APPENDIX A

Groundwater Modeling

Flow Model. KUCC developed a groundwater model of the southwestern Jordan Valley (SWJV) as part of the RI/FS to analyze flow paths and groundwater velocities in the principal aquifer and to evaluate remedial options. The model area extends from the bedrock/alluvial interface at the base of the Oquirrh Mountains on the west, to the bedrock/alluvial interface at the base of the Wasatch Mountains on the east, and from approximately 6000 South on the north to the base of the Traverse Mountains on the south. The model has eight sloping layers ranging in thickness from 100 to 400 feet. The model uses a three--dimensional, finite difference, numerical code called MODFLOW (McDonald and Harbaugh 1988) with a typical elemental size of 500 by 500 feet. This code is internationally accepted and was used for the Salt Lake Valley Regional Groundwater Flow Model developed by the United States Geological Survey (Lambert 1995).

Recharge to the principal and shallow unconfined aquifers comes from precipitation, bedrock aquifer, irrigation canals, irrigated fields, lawns and gardens, stream and channel fill, and reservoirs and evaporation ponds.

Water loss comes from well extraction, evapotranspiration and removal at head-dependent boundaries.

The model was calibrated for both steady and transient states. The steady state simulated hydrologic conditions in 1965. The transient state simulated the period between 1966 and 1998 and included annual stress periods. Calibration variables were adjusted within reasonable ranges, as determined from data collected by the RI and other work. KUCC considered the calibration process to be successful when a reasonable match was made between observed and modeled conditions for the years being simulated.

The calibrated transient model closely simulated observed water level declines and vertical hydraulic gradients throughout the SWJV, yielded reasonable groundwater flow to the Jordan River, and accurately computed flows through the northern boundary.

Transport Model. KUCC's calibrated groundwater flow model was then coupled with a contaminant transport code, MT3D, to model historical and future migration of storm and mine waste water that leaked from the former Bingham Creek reservoir.

Transport models attempt to combine groundwater flow with the physical aspects of contaminant transport, including advection, dispersion and chemical reactions. Although a flow model can provide information about contaminant migration through the use of particle tracking techniques, these techniques do not provide information about the concentration of a contaminant at a given point in time and space. Transport modeling is different from particle tracking because it considers dispersion and the effects of chemical reactions and produces a three-dimensional distribution of concentrations with time. The KUCC transport model report is presented in the 1998 South End Groundwater RI, Appendix G.

The transport model was calibrated to observed 1996-1997 sulfate concentrations down gradient of the former Bingham Creek reservoirs. Calibration was achieved by finding a set of transport parameters (i.e., retardation, dispersivity and porosity) within an accepted range that reasonably reproduced field-measured concentrations. The large amount of data available for calibration provided good control for the rate and direction of plume movement. For example, the transport model was able to reproduce the southeast component of the sulfate plume geometry. The model was then expanded to include the sulfate contamination near the former KUCC evaporation ponds.

The transport model uses the following parameters for simulation and calibration:

- Specified concentration cells on the western and southern boundaries to simulate alluvial underflow and flow from the bedrock aquifer to the principal aquifer.

- Specified concentrations for the Large Bingham Creek Reservoir from 1965 to 1991, and for infiltration from precipitation.

- Retardation of sulfate, that was varied as a function of sulfate concentration, and constant porosity, were used for all layers.

The transport model is an approximation of the field environment. Many of the transport parameters are not known absolutely, and change in any of them can affect the results. Other limitations almost certainly include local, but significant variations in the hydrogeology of the principal aquifer, uncertainties in the flow model and boundary conditions, density dependent flow, and the lack of modeling of geochemical reactions, particularly neutralization. However, geochemical reactions are partially mimicked in the transport model through the use of the retardation factor. Nevertheless, the model is probably a reasonable first approximation of the kinematics of the Bingham Creek and former evaporation ponds plumes and allows the feasibility of various remedial strategies to be tested.

Hydrogeology

Groundwater Recharge. The principal aquifer is recharged from surface infiltration of precipitation, irrigation water and canal water, bedrock inflow, and to a limited extent from surface infiltration of waters emanating from Butterfield Creek. The bedrock of the Oquirrh Mountains provides recharge to the groundwater in the western part of the SWJV, and this groundwater then travels eastward into the basin. Aquifer recharge is greater in the eastern part of the SWJV and in the Herriman area due to recharge from surface water.

