IX. NUMERICAL MODEL OF DEER CREEK WATERSHED

The natural water budget and allocation tables displayed in this report present an accounting of the water balance of the Deer Creek Watershed, but do not present the response of the watershed to stresses such as increases in pumping or surface water withdrawal. To better understand the natural response of the watershed to such changes, and how these changes might be observed, a numerical model of groundwater and surface water flow in the watershed was developed.

The groundwater flow model was assembled using MODFLOW-2000, a finite difference flow simulation code developed by the USGS (Harbaugh et al., 2000). The input data sets for the model were prepared using Groundwater Vistas (Rumbaugh, 2003). The model tracks and moves groundwater in the Deer Creek drainage, and simulates the response of groundwater to withdrawals from wells or streams and the impact of such movement to the base flow in Deer Creek and its tributaries.

The model grid consists of 95 rows and 159 columns. Row and column spacing is 1,000 feet uniformly (Figure 33). The model domain is approximately 18 miles long and 30 miles wide, and the basin boundaries are represented by no-flow boundary conditions, meaning that groundwater available for discharge into Deer Creek is limited to what infiltrates from precipitation in the topographically delineated watershed. Once it is in the aquifer, the groundwater cannot move to adjacent watersheds. The numerical model consists of two layers representing the saprolite/alluvial aquifer and the underlying fractured bedrock. Both of the model layers have a uniform thickness. The thickness of top and second layer is 50 feet and 350 feet, respectively. No horizontal anisotropy was incorporated in the layers, meaning that the resistance to groundwater flow is the same in all directions within the horizontal plane of the model. Incorporating this simplifying assumption into the model greatly reduces model complexity while allowing achievement of the goals for which the model was intended.

MODFLOW's stream package was used to simulate both Deer Creek, as well as its major tributaries. Overall, the stream network was simulated by 1,427 reaches and 338 segments. Monthly recharge was specified as a percentage of monthly precipitation, with the percentage varying with the amount of precipitation according to the relationship shown on Figure 32. The recharge rate to model grid cells with stream segments was adjusted to account for increased recharge relative to upland areas during wet periods and evapotranspiration during summer months using the relationship shown on Figure 34. Both of the recharge relationships shown on Figure 34 were defined during the model calibration process.

The basic hydrologic parameters used in the model are summarized in Table 27. Values of transmissivity and storage for the bedrock and saprolite/alluvium layers were based upon aquifer test data and previous hydrologic analyses (see Reference list). Final values were attained through model calibration. Similarly, the recharge function was developed based upon values typical for the Piedmont geology in Baltimore County.

The model was calibrated to groundwater levels and base flows in the main stream of Deer Creek for the period 1961 to 2004. The primary target of the calibration was to match

gaged flow at the USGS stream gages; appropriate recharge rates were assigned to achieve that match as closely as possible. The comparison between observed and calculated monthly base flows is illustrated on Figure 33, and the comparison between observed and calculated annual base flows is shown on Figure 34.

