Appendix D2

Groundwater Resources

Tennessee Valley Authority
Reservoir Operations Study – Final Programmatic EIS

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D2.1 Reservoir Analysis

Assessment of the surface water and groundwater interactions involved two phases: (1) an initial screening-level analysis to determine the maximum zone of surface water influence on groundwater resources, and (2) a reservoir-specific analysis to determine potential effects on groundwater wells situated within the maximum zone of surface water influence identified in the screening-level analysis.

D2.1.1 Screening-Level Analysis

A screening-level analysis was performed to determine the maximum zone of surface water influence on groundwater resources around each TVA reservoir. The furthest distance from the reservoirs where a change in reservoir elevation could be discerned in the groundwater zone was calculated.

The calculation used an analytical solution to the natural situation and assumed a sudden change in reservoir elevation that propagates through groundwater. The calculation took as input the elevation change in the reservoir and calculated the decrease in this elevation change as it propagates into the subsurface groundwater zone. The model depends on the magnitude of the elevation change in the reservoir, aquifer properties (transmissivity and specific yield), and the duration of the changed condition. The distance at which no effect of the reservoir change is discernable in the groundwater zone was calculated for the duration of water increase. “No effect” is considered to be a change in groundwater elevation less than or equal to 0.1 feet.

The screening-level analysis used January 1 (minimum pool) and June 1 (maximum pool) elevations and a duration of 150 days as inputs to the calculation. This range in elevation provided an upper bound for changes in groundwater levels. None of the reservoir operations policy alternatives would produce a greater change in groundwater levels than those predicted by the screening-level analysis.

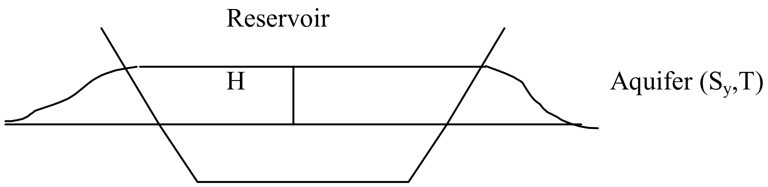
As discussed in Section 4.1, Introduction to Affected Environment, Zurawski (1978) divided the Tennessee River region into six physiographic and hydrologic provinces with distinctive characteristics: the Coastal Plain, Highland Rim, Central Basin, Cumberland Plateau (including the geologically distinct Sequatchie Valley), Valley and Ridge, and Blue Ridge. The approach of this analysis was to treat each province as consisting of a specific range of aquifer properties. This simplification allowed an initial breakdown of the Tennessee River Valley region, but did not lead to a site-specific analysis.

Calculation

The background and derivation of the calculation approach are described in Marsily (1986). The solution is appropriate for sudden variation in water elevation, in a semi-infinite domain. It fits the case of a semi-infinite aquifer initially in equilibrium with an initial elevation that is then subjected to a change in water elevation at the boundary. The aquifer can be confined or unconfined. The solution is taken from consideration of problems of heat and mass transport presented in Carslaw and Jaeger (1959), in Figure D2-01.

Figure D2-01 Calculation of Groundwater Table Elevation Changes

$$h\ (x, t) = H\ \mathrm{erfc}\ (x\ \sqrt{S_y / 4Tt}\ )$$



In the equation $h\ (x, t) = H\ \mathrm{erfc}\ (x\ \sqrt{S_y / 4Tt}\ )$, h (x,t) is the change in water table elevation resulting from a change H in reservoir pool levels with distance (x) and time (t) from the edge of the reservoir. S_y is the specific yield of the unconfined aquifer, a property of the aquifer. T is the transmissivity of the aquifer, a measure of the resistance to water flow in the aquifer. Values for transmissivity and specific yield used in the calculation are summarized in Table D2-01.

Calculation Assumptions, Limitations, and Sensitivity Analysis

This simple representation of surface water/groundwater interaction made several assumptions. A sensitivity analysis was conducted to test some of the assumptions. In general, the calculation results present the likely maximum extent of groundwater influence. Some of the key assumptions, and associated limitations, are described in the following:

Assumption One: Surface water and groundwater are interconnected. In addition, groundwater gradients were assumed to be away from reservoirs. These assumptions are the basis for this analysis, but in all provinces it is possible that the reservoirs are not connected to groundwater or that there is a connection, but the groundwater gradient is towards the reservoir. For example, in a study of Reelfoot Reservoir in the Coastal Plain physiographic province, McLaughlin (1988) concluded that the reservoir was not in communication with groundwater, despite being in an alluvial setting. In a study of the Highland Rim, Brahana and Bradley (1986a) identify sections of the Highland Rim region west of the Tennessee River where groundwater movement is primarily toward the Tennessee River. By assuming that all reservoirs are in communication with groundwater and that the groundwater moves in a direction toward the reservoirs, this analysis predicted a greater zone of groundwater influence than may be the case.

