Appendix 4.3-A

Assessment of Groundwater Corrective Action Alternatives

TECHNICAL MEMORANDUM

To: Brad Bingham, Closure Manager	**Date:** June 2022
From: Toby Wright Wright Environmental Services, Inc.	**Subject:** Homestake Mining Company Grants Reclamation Project Assessment of Groundwater Corrective Action Alternatives
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1 Introduction

This Technical Memorandum presents analysis of the corrective action alternatives and selection of the Proposed Action based on results from calibrated base-case groundwater flow and transport models described in Section 3.1 of the Alternative Concentration Limit (ACL) Application for the Homestake Mining Company (HMC) r Grants Reclamation Project (GRP) near Grants, New Mexico. the development of the predictive groundwater flow and transport simulations for each alternative is presented in Appendix 4.2-B of the ACL Application. The corrective action alternative predictive simulations use the calibrated base-case model runs (best-estimate long-term input conditions). This assessment focuses on achieving the Nuclear Regulatory Commission (NRC) License SUA-1471 (License) groundwater protection standard for uranium as the metric for overall alternative performance. No lower Point of Exposure (POE) concentration targets are considered for assessment of alternatives and selection of the Proposed Action. Assessment of costs and benefits for all alternatives, presented in Section 4.4 of the ACL Application, are used to confirm that the previous 45 years of corrective action have reduced concentrations to levels that are both protective of public health and the environment and ALARA. Three corrective action alternatives have been identified for detailed analysis and comparison and include combinations of all engineering-feasible, practicable technologies and processes options:

- Alternative 1 – Groundwater Containment and Removal (No Action)
- Alternative 2 – Groundwater Containment and Removal and *In Situ* Treatment
- Alternative 3 – Alternate Concentration Limits

The following sections summarize the results of that modeling and analysis of the alternatives using eight evaluation criteria, and compare each alternative's relative performance for each evaluation criterion.

1.1 Evaluation Criteria

The evaluation of practicable corrective action alternatives, as identified in Section 4 of NUREG-1620 (NRC, 2003) should assess "*…the technical feasibility, costs, and benefits of each alternative.*" Finally, this evaluation addresses the ability of the corrective action alternative to assure protection of public health and the environment. Analysis of technical feasibility is addressed under the following criteria:

1. Protection of Human Health - Occupational Health and Safety
2. Protection of Human Health - Public Health and Safety
3. Protection of the Environment - Risks to Wildlife

4. Protection of the Environment - Preservation of Groundwater Resource
5. Implementation - Ability to Construct and Operate
6. Implementation – Administrative Feasibility
7. Implementation – Restoration of Resource
8. Implementation - Source Reduction and Control

These evaluation criteria are addressed qualitatively, as discussed further below. In the following sections, each alternative is assessed as fully meeting, partially meeting, or not meeting each evaluation criterion. The remedial action objectives, summarized below, are addressed in these evaluation criteria.

- Prevent human ingestion of contaminated groundwater.
- Restore groundwater quality in the alluvium, Upper Chinle, Middle Chinle, and Lower Chinle.
- Reduce seepage and migration of constituents from the tailing piles to groundwater.

Costs are not used as a criterion to select the Proposed Action.

1.1.1 Protection of Human Health – Public Health

Protection of human health is assessed considering both public health and worker occupational health associated with constructing and operating an alternative. Public health is assessed considering the human access pathway to groundwater and considering maximum predicted POE concentrations in relation to the License groundwater protection standards. Predicted maximum groundwater concentrations from base-case calibrated predictive groundwater model simulations at representative POE are assessed for each alternative. Fully meeting the criteria for protection of human and environmental health means that all maximum POE groundwater constituent concentrations are below License groundwater protection standards at and beyond the POE. Not meeting the criteria means one or more hazardous constituent maximum concentration(s) in groundwater are above License groundwater protection standards at and beyond the POE.

1.1.2 Protection of Human Health – Occupational Health and Safety

Occupational health is assessed considering the overall exposure potential for implementing and operating each alternative. This considers the potential exposure workers can have throughout the duration of a given alternative action. The lowest criteria rating is assigned to the alternative with the highest opportunity for exposure to workers, while the highest criteria rating is assigned to the alternative with the lowest opportunity for exposure to workers. The exposure opportunity is generally related to the amount of intrusive work in contaminated media, the duration of the action during which workers operating, maintaining or replacing treatment systems are needed, and the relative quantity of contaminated wastes generated and handled.

1.1.3 Environmental Protection - Risks to Wildlife

Protection of environmental receptors is assessed considering the type and duration of ecological exposure pathways to impacted groundwater and/or treatment wastes, as well as the overall consumption of groundwater related to implementing the alternative. The highest criteria rating is assigned to the alternative with no pathway for ecological exposure and no consumption of groundwater during the corrective action alternative; the lowest criteria rating is assigned to the alternative with the longest exposure duration to impacted groundwater and/or treatment wastes, and the highest consumption of groundwater during the corrective action alternative.

1.1.4 Environmental Protection - Preservation of Resource

Preservation of groundwater resource considers the amount of groundwater irrevocably removed from the local groundwater basin in the water treatment process as waste water that cannot be re-injected or returned to the groundwater system. The highest criteria rating is assigned to the alternative with no pathway for ecological exposure and no consumption of groundwater during the corrective action alternative; the lowest criteria rating is assigned to the alternative with the longest exposure duration to impacted groundwater and/or treatment wastes, and the highest consumption of groundwater during the corrective action alternative.

1.1.5 Implementability – Ability to Construct and Operate

Implementability of each corrective action alternative is assessed with respect to four criteria, 1) the ability to construct and operate the designed alternative; 2) the administrative feasibility of implementing the alternative; 3) the ability to restore groundwater to License groundwater protection standards; and 4) the ability to reduce seepage and migration from the tailings.

The ability to construct and operate the designed alternative is assessed qualitatively by considering such factors as the relative technical complexity of the alternative, the relative amount of demonstrated successful construction and operation of the technology in other applications, and the availability of materials and services needed to design construct and operate the alternative. The highest criteria rating is assigned to the alternative with the overall least technical complexity, largest amount of demonstrated successful construction and operation, and the fewest expected limitations on the availability of materials and services. The lowest criteria rating is assigned to the alternative with the overall highest technical complexity, least amount of demonstrated successful construction and operation, and the most expected limitations on the availability of materials and services.

1.1.6 Implementability – Administrative Feasibility

The administrative feasibility of implementing the alternative is assessed qualitatively by considering the permitting and/or licensing burdens associated with each alternative. The highest criteria rating is assigned to the alternative(s) with the overall least administrative burden and most precedents for permitting and/or licensing comparable actions; the lowest criteria rating is assigned to the alternative with the overall highest administrative burden and fewest precedents for permitting and/or licensing.

1.1.7 Implementability – Restoration of Resource

The ability to restore the groundwater to License groundwater protection standards is assessed by comparison of predictive modeling results for uranium transport. Specifically, the areas of the extent of uranium concentrations above the License groundwater protection standards for all groundwater for the current period (2019 predicted groundwater conditions at end of model calibration), at 200 years and at 1,000-years of model simulation are identified for each alternative. These areas are the projection to the ground surface of the isocontours of groundwater concentrations above the License groundwater protection standards for each water yielding unit and represent the area over which control of access to groundwater would be needed for each alterative in each time frame. This approach is based, in part, on the idea that a potential water user could penetrate more than one water-yielding unit and, even if a groundwater in single water-yielding unit is restored to its protective standard concentration at a specific location, an underlying or overlying water-yielding unit that contains groundwater is not restored at that location would preclude use of groundwater from that area. In other words, for an area to be available for unrestricted

access to groundwater, all groundwater constituent concentrations in all water-yielding units at a given location must be below their protective standards. The differences in areas between the present period and the predicted uranium distributions at 200 years and 1,000 years are used as a means for assessing the degree of groundwater restoration for assessment of the alternatives. The highest criteria rating is assigned to the alternative(s) with the overall greatest area of groundwater restoration (or least amount of overall plume expansion), the lowest criteria rating is assigned to the alternative(s) with the overall least area of groundwater restoration (or greatest amount of overall plume expansion).

1.1.8 Implementability – Source Reduction and Control

Source reduction and control of seepage from the tailings is assessed by predictive modeling of tailings seepage and related groundwater uranium concentrations. All alternatives assume the same final tailings reclamation covers are promptly placed and limit long-term seepage from infiltration of precipitation through the final cover. The impacts to groundwater from tailings seepage alone are evaluated independently from existing groundwater impacts by performing a model sensitivity run in which it is assumed there is no current groundwater impact and the tailings seepage is the only input to groundwater constituent concentrations and mass. The sensitivity model is run for 1,000 years and the maximum extent of uranium in groundwater from tailings seepage alone is isolated and assessed. Since all alternatives share the same cover design and, therefore, the same control of this long-term source, this factor is not a discriminating consideration between alternatives. However, the engineered cover providing long-term source control of tailings seepage is relevant factor addressing a remedial action objective and, therefore, is addressed as a criterion.

1.1.9 Nominal and Present Value of Alternative Costs

Although costs are not used to select the Proposed Action, the costs for each alternative are developed in Appendix 4.3-B of the ACL Application and the calculation of the present value of those costs is briefly addressed below.

The sum of all annual undiscounted costs over the 1,000-year period is called the nominal cost. The present value of future costs (discounted costs) is calculated using a discounted cash flow analysis, which treats the future monthly payment for the alternate water supply as a periodic cash flow and is calculated using the following equations.

Equation 1:

Percent Cash Flow Discount = $\frac{1}{1+({r}/{n})^{(n\ x\ y_f)}}$

Where:

r = Annual discount rate (inflation rate, or 1.5%)
n = Number compounding periods per year (12)
y_f = Year fraction of total period for each payment period (e.g., y_f for 2nd month of 3rd year = 25 months = 25/12 = 2.08)

Equation 2:

Present value of monthly payments equals the sum of percent cash flow discount times nominal monthly cost.

These costs calculations for each alternative are provided in a Microsoft Excel spreadsheet included as a digital attachment to this technical memorandum.

2.2 Analysis of Alternatives

The following subsections provide assessment of the alternatives described in Section 4.2 of the ACL Application using the criteria described above. The predictive groundwater modeling results used to support this analysis in the following subsections are summarized from the detailed report on the predictive modeling presented in Appendix 4.2-B of the ACL Application. The groundwater simulation timeframe of 1,000 years reasonably captures long-term effects of seepage from the Large Tailings Pile, diffusion of contaminants from fine-grained material pore space into the primary porosity of the water yielding units, and existing groundwater contaminants, and is consistent with the requirements of Criterion 6(1)(i) of Appendix A to 10 CFR 40 to provide reasonable assurance of control of radiological hazards to be "*….effective for 1,000 years, to the extent reasonably achievable, and, in any case, for at least 200 years*".

2.2.1 Predictive Modeling of Alternatives

Calibrated (base-case) groundwater flow and transport models were used to simulate changes in groundwater uranium concentrations for a 1,000-year period to support evaluation of the relative feasibility and efficacy of the three groundwater corrective action alternatives. In addition, base-case predictive model simulations for molybdenum were run using the calibrated model for Alternative 3, which affords comparison of calibrated uranium versus molybdenum transport conditions and predicted maximum concentrations at the POE for the same alternative.

Finally, the calibrated model was used to simulate the groundwater impacts of the two long-term sources of hazardous constituents (Large Tailings Pile seepage and diffusion from the immobile domain) in isolation from current groundwater impacts. These model simulations were performed by assuming the current groundwater has ambient uranium concentrations. The predicted groundwater constituent concentrations that result from these two individual base-case model sources in isolation from current groundwater impacts allows assessment of the relative significance and impacts of each source.

Primary base-case predictive model inputs are summarized in Table App4.3A-1. Large Tailings Pile seepage rates are illustrated in Figure App4.3A-1 and are supported by tailings drainage modeling described in Appendix 4.2-B of the ACL Application. Bounding-case modeling inputs for the Proposed Action used to conservatively calculate ACLs, discussed in Section 5.1 of the ACL Application, are also shown on Table App4.3A-1.

Historical San Andres-Glorieta groundwater pumping rates for simulating future San Andres-Glorieta stresses from municipal water supply and supply of water for the corrective action alternatives (Table App4.3A-2) are based on data reported by the United States Department of Energy (DOE, 2020b). The locations of all existing San Andres-Glorieta groundwater pumping locations are illustrated in Figure App4.3A-2. HMC wells Deepwell 1R and Deepwell 2R, used to collect makeup water from the San Andres-Glorieta as part of the currently approved groundwater corrective action, as also shown on this figure.