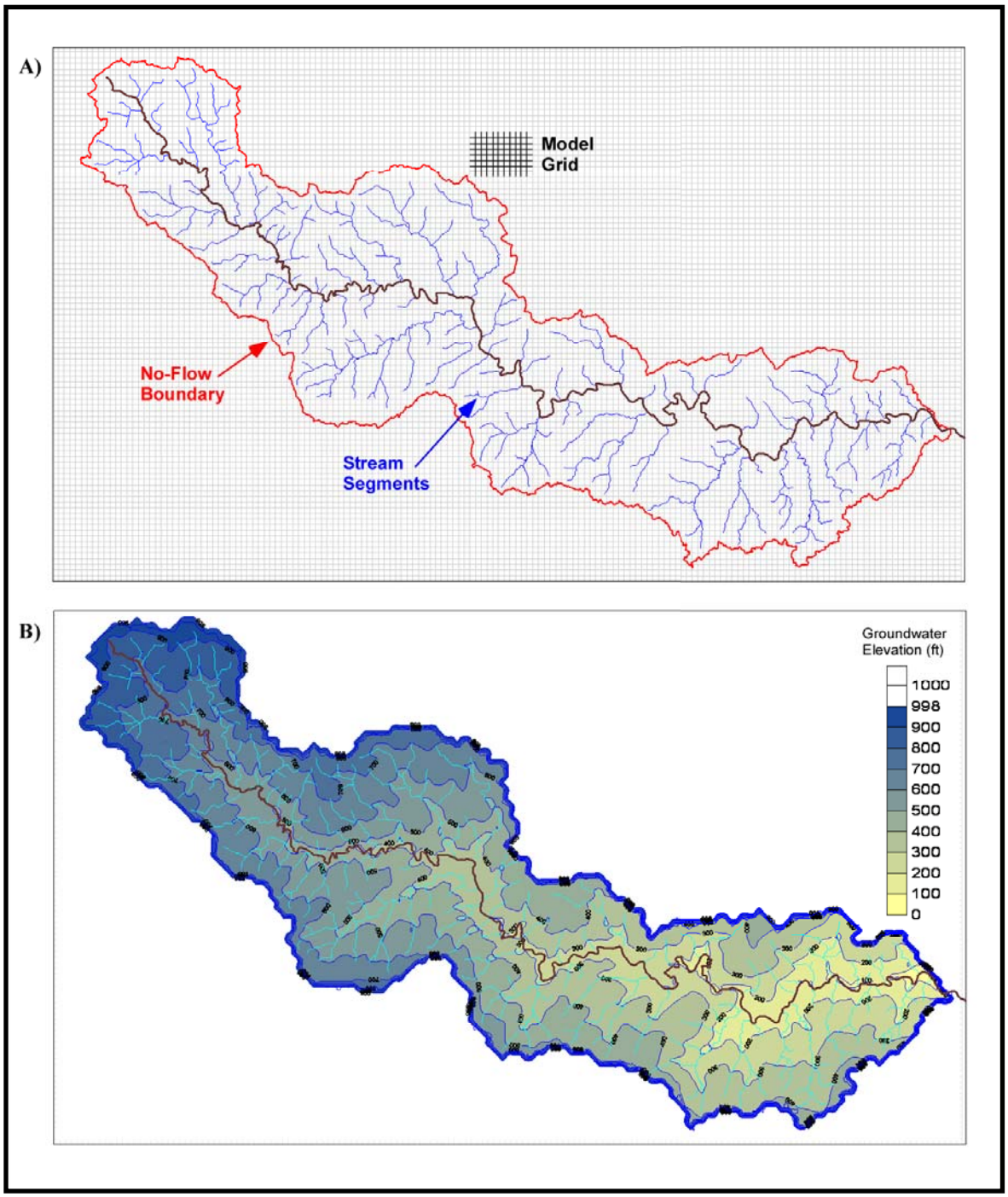
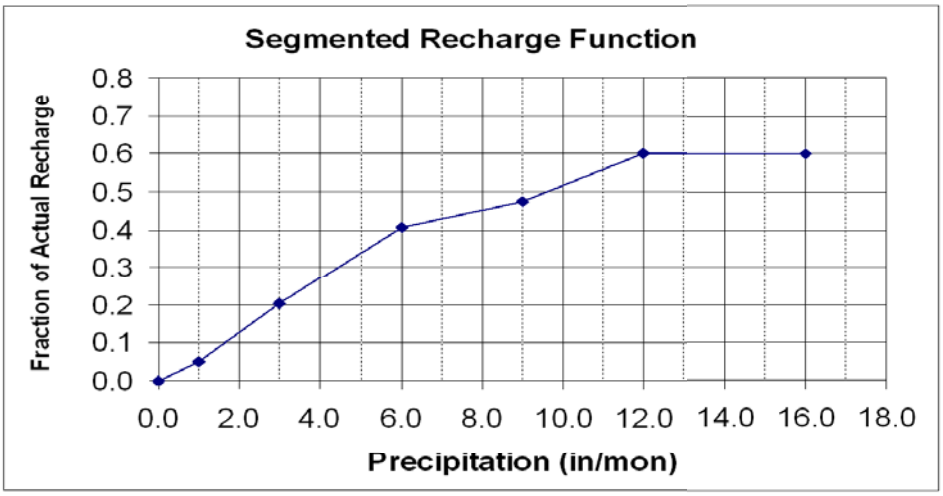