Table D2-01 Summary of Aquifer Properties for the Physiographic Provinces in the Tennessee River Region

Physiographic Province	Transmissivity (ft^2/day)		Specific Yield	
	Mean	Range	Representative Value	Range
Coastal Plain	500	10 to 10,000	0.2	0.1 to 0.3
Highland Rim	320	1 to 100	0.2	0.1 to 0.3
Central Basin	79	1 to 500	0.2	0.1 to 0.3
Cumberland Plateau	480	10 to 5,000	0.2	0.1 to 0.3
Sequatchie Valley	79	1 to 100	0.2	0.1 to 0.3
Valley and Ridge	140	10 to 5,000	0.2	0.1 to 0.3
Blue Ridge	120	10 to 500	0.2	0.1 to 0.3

Note:

Values for transmissivity, a measure of resistance to groundwater flow, are taken from the following Tennessee-specific literature sources: Brahana and Broshears (2001), Broshears and Bradley (1992), Hoos (1990), Wolfe et al. (1997), and Zurawski (1978). In addition, wider-ranging data compilations were consulted to broaden the range of properties, including the following: Lohman (1979), Freeze and Cherry (1979), De Marsily (1986) and Kruseman and de Ridder (1990). Values for specific yield, a measure of aquifer water storage volume, were obtained from Lohman (1979), Freeze and Cherry (1979), and Spitz and Moreno (1996).

Assumption Two: A single set of aquifer properties (transmissivity and specific yield) applies to an entire physiographic province. This assumption was variably true throughout the Tennessee River Valley. A sensitivity analysis was performed using high transmissivity/low specific yield and low transmissivity/high specific yield values for six reservoirs in the TVA system, Appalachia, Bear Creek, Blue Ridge, Boone, Normandy, and Wilson reservoirs. These reservoirs were chosen as they span the major types of aquifers in the Tennessee River Valley region including fractured bedrock, limestone, and unconsolidated aquifers.

In fractured bedrock of the Blue Ridge, the assumptions may be fairly good, except in heavily fractured areas. The sensitivity analysis indicated variation by a factor of 10 between the high transmissivity/low specific yield case and the low transmissivity/high specific yield case. Although a high degree of variation, it is relatively low for a general analysis of this sort.

In the limestone areas of the Central Basin Highland Rim, and Valley and Ridge provinces, the assumption may also be fairly good except in areas of karst. The sensitivity analysis gave a comparable range in variation to the fractured bedrock case. In karst terrains within these provinces, however, porosity and permeability can be very large, approaching open, interconnected cavities. In the karst subareas of these provinces the assumption could be very far off, and cannot be adequately modeled with this approach. The area of groundwater influence calculated for these provinces is reasonably accurate in non-karst zones; influence in karst zones are better addressed by identifying areas of seepage. Seeps and springs are the surface outlet for some karst areas. The discharge rate may be affected by project operations, but the range of change will be much smaller than other influences on seeps and springs, including precipitation, recharge, and existing reservoir operations.

In the alluvium of the Coastal Plain and regolith areas of the Highland Rim, Blue Ridge, and Valley and Ridge, the aquifer properties can vary by three or more orders of magnitude. A high degree of variation in groundwater influences is expected in these areas. The sensitivity analysis indicated a correspondingly high degree of variation: a factor of approximately 50 separated the results for the high transmissivity/low specific yield case from the low transmissivity/high specific yield case.

Owing to this variability, the “base case” analysis took a reasonable set of aquifer properties based on the literature. The values were chosen based on field observations of some of the surrounding materials of the reservoirs, and mid-range values from the literature.

Assumption Three: The boundary condition for the calculation is a constant head boundary at the edge of the reservoir. This condition is independent of the conditions in the reservoir, and assumes no change in elevation. This assumption gave a larger zone of groundwater influence than may actually be the case.

Assumption Four: The calculation only considers changes to water table elevation resulting from changes in reservoir level for cases of the water table being initially equal to the starting reservoir level. It does not consider the actual groundwater level, which could be less than the initial reservoir level. In this case, the model predicted greater zone of influences and greater groundwater elevation changes than are actually the case.

Assumption Five: The calculation assumes an immediate change in reservoir elevation. The change in elevation at the edge of the reservoir is also assumed to dissipate in the groundwater system according to a diffusion-like model. This model is appropriate for a one-dimensional analysis, but cannot reproduce effects in three dimensions, or effects due to changes in aquifer properties. No boundary condition was used for elevations in the surrounding aquifer, since this was the objective of the analysis.