The permeable reactive barrier in Alternative 2 was modeled using the USG-Transport Prescribed Concentration Boundary package in the groundwater model. Simulated groundwater collection and injection rates for this scenario are summarized in Table App4.3A-3 and Table App4.A-4 and tabulated by specific location in Appendix 4.2-B of

the ACL Application. Appendix 4.2-B of the ACL Application also presents the predictive modeling design and execution details for the corrective action alternatives.

2.2.1.1 Points of Exposure

The groundwater POEs are, herein, defined as the control boundary. This control boundary circumscribes the area over which control of access to and use of groundwater is proposed through fee title ownership and/or institutional controls for the compliance period of up to 1,000 years, to the extent reasonably achievable, per 10 CFR Part 40, Appendix A, Criterion 6(1)(i). It is at this boundary where maximum potential future exposures that hypothetically could occur are assessed.

To assess representative maximum predicted groundwater concentrations along the control boundary, observation points were placed in the predictive model at 12 key points along the boundary to report predicted groundwater concentrations over the next 1,000 years (Figure App4.3A-3). Observation points were placed in each water-yielding unit at downgradient edges of the control boundary along the principal transport paths and at points where predicted solute isoconcentration contours were closest to the control boundary. These representative observation points are locations in the groundwater model where predicted future concentrations are quantified, these locations are not physical monitoring wells currently in place.

2.2.1.2 Predicted Exposure Point Concentrations

Potential future groundwater exposure point concentrations for each alternative are developed by assessing base-case predicted maximum uranium concentrations in each water yielding unit at the 12 representative observation points along the identified control boundary, described above (Figure App4.3A-3).

To assess the relative transport of uranium versus molybdenum in groundwater, two of the constituents with the highest source area groundwater concentrations, the maximum uranium and molybdenum POE concentrations for each water yielding unit are established from the base-case models output for a single alternative, Alternative 3 (Table App4.3A-5 and Table App4.3A-6). Comparison of these model results (see Table App4.3A-6 and figures in Appendix 4.2-B of the ACL Application) identifies that molybdenum has substantially more retarded transport, as evidenced by the greater relative decrease in concentrations between maximum POC concentrations and maximum POE concentrations, when compared to those from the uranium model. The ratio of the maximum source area groundwater concentration to the maximum predicted POE concentration is herein termed the attenuation factor. The attenuation factor is calculated by dividing the source groundwater concentration by the maximum predicted POE concentration and is a measure of the amount of concentration decrease between source area and POE, with a lower attenuation factor representing less amount of decrease in concentration (i.e., lesser retardation in transport). Therefore, because uranium has consistently lower attenuation factor values for each water yielding unit than molybdenum (i.e., having less retardation in transport) and because uranium is observed to be the hazardous constituent with the most wide-spread current distribution in groundwater, assessment of the performance of each alternative using just uranium provides a reasonable basis for comparison of alternatives. Consequently, predicted maximum uranium source area and predicted POE concentrations are used for comparative assessment of the corrective action alternatives.

Figures App4.3A-4 through App4.3A-6 illustrate the predicted maximum extent of uranium in all groundwater above the License groundwater protection standard for each unit or mixing zone for the periods 2019, year 200 and year

1,000 of the simulations period for each alternative. In other words, these areas are the projection to the ground surface of the isocontours that outline groundwater concentrations above the License groundwater protection standard for each water yielding unit and represent the area over which control of access to groundwater would be needed for each alterative at each timeframe. The difference in area between (i) the present period, represented by 2019 groundwater uranium concentration distributions at the end of the model calibration, and (ii) the predicted uranium distributions at 200 years and 1,000 years, is used to assess the degree of groundwater restoration. This approach is based, in part, on the idea that a potential groundwater user could penetrate more than one water yielding unit. Thus, even if groundwater within a single unit were within License groundwater protection standards under a particular surface location, an underlying or overlying unit beneath that same surface location would not necessarily comply with License groundwater protection standards, precluding groundwater use there. In other words, for an area to be available for unrestricted access to groundwater, all groundwater in all units at a given location must be below the License groundwater protection standards.

Table App4.3A-7 summarizes the results of this analysis for the evaluation criteria. The report detailing the predictive modeling is provided in Appendix 4.2-B of the ACL Application, which include figures illustrating the predicted constituent concentration isocontours in groundwater for each alternative every 10 years through model prediction year 100, every 50 years through year 300, and every 100 years thereafter to 1,000 years of model prediction.

2.2.2 Analysis of Each Alternative

Overall, all the alternatives analyzed below provide reasonable assurance of protection of public health, safety and the environment and are technically feasible. All alternatives rely on control over access to and use of affected groundwater, although the area over which these controls are required and the duration over which they are required vary between alternatives.

Although Alternatives 1 and 2 would remove contaminant mass from groundwater through active and/or passive treatment, reduce hazardous constituent concentrations to License groundwater protection standards in some but not all groundwater areas, these alternatives cannot fully restore all affected groundwater in all water yielding units for the full compliance period of at least 200 years and, the extent practicable, 1,000 years. Long-term containment of contaminant mass back-diffusion from the immobile transport domain directly under the Large Tailings Pile and Small Tailings Pile footprints and long-term seepage from the Large Tailings Pile is required to maintain alluvial groundwater restoration. Portions of the Chinle sandstone units are not remediated to groundwater protection standards for the full compliance period with either Alternative 1 or alternative 2. These long-term ongoing treatment operations would cause the permanent loss of billions of gallons of groundwater from the local hydrologic basin, as that water would be evaporated during the treatment of waste for disposal. This process would also require long-term use of evaporation ponds, with high concentrations of hazardous constituents, creating an exposure risk to wildlife that would not otherwise exist, because local groundwater is not accessible to wildlife.

Alternative 3 does not actively remove mass through treatment but rather relies on natural attenuation and controls to ensure long-term public health protection. It thus does not require the permanent loss of large quantities of groundwater and does not create evaporation pond hazards or generate wastes over the long-term that require handling and management.

2.2.2.1 Alternative 1 - Groundwater Containment and Removal (No Action)

This section evaluates Alternative 1, the No Action Alternative, under which NRC does not grant the requested ACLs and the current groundwater corrective action continues until License groundwater protection standards are met. Table App4.3A-5 and Table App4.3A-6 summarize the maximum predicted groundwater uranium concentrations at the representative POE. Figure 4.3-4 illustrates the predicted maximum extent of uranium above the License groundwater protection standards in the various water yielding units and zones over the entire predictive period of 1,000 years.

The modeled Alternative 1 groundwater corrective action, presented in Appendix 4.2-B of the ACL Application, would restore Off-Site area groundwater in the alluvium (alluvial groundwater relatively distant from the tailings, in which uranium is the only contaminant currently above License groundwater protection standards) to below License groundwater protection standards within 150 to 200 years.

Under Alternative 1, reinjection of compliant treated water (water meeting License groundwater protection standards) into the alluvium will continue. Modeling results indicate that injection from current groundwater corrective action, in combination with historically higher tailings seepage rates and upgradient water discharges to alluvium from sources not related to the former Homestake Mill, have artificially increased the saturation of the alluvium. When those artificial recharge sources are removed, the saturated extent of the alluvium decreases to extents lower than currently observed. Alternative 1 (No Action) would continue major artificial recharge source associated with groundwater reinjection, and thus continue the artificially high saturation of the alluvium. The more continuous extent of alluvial saturation observed for Alternative 1 allows longer more continuous flow paths for constituent transport compared to conditions for Alternative 3.

Modeling indicates that groundwater constituent concentrations would be reduced to below License groundwater protection standards in the Upper Chinle outside of the tailings piles footprints after approximately 300 years, with possible minor exceptions at the southern Broadview Acres area near Highway 605 and a very limited location east of Highway 605 and the Small Tailings Pile, where very limited extents of groundwater uranium concentrations above 0.09 mg/L may persist (See figures in Appendix B of Appendix 4.2-B).

Reduction of that groundwater constituent concentrations to levels below License groundwater protection standards in the Middle Chinle, outside of the tailings piles footprints, would be achieved after approximately 300 years, with the exception of a limited zone near the Murray Acres and Broadview Acres areas, south of the Large Tailings Pile, where groundwater uranium concentrations above the 0.18 mg/L mixing zone standard and the 0.07 mg/L non-mixing zone groundwater protection standard may persist for the entire 1,000 years modeling period (See figures Appendix B of Appendix 4.2-B).

Reduction of groundwater constituent concentrations to below License groundwater protection standards in the Lower Chinle outside of the tailings piles footprint is generally not achieved under this alternative. Recharge through the subcrop from alluvial groundwater, which has uranium concentrations of less than 0.016 mg/L but above 0.03 mg/L (the License groundwater protection standard for the Lower Chinle), may allow persistence and even expansion of contaminant distributions above 0.03 mg/L in the Lower Chinle throughout the 1,000-year predictive period (See figures in Appendix B of Appendix 4.2-B).

No groundwater uranium concentrations above 0.03 mg/L (maximum contaminant level for drinking water) were predicted in the San Andres-Glorieta aquifer at any time during the 1,000-year predictive period. Maximum POE

groundwater uranium concentrations for this alternative for the 1,000-year predictive simulation are in Table App4.3A-5.

2.2.2.1.1 Protection of human health

Potential occupational exposures associated with this alternative relate to installing new wells, abandoning old wells, and operating the treatment systems, which include reverse osmosis, zeolite treatment, and evaporation ponds. The potential for significant occupational health risks is considered to be low, as potential exposures would be sufficiently mitigated by the use of standard operating procedures for routine tasks, training for those procedures, radiation work permits for non-routine tasks, personal protective equipment as appropriate, and occupational health monitoring. Although the overall potential for occupation exposures is considered low due to the identified mitigations, this alternative is considered to have the highest overall potential for occupation exposures of all the alternatives because this alternative has the longest duration (1,000 years) and manages the most water and waste materials. Therefore, this alternative is ranked as partially meeting this criterion.

Potential public exposures to groundwater above the License groundwater protection standards are prevented for this alternative by use of a municipal water supply and ownership controls over access to groundwater during the corrective action. Maximum groundwater uranium concentrations at the representative POE observation points over the 1,000-year predictive period are below the License groundwater protection standards. Therefore, this alternative fully meets the criteria for protection of public health and this alternative is ranked as fully meeting this criterion for protection of public health.

2.2.2.1.2 Environmental Protection

Potential wildlife exposures associated with the No Action Alternative relate primarily to access and use of the contaminated water in the evaporation ponds, which would be operated for 1,000 years. Potential for significant health risks to wildlife populations are considered to be low, as potential exposures would be sufficiently mitigated by best management practices for wildlife access deterrence (e.g., fencing, reflective flagging, and other deterrents). Therefore, this alternative is ranked as partially meeting this criterion, in that it creates a wildlife exposure pathway that would not otherwise exist, but that risk is largely mitigated by best management practices.

This alternative collects an estimated 443,718,878,400 gallons of groundwater, reinjects an estimated 497,455,696,800 gallons of water, and consumes an estimated 85,757,263,920 gallons of groundwater that is permanently removed from the local hydrologic system for potential beneficial use (Table App4.3A-4). This alternative includes pumping more than 35 billion gallons from the San Andres-Glorieta aquifer as make up water over the 1,000-year period. This is the highest consumption of groundwater of all alternatives. Therefore, this alternative is ranked as not meeting this criterion, in that it permanently removes over 100 billion gallons of groundwater, which otherwise would be usable for all beneficial uses once transported outside the control boundary. Further, this alternative would require the largest amount of electrical energy consumption of all alternatives to operate these collection, treatment and injection systems of all alternatives, which would, commensurately, have the largest carbon emissions associated with those energy consumption.

2.2.2.1.3 Implementability

Both the ability to construct and operate this alternative and the administrative feasibility of approving this alternative are considered high, as the proposed technology and approach are the same as those technologies and actions

currently in use for the groundwater corrective action approved in License Condition 35C. The technical complexity of the alternative is moderate but the successful construction and operation of the technology in this alternative is well established. The availability of materials and services needed to construct and operate the technologies in this alternative are currently high and their future availability is also considered high as they are based on relatively conventional methods and equipment in wide use in other applications nationally and internationally. Therefore, Alternative 1 is ranked as fully meeting these criteria.

The ability of Alternative 1 to restore groundwater to License groundwater protection standards is assessed by comparison of predictive modeling results for uranium transport. The area of affected groundwater modeled in 2019, 200 years, and 1,000 years under this alternative are approximately 2.19, 0.9, and 3.63 square miles, respectively (Table App4.3A-8). Alternative 1 results in restoration of approximately 1.29 square miles of groundwater with 200 years of corrective action, although the total area with groundwater above License groundwater protection standards by 1,000 years has expanded from current conditions by 1.44 square miles. This is largely due to compliant alluvial groundwater with uranium concentrations less than 0.16 mg/L but greater than the Chinle groundwater protection standards migrating into the Chinle through subcrops beneath the alluvium. At 1,000 years, Alternative 1 has the largest area over which control of access to and use of groundwater is required. Therefore, this feasibility criterion to restore the groundwater is ranked as not meeting this criterion as the level of groundwater restoration achieved is only partial, requires several hundred years to achieve that restoration, relies on active recovery and treatment for 1,000 years and results in the largest area requiring access controls.