Figure 33. Grid Spacing, Boundary Conditions, and Stream Segments; (A) in MODFLOW Model; and (B) Groundwater Elevations in Layer 1 (Water Table)

Table 27. Hydrologic Parameters for MODFLOW Model

	Layer 1		Layer 2	
	Zone A (upstream)	**Zone B (downstream)**	**Zone A (upstream)**	**Zone B (downstream)**
Horizontal Hydraulic Conductivity (Kh) (feet/day)	5	5	2.2	2.2
Vertical Hydraulic Conductivity (Kv) (feet/day)	0.05	0.05	0.05	0.05
Specific Yield (Sy)	2.00E-06	1.00E-05	2.00E-06	1.00E-05
Storage Coefficient (Sc)	0.05	0.05	0.004	0.004



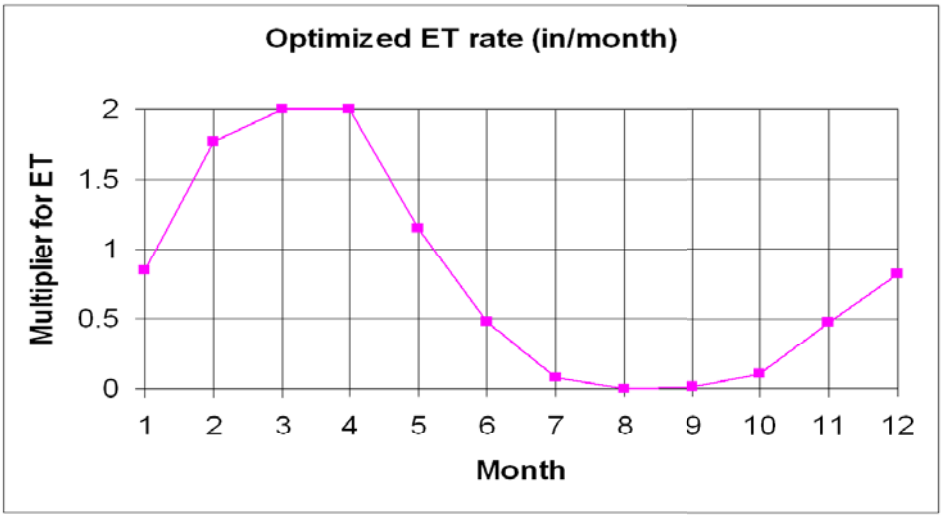


Figure 34. Recharge and Evapotranspiration (ET) Functions Used in MODFLOW Model

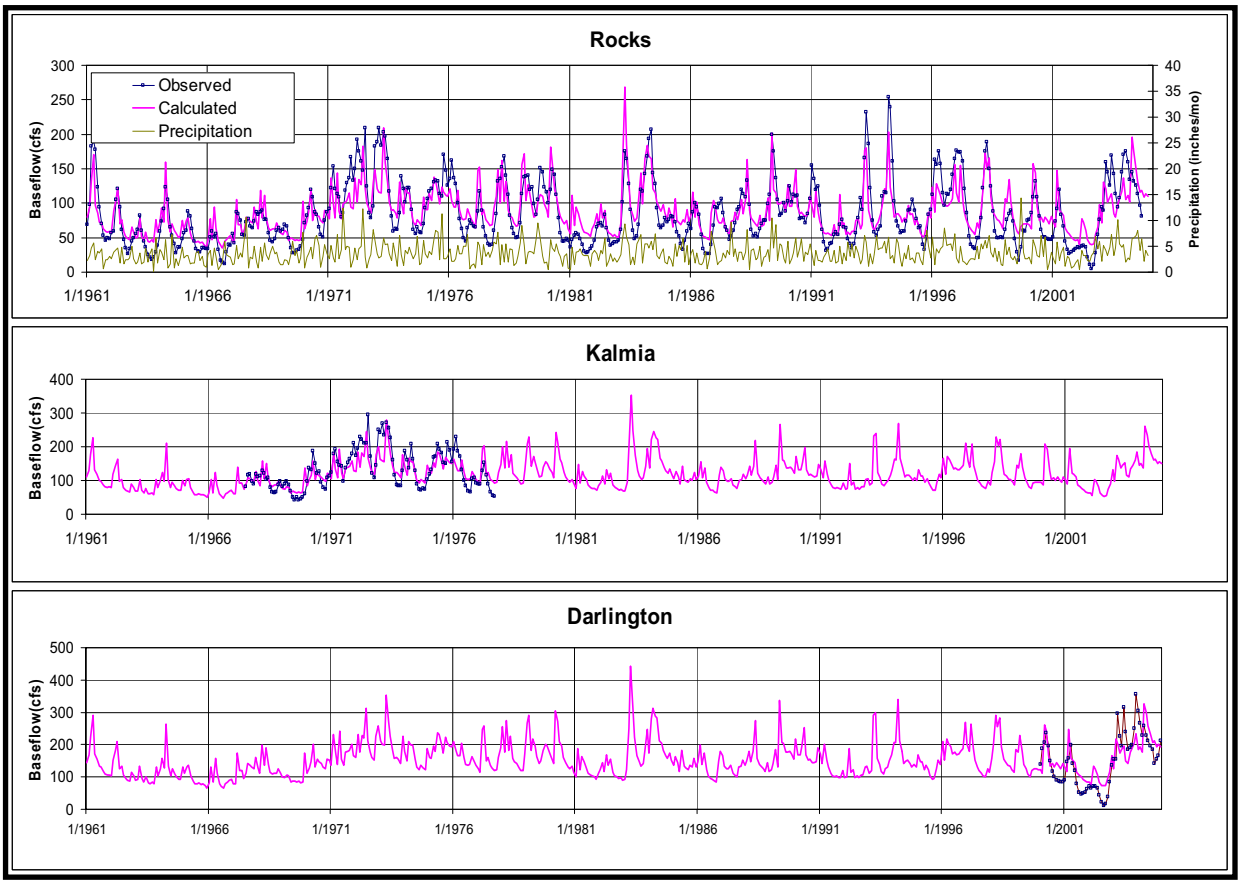


Figure 35. Observed and Calculated Base Flows for 1961 to 2004 – MODFLOW Model

On Figure 35, the plots of the calculated base flows at the three gage locations (red line) mimic very well the plots of the observed base flows (blue line), indicating successful modeling of the watershed's monthly base flows.

On Figure 36, the calculated and observed base flow values for each year of available record at the three gage locations are plotted against each other and shown relative to a line representing equivalence. The closer the plotted points fall to the red equivalence line, the better the calculated base flow values compare to the observed values. There are not a significant number of records available at Kalmia and Darlington, but the many years of record at the Rocks gage span the spectrum of hydrologic conditions from very dry to very wet. As shown by the proximity of the blue dotes to the red line, the model was successful at predicting base flow values at both extremes.

