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Groundwater Flow Model of Corrective Action Units 101 and 102: Central and Western Pahute Mesa, Nevada Test Site, Nye County, Nevada

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8.0 THERMAL SENSITIVITY AND VERIFICATION

8.1 Introduction

The flow model calibration described in earlier sections utilizes a thermal field based upon calibration of the heat flux at the base of the model domain (Appendix C). In calibrating the heat fluxes with a conduction-only model to minimize residuals between observed and simulated temperatures in boreholes, certain anomalies were identified indicating convective flow. These anomalies indicate that cooler water from near the water table is likely flowing vertically downward, resulting in borehole temperatures cooler than would be explained with the pure convection model. Therefore, Section 8.2 investigates whether such downward flow is captured with the calibrated flow model, thus providing qualitative confirmation. Section 8.3 investigates the sensitivity (qualitatively again) of the variable heat-flux-based temperatures as compared to much simpler linear temperature profiles in the flow model.

8.2 Flow Model Verification to Vertical Flow Indicated by Temperature Analysis

The role and potential value of thermal data analysis for constraining groundwater flow models is presented in Appendix C. One of the primary results of that analysis is the identification of specific locations where pure vertical conduction of heat does not adequately explain thermal anomalies observed in borehole temperature profiles. The process of identifying such locations involved calibrating heat-conduction-only models to the thermal data in the Pahute Mesa CAU model domain (described in Appendix C). Then, following calibration, temperature datasets that still are not matched well and that show a systematic variance from the conduction-only simulations are examined with respect to other datasets and potential vertical groundwater (and hence heat) convection. Four locations within the CAU flow model domain where downward vertical flow would explain convective cooling are discussed in detail in Appendix C. They are summarized here, and the flow model is evaluated for consistency with respect to the hypothesized downward flow through the use of reverse-particle-tracking simulations. Only the BN-MME-LCCU1 reduced permeability alternative is evaluated here, but the results are qualitatively representative for any of the calibrated flow models.

8.2.1 Southwestern Silent Canyon Caldera

In the southwestern part of the SCCC, it is likely that the deep heat flux is actually higher than the heat flux of 73 milliwatts per square meter (mW/m^2) estimated for the caldera complex as a whole with the variable heat-flux model described in Appendix C, and that cool groundwater from the shallow saturated zone flows downward through the upper units. These interpretations are supported by a detailed examination of temperature residuals from this area. The heat-conduction model with a uniform heat flux of 85 mW/m^2 provides a good match to the measured temperatures at borehole ER-EC-6, but underestimates the deepest measurement in the region – the temperature of 121 degrees Celsius (°C) measured at a 12,270 ft depth in borehole UE-20f. Conversely, simulated temperatures in nearby boreholes U-20c, U-20d, and ER-20-5 #3 in the southwest part of the caldera complex are warmer than the measured temperatures for deep heat fluxes of either 85 or 73 mW/m^2. A heat flux of 85 mW/m^2 would improve the match between simulated and measured temperatures at boreholes UE-20f, ER-EC-6, and ER-EC-1, where measured temperatures are underestimated by the model with a deep heat flux of 73 mW/m^2 for the SCCC. However, the use of a higher heat flux in the heat-conduction model would increase the mismatch between simulated and measured temperatures at boreholes U20c, ER-20-5 #3, and U-20d, which the model indicates are already too warm for a heat flux of 73 mW/m^2.

To offset the temperature increases that would result from higher deep heat fluxes, a mechanism to cool the subsurface temperatures in the southwestern part of the SCCC is required. The downward hydraulic gradient, dipping beds, and discontinuous HSUs across faults in the upper part of southwest Area 20 (Wolfsberg et al., 2002; BN, 2002, cross-sections J-J’ and C-C’) indicate that hydrogeologic conditions are favorable for cool groundwater near the water table to flow downward along the dipping beds or faults to deeper aquifers such as the IA, thereby reducing temperatures and heat fluxes below the wells in this region.