The ability of this alternative to reduce seepage and migration from the tailings is assessed by predictive modeling of tailings pile seepage and related groundwater uranium concentrations. All alternatives assume the same final tailings reclamation covers are promptly placed and limit long-term seepage from infiltration of precipitation through the final cover. The predicted long-term impacts to groundwater from Large Tailings Pile seepage is limited to the footprints of the tailings piles, as discussed in more detail in Section 4 of the ACL Application. Therefore, the engineered tailings cover is understood to provide a reasonable assurance that seepage rates and concentrations are reduced to levels such that groundwater constituent concentrations beyond the tailings piles footprints are generally not above the License groundwater protection standards.

Alternative 1 relies on long-term active removal, treatment, and treated water injection to manage the secondary groundwater source from back diffusion of contaminant mass in the immobile domain of the water yielding units. Predictive model output provided in Appendix B to the predictive modeling report (see figures in Appendix B to Appendix 4.2-B) identify that long-term On-Site area corrective action effectively contains the secondary source in the alluvium and diminishes long-term impacts to the Upper Chinle, relative to Alternatives 2 and 3, but long-term expansion of the plume in the Middle Chinle and Lower Chinle continues. Therefore, this alternative is assigned a rank of partially meets this criterion.

The nominal capital costs of Alternative 1 are calculated to be $925,355,010, the nominal operating, maintenance cost of this alternative is calculated to be $7,343,552,534. The decommissioning costs are calculated to be $20,144,769, including a capital cost charge for long-term surveillance of $2,500,000 per Criterion 10 of Appendix A to 10 CFR 40 is assumed in year five prior to License termination. The present value of all costs for the 1,000-year period is calculated to be $318,548,475.

2.2.2.2 Alternative 2 - Groundwater Containment and Removal and In Situ Treatment

The following section evaluates Alternative 2, under which (i) corrective action to address Off-Site area groundwater (alluvial groundwater relatively distant from the Large Tailings Pile in which uranium is the only contaminant currently above License standards) continues for 150 years in the same manner as in Alternative 1; and (ii) corrective action to address On-Site area groundwater (alluvial groundwater relatively close to the tailings in which multiple constituents are currently above License groundwater protection standards) continues for 36 years. After 36 years, On-Site area removal, treatment, and reinjection are terminated, and a permeable reactive barrier of hydroxyapatite is installed for *in situ* passive long-term treatment of On-Site area groundwater. Figure 4.3-5 illustrates the predicted maximum extent of uranium above the License groundwater protection standards in the various water yielding units and zones over the entire predictive period of 1,000 years. Table App4.3A-5 and Table App4.3A-6 summarize the maximum predicted uranium concentrations at the representative POE.

The modeled Alternative 2 groundwater corrective action, presented in Appendix 4.2-B of the ACL Application, would reduce concentrations of constituents in Off-Site areas of alluvial groundwater to below License groundwater protection standards within 150 to 200 years. As discussed above, however, concentrations would only remain within License groundwater protection standards for as long as treatment continued. In contrast to Alternative 1, control of groundwater contamination sources in Alternative 2 in the On-Site area from the Large Tailings Pile seepage and back diffusion of mass from the immobile domain beneath the Large Tailings Pile footprint in the alluvial groundwater after 36 years is performed by a passive *in situ* permeable reactive barrier rather than long-term containment by groundwater collection, treatment and reinjection. It is noted that the cessation of long-term On-Site area reinjection of water allows the extent of alluvial saturation to decrease, reducing future groundwater constituent transport in the alluvium (See figures in Appendix B of Appendix 4.2-B).

Installation of the permeable reactive barrier would reduce groundwater constituent concentrations migrating west from the Large Tailings Pile footprint. However, the estimated removal capacity of the hydroxyapatite, which is calculated to remove approximately 75 percent of influent concentration and mass, would allow groundwater constituent concentrations above License groundwater protection standards to persist in alluvial groundwater downgradient of the permeable reactive barrier. Concentrations of groundwater constituents above License groundwater protection standards in the alluvium would extend roughly one mile west from the Large Tailings Pile.

Reduction of groundwater constituent concentrations to below License groundwater protection standards in the Upper Chinle would generally not be achieved, due to recharge to the Upper Chinle directly from below the Large Tailings Pile and cessation of On-Site removal and injection after 36 years. Under this alternative groundwater constituent concentrations above License groundwater protection standards in the Upper Chinle extend approximately 1.5 miles to the south of the Large Tailings Pile and extend slightly east of Highway 605 (See figures in Appendix B of Appendix 4.2-B).

Similarly, reduction of groundwater constituent concentrations below License standards in the Middle and Lower Chinle would generally not be achieved. The areas in which groundwater concentrations exceed the mixing zone uranium standard of 0.18 mg/L or the non-mixing zone standards of 0.07 mg/L (Middle Chinle) and 0.03 mg/L (Lower Chinle) would expand over the course of the predicted period (See figures Appendix B of Appendix 4.2-B).

No uranium concentrations above the 0.03 mg/L maximum contaminant level for drinking water were predicted to occur in the San Andres-Glorieta aquifer at any time during the simulation period. Maximum POE uranium concentrations for this alternative for the 1,000-year predictive simulation are summarized in Table App4.3A-5.

2.2.2.2.1 Protection of human health

Potential occupational exposures associated with this Alternative relate to installing new wells, abandoning old wells, and operating the treatment systems, which include reverse osmosis, zeolite treatment, and evaporation ponds, as well as periodic replacement of the permeable reactive barrier over the 1,000-year operational period. Potential for significant occupational health risks is considered to be low, as potential exposures would be sufficiently mitigated by the use of standard operating procedures for routine tasks, training for those procedures, radiation work permits for non-routine tasks, personal protective equipment, and occupational health monitoring. Although the overall potential for occupational exposures is considered low due to the identified mitigations, Alternative 2 is considered to have an intermediate overall potential for occupation exposures, because this alternative has limited duration of Off-Site action (150 years) and periodic replacement of the permeable reactive barrier every 50 years after installation (replaced 19 times over 950 years). Therefore, this alternative is ranked as partially meeting this criterion.

Potential public exposures to groundwater above the License groundwater protection standards are prevented because a municipal water supply is in place and fee title ownership controls over access to and use of groundwater would be employed. Maximum uranium groundwater concentrations at the control boundary and representative POE observation points over the 1,000-year predictive period would be below the License groundwater protection standards. Therefore, this alternative fully meets the criteria for protection of public health. Therefore, this alternative is ranked as fully meeting this criterion for protection of public health.

2.2.2.2.2 Environmental Protection

Potential wildlife exposures associated with this alternative relate primarily to access and use of the contaminated waters in the evaporation ponds, which are operated for 1,000 years. Potential for significant health risks to wildlife populations are considered to be low, as potential exposures would be sufficiently mitigated by best management practices for wildlife access deterrence (e.g., fencing, reflective flagging, and other deterrents). Therefore, this alternative is ranked as partially meeting this criterion, because it creates a wildlife exposure pathway that would not otherwise exist, but that risk is largely mitigated by best management practices.

This alternative would collect an estimated 48,564,388,800 gallons of groundwater, reinject an estimated 88,555,716,000 gallons of water, and consume an estimated 9,834,343,920 gallons of water that would be permanently removed from the local hydrologic system for potential beneficial use (Table App4.3A-4). This is the second highest consumption of groundwater of all alternatives. Therefore, Alternative 2 is ranked as partially meeting this criterion, because it irretrievably removes over 9.8 billion gallons of groundwater from the hydrologic system, which otherwise would be available for all beneficial uses after transported beyond the control boundary. A rank of “partially meets,” rather than “does not meet” this criterion is assigned: the volume of water permanently lost is lower than that of Alternative 1 but is still a substantial loss.

2.2.2.2.3 Implementability

The ability to construct and operate this alternative is considered moderate, as the number of sites that have demonstrated successful construction and operation of the hydroxyapatite permeable reactive barrier technology is limited and have involved other applications (see Appendix D to Appendix 4.2-B). Further, the practicability and quality of field-scale injection of this reactive media are uncertain in the heterogeneous alluvial material present here. Therefore, the technical complexity of the alternative is considered high. The availability of materials and

services needed to construct and operate the technologies in this alternative are currently high and their future availability is also considered high, as the materials (well components and reactive media solutions) are widely available nationally and internationally.

The administrative feasibility of approving this alternative is considered moderate, as the proposed technology and approach have limited precedent for uranium mill applications, current estimates of groundwater treatment indicate limited efficacy, and outcomes of additional testing are unknown. Overall, this alternative is ranked as partially meeting each of these two criteria.

The ability of Alternative 2 to restore groundwater to License groundwater protection standards is assessed by comparison of predictive modeling results for uranium transport. The areas of affected groundwater modeled in 2019, 200 years, and 1,000 years under this alternative are approximately 2.19, 2.34, and 2.79 square miles, respectively. Alternative 2 corrective action results in an expansion of the area above License groundwater protection standards by 0.15 square miles in 200 years and by 0.59 square miles by 1,000 years. This represents less groundwater restoration by 200 years compared to Alternative 1 but produces a smaller total area (approximately 0.85 square miles, or 544 acres less [Table App4.3A-8]) above License groundwater protection standards at year 1,000 compared to Alternative 1. The areal extent of groundwater reduced below License groundwater protection standard concentrations is intermediate between those of Alternative 1 and Alternative 3 (Table App4.3A-8). Therefore, this feasibility criteria for reduction of constituent concentrations below License groundwater protection standards is ranked as partially meeting the criteria. It is noted that the level of groundwater restoration achieved is only partial, requires over one hundred years to achieve that restoration, and relies on on-going maintenance of the permeable reactive barrier for 1,000 years. The total area requiring control for access to groundwater after 1,000 years is the smallest of all alternatives at 2.78 square miles and represents an expansion of 0.59 square miles from current (2019) conditions (Table App4.3A-8).

The ability of this alternative to reduce seepage and migration from the tailings is assessed by predictive modeling the uranium sources and related groundwater uranium concentrations. All alternatives assume the same final tailings reclamation covers are promptly placed and limit long-term seepage from infiltration of precipitation through the final cover. The predicted long-term impacts to groundwater from Large Tailings Pile seepage is limited to the tailings piles footprints, as discussed in more detail in Section 4 of the ACL Application. Therefore, the engineered tailings cover is understood to provide a reasonable assurance that seepage rates and concentrations are reduced to levels such that groundwater concentrations beyond the tailings footprints are generally not likely to increase above the License groundwater protection standards. The tailings cover does not address the secondary source of contaminants to groundwater from back diffusion of mass in the immobile domain under the tailings piles.

This alternative relies on short-term (36 years, On-Site) to long-term (150 years, Off-Site) active removal, treatment, and treated water injection as well as long-term (1,000 years) passive treatment to manage the secondary groundwater source from back diffusion of contaminant mass in the immobile domain of the water-yielding units. Predictive model output provided in Appendix B to the predictive modeling report (see figures in Appendix B to Appendix 4.2-B) identify that long-term On-Site passive corrective action does not contain the secondary source in the alluvium or impacts to the Upper Chinle. However, the degree of contamination is intermediate between Alternative 1 and Alternative 3. Therefore, Alternative 2 is assigned a rank of partially meets this criterion.

The capital costs of Alternative 2 are calculated to be $195,624,060, the total operating and maintenance costs of this alternative are calculated to be $3,007,461,514, and the decommissioning costs are calculated to be $20,181,320, including a capital cost charge for long-term surveillance of $2,500,000 per Criterion 10 of Appendix A to 10 CFR 40 assumed in year five prior to License termination. The present value of all costs for the 1,000-year period is calculated to be $251,753,065.

2.2.2.3 Alternative 3 - Alternate Concentration Limits

This section evaluates Alternative 3, under which the License is amended to incorporate the proposed ACLs, corrective actions cease, and proposed groundwater monitoring is implemented. Figure App4.3A-6 illustrates the predicted maximum extent of uranium above the License groundwater protection standards for the respective water-yielding units and zones over the entire predictive period of 1,000 years. Table App4.3A-5 and Table App4.3A-6 summarize the maximum predicted uranium concentrations at the representative POE.