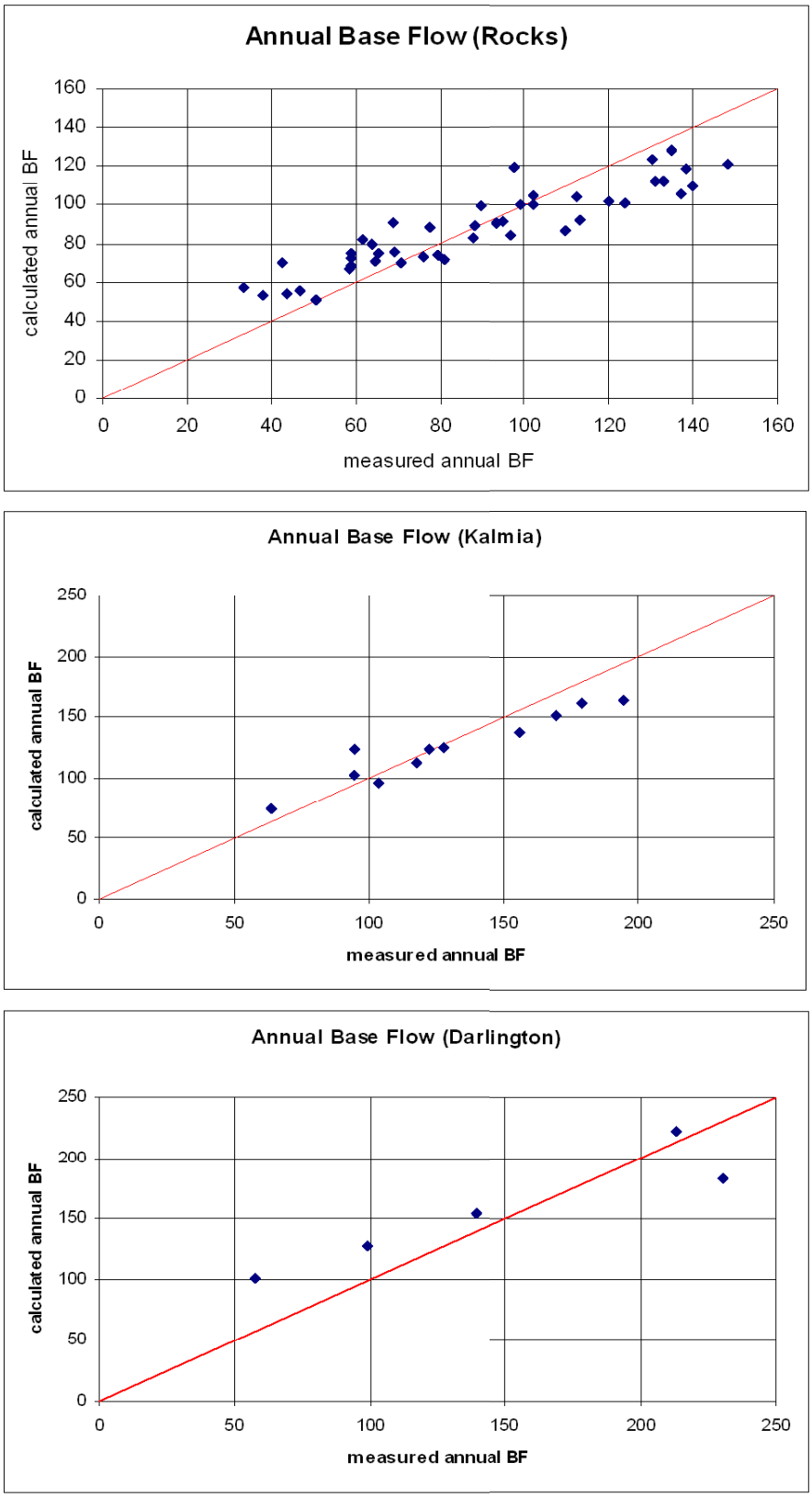


Figure 36. Scatter Diagrams for Annual Base Flow at U.S. Geological Survey Gages

As per the conceptual hydrologic model for the Maryland and Pennsylvania Piedmont (Figure 6), groundwater flow in the model is generally local and closely linked to local recharge/discharge areas. In contrast, depletions of base flow due to groundwater use can impact the base flow in all stream segments downstream of the pumping. The total base flow in each stream segment is the sum of base flow accumulated in that segment, as well as base flow from any upstream tributaries. Groundwater withdrawn from the bedrock is initially replaced by release of groundwater from storage. As the area of groundwater depletion expands over time, the depletion from storage is replaced by depletion of flow from the nearest stream segment. For a non-first-order stream segment, the total base flow depletion may include base flow derived from upstream tributaries. Any base flow depletion due to pumping is therefore unavailable downstream as well.