To test this hypothesis, a reverse streamline particle-tracking simulation (SPTR Module in FEHM simulation) was conducted for calibrated flow model BN-MME-LCCU1 reduced permeability alternative with 1,000 particles originating in the IA, below ER-20-5 #3 (which terminates in the

CHZCM). Figure 8-1 shows the particle paths moving upgradient and to higher elevations from their origin. This simulation confirms that cool shallow water from central and northern Areas 20 and 19 can flow vertically to deeper units. In this case, the primary elevation drop occurs at the West Greeley Fault, the Boxcar Fault, and within the block between the two faults. The movement of cool shallow water to depths below wells such as ER-20-5 #3 would result in the observed cooler temperatures, which lead to lower-than-expected estimations of deep thermal flux in conduction-only models.

8.2.2 Northeastern Silent Canyon Caldera

In the northeastern part of the SCCC, the simulated temperatures are higher than the measured temperatures at borehole U-19e for the calibrated variable heat-flux conduction model. Although the temperature data at borehole U-19e are reasonably well matched with a uniform heat flux of 45 mW/m^2, temperatures at borehole U19-i, located about 5 km (3 mi) to the south of borehole U-19e, are underestimated using this low heat flux, and better matched with a heat flux of 85 mW/m^2 (consistent with what is reasonable for other parts of the Silent Canyon Caldera). A hydrologic explanation is that downward groundwater movement through the Halfbeak Fault or Split Ridge Fault and along the down-dipping Belted Range Aquifer (BRA) (see BN, 2002, cross-section C-C’) significantly cools the rocks and reduces heat flux near borehole U-19e.

To test this hypothesis, a reverse-particle-tracking simulation was conducted for calibrated flow model BN-MME-LCCU1 with 1,000 particles originating in the BRA below ER-19e. Figure 8-2 shows the reverse-particle paths moving upgradient to the Split Ridge Fault, which defines the Silent Canyon Caldera Margin, and then vertically upward to the water table. This simulation confirms that cool shallow water from the northeast can flow vertically to deeper HSUs along the Silent Canyon Caldera margin. In this case, the primary elevation drop occurs at the Split Ridge Fault, with additional elevation drop along dip with the BRA. The elevation drop of cool shallow water to depth below Well U-19e would result in the observed cooler temperatures, which lead to lower-than-expected estimations of deep thermal flux in conduction-only models at this well.