The modeled Alternative 3 groundwater corrective action, presented in Appendix 4.2-B, removes all the hydraulic stresses associated with corrective action (e.g., groundwater collection and injection), although municipal pumping of the San Andres-Glorieta aquifer for municipal water supply continues at current rates. The modeling results indicate that the absence of injection of water associated with the current groundwater corrective action, in combination with diminished tailings seepage rates resulting from tailings drain down and cessation of historical discharges to the alluvial groundwater from upgradient sources not related to the HMC milling activities, would decrease the area of saturation within the alluvium. The diminished extent of alluvial saturation predicted under Alternative 3, and to a lesser degree, under Alternative 2, provide shorter, less continuous, flow paths for constituent transport relative to conditions under Alternative 1. The reduced areal extent of saturation in the alluvium, evident after approximately 200 years, restricts long-term transport in the alluvium and generally precludes transport to the Rio San Jose Alluvial system west and southwest of the GRP (See figures in Appendix B of Appendix 4.2-B).

Concentrations of uranium and molybdenum in the Upper Chinle groundwater are predicted to generally migrate south, parallel to the subcrop strike, to where the subcrop abuts the east fault splay just south of the Broadview Acres area, near Highway 605. The areal extent of uranium above the License groundwater protection standard of 0.09 mg/L after 200 years and 1,000 years are both similar to those predicted for Alternative 2 and less extensive than that predicted for Alternative 1 at 1,000 years. (See figures in Appendix B of Appendix 4.2-B).

Groundwater uranium concentrations in the Middle Chinle, outside of the tailings piles footprints, generally do not change substantially from current conditions over the next 200 years. However, predicted groundwater uranium concentrations under the tailings piles footprints that are greater than the License groundwater protection standard of 0.07 mg/L are predicted to be present by 400 years and migrate to the south. The source of this uranium is slow downward migration from the overlying Upper Chinle groundwater.

Groundwater uranium concentrations in the Lower Chinle, outside of the tailings piles footprints, generally do not change substantially from current conditions during the next 300 years. Predicted groundwater uranium concentrations west of the west fault splay that are above the License groundwater protection standard of 0.03 mg/L are predicted to be present by 400 years and continue to expand to the west toward the Upper Chinle subcrop over the remaining 600 years. The source of this uranium is slow downward migration from the overlying Middle Chinle.

No groundwater uranium concentrations above the 0.03 mg/L maximum contaminant level for drinking water were predicted in the San Andres-Glorieta aquifer at any time during the simulation period. Maximum POE groundwater

uranium and molybdenum concentrations for this alternative for the 1,000-year predictive simulation are summarized in Table App4.3A-6.

2.2.2.3.1 Protection of human health

Because this alternative does not continue active groundwater treatment, the potential for occupational exposure arises solely during the brief period (2 to 3 years) of corrective action infrastructure decommissioning and reclamation. Potential for significant occupational health risks is considered to be very low, as the duration of potential exposure is very short and potential exposures would be sufficiently mitigated by the use of standard operating procedures for routine tasks, training for those procedures, radiation work permits for non-routine tasks, personal protective equipment as appropriate, and occupational health monitoring. Unlike the other alternatives, Alternative 3 generates no additional waste streams. Occupational exposure potential is de minimis in comparison to the other alternatives, Alternative 3 is ranked as fully meeting this criterion.

Potential public exposures to groundwater above License groundwater protection standards are prevented because a municipal water supply is in place and fee title ownership controls over access to and use of groundwater would be employed. Maximum groundwater uranium concentrations at the control boundary and representative POE model observation points during the 1,000-year predictive period are below the License groundwater protection standards. It should be noted that the maximum predicted uranium concentrations at all the representative POE modeling points except in the Lower Chinle mixing zone are below 0.03 mg/L. Therefore, this alternative is ranked as fully meeting this criterion for protection of public health.

2.2.2.3.2 Environmental Protection

Because this alternative does not continue active groundwater treatment, the potential for wildlife exposures associated with this alternative arise solely during the brief period (2 to 3 years) of corrective action infrastructure decommissioning and reclamation. Potential for significant health risks to wildlife populations are considered to be very low, as the duration of potential exposure is very short and potential exposures would be sufficiently mitigated by best management practices for wildlife access deterrence (e.g., fencing, reflective flagging, and other deterrents). Therefore, this alternative is ranked as fully meeting this criterion.

This alternative has no further groundwater collection or treatment, and therefore, no additional consumption of groundwater.

2.2.2.3.3 Implementability

The ability to construct and operate this alternative is considered high as there are no operations other than decommissioning and reclamation of groundwater corrective action infrastructure, which are well established as feasible activities. Similarly, the administrative feasibility of Alternative 3 is considered high, as NRC has granted ACLs to many other uranium mill sites regulated under Tile II of the Uranium Mill Tailings Radiation Control Act, including sites that have similar sources of groundwater impacts, similar hydrogeologic and exposure conditions, and that have implemented substantially smaller scale and shorter duration groundwater corrective action programs. Therefore, this alternative is ranked as fully meeting each of these two criteria.

Alternative 3 does not restore groundwater constituent concentrations to License groundwater protection standards but rather restricts access to and use of groundwater through fee title ownership controls and natural attenuation of

contaminant transport to ensure long-term protection at the POE. Therefore, this alternative is ranked as not meeting the feasibility criterion for restoration of groundwater. The total area requiring control for access to groundwater after 1,000 years is the intermediate of the three alternatives at 2.97 square miles, and expansion of 0.78 square miles from current (2019) conditions (Table App4.3A-8).

The ability of this alternative to reduce seepage and migration from the tailings is assessed by predictive modeling the tailings seepage and related groundwater concentrations of uranium. All alternatives assume the same final tailings reclamation covers are promptly placed and limit long-term seepage from infiltration of precipitation through the final cover. The predicted long-term impacts to groundwater from Large Tailings Pile seepage are limited to the footprints of the tailings impoundments, as discussed in more detail in Section 4 of the ACL Application. Therefore, the engineered tailings cover is understood to provide a reasonable assurance that seepage rates and concentrations are reduced to levels such that groundwater constituent concentrations beyond the tailings footprints are generally not above the License groundwater protection standards. Alternative 3 manages the secondary groundwater source from back diffusion of contaminant mass in the immobile domain by means of natural attenuation and ownership controls restricting access to, and use of, groundwater and thus ensures long-term protection at the POE. Predictive model output provided in the predictive modeling report (see figures in Appendix B to Appendix 4.2-B) identify that Alternative 3 does not mitigate or contain the secondary source in the alluvium or impacts to Upper Chinle groundwater. Therefore, this alternative is assigned a rank of partially meets this criterion.

There are no upfront capital costs for this alternative. The total operating and maintenance costs of this alternative relate to site staffing, groundwater and environmental monitoring and reporting over a four-year period until license termination and transfer to the long-term custodian and is calculated to be $11,595,420. The total decommissioning costs for this alternative are calculated to be $19,807,839, including a capital cost charge for long-term surveillance of $2,500,000 per Criterion 10 of Appendix A to 10 CFR 40 is assumed in year five prior to License termination. The present value of all costs for Alternative 3 is calculated to be $28,943,053.

3 Summary of Corrective Action Alternatives Analysis and Selection of Proposed Action

All of the three identified Corrective Action Alternatives are technically feasible and provide long-term protection of public health, safety, and the environment. All alternatives rely on fee title ownership to provide long-term control of access to and use of groundwater to ensure no unprotective groundwater exposures occur, although the areas over which those controls are needed and the time over which those controls are needed vary by alternative. Table App4.3A-7 summarizes the ranking of the eight assessment criteria identified in Section 4.

Overall, the alternatives rank similarly with respect to protection of human health, although Alternative 1 ranks the lowest of the alternatives for this criterion due to the potential for occupational exposures due to waste generation and handling associated with 1,000 years of operation, while Alternative 3 ranks the highest for this criterion as there are no additional wastes generated or managed and occupational health and safety risks are minimal in comparison to other alternatives.

Alternative 3 ranks higher than the other alternatives for environmental protection, as it does not develop any exposure pathways for ecological receptors, while alternatives 1 and 2 both continue to have evaporation ponds and waste generation for extended periods, although best management practices are expected to reduce wildlife impacts to acceptable levels.

Alternatives 1 and 3 have similar implementability rankings, while Alternative 2 has the lowest implementability ranking, primarily due to the unproven efficacy in the permeable reactive barrier technology under these concentrations and hydrogeologic conditions. Alternative 3 has the highest relative implementability ranking of the three alternatives as there is (1) ample precedent for ACL approval with groundwater access controls, (2) there is no NRC precedent for Alternative 1 groundwater corrective action for many hundreds of years and (3) no precedent for approval of Alternative 2 *in situ* passive treatment for centuries at uranium mill sites regulated under Tile II of the Uranium Mill Tailings Radiation Control Act. There are NRC-approved demonstration studies of passive *in situ* groundwater treatment systems at uranium mill sites regulated under Tile I of the Uranium Mill Tailings Radiation Control Act (managed by DOE), but none using permeable reactive barrier technology proposed by Alternative 2 applied for such an extended duration and at these groundwater constituent concentrations.

Table App4.3A-8 summarizes the areas over which groundwater access must be controlled at different time periods, reflecting the areas over which groundwater access is restored. Alternative 1 restores the largest amount of area after 200 years (1.29 square miles) but does not sustain that amount of restoration over the 1,000-year period and eventually requires the largest area for groundwater access control. Alternative 2 results in the smallest total area of affected groundwater after 1,000 years (2.78) and the least amount of increase affected area from 2019 conditions (0.59 square miles). Alternative 3 results in an intermediate total area of affected groundwater after 200 years (2.79) and after 1,000 years (2.97 square miles) compared to the other alternatives. Alternative 3 results in control over access to groundwater of approximately 0.66 square miles less than Alternative 1 at 1,000 years.

Table App4.3A-9 summarizes the maximum predicted uranium concentrations at any POE for all water-yielding units over the 1,000-year prediction for each alternative. All predicted maximum POE groundwater uranium concentrations are below the respective License groundwater protection standards for each water-yielding unit. Alternative 1 results in the highest POE groundwater constituent concentrations of all alternatives for all groundwater except the Upper Chinle. Alternative 3 results in the lowest POE groundwater constituent concentrations of all alternatives for all groundwater except the Upper Chinle. Alternative 2 results in the intermediate POE groundwater constituent concentrations of all the alternatives for all groundwater except the Upper Chinle, for which it has the lowest predicted maximum groundwater uranium concentration.

The analysis and comparison of corrective action alternatives presented above identifies Alternative 3 as the appropriate Proposed Action. The costs and benefits of each corrective action alternative are further evaluated in Section 4 of the ACL Application.

