LMS/SHP/S25052

Estimates of Historical and Future Water Infiltration Volumes at the Shiprock, New Mexico, Disposal Site

August 2019

U.S. DEPARTMENT OF ENERGY | Legacy Management

This page intentionally left blank

Contents

Figures

Tables

Appendixes

Abbreviations

CFR	*Code of Federal Regulations*
CSL	compacted soil layer
ET	evapotranspiration
ft	feet
ft^2	square feet
ft^3	cubic feet
gal	gallons
gpm	gallons per minute
UMTRCA	Uranium Mill Tailings Radiation Control Act

This page intentionally left blank

Executive Summary

This report presents a semiquantitative sitewide water-balance evaluation for the Shiprock, New Mexico, Disposal Site, to establish the relative magnitude of potential impacts to groundwater over time. The water-balance evaluation covers four discrete periods:

- 1954–1968, when the mill was operating
- 1969–1984, when the mill was abandoned
- 1985–1986, when the site was undergoing surface remediation
- 1987–2987, the maximum postclosure design period for the disposal cell

The projections presented in the report are based on calculated estimates of the volume of water infiltration from surface features to the aquifer (surface features are primarily the tailings impoundments and raffinate pond until surface remediation was completed and the disposal cell thereafter). These estimations are the first step toward characterizing groundwater impacts of mill-related contamination. Though the report provides qualitative discussion of potential contaminant loading rates for each period, the infiltration estimates address movement of water only and do not quantitatively include contaminant concentrations or their fate and transport in the aquifer.

The site features and activities for each period are described as a conceptual model and include key concepts for each period:

1954–1968. The water balance for the period of mill operation includes seepage from the unlined tailings impoundments and raffinate pond, as well as the natural processes of precipitation, evaporation, and infiltration. It is likely that the level of standing liquid in the tailings impoundments and raffinate pond provided a constant driving force for infiltration, resulting in mounding of the water table into the normally unsaturated subsurface. Contaminant concentrations were likely at their highest level in this period and may have been relatively mobile through the subsurface to the aquifer.

1969–1984. During the 16 years when the site was abandoned, the water-balance inputs and outputs include precipitation, evaporation, and infiltration.

1985–1986. During surface remediation, water was used to suppress construction-related dust. Water was sprayed on the ground, tailings, demolition debris, and impacted soils; it was an additional input to the water balance only in this period. It is likely that the greatest use of dust suppression water would have occurred in the driest and windiest times of year. Thus, this additional water source may have had minimal impact on the rate of subsurface infiltration. The natural components of the water balance (precipitation and evaporation) were applicable, as they are in all other periods.

1987–2987. The final period evaluated covers the maximum postclosure design period for the disposal cell. The cell cover is designed to be effective (as a barrier to radon emissions) for 1000 years, to the extent reasonably achievable, and, in any case, for at least 200 years (40 CFR 192.02), with minimal need for routine maintenance. The cover's compacted soil layer (CSL) is a radon barrier, which also potentially acts as a barrier to prevent infiltration of precipitation into the contaminated material and the subsurface. The water balance for this period includes natural components (precipitation, evaporation, and infiltration) and transient drainage of tailings pore water. The CSL will gradually lose compaction over time, and soil-forming processes will lead to increased hydraulic conductivity and consequent infiltration of meteoric precipitation such as rainfall. The estimation of infiltration volume over a 1000-year time span depends on the rate at which the soil loses compaction and becomes more permeable. If physical changes in the CSL are minimal over hundreds of years, the infiltration rate will likewise be minimal. Conversely, if significant physical changes in the CSL occur in a time frame of tens of years and no mitigation is attempted, infiltration through the cover and cell and into the subsurface will be much greater. The potentially large volume of infiltration in the cell's life span is difficult to relate to contaminant release from the disposal cell without more information about the current and future geochemistry within the entombed tailings (e.g., oxygen and water content).

Estimated maximum and minimum volumes and rates of water infiltrating to the subsurface through the footprint of the mill's tailings impoundments and raffinate pond were calculated for each of the four periods listed above. The estimated total infiltration volume and rates were compared to the infiltration volumes and rates for each period to better understand the relative impacts to groundwater that might have occurred (or will occur).