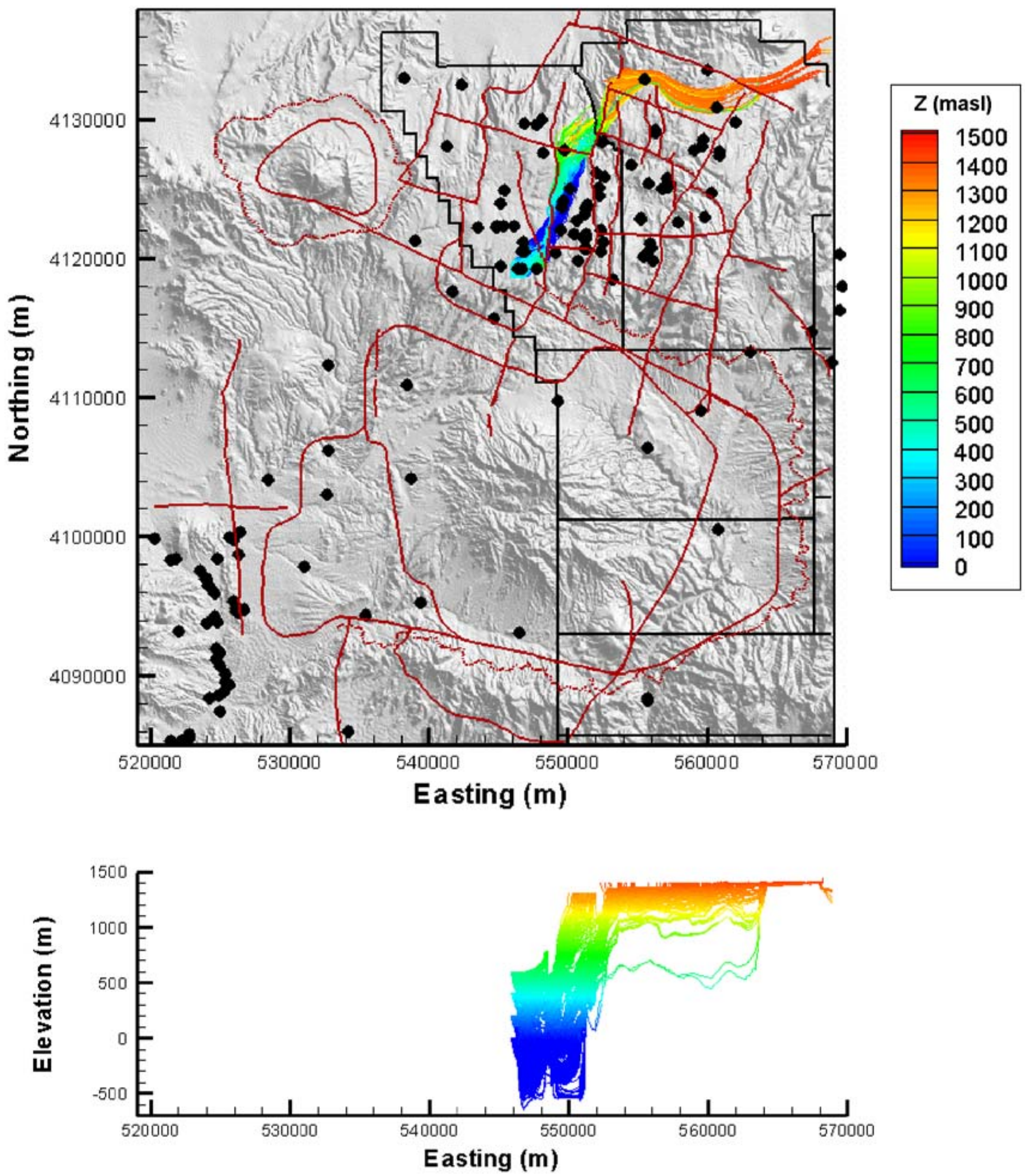

Figure 8-1
Reverse-Particle Paths Originating in Inlet Aquifer Below ER-20-5 #3
Simulated for the BN-MME-SDA Reduced LCCU1 Permeability Alternative Flow Model