TABLES

Table App4.3A-1 Base-Case and Bounding-Case Model Input Summary

Model Input Parameter	Base-Case Condition	Bounding-Case Condition	Modeled Constituent	Rationale
Precipitation-Based Areal Groundwater Recharge	Water recharge inputs assumed future precipitation was based on the historical model period (2002-2019) average PRISM precipitation (approximately 10.6 in/yr) and was varied over 200-year cycles in which the precipitation rates were linearly varied from a low of approximately 8.9 inches/year and a high of 12.3 inches/year in a sawtooth pattern (PRISM Climate Group, 2004). Recharge was assigned as a percentage of precipitation based on a modified Maxey-Eakin methodology (Maxey and Eakin, 1949; Wilson and Guan, 2004). If the average precipitation rate in a stress period was less than 11 inches/year diffuse areal recharge was assigned as 3% of precipitation. If the average precipitation rate in a stress period was between 11 and 12 inches/year, diffuse areal recharge was assigned as 4% of precipitation. If the precipitation rate in a stress period was greater than 12 inches/year, diffuse areal recharge was assigned as 5% of precipitation.	Water recharge assumed future precipitation rates were varied over the 200-year cycles based on the 1981-2010 PRISM 30-year normal average of approximately 11.7 in/yr across the model domain (PRISM, 2012). The linear variations range from a low of approximately 8.9 inches per year to a high of approximately 12.8 inches per year, although the first 100 years were the same as the base-case condition as a warmup period. The percentages of recharge were assigned based on the same modified Maxey-Eakin methodology, and the same calculations of enhanced ephemeral channel recharge were performed as the base-case condition (Maxey and Eakin, 1949; Wilson and Guan, 2004).	Uranium and Molybdenum	While the ranges of assumed future precipitation rates are somewhat similar between the core and bounding conditions, the variation around the greater normal 30-year PRISM precipitation leads to many more model stress periods where precipitation rates are above 11 and 12 inches per year and thus greater lengths of time in which recharge is 4% and 5% of precipitation rather than 3%. As such, the volumes of groundwater recharge assigned in the bounding condition simulation are much greater than in the base-case condition
Large Tailings Pile Seepage Recharge Rate	Base-case condition Large Tailings Pile seepage rate with asymptotic decline to 0.6 gpm (Hydro-Engineering, 2020b)	Bounding-case condition Large Tailings Pile seepage rate with asymptotic decline to 2.4 gpm (Hydro-Engineering, 2020b)	Uranium and Molybdenum	Bounding-case condition of greater seepage rate than base-case rate. Bounding-case infiltration rates through tailings cover are comparable to native ground infiltration rates.
Large Tailings Pile Seepage Recharge Concentration	Base-case Large Tailings Pile seepage uranium concentration with asymptotic decline to 5.16 mg/L (Hydro-Engineering, 2020b) Base-case Large Tailings Pile seepage molybdenum concentration with asymptotic decline to 13 mg/L (Hydro-Engineering, 2020b)	Bounding-case Large Tailings Pile seepage uranium concentrations set to 45 mg/L based on pre-flushing toe drain seepage concentrations	Uranium	Bounding-case condition of greater uranium concentrations in tailings seepage to alluvial groundwater recharge, basically assumes tailings concentrations rebound to roughly average pre-flushing concentrations. Concentration rebound is not indicated by site-specific tailings studies and characterization.
Freundlich Sorption-Based Retardation Factor	Freundlich sorption parameter values determined from geochemical modeling and used in calibration of historical period model.	Freundlich sorption parameter values that produce retardation factors that are approximately 80% of those produced by the calibrated parameter values across the observed range of aqueous uranium concentrations	Uranium	Bounding-case condition of greater advective transport than suggested by site data and calibration of the historical model. Generic conservative constituent is assumed to be non-reactive and non-sorptive, so sorptive processes were not simulated.
Initial Mobile Domain Concentration Conditions in Alluvial Aquifer Beneath the Large Tailings Pile and Small Tailings Pile	Historical period model simulated final concentrations (end of 2019)	Historical period model simulated final concentrations (end of 2019), except in alluvium beneath the Large and Small Tailings Piles where mobile domain initial concentrations were increased equivalent to the addition of 25% of the immobile domain mass in each model cell	Uranium	Increases initial mobile domain mass beneath the Large and Small Tailings Piles to mimic the bounding-case condition of a under-characterization of uranium concentrations beneath the tailings piles.
San Andres-Glorieta Aquifer Municipal Groundwater Supply Extraction	Simulation of constant average 2012-2018 extraction rates presented in DOE 2020b at existing municipal wells	Simulation of constant average 2012-2018 extraction rates presented in DOE 2020b at existing municipal wells, plus 5 theoretical new wells simulated to increase the total San Andres-Glorieta aquifer municipal groundwater pumping to 5 times that of the base-case simulations. The theoretical new wells are simulated to be completed and extracting with increasing rates through time.	Uranium and Molybdenum	Bounding-case condition of increased population and thus increased municipal extraction from the San Andres-Glorieta aquifer such that downward gradients from the alluvium to the San Andres-Glorieta aquifer would be increased at the San Andres-Glorieta aquifer subcrop, promoting greater potential transport of groundwater from the Rio San Jose alluvium to the San Andres-Glorieta aquifer through the subcrop.
Dual-Domain Mass Transfer Coefficients	Mass transfer rate coefficient values determined during calibration of the historical period	Increase by one order of magnitude mass transfer rate coefficients determined during calibration of the historical period	Uranium and Molybdenum	Bounding-case condition of greater back-diffusion of mass from the immobile domain to the mobile domain. (Note: observed to be a generally insensitive parameter)
Dual-Domain Mobile/Immobile Alluvium Porosity Ratio	Mobile and immobile domain alluvium porosity values determined during calibration of the historical period	Decrease ratio of mobile/immobile domain porosity values by increasing immobile domain porosity from 13% to 21% in the lower total porosity alluvium and from 13% to 24% in the higher total porosity alluvium (to preserve effective porosity values used in calculation of advective transport)	Uranium and Molybdenum	Bounding condition of producing slightly greater transport distances during sensitivity simulations. (Note: observed to be a generally insensitive parameter)

Table App4.3A-2 San Andres - Glorieta Aquifer Pumping Rates for Model Calibration

	B-18	B-19	949	Milan 1	Milan 3	Milan 4	Grants 1	Grants 3
Steady State	390	468	612	122	120	84	69	1409
2002	390	468	612	122	120	84	69	1409
2003	390	468	612	122	120	84	69	1409
2004	390	468	612	122	120	84	69	1409
2005	390	468	612	122	120	84	69	1409
2006	390	468	612	122	120	84	69	1409
2007	390	468	612	122	120	84	69	1409
2008	390	468	612	122	120	84	69	1409
2009	390	468	612	122	120	84	69	1409
2010	390	468	612	122	120	84	69	1409
2011	390	468	612	122	120	84	69	1409
2012	420	592	502	115	181	110	32	1133
2013 1st Half	97	702	920	122	202	87	36	1242
2013 2nd Half	412	418	478	132	213	29	35	1227
2014 1st Half	632	590	435	123	158	113	59	1299
2014 2nd Half	377	368	625	79	119	3	30	1184
2015 1st Half	210	484	831	205	23	147	7	1256
2015 2nd Half	338	462	666	81	116	106	4	927
2016 1st Half	233	160	909	142	119	94	14	1136
2016 2nd Half	641	527	541	119	92	112	32	1216
2017	401	333	548	107	80	85	269	2887
2018	437	493	528	130	57	52	80	1088
2019	390	468	612	122	120	84	69	1409
Simulated Future Pumping Rates				122	120	84	69	1409

Units in gallons per minute (gpm)

Table App4.3A-3 Groundwater Predictive Model Collection and Injection Summary

Collection/ Injection Round	Predictive Simulation Years for Alternative 1 (Collection & Injection)	Predictive Simulation Years for Alternative 2 (Collection & Injection & Permeable Reactive Barrier)	Corrective Action Area	Simulated Collection (-) Rate (gpm)	Simulated Injection (+) Rate (gpm)
1 On-Site	1 through 12	1 through 12	On-Site	-600	700
2 On-Site	13 through 24	13 through 24	On-Site	-600	700
3 On-Site	25 through 1,000	25 through 36	On-Site	-600	700
1 Off-Site	1 through 3	1 through 3	North Off-Site	-300	273
			South Off-Site	-300	283
2 Off-Site	4 through 6	4 through 6	North Off-Site	-300	273
			South Off-Site	-300	280
3 Off-Site	7 through 9	7 through 9	North Off-Site	-300	280
			South Off-Site	-300	280
4 Off-Site	10 through 12	10 through 12	North Off-Site	-300	280
			South Off-Site	-300	280
5 Off-Site	13 through 15	13 through 15	North Off-Site	-300	280
			South Off-Site	-300	280
6 Off-Site	16 through 18	16 through 18	North Off-Site	-300	280
			South Off-Site	-254	250
7 Off-Site	19 through 150	19 through 150	North Off-Site	-345	310
			South Off-Site	-251	248

Reverse osmosis treatment efficacy of On-Site groundwater is 75%, 25% of influent as non-compliant waste water

Zeolite treatment efficacy of Off-Site groundwater is 85%, 15% of inlfuent as non-compliant waste water

Table App4.3A-4 Summary of Total Water Collection, Injection and Waste Water Production Rates and Volumes

Collection/Injection Round	Model Years	Off-Site Collection Rate (gpm)	Off-Site Waste Production Rate[1] (gpm)	Off-Site Injection Rate (gpm)	On-Site Collection Rate (gpm)	On-Site Waste Production Rate[2] (gpm)	On-Site Injection Rate (gpm)	Total Collection Rate (gpm)	Total Treatment Volume (gallons)	Total Injection Rate[3] (gpm)	Total Injection Volume (gallons)	Total Waste Production Rate (gpm)	Total Waste Water Volume (gallons)
Alternative 1													
1	1 through 3	-600	-90	556	-600	-150	700	-1200	1,892,160,000	1256	(1,980,460,800)	-240	378,432,000
2	4 through 6	-600	-90	553	-600	-150	700	-1200	1,892,160,000	1253	(1,975,730,400)	-240	378,432,000
3	7 through 9	-600	-90	560	-600	-150	700	-1200	1,892,160,000	1260	(1,986,768,000)	-240	378,432,000
4	10 through 12	-600	-90	560	-600	-150	700	-1200	1,892,160,000	1260	(1,986,768,000)	-240	378,432,000
5	13 through 15	-600	-90	560	-600	-150	700	-1200	1,892,160,000	1260	(1,986,768,000)	-240	378,432,000
6	16 through 18	-554	-83.1	530	-600	-150	700	-1154	1,819,627,200	1230	(1,939,464,000)	-233.1	367,552,080
7	19 through 36	-596	-89.4	558	-600	-150	700	-1196	82,348,905,600	1258	(86,617,828,800)	-239.4	2,264,915,520
8	37 through 150	-596	-89.4	558	-600	-150	700	-1196	82,348,905,600	1258	(86,617,828,800)	-239.4	14,218,636,320
9	151 through 1,000	0	0	0	-600	-150	700	-600	267,740,640,000	700	(312,364,080,000)	-150	67,014,000,000
									443,718,878,400		**(497,455,696,800)**		**85,757,263,920**
Alternative 2													
1	1 through 3	-600	-90	556	-600	-150	700	-1200	1,892,160,000	1256	(1,980,460,800)	-240	378,432,000
2	4 through 6	-600	-90	553	-600	-150	700	-1200	1,892,160,000	1253	(1,975,730,400)	-240	378,432,000
3	7 through 9	-600	-90	560	-600	-150	700	-1200	1,892,160,000	1260	(1,986,768,000)	-240	378,432,000
4	10 through 12	-600	-90	560	-600	-150	700	-1200	1,892,160,000	1260	(1,986,768,000)	-240	378,432,000
5	13 through 15	-600	-90	560	-600	-150	700	-1200	1,892,160,000	1260	(1,986,768,000)	-240	378,432,000
6	16 through 18	-554	-83.1	530	-600	-150	700	-1154	1,819,627,200	1230	(1,939,464,000)	-233.1	367,552,080
7	19 through 36	-596	-89.4	558	-600	-150	700	-1196	1,885,852,800	1258	(1,983,614,400)	-239.4	2,264,915,520
8	37 through 150	-596	-89.4	558	0	0	700	-596	35,398,108,800	1258	(74,716,142,400)	-89.4	5,309,716,320
9	151 through 1,000	0	0	0	0	0	0	0	-	0	-	0	-
									48,564,388,800		**(88,555,716,000)**		**9,834,343,920**
Alternative 3													
NA	1 through 1,000	None	None	None	None	None	None	None	None	None		None	None

Groundwater collection represents a withdrawal from the unit and is assigned a negative value (-) while injection adds water to the aquifer and is assigned a positive (+) value

[1]Off-site water treated with Zeolite, zeolite treatment efficacy: 85% (15 % of collected water as waste)

[2]On-site water treated with RO, RO treatment efficacy: 75% (25 % of collected water as waste)

[3]Injection rates exceed collection rates to support containment

Table App4.3A-5 Summary of Base-Case Predictive Modeling by Alternative

Alternative 1: Base-Case Groundwater Uranium Concentrations For Collection and Injection Predictive Model

	Alluvial Aquifer	Upper Chinle	Middle Chinle	Lower Chinle Non-Mixing	Lower Chinle Mixing	San Andres-Glorieta Aquifer
POE Protective Limit (mg/L)	0.16	0.09	0.07	0.03	0.18	0.03
Maximum POE 1 Concentration (mg/L)	NA	NA	0.0200	0.0200	NA	0.0056
Maximum POE 2 Concentration (mg/L)	0.0228	0.0205	0.0209	0.0200	NA	0.0056
Maximum POE 3 Concentration (mg/L)	0.0192	0.0202	0.0197	0.0200	NA	0.0056
Maximum POE 4 Concentration (mg/L)	0.1462	0.0207	0.0201	0.0200	NA	0.0056
Maximum POE 5 Concentration (mg/L)	0.0720	0.0201	0.0201	0.0200	NA	0.0057
Maximum POE 6 Concentration (mg/L)	NA	NA	0.0350	0.0204	NA	0.0057
Maximum POE 7 Concentration (mg/L)	NA	NA	NA	NA	0.1032	0.0068
Maximum POE 8 Concentration (mg/L)	NA	NA	NA	NA	0.0422	0.0076
Maximum POE 9 Concentration (mg/L)	0.0754	NA	NA	NA	NA	0.0100
Maximum POE 10 Concentration (mg/L)	0.0577	NA	NA	NA	NA	0.0133
Maximum POE 11 Concentration (mg/L)	0.0145	NA	NA	NA	NA	0.0065
Maximum POE 12 Concentration (mg/L)	NA	NA	NA	NA	NA	0.0056
Maximum POE Concentration	0.1462	0.0207	0.0350	0.0204	0.1032	0.0133

