 acre feet per month (68,200 and 105,000 acre-feet per year). The reservoir seepage losses are expected to peak at 13 months between 6,000 and 9,950 acre-feet per month (72,933 and 121,043 acre-feet per year). Cumulative seepage losses during the first 13 months of reservoir operation are expected to be between 45,700 and 77,900 acre-feet.

3. What is the expected seepage rate from the reservoir over time, once filled to capacity?

The GHP version of the model predicts a range of reservoir seepage rates based on six model runs that assume two different hydraulic conductivity distributions, and three different estimates of specific-storage. Seepage estimates are bounded by the *permeability 1 minimum storage* model, which produces the minimum estimate of seepage; and the *permeability 2 maximum storage* model, which produces the maximum estimate.

After the first few years of operation, the GHP version of the Black Rock model predicts that reservoir seepage rate would begin decreasing. After 5 years seepage is expected to range between 32,100 and 54,300 acre-feet per year, the most likely seepage rate is 44,900 acre-feet per year. After 25 years, seepage is expected to range between 30,700 and 53,400 acre-feet per year, and the most likely rate is 42,200 acre-feet per year. After 100 years, the range is 29,900 and 53,200 acre-feet per year, and the most likely rate is 41,300 acre-feet per year. Finally, after 300 years reservoir seepage approximates a steady-state rate that ranges between 29,800 and 52,300 acre-feet per year. The most likely rate, based on model results, is 40,900 acre-feet per year.

4. What impact will the full reservoir have on groundwater discharge to creeks, drains, and springs, aquifer storage, and aquifer head conditions?

The range of estimates for discharge to creeks, drains, and springs is bounded by results of the *permeability 1 maximum storage* model, which produces the minimum estimate of discharge; and the *permeability 2 minimum storage* model, which produces the maximum estimate.

Groundwater discharge to creeks, drains, and springs in the vicinity of a full reservoir is expected to gradually increase from year to year. After 5 years, the GHP version of the Black Rock model predicts the discharge rate will increase by between 25,600 and 51,100 acre-feet per year and the most likely increase in discharge is 36,300 acre-feet per year. After 25 years, the increase in discharge is expected to range between 27,600 and 51,400 acre-feet per year and the most likely increase is 38,800 acre-feet per year. After 100 years, the increase is expected to be between 29,000 and 51,500 acre-feet per year and the most likely increase is 40,000 acre-feet per year. After 300 years, the increase in discharge to creeks, drains, and springs over base-case conditions is expected to be between 29,500 and 51,600 acre-feet per year. The most likely increase after 300 years is 40,400 acre-feet per year, which approximates the steady-state discharge rate.

The range of estimates for the increase in aquifer storage is bounded by the results of the *permeability 1 minimum storage* model, which produces the minimum estimate of increased storage; and the *permeability 1 maximum storage* model, which produces the maximum estimate.

The rate of increase in aquifer storage is expected to peak within a year or two after the reservoir is first filled, and then decline from year to year after that. After 5 years, the GHP model predicts that aquifer storage will be increasing at the rate of between 2,400 and 14,700 acre-feet per year, and the most likely rate of increase in aquifer storage is 8,600 acre-feet per year. After 25 years, the rate of increase is expected to be between 1,000 and 6,500 acre-feet per year and the most likely rate is 3,400 acre-feet per year. After 100 years the increase ranges between 200 and 2,900 acre feet per year and the most likely rate is 1,300 acre-feet per year. After 300 years the rate of increase in aquifer storage is reduced to between 1 and 1,500 acre feet per year and the most likely rate is 600 acre-feet per year, indicating a near steady-state condition.

Ultimately, a full reservoir will increase aquifer heads directly beneath the reservoir in layers 1, 2 and 3 (sediments, and the Saddle Mountains and Wanapum layers) by between 250 and 650 feet over base-case conditions. The greatest increases are expected to occur at the east end of the reservoir, where reservoir depth is greatest.

Away from the reservoir, increased aquifer heads that are a direct result of reservoir seepage are expected mainly in layers 2 and 3, and mainly south and northwest of the reservoir. For the most part, head increases in layer 1 are not a direct result of reservoir seepage but rather the result of re-infiltration in the Dry Creek drainage, and are spread out mainly to the east of the reservoir.