- An evapotranspiration (ET) cover could be intentionally developed or allowed to develop naturally. ET covers limit infiltration by the processes of vegetative uptake of water from the cover material, and release of water to the atmosphere. Assuming an ET cover is present, remains viable for the maximum 1000-year postclosure design period, and performs similarly to U.S. Department of Energy Office of Legacy Management test ET covers: precipitation infiltration through the disposal cell cover could be as low as 0.3 gallons per minute (gpm). This infiltration rate is an order of magnitude lower than the calculated maximum precipitation infiltration rate through a rock-armored disposal cell cover.
- For the minimum infiltration case, an estimated 102 million gallons contributed during the 1000-year disposal cell life span represents the largest share of all infiltration at 70%, followed by an estimated 43 million gallons contributed during the milling period, representing 30% of all infiltration. On a unit basis for the minimum infiltration case, infiltration to the subsurface during the 15 years of milling was 5.8 gpm compared to 0.2 gpm over the 1000-year life span of the disposal cell; the rate of inflow was 29 times greater during milling than that today. The key assumption for the minimum case is that the disposal cell cover's low permeability remains constant throughout a 1000-year design life span.
- For the maximum infiltration case, the estimated 3.1 billion gallons contributed during a 1000-year disposal cell life span represents the largest share of all infiltration at 92%, followed by an estimated 163 million gallons contributed during the milling period, or 5% of all infiltration. On a unit basis for the maximum infiltration case, infiltration to the subsurface during the 15 years of milling was 22 gpm compared to 5.9 gpm over the 1000-year life span of the disposal cell; the rate of inflow was approximately 4 times greater during milling than that today. The key assumptions for the maximum case are that the disposal cell cover degrades in a relatively short period (tens of years) and no corrective action is taken, allowing 20% of precipitation to infiltrate through the cover and into the subsurface for approximately 1000 years.

In both the minimum and maximum infiltration cases, the periods of site abandonment and site remediation are minor contributors, combined at about 0%–3% of the total estimated volumes. Because the ET cover reduces precipitation infiltration into the disposal cell, for the ET cover scenario the periods of site abandonment and site remediation cumulatively contribute 18% of the total estimated volumetric inflow to the subsurface for all evaluation periods. The postclosure design period for the disposal cell contributes the greatest degree of uncertainty to the infiltration estimates, because a defensible assumption of cover performance over such a long duration cannot be made. Evaluations of uncertainties in the other three periods become negligible in comparison to the long-term future performance of the cell cover.

Regardless of the potentially greater volume of infiltration throughout the maximum postclosure design period for the disposal cell, it can reasonably be asserted that the greatest contaminant load reached the aquifer during the milling period as a result of hydraulic driving force from the surface and relatively high concentrations of dissolved contaminants.

This page intentionally left blank

1.0 Introduction

This report presents a semiquantitative infiltration evaluation for the Shiprock, New Mexico, Disposal Site. The evaluation covers four discrete periods: when uranium was milled, when milling operations were abandoned, when surface contamination was remediated, and throughout the future design life span of the site's engineered disposal cell. The primary objective of the evaluation is to establish the relative magnitude of potential impacts to groundwater through time. The report presents background information, objectives of the evaluation, conceptualization of the infiltration mechanisms in each of the four discrete periods, estimated ranges of infiltration to groundwater, and the uncertainties that affect the estimates.

Actual and potential impacts to groundwater at the site are only partially described through the infiltration evaluation. Contaminant concentrations, physical properties of the aquifer, and geochemistry are significant factors in the determination of past and future groundwater quality but these parameters were not quantitatively studied as part of the infiltration evaluation.

1.1 Site Background

The 105-acre Shiprock disposal site is located adjacent to the town of Shiprock in San Juan County, New Mexico, and within the Navajo Nation at the location of a former uranium mill (Figure 1). From 1954 to 1968, ore was milled and processed by mechanical and chemical means; the end product was a concentrate powder of uranium oxides (U_3O_8, UO_2, UO_3) also known as yellowcake.

Figure 2 is an undated aerial photo of the processing site. The photograph is believed to have been taken in 1954 or 1955, shortly after milling began. The mill is at the center of the photo, with the tailings impoundment just beyond, to the right. Elevated berms, likely constructed of native soil, run along the perimeter of and within the tailings impoundment to contain the tailings and associated liquid.

An undated aerial photo taken after mill closure shows the upper and lower tailings impoundments (labeled as tailings piles) and the raffinate pond (Figure 3). The upper and lower tailings impoundments covered 30.6 and 38.8 acres, respectively. The raffinate pond was 4.3 acres in size. The tailings impoundment and raffinate pond areas, as depicted in Figure 3, are used for the milling and abandoned mill infiltration evaluations. The site remediation and postclosure infiltration evaluations use the area covered by the disposal cell for infiltration evaluations. The Figure 2 aerial photo shows that the upper tailings impoundment wasn't yet constructed at mill startup. The upper tailings impoundment is shown in a 1960 site map (HEW 1962), indicating the impoundment was constructed sometime between 1955 and 1960. The upper tailings impoundment was possibly constructed in response to plant's ore process capacity being increased from 400 tons per day to 400 to 500 tons per day, which occurred prior to 1960 (HEW 1962).

The site was one of the 22 sites designated for remedial action under the Uranium Mill Tailings Radiation Control Act (UMTRCA) in 1978, and surface remediation activities began in 1985. Over the next 2 years, demolished building materials and surface contamination were collected and moved to a 76-acre onsite disposal cell that was constructed over the tailings impoundments and currently occupies the majority of the 105-acre Shiprock disposal site (Figure 1).

In accordance with UMTRCA regulations (Title 40 *Code of Federal Regulations* Section 192 [40 CFR 192.02]), the disposal cell cover is designed to effectively control residual radioactive materials and their listed constituents for up to 1000 years to the extent reasonably achievable, and in any case, for at least 200 years.