Alternative 2: Base-Case Groundwater Uranium Concentrations For Collection and Injection with PRB Predictive Model

	Alluvial Aquifer	Upper Chinle	Middle Chinle	Lower Chinle Non-Mixing	Lower Chinle Mixing	San Andres-Glorieta Aquifer
POE Protective Limit (mg/L)	0.16	0.09	0.07	0.03	0.18	0.03
Maximum POE 1 Concentration (mg/L)	NA	NA	0.0200	0.0200	NA	0.0055
Maximum POE 2 Concentration (mg/L)	0.0232	0.0243	0.0209	0.0200	NA	0.0055
Maximum POE 3 Concentration (mg/L)	0.0191	0.0204	0.0194	0.0200	NA	0.0055
Maximum POE 4 Concentration (mg/L)	0.0187	0.0210	0.0201	0.0200	NA	0.0055
Maximum POE 5 Concentration (mg/L)	0.0214	0.0201	0.0201	0.0200	NA	0.0056
Maximum POE 6 Concentration (mg/L)	NA	NA	0.0201	0.0200	NA	0.0056
Maximum POE 7 Concentration (mg/L)	NA	NA	NA	NA	0.0436	0.0057
Maximum POE 8 Concentration (mg/L)	NA	NA	NA	NA	0.0200	0.0060
Maximum POE 9 Concentration (mg/L)	0.0567	NA	NA	NA	NA	0.0097
Maximum POE 10 Concentration (mg/L)	0.0198	NA	NA	NA	NA	0.0133
Maximum POE 11 Concentration (mg/L)	0.0145	NA	NA	NA	NA	0.0057
Maximum POE 12 Concentration (mg/L)	NA	NA	NA	0.0200	NA	0.0055
Maximum POE Concentration	0.0567	0.0210	0.0209	0.0200	0.0436	0.0133

Alternative 3: Base-Case Groundwater Uranium Concentrations For Natural Attenuation Predictive Model

	Alluvial Aquifer	Upper Chinle	Middle Chinle	Lower Chinle Non-Mixing	Lower Chinle Mixing	San Andres-Glorieta Aquifer
POE Protective Limit (mg/L)	0.16	0.09	0.07	0.03	0.18	0.03
Maximum POE 1 Concentration (mg/L)	NA	NA	0.0200	0.0200	NA	0.0055
Maximum POE 2 Concentration (mg/L)	0.0231	0.0243	0.0209	0.0200	NA	0.0055
Maximum POE 3 Concentration (mg/L)	0.0191	0.0204	0.0194	0.0200	NA	0.0055
Maximum POE 4 Concentration (mg/L)	0.0142	0.0213	0.0201	0.0200	NA	0.0055
Maximum POE 5 Concentration (mg/L)	0.0214	0.0201	0.0201	0.0200	NA	0.0055
Maximum POE 6 Concentration (mg/L)	NA	NA	0.0200	0.0200	NA	0.0056
Maximum POE 7 Concentration (mg/L)	NA	NA	NA	NA	0.0250	0.0057
Maximum POE 8 Concentration (mg/L)	NA	NA	NA	NA	0.0200	0.0059
Maximum POE 9 Concentration (mg/L)	0.0188	NA	NA	NA	NA	0.0089
Maximum POE 10 Concentration (mg/L)	0.0198	NA	NA	NA	NA	0.0128
Maximum POE 11 Concentration (mg/L)	0.0145	NA	NA	NA	NA	0.0057
Maximum POE 12 Concentration (mg/L)	NA	NA	NA	0.0200	NA	0.0055
Maximum POE Concentration	0.0214	0.0213	0.0209	0.0200	0.0250	0.0128

NA = Saturated conditions in unit not present at this location

Excluded, value reflects upgradient inputs, not mill-related source

Table App4.3A-6 Alternative 3 Base-Case Predictive Modeling for Uranium and Molybdenum

Alternative 3: Base-Case Groundwater Uranium Concentrations For Natural Attenuation Predictive Model

	Alluvial Aquifer	Upper Chinle	Middle Chinle	Lower Chinle Non-Mixing Mixing		San Andres-Glorieta Aquifer
POE Protective Limit (mg/L)	0.16	0.09	0.07	0.03	0.18	0.03
Maximum POE 1 Concentration (mg/L)	NA	NA	0.0200	0.0200	NA	0.0055
Maximum POE 2 Concentration (mg/L)	0.0231	0.0243	0.0209	0.0200	NA	0.0055
Maximum POE 3 Concentration (mg/L)	0.0191	0.0204	0.0194	0.0200	NA	0.0055
Maximum POE 4 Concentration (mg/L)	0.0142	0.0213	0.0201	0.0200	NA	0.0055
Maximum POE 5 Concentration (mg/L)	0.0214	0.0201	0.0201	0.0200	NA	0.0055
Maximum POE 6 Concentration (mg/L)	NA	NA	0.0200	0.0200	NA	0.0056
Maximum POE 7 Concentration (mg/L)	NA	NA	NA	NA	0.0250	0.0057
Maximum POE 8 Concentration (mg/L)	NA	NA	NA	NA	0.0200	0.0059
Maximum POE 9 Concentration (mg/L)	0.0188	NA	NA	NA	NA	0.0089
Maximum POE 10 Concentration (mg/L)	0.0198	NA	NA	NA	NA	0.0128
Maximum POE 11 Concentration (mg/L)	0.0145	NA	NA	NA	NA	0.0057
Maximum POE 12 Concentration (mg/L)	NA	NA	NA	0.0200	NA	0.0055
Maximum POE Concentration	0.0214	0.0213	0.0209	0.0200	0.0250	0.0128

Alternative 3: Base-Case Groundwater Molybdenum Concentrations For Natural Attenuation Predictive Model

	Alluvial Aquifer	Upper Chinle	Middle Chinle	Lower Chinle Non-Mixing Mixing		San Andres-Glorieta Aquifer
POE Protective Limit (mg/L)	0.1	0.1	0.1	0.1	0.1	0.1
Maximum POE 1 Concentration (mg/L)	NA	NA			NA	
Maximum POE 2 Concentration (mg/L)					NA	
Maximum POE 3 Concentration (mg/L)					NA	
Maximum POE 4 Concentration (mg/L)					NA	
Maximum POE 5 Concentration (mg/L)					NA	
Maximum POE 6 Concentration (mg/L)	NA	NA			NA	
Maximum POE 7 Concentration (mg/L)	NA	NA	NA	NA		
Maximum POE 8 Concentration (mg/L)	NA	NA	NA	NA		
Maximum POE 9 Concentration (mg/L)		NA	NA	NA	NA	
Maximum POE 10 Concentration (mg/L)	0.0050	NA	NA	NA	NA	0.0109
Maximum POE 11 Concentration (mg/L)	0.0086	NA	NA	NA	NA	0.0055
Maximum POE 12 Concentration (mg/L)	NA	NA	NA	0.0050	NA	0.0050
Maximum POE Concentration	0.0195	0.0128	0.0050	0.0050	0.0050	0.0109
NA = Saturated conditions not present at this location	Excluded, value reflects upgradient input, not mill-related source					

[a]Maximum concentration in predictive groundwater model source area

Table App4.3A-7 Summary of Alternatives Analysis

Evaluation Criteria	Alternative 1 (No Action)		Alternative 2		Alternative 3 (Proposed Action)	
Alternative Ranking	**3**		**2**		**1**	
Human Health Protection						
Occupational Health and Safety Risks	◒	Highest potential for occupational exposure due to 1,000 year duration of action. Low overall risk, mitigated by use of SOPs, PPE, training, and monitoring	◒	Intermediate potential for occupational exposure due to 150 year duration of active pumping and periodic permeable reactive barrier replacement over 850 years. Low overall risk, mitigated by use of SOPs, PPE, training, and monitoring	●	Occupational exposures related to one-time decommissioning and reclaiming of corrective action infrastructure.
Public Health Protection	●	Exposure pathway eliminated through alternate water supply, groundwater access control, long-term active containment	●	Exposure pathway eliminated through alternate water supply, groundwater access control, plume area reduction	●	Exposure pathway eliminated through alternate water supply and groundwater access control
Environmental Protection						
Risks to Wildlife	◒	Highest relative risks, due to 1,000 year operation of evaporation ponds. Low overall risk, mitigated by best practices for wildlife use deterrents and monitoring	◒	Intermediate relative risks, due to 150 year operation of evaporation ponds. Low overall risk, mitigated by best practices for wildlife use deterrents and monitoring	●	Least risks, no wildlife pathway for groundwater exposure.
Preservation of Resource	○	Irretrievable commitment of 85.7 billion gallons of groundwater as treatment waste	◒	Irretrievable commitment of 9.7 billion gallons of groundwater as treatment waste	●	No additional irretrievable commitment of groundwater or waste water
Implementation						
Ability to Construct and Operate	●	Highly technically feasible, difficulties and unknowns relate to extreme duration of activity. High technology reliability. Additional corrective actions not precluded High ability to monitor effectiveness	◒	Moderately technically feasible, difficulties and unknowns relate to extreme duration of activity and ability install in heterogeneous geologic environment. High technology reliability. Additional corrective actions not precluded. High ability to monitor effectiveness	●	Highly technically feasible, difficulties and unknowns relate to extreme duration of activity. No technology applied Additional corrective actions not precluded. High ability to monitor effectiveness
Administrative Feasibility	●	High administrative feasibility, permits from NMED and License Amendment from NRC.	◒	High administrative feasibility, permits from NMED and License amendment from NRC.	●	High administrative feasibility, License amendment from NRC.
Restoration of Resource	○	Progressive restoration through first 300 to 500 years, long term plume expansion through 1,000 years	◒	Progressive and partial restoration through first 150 years, partial containment through 1,000 years	○	No active restoration
Reduce Tailings Seepage and Migration	◒	Seepage and migration limited by approved tailings cover, back diffusion source contained, plume migration continues	◒	Seepage and migration limited by approved tailings cover, back diffusion source not contained, plume migration continues	◒	Seepage and migration limited by approved tailings cover, back diffusion source not contained, plume migration continues
Cost						
Capital Costs	$925,355,010	Reverse osmosis system capital replacements, zeolite relocation and capital replacements, evaporation pond re-linings, monitoring well capital replacements, spray evaporation system capital replacements	$195,624,060	Zeolite relocation and capital replacements, permeable reactive barrier design/installation & capital replacements, evaporation pond re-linings, monitoring well capital replacements, spray evaporation system capital replacements	$0	None
Operation and Maintenance Costs	$7,343,552,534	1,000 year operation	$3,007,461,514	150 year active removal/treatment 965 years passive *in situ* treatment	$11,595,420	Groundwater corrective action decommissioning, four years of monitoring and staffing
Decommissioning Costs	$20,144,769	Year 1001-1005	$20,181,320	Year 1001-1005	$19,807,839	Year 5-10
Total Nominal Costs	**$8,289,052,313**		**$3,223,266,894**		**$31,403,259**	
Total Present Value	**$318,548,475**		**$251,753,065**		**$28,943,053**	

● Fully meets criteria
◒ Partially meets criteria
○ Does not meet criteria

Table App4.3A-8 Summary of Areas of Groundwater and Areas of Restoration

	Square Feet	Acres	Square Miles
2019 Uranium	61,139,707	1,404	2.19
Alternative 1 200 Year Uranium	25,065,816	575	0.90
Area Restored (200 years)	36,073,891.6	828	1.29
Alternative 1 1000 Year Uranium	101,334,741	2,326	3.63
Area Restored (1,000 years)	(40,195,034)	(923)	(1.44)
Alternative 2 200 Year Uranium	65,283,048	1,499	2.34
Area Restored (200 years)	(4,143,340.6)	(95)	(0.15)
Alternative 2 1000 Year Uranium	77,617,892	1,782	2.78
Area Restored (1,000 years)	(16,478,185)	(378)	(0.59)
Alternative 3 200 Year Uranium	77,896,416	1,788	2.79
Area Restored (200 years)	(16,756,708.8)	(385)	(0.60)
Alternative 3 1000 Year Uranium	82,851,612	1,902	2.97
Area Restored (1,000 years)	(21,711,905)	(498)	(0.78)

[1]Areas with groundwater above License groundwater protection standards in one or more water-yielding units

Negative value in parentheses means total area over which groundwater is not below License groundwater protection standard has increased since 2019.