As noted above, the model was developed using regional calibration parameters, and a cell size of 1,000 feet. Although the model parameters are appropriate for analyses at the scale discussed here, there are local variations in geological and hydrogeologic conditions that are not incorporated into the model. These may include local variations in layer thickness, hydraulic conductivity, storage coefficients, or recharge. Use of the model for larger-scale (smaller area) evaluations should consider potential impacts of the cell size and local conditions on the results.

A. Results – Impact of Pumping on Streamflows

The primary use of the groundwater flow model is to evaluate the interaction between groundwater use and discharge to surface water (base flows) in the streams of the watershed. To evaluate this in a general way, we considered hypothetical water use scenarios in which new "well fields" were developed, and the response in the streamflow was observed.

Figure 37 illustrates the locations of the hypothetical well fields with respect to the watershed and stream segments. The well fields were situated so as to simulate the effects of pumping at varying distances from the main stem of Deer Creek. At each well field, unit pumping rates of 100 and 200 gpm were simulated for a period of 3 years. The results are shown on Figure 38.

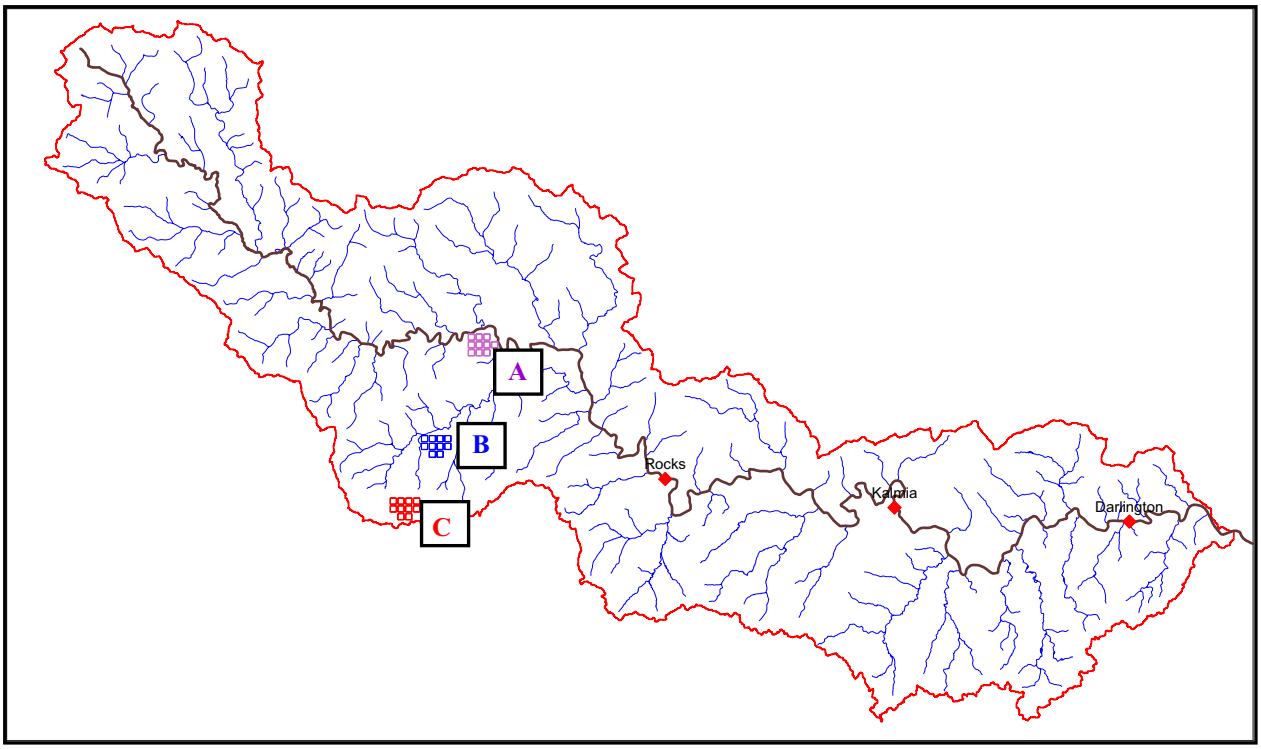


Figure 37. Locations of Hypothetical Well Fields (A, B, and C) in Modeling Domain

Under any scenario, the total volume of groundwater extracted by pumping will be compensated by a reduced volume of base flow in Deer Creek exactly equal to the amount pumped. If a well is operated for a short period of time, the change in base flow will not equal the pump rate, as some of the water that is pumped comes from a change in amount of water stored in the subsurface. When pumping from the well ceases, though, changes in base flow continue to occur until the water that was removed from storage is replenished. If a well is operated for a long period of time, after some period of pumping, all water will be derived from water that otherwise would discharge to the stream, and the change in base flow will equal the pumping rate. A pumping rate of 100 gpm is equivalent to a flow of 0.228 cfs. As can be seen from Figure 38, under all three modeled scenarios, the maximum impact of the 100 gpm pumping is about 0.23 cfs. The irregularities in the shape of the curves are artifacts of the numerical methods used to calculate the flows and their differences.