5. What impact will the reservoir have on groundwater flow and head conditions at the boundary of the Hanford Reservation (along Cold Creek)?

The GHP model predicts that the west-to-east flow of groundwater in the sediment layer, beneath Cold Creek into the Hanford Reservation could be expected to increase as a result of reservoir seepage. The increased groundwater flow results from increased surface flow in the Dry Creek drainage, which re-infiltrates the sediment layer near the confluence of Dry Creek and Cold Creek drainages.

The base-case model estimate of west-to-east groundwater flow beneath Cold Creek in the sediment layer is about 7,800 acre feet per year. As a result of re-infiltration, the GHP model estimates that groundwater flow beneath Cold Creek, along its entire length, could ultimately (after 300 years) increase to between 22,700 and 29,500 acre-feet per year, an increase of between 14,500 and 21,700 acre-feet per year over base-case conditions. Most of the increased flow beneath Cold Creek would be near the confluence with Dry Creek. The GHP model predicts little increase in groundwater flow beneath Cold Creek in the Saddle Mountains and Wanapum layers.

Head increases at the center of the re-infiltration area (along Dry Creek, west of Cold Creek) could ultimately be expected to range between 220 feet and 250 feet.

The impact of re-infiltration on head conditions in layer 1 could also be expected to extend across the entire area between Cold Creek, and the Columbia River.

The smallest impact on head conditions at the boundary of the Hanford Reservation is predicted by the *permeability 1 maximum storage* model. In this model, head in the sediment layer along the 21-mile length of Cold Creek would ultimately increase between 1 and 40 feet. The impact of the *permeability 2 average storage* model at the Hanford boundary is somewhat greater. Under this scenario the increase in head along the length of Cold Creek ranges between 1 and 60 feet. The greatest impact is predicted by the *permeability 2 minimum storage* model. In this model the increase in head along the length of Cold Creek would ultimately range between 1 and 90 feet.

6. What additional field testing would be most valuable in reducing uncertainty in model predictions of reservoir hydrologic impacts?

Groundwater model development is, fundamentally, a rigorous investigative process in which numerical modeling tools are used to build a coherent hydrologic picture from contrasting elements of hydrogeology, groundwater mechanics, aquifer testing, and observation. The model development process itself invariably results in new hydrologic insights and understanding that can serve as a guide to the acquisition of other important hydrologic data.

Modeling, together with geologic drilling and aquifer testing at the reservoir site provide indications that much of the hydrogeologic complexity of site (i.e. heterogeneity in aquifer properties including hydraulic conductivity and specific-storage) is concentrated near the right dam abutment and in the Dry Creek drainage.

While high hydraulic conductivity zones within the Saddle Mountains and Wanapum Basalts are mainly concentrated in flow tops, horizontal and vertical hydraulic conductivities can also be affected by subsequent folding and faulting of these basaltic layers. The hydrogeologic complexity of the right abutment area and the Dry Creek drainage is mainly the result of this complex geologic structure.

Multi-well aquifer testing involving cross borehole packer tests is standard practice for characterizing the directional components of hydraulic conductivity in heterogeneous fault and fracture zone settings (Committee on Fracture Characterization and Fluid Flow, 1996). Additional multi-well testing aimed at characterizing hydraulic conductivity (and layering) within Saddle Mountains Basalts at the east end of the reservoir site and along Dry Creek drainage could reduce uncertainty in Black Rock model predications of reservoir seepage and potential impacts on Hanford Reservation groundwater levels.

The seepage rates presented in this report have been calculated using the best available hydrologic data. Since no measured hydraulic conductivity data is available in the Dry Creek drainage, values from the U.S. Geological Survey's regional model were used and then adjusted until water levels predicted by the model matched measured water levels in local wells in the area.

We believe that the seepage rates produced by this model are accurate based on the data we have available. However given the geologic complexity of the area at the damsite and the Dry Creek drainage, gathering new hydrologic data in the Dry Creek drainage could change the seepage rates that are presented in this report.