@ 200 years

Alternative 1 restores 1.29 sq mi, compared to current (2019) modeled conditions

Alternative 2: non-compliant area expands 0.15 sq. mi, compared to current (2019) modeled conditions

Alternative 3: non-compliant area expands 0.60 sq. mi, compared to current (2019) modeled conditions

@ 1,000 years

Alternative 1: non-compliant area expands 1.44 sq. mi, compared to current (2019) modeled conditions

Alternative 2: non-compliant area expands 0.95 sq. mi, compared to current (2019) modeled conditions

Alternative 3: non-compliant area expands 0.78 sq. mi, compared to current (2019) modeled conditions

Table App4.3A-9 Summary Maximum Uranium POE Concentrations Between Alternatives

	Alluvial Aquifer	Upper Chinle	Middle Chinle	Lower Chinle	
				Non-Mixing	Mixing
	(mg/L)	(mg/L)	(mg/L)	(mg/L)	(mg/L)
Protective Limit	0.16	0.09	0.07	0.03	0.18
Alternative 1 Maximum Groundwater Uranium Concentration at POE	0.1462	0.0207	0.0350	0.0204	0.1032
Alternative 2 Maximum Groundwater Uranium Concentration at POE	0.0567	0.0210	0.0209	0.0200	0.0436
Alternative 3 Maximum Groundwater Uranium Concentration at POE	0.0214	0.0213	0.0209	0.0200	0.0250
Difference Alternative 2 to Alternative 1 (mg/L)	0.0895	(0.0003)	0.0141	0.0004	(0.0017)
Percent difference	61%	-1%	40%	2%	-2%
Difference Alternative 3 to Alternative 1 (mg/L)	0.1193	(0.0006)	0.0141	0.0004	(0.0643)
Percent difference	82%	-3%	40%	2%	-62%
Difference Alternative 3 to Alternative 2 (mg/L)	0.0298	(0.0003)	-	-	(0.0625)
Percent difference	53%	-1%	0%	0%	-143%

Percent Difference = Difference ÷ Max POE concentration of reference alternative

(-) = Alternative increase concentration relative to reference alternative

FIGURES

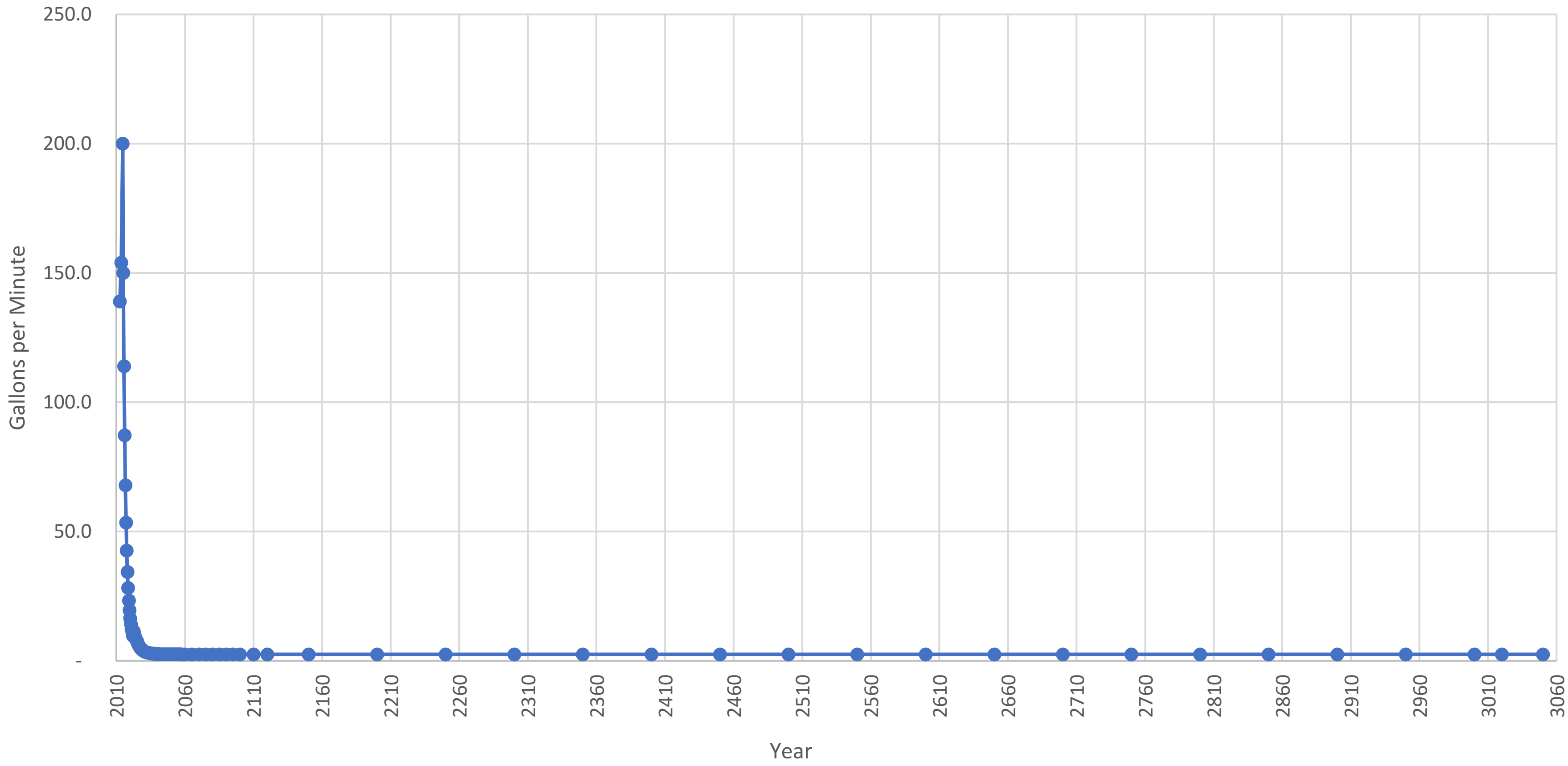

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Figure App4.3A-1
Large Tailings Pile
Predicted Seepage Rates

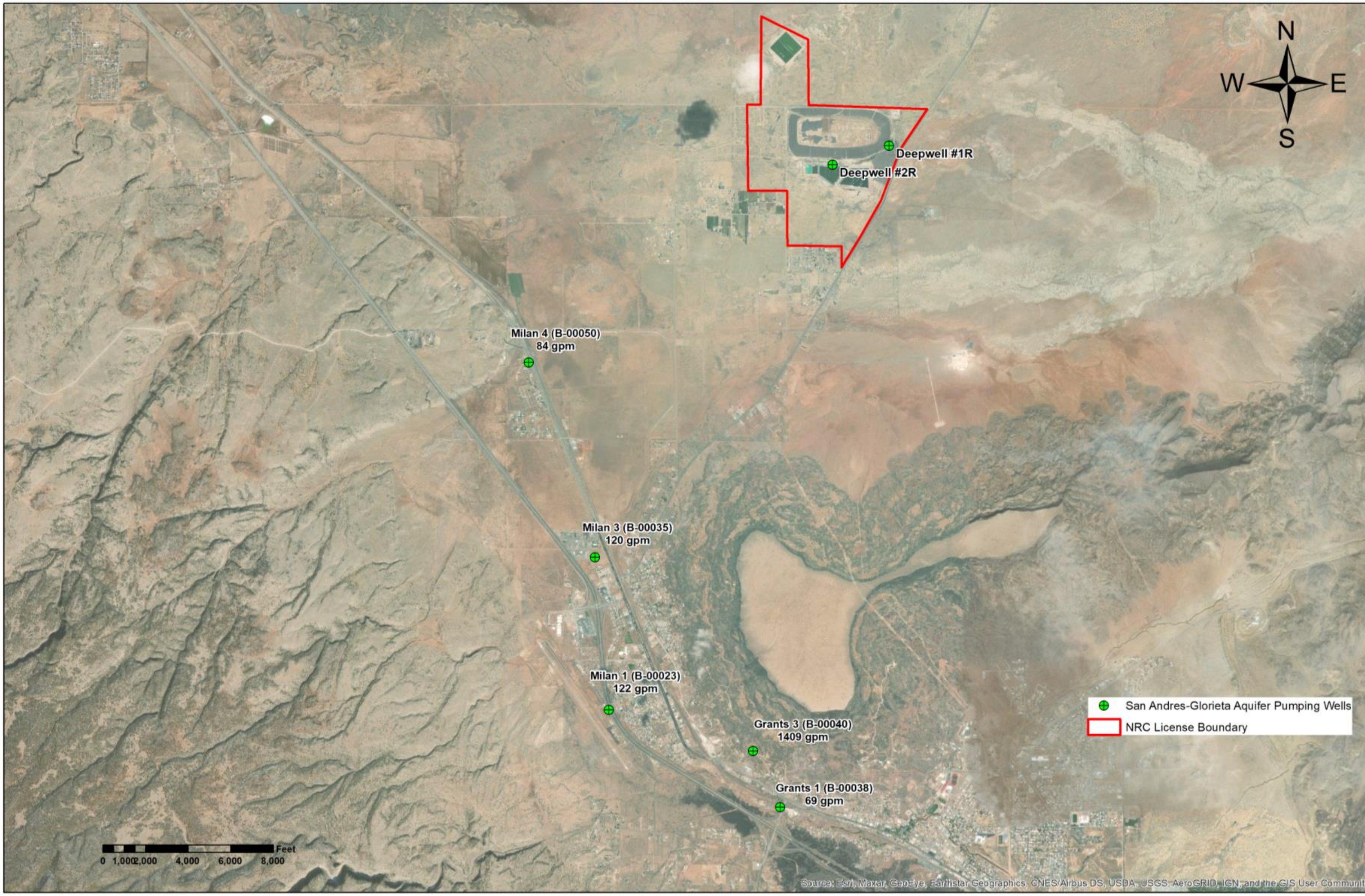

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Figure App4.3A-2
San Andres-Glorieta Aquifer
Pumping Wells

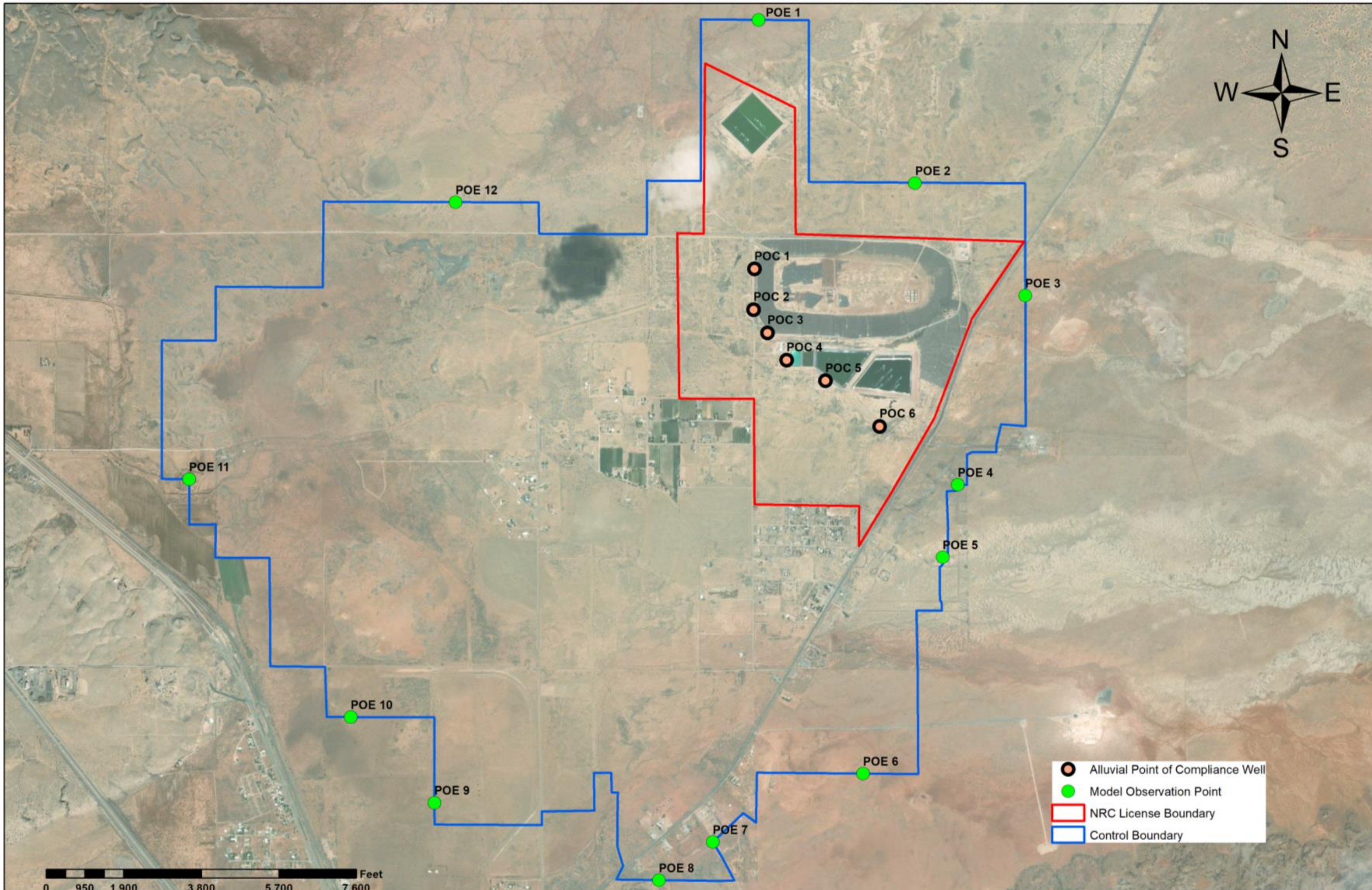

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Figure App4.3A-3
Control Boundary