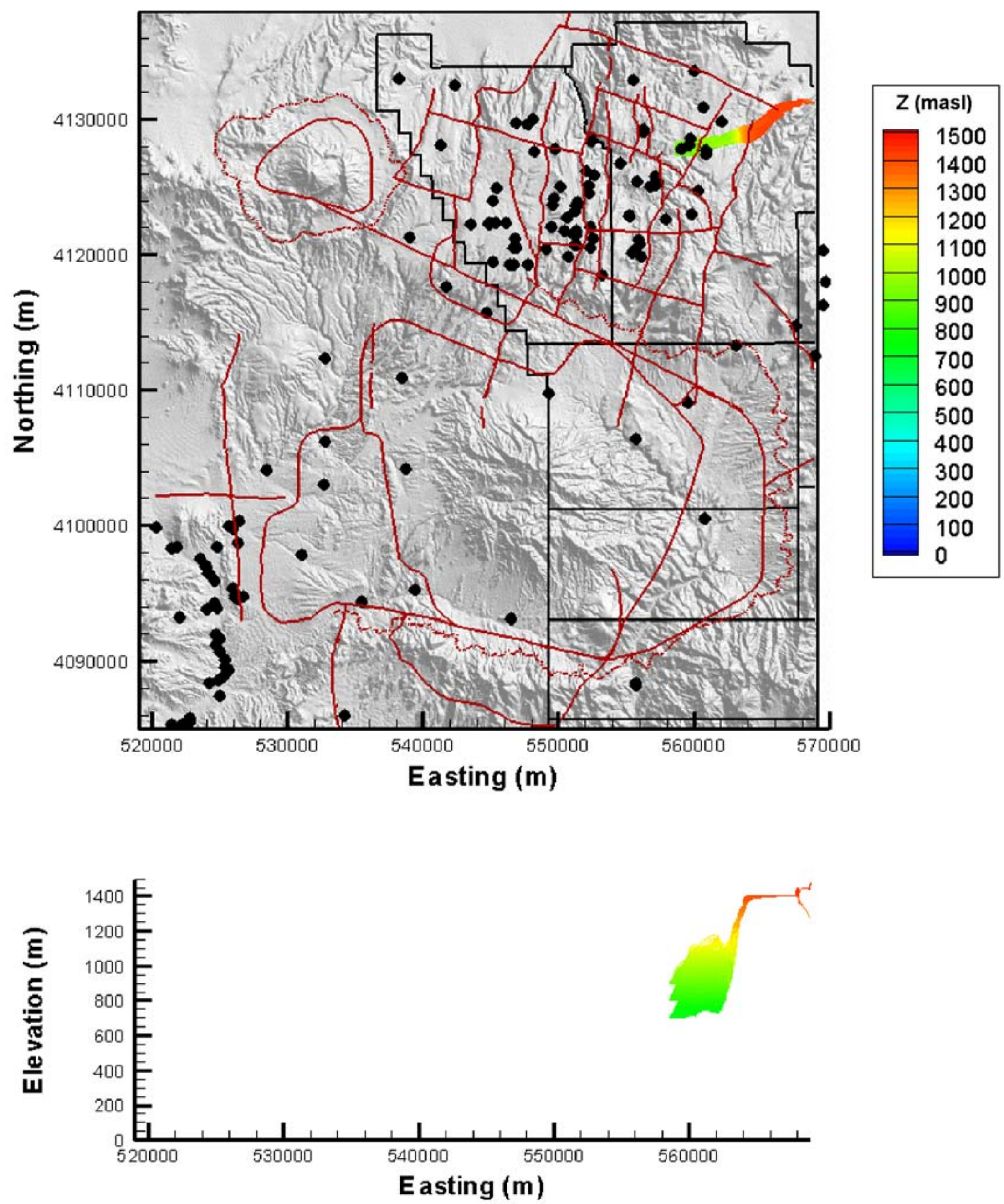

Figure 8-2
Reverse-Particle Paths Originating in UE-19e for BN-MME-SDA Reduced LCCU1 Permeability Alternative Flow Model

8.2.3 Eastern Timber Mountain Caldera

Borehole UE-18r was characterized by Gillespie (2003) as having dominantly conductive heat flow (about 25 mW/m^2) and reliable temperature measurements above the bottom of the borehole casing at a depth of 496.5 m (elevation 1,192 m). Unfortunately, simulated temperatures at these elevations are dominated by the upper boundary conditions and are insensitive to the assumed thermal conductivity estimates and lower boundary conditions. Hence, it was necessary to use a deep temperature measurement from below the borehole casing as a calibration target in the inverse models. The simulated temperatures are significantly warmer than this deep measurement from borehole UE-18r for all lower boundary conditions considered in this report. The consistent overestimation of the measured temperature indicates that downward groundwater flow may have cooled the rocks near the bottom of the temperature profile. Borehole UE-18r penetrates a fault breccia at depth, which suggests that groundwater flow along the fault associated with this breccia or a nearby similar fault may have cooled nearby temperatures. This interpretation is also consistent with the relatively low heat flux of 25 mW/m^2 estimated by Gillespie (2003, Table 7) above elevations of 1,192 m and the much larger heat flux (greater than 75 mW/m^2) estimated below the elevation of 443 m. Based on one-dimensional scoping simulations (Appendix C), heat flux is expected to decrease with elevation in areas of downward groundwater flow. However, groundwater carbon-14 measured in the borehole is very low (Chapman et al., 1995), ruling out modern recharge as a likely influence on groundwater temperatures and suggesting that the downward movement of groundwater from laterally upgradient areas is a more likely explanation for the decrease in heat flux with elevation at borehole UE-18r.