Potentially Affected Groundwater Resources

Table D2-02 summarizes the results of the maximum groundwater influence calculations for the screening-level analysis. For the following reservoirs, at least one public water supply well was located within the calculated maximum zone of influence and was identified for further analysis: Cherokee, Douglas, Fort Loudoun, Kentucky, Norris, Ocoee #3, Tims Ford, and Watts Bar.

Table D2-02 Public Groundwater Wells within Maximum Zones of Influence of TVA Reservoirs

TVA Reservoir	Calculated Maximum Zone of Influence (feet)	Public Wells within Maximum Zone of Influence of Reservoir
Apalachia	1,050	0
Bear Creek	2,200	0
Blue Ridge	1,150	0
Boone	1,300	0
Cedar Creek	1,850	0
Chatuge	1,150	0
Cherokee	1,350	3
Chickamauga	1,140	0
Douglas	1,400	2
Fontana	1,325	0
Fort Loudoun	1,075	2
Fort Patrick Henry	1,050	0
Great Falls	1,870	0
Guntersville	1,600	0
Hiwassee	1,325	0
Kentucky	1,600	1
Little Bear Creek	1,820	0
Melton Hill	1,100	0
Nickajack	1,820	0
Normandy	1,800	0
Norris	1,350	1
Nottely	1,250	0
Ocoee #1	1,050	0
Ocoee #2	0	0
Ocoee #3	1,040	1
Pickwick	2,050	0
South Holston	1,330	0
Tellico	1,100	0
Tims Ford	1,875	1
Upper Bear Creek	2,090	0
Watauga	1,150	0
Watts Bar	1,100	2
Wheeler	1,650	0
Wilbur	1,150	0
Wilson	1,125	0

Notes:

The “maximum zone of influence” is the maximum zone of surface water influence on groundwater resources. No influence (0) is defined as changes in groundwater levels of less than 0.1 feet.

D2.1.2 Reservoir-Specific Analysis

Reservoirs identified in the screening-level analysis as containing public wells within the maximum zone of surface water influence were further analyzed with respect to specific policy alternatives. For each of the reservoir areas chosen for further analysis, the closest public well to the reservoir was designated as the most sensitive groundwater resource. The distances from these wells to the reservoirs were determined. In addition, median monthly changes in reservoir water levels were determined for all the alternatives. For all alternatives, the potential monthly change in groundwater levels at the wells closest to the reservoirs was calculated with respect to the Base Case.

The same solution to the differential equation and assumptions discussed in Section D2.1.1 was used to calculate the potential monthly change in groundwater levels at the closest wells to TVA reservoirs for each alternative. As inputs into the equation, values for transmissivity and specific yield appropriate to the reservoir area remained the same as the screening-level analysis. The distance from the reservoir to the closest groundwater well was used for distance (x) in the equation.

The analysis assumed that initial groundwater elevation at the wells was equal to reservoir water level elevations. Reservoir water level elevations in January were used as a starting point for the calculation as reservoir levels are usually lowest in this month. For each consecutive month (February to December), the change in median reservoir elevations from the previous month to the current month was used for H in the equation (H= median elevation for current month – median elevation for previous month). Time (t) was assumed to be 30 days for all months. For each alternative, the analysis was iterated for each month of the year. Changes in groundwater elevations at the closest groundwater wells for each month were added or subtracted from initial groundwater elevations (assumed to equal January reservoir water elevations) to project the cumulative change in groundwater elevations over the year. This result gives an estimation as to how groundwater elevations at the closest wells to the reservoirs would change for each alternative each month of the year, assuming that January groundwater elevations are equal to January reservoir elevations.

The Base Case would continue existing conditions to the year 2030. Since this alternative does not include a physical change and groundwater usage was assumed to remain fairly constant, there would be no adverse consequence to groundwater resources. All other alternatives were, therefore, analyzed with respect to the Base Case. The projected monthly changes in groundwater elevations at the wells for each alternative were then compared to the projected monthly changes in groundwater elevations at the wells for the Base Case. Any increase in groundwater levels was considered a beneficial effect on groundwater resources. A decrease in groundwater levels of more than 3 feet was considered an adverse effect on groundwater resources if the change occurred at or near reservoir minimum pool. This 3-foot threshold was based on the typical seasonal and annual changes in groundwater elevations attributable to non-reservoir influences and variation in groundwater use patterns. Due to the conservative nature of the calculations used in this analysis, any adverse effects on groundwater resources at any of the reservoirs were further analyzed to determine, to the extent possible, consistency with the assumptions outlined in the above calculations.