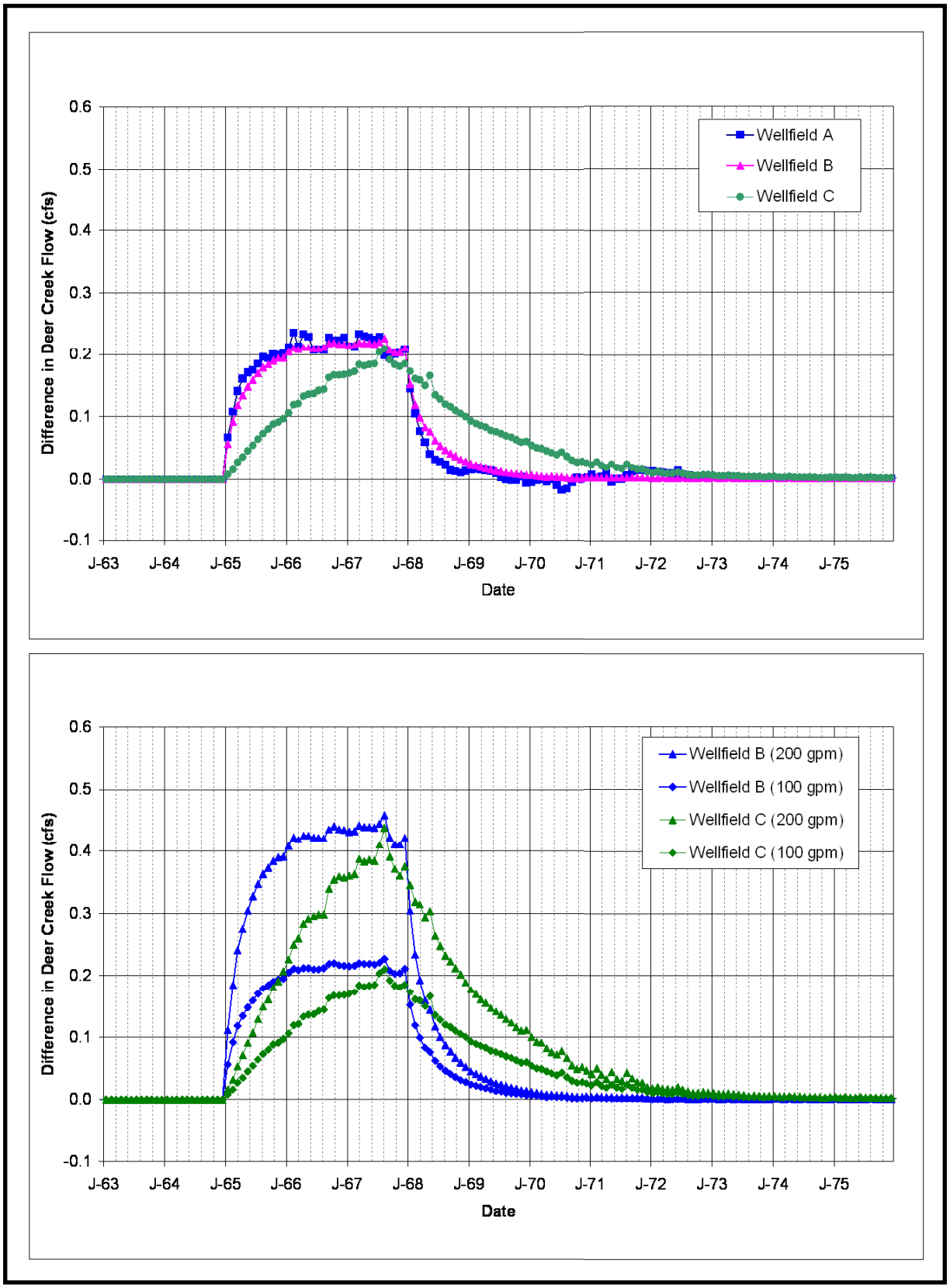


Figure 38. Difference in Base Flow in Deer Creek due to: (A) 100 gpm Pumping in Each Well Field; and B) Pumping at 100 or 200 gpm

The key differences between the three well field scenarios are the times until the maximum impact is observed in base flows. In the Deer Creek Watershed, there is a mature and extensive network of tributaries, all of which are gaining or discharging base flow from groundwater. Consequently, the primary indicator of how quickly a well field will impact the total flow in Deer Creek is its proximity to a tributary. Well fields A and B, while situated at different distances from the main stem of Deer Creek, have nearly identical curves for impact versus time on the Deer Creek base flow. The maximum impact on Deer Creek base flow is felt within about one year of pumping. While well field B is located miles from Deer Creek, it is adjacent to Little Deer Creek and its tributaries. Consequently, the base flow from the Little Deer Creek is diminished, ultimately reducing the total base flow for the Deer Creek main stem in about the same period of time as well field A situated immediately adjacent to Deer Creek.

Well field C was situated to be as far from Deer Creek or its tributaries as possible within the model domain. As can be seen, the maximum base flow impact (~0.21 cfs) is attained in about 2.75 years. We estimate that 2.75 years would be the maximum time until complete impact of a new pumping project would be observed on base flow in Deer Creek. For comparison, the same model was run, but using a total pumping rate of 200 gpm. As can be seen from Figure 38, the timing of impacts from well fields B and C are nearly identical, regardless of the pumping rate. The total impact is, however, twice as large for the 200 gpm scenario as for the 100 gpm scenario.

Although model results showing the direct impact of groundwater withdrawals on the availability of Deer Creek water resources would seem to suggest that such withdrawals conflict with desirable resource management, which is not necessarily the case. Because some water initially comes from storage when pumping begins, the use of wells as an alternative to surface water withdrawals during times of drought has the potential to avoid undue adverse impacts. Depending on the proximity of the well to the affected stream reach, a well could supplement a surface water intake for between 1 and 2.75 years before the impact is fully realized. In watersheds like Deer Creek with interrupted availability, the conjunctive use of surface and groundwater supplies is often a successful strategy.