Figure 8-3 shows the reverse-particle paths originating in the fault breccia zone of UE-18r for BN-MME-LCCU1 reduced permeability alternative. The paths show a major elevation change along the Timber Mountain Caldera structural margin fault (the fault intersected by UE-18r is not explicitly identified in the CAU flow model). As the reverse particles encounter the fault, they change elevation drastically. Also consistent with the age consideration mentioned above, the reverse particles do not leave the system immediately upon gaining shallow depths. Rather, they move laterally until finally leaving the flow model at higher elevations in Area 19. The combination of the distance between where the recharge occurs and UE-18r coupled with the permeability of the porous media may be sufficient to produce large residence times that would result in low carbon-14 signatures.

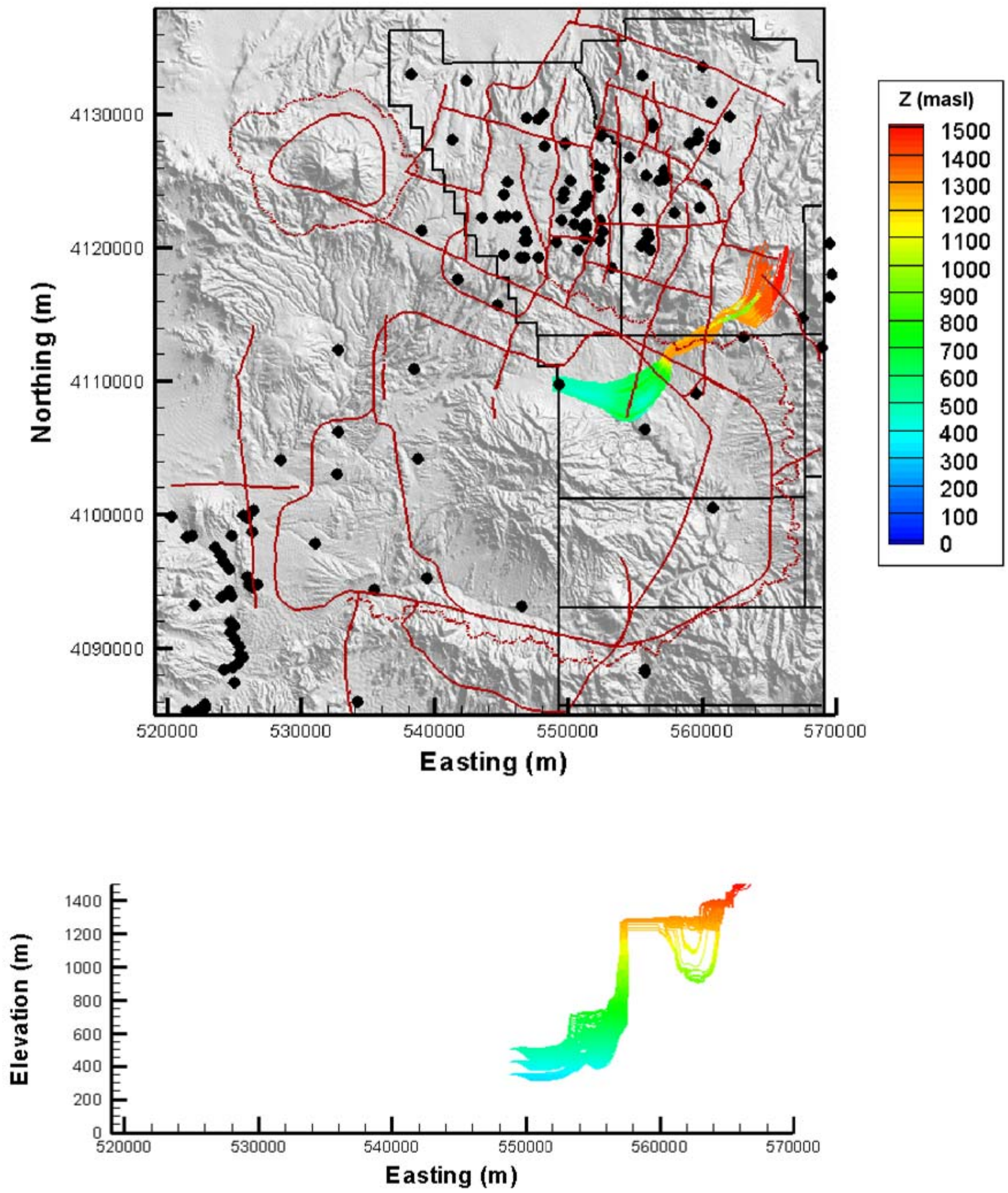

Figure 8-3
Reverse-Particle Paths Originating in the Fault Breccia Lithologic Subunit of the Timber Mountain Composite Unit at UE-18r for BN-MME-SDA Reduced LCCU1 Permeability Alternative Flow Model

8.2.4 Extra Caldera Zone Western Timber Mountain Caldera

Measured temperatures at borehole ER-EC-4 are consistently cooler than the temperatures calculated with the calibrated variable heat-flux model. These temperature differences, along with a decrease in the estimated heat flux from 54 to 28 mW/m^2 through the lower part of the borehole, indicate the presence of downward groundwater movement affecting temperatures below this borehole. One hypothesis that explains the low temperatures and heat flux at borehole ER-EC-4 is that cool shallow groundwater in the northwest flows to depth in this area within the southward dipping LCA (BN, 2002, cross-section G-G'). As groundwater moves southward through this area, the downward flow component induced by the dip of the beds causes the groundwater to become warmer, thereby consuming heat and decreasing the temperature and heat flux in the overlying rocks.

Figure 8-4 shows the complex origins of water in the LCA below ER-EC-4 as mapped with 1,000 reverse tracking particles in model BN-MME-LCCU1 reduced permeability alternative. The primary sources include: (a) a small component from the northeast, (b) inflow within the LCA along the northern boundary, and (c) shallow groundwater between the Black Mountain and Silent Canyon Calderas north of ER-EC-4. The latter source is consistent with the hypothesis that cool, shallow water flows to depth below ER-EC-4, reducing the temperature and giving and apparent lower heat flux for conduction-only models. Likewise, LCA water entering along the northern boundary has a shallower and, thus, cooler source to the north of the model domain.

8.2.5 Summary

Four different locations within the CAU model domain were identified as being affected by downward-groundwater flow. Identification was made for thermal profiles in wells that could not be explained with a heat conduction-only model. Following these identifications, reverse-particle-tracking simulations were conducted to investigate whether shallow groundwater sources were feasible at the depths indicated in the heat-conduction study. For two locations within the Silent Canyon Caldera, one within the Timber Mountain Caldera, and one to the west of the Timber Mountain Caldera, these simulations demonstrate that the flow model qualitatively captures the convective components identified, thus supporting the hypothesis that convective cooling explains the apparent low conductive fluxes.