Groundwater Extraction. Most of the water extracted from the principal aquifer is used for municipal or industrial purposes. The largest extractions in the study area, in or near the Affected Area, are from the West Jordan and Riverton city well fields and KUCC process water wells. West Jordan City extracted an average of 6,012 acre-feet per year (afy) from 1990-1996 (West Jordan City 1996); Riverton City extracted about 3,300 afy (Lambert 1995). Kennecott production wells (1193 and 109) extract about 5,000 to 5,400 afy.

Groundwater Potentiometric Surface. The average depth below ground surface to the potentiometric surface in the principal aquifer of the SWJV is about 235 ft. Groundwater flow is predominantly west to east from the base of the Oquirrh Mountains to the Jordan River. Groundwater in the principal aquifer near the Traverse Mountains generally flows to the northeast, changing to an easterly flow near the center of the basin.

Groundwater Elevation Changes. Groundwater elevations declined substantially throughout the SWJV from 1986 to 1996. Water-level declines observed during this period are as much as 81 feet, depending on location in the aquifer. The largest declines have occurred in the West Jordan City well field area (81 feet) and near KUCC process water wells (72 feet). The rate of decline in this area has averaged 4-8 ft/yr. The rate of decline increased substantially during 1991-1996 due to increased pumping by West Jordan City.

Water-level declines along the eastern boundary of the KUCC waste rock piles have averaged 0.7 ft/yr since 1986. Some of this decline may be associated with the upgraded Eastside collection system, but is more likely due to several years of below-average precipitation during the late 1980s and early 1990s.

The overall average rate of water-level decline for the SWJV was approximately 2.4 ft/yr from 1986 to 1996. The continued decline of groundwater elevations, and the relatively rapid increase in decline in recent years. indicates that more groundwater is being removed from the principal aquifer than is currently supplied by natural recharge.

Hydraulic Gradients. Horizontal hydraulic gradients in the SWJV vary considerably depending on the region. They are generally steeper near the mountains and shallower in the valley. Along a flow line from the Oquirrh Mountains to the Jordan River, the average composite horizontal hydraulic gradient is approximately 0.025.

Upward vertical hydraulic gradients are greatest near the base of the Oquirrh Mountains. Downward vertical gradients are present east of the Bingham Creek reservoir system and near the KUCC production wells. In the center of the western side of the basin (east of 1193 and 109 to the former KUCC evaporation ponds), vertical hydraulic gradients are nearly non-existent. Both upward and downward gradients are found east of the former KUCC evaporation ponds, that reflects infiltration from canals and regional flow of groundwater to the Jordan River, respectively. Near the Jordan River, the vertical gradients are upward. Location variations in vertical gradients are also observed around municipal and KUCC well fields.

Groundwater Velocity. Average horizontal groundwater velocities are based on Darcy's Law, using average gradients and hydraulic conductivity, and an effective porosity of 0.225, which is typical for gravel (Freeze and Cherry 1979). The overall linear groundwater velocity, based on a groundwater flow path from the Oquirrh Mountains to the Jordan River, is about 550 ft/yr (standard deviation of ± 525 ft/yr). This velocity is based on an average gradient of 0.025. In general, the average linear velocity of groundwater between the Oquirrh Mountains and Highway 111 is lower than farther east in the KUCC production well area. The lower velocity near the mountain front is due to lower hydraulic conductivity material (volcanic gravel) than in the production well area, which consists of quartzitic gravel.

Isotopic data, specifically tritium and CFCs (chlorofluorocarbons), also allow an estimate of average linear groundwater velocity. In 1997, six CFC samples were collected along a flow line of the plume extending from the former Bingham Creek reservoir to the eastern edge of the plume (Solomon and Bowman 1997). Monitoring well P190A, located southeast of K60 just down gradient of the former Bingham Creek reservoir sulfate plume, yields a CFC-12 recharge age of 1961, which is consistent with the observed tritium activity in this well. The computed travel time from the Bingham Creek reservoir to P190A is 36 years, which yields an average linear groundwater velocity of about 500 ft/yr. Because dispersion (i.e., mechanical mixing of two fluids in the aquifer) could increase flow rates, this velocity may be in error by about 30 percent, suggesting a range in average groundwater velocity from 500 to 650 ft/yr.