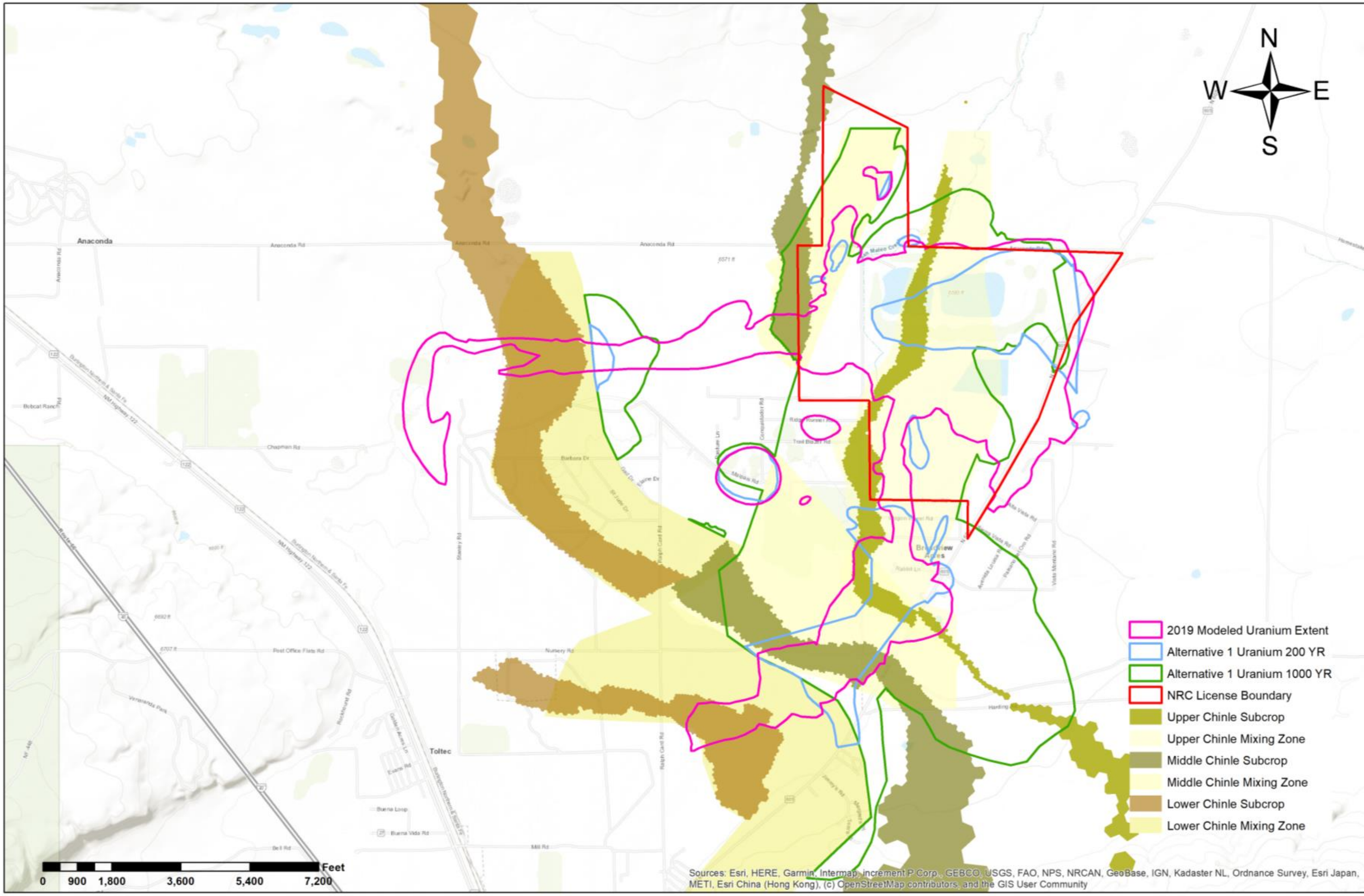

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Figure App4.3A-4
Alternative 1
Maximum Extent of Uranium

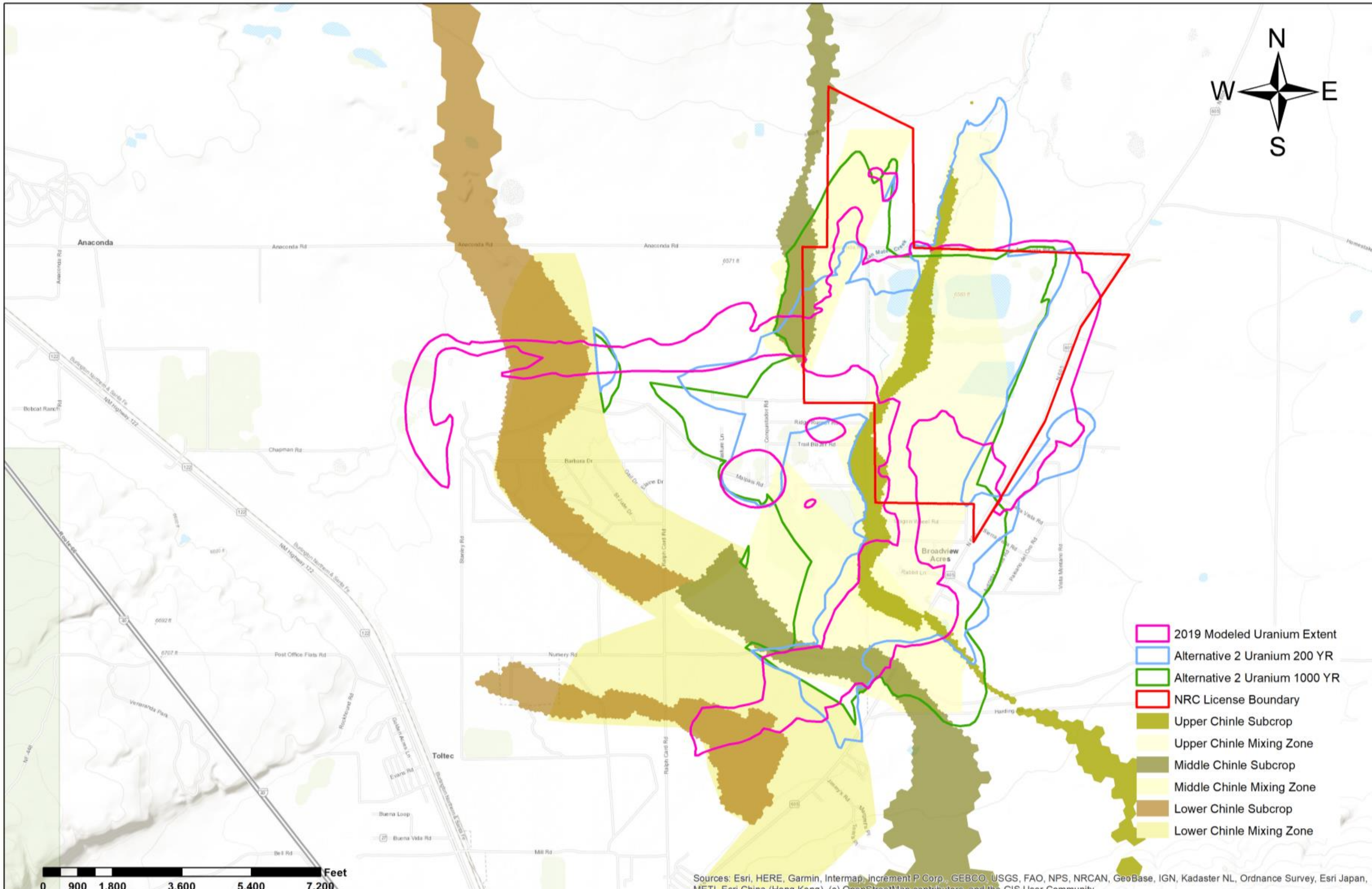

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Figure App4.3A-5
Alternative 2
Maximum Extent of Uranium

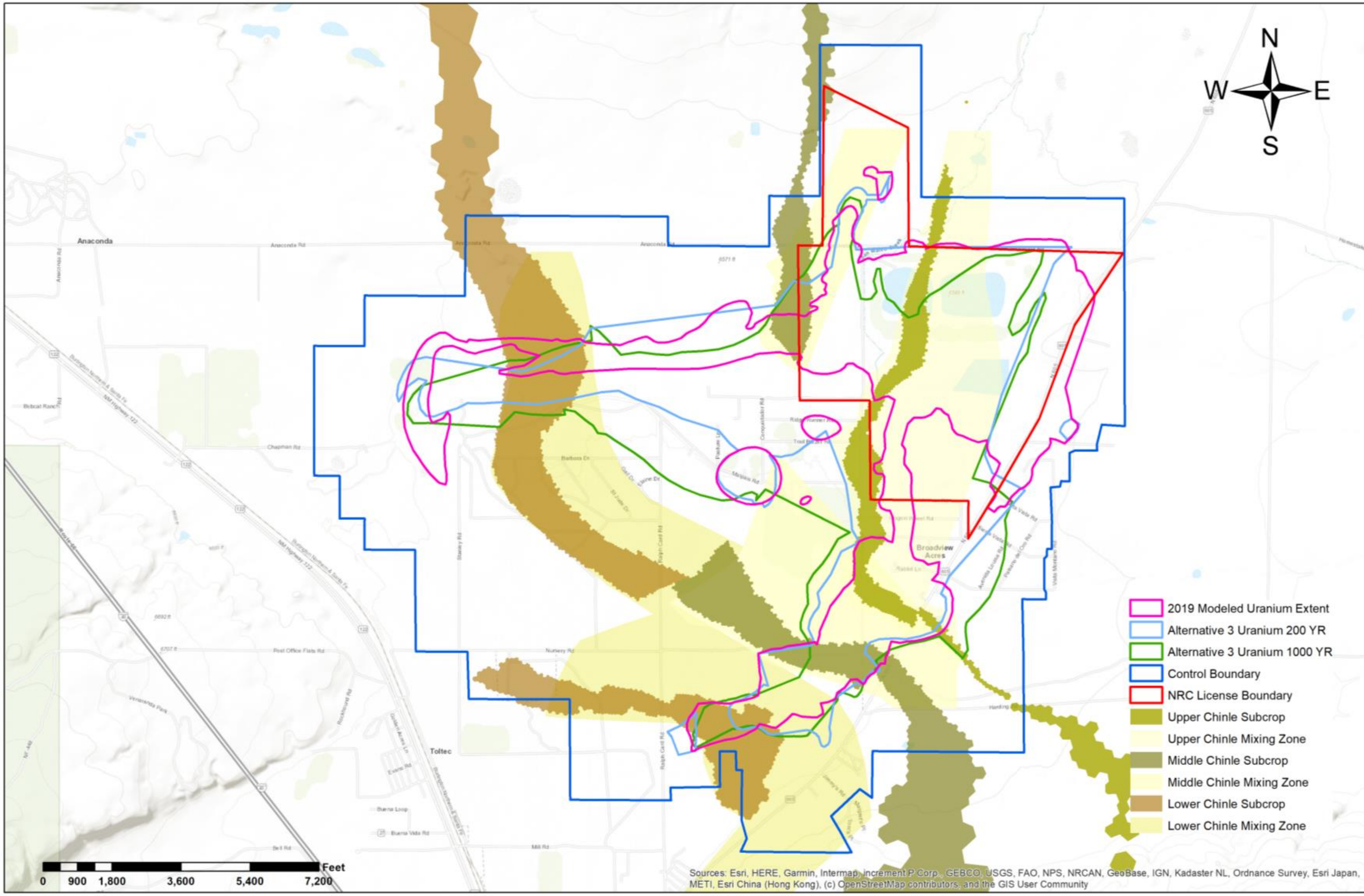

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Figure App4.3A-6
Alternative 3
Maximum Extent of Uranium