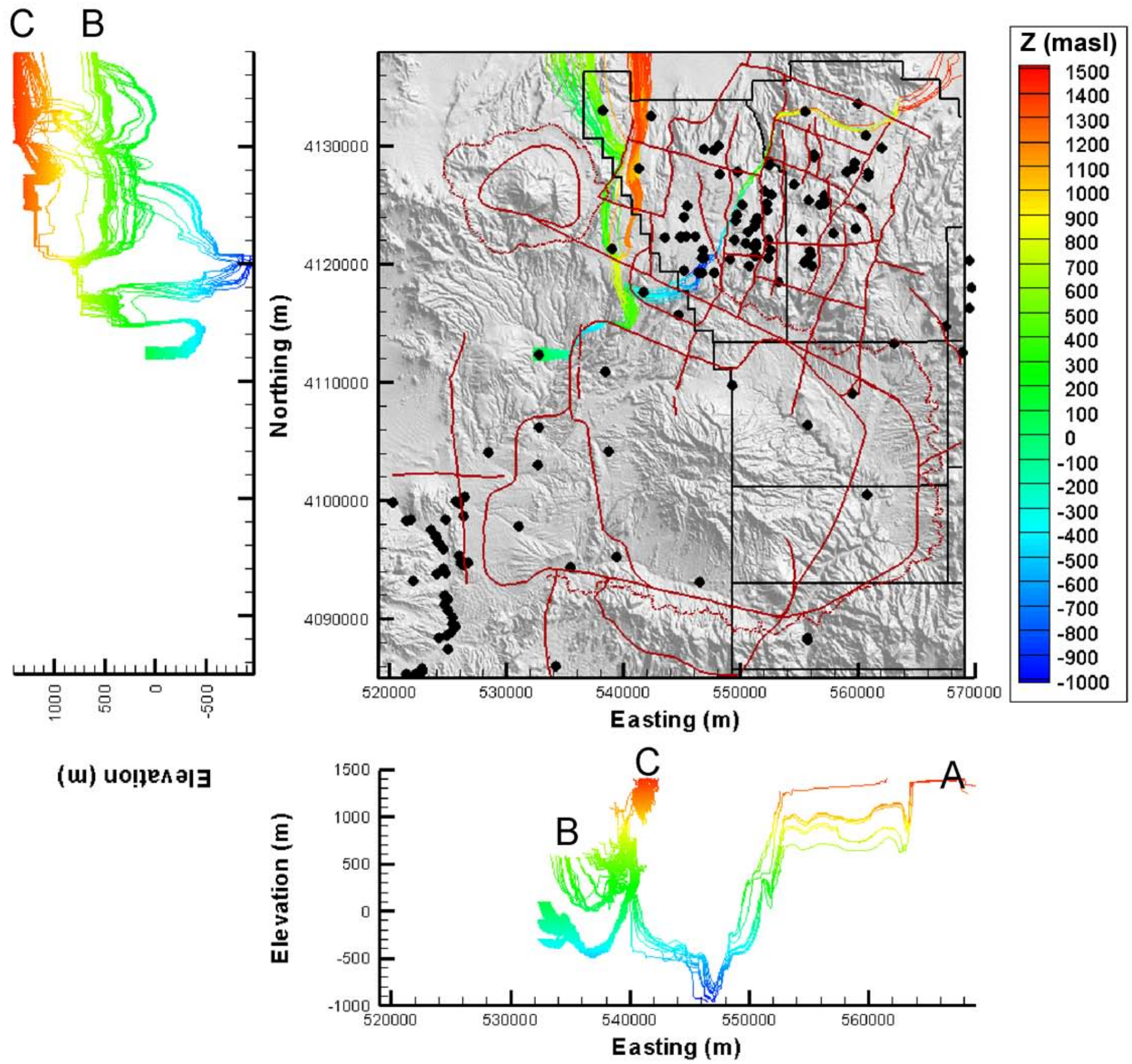

Figure 8-4
Reverse-Particle Paths Originating in the LCA Below ER-EC-4 for BN-MME-SDA Reduced LCCU1 Permeability Alternative Flow Model