In response to UMTRCA regulations guiding groundwater cleanup, an active remediation system consisting of extraction wells and trenches was added between 2005 and 2006 on the terrace and floodplain areas. Groundwater quality is evaluated through semiannual sampling of monitoring wells and analysis.

1.2 Objectives

The primary objective of the water balance is to estimate the volume of water entering the subsurface through the footprint of contaminated material at the site for the following periods:

- During milling operations (1954−1968)
- When the mill was idled and abandoned (1969−1984)
- During surface remediation activities (1985−1986)
- Throughout the maximum postclosure design period (1987−2987)

The following sections provide descriptions of the conceptual water-balance model, comparative estimates of surface water (e.g., mill process water in ponds and tailings impoundment, incipient meteoric precipitation such as rainfall) available for infiltration to groundwater in each of the four periods, uncertainties that affect the estimates, and assumptions based on engineering judgment to reduce uncertainties and tighten the estimates.

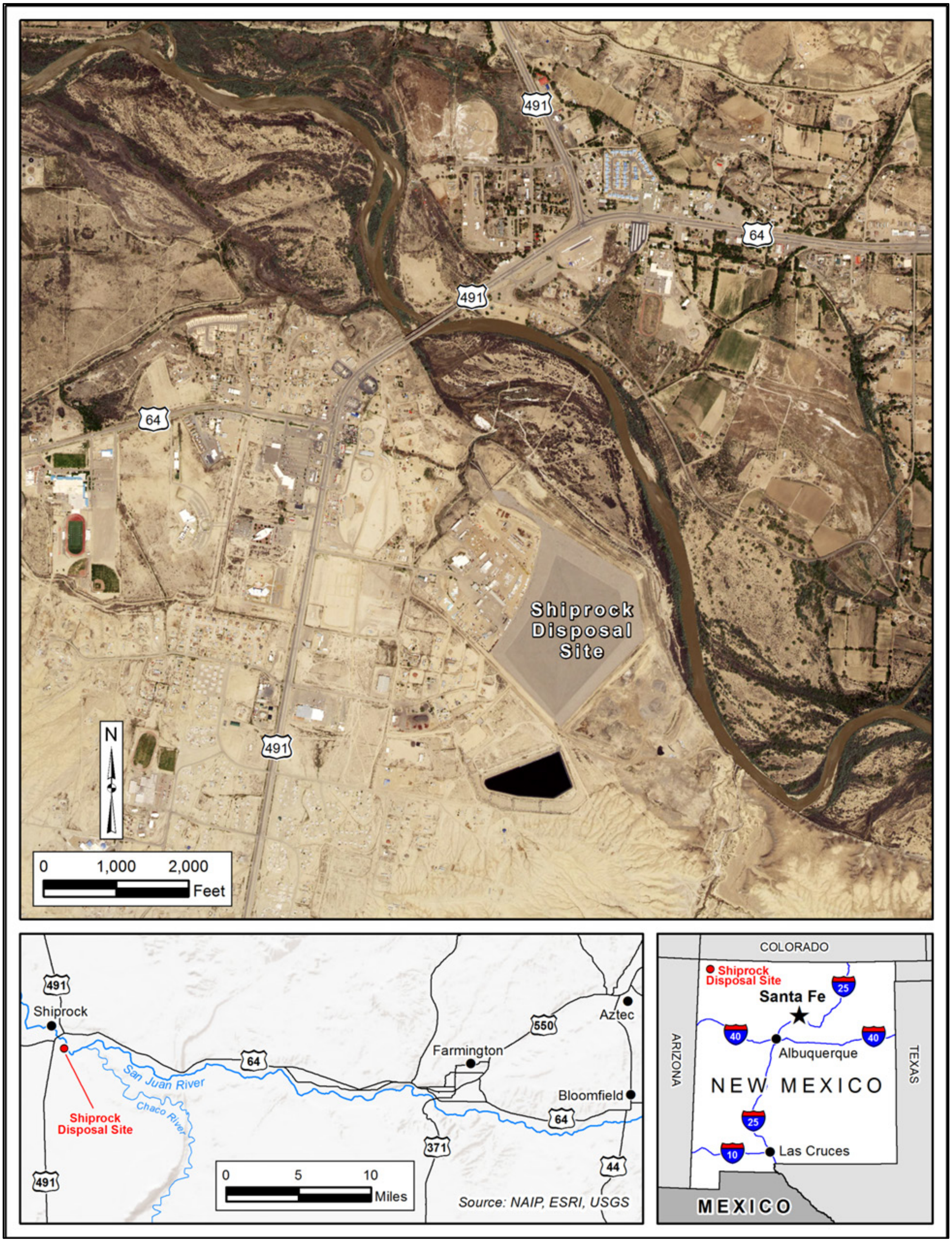
2.0 Site Conceptual Model

The conceptual basis for estimations of infiltration to groundwater includes the durations for each period of site activities and the sources of water applicable to each activity. The conceptualization is summarized in Table 1 and described in more detail below. The potential for contaminant transport is also discussed qualitatively for each period.

Table 1. Shiprock Site Activities and Sources Contributing Water to the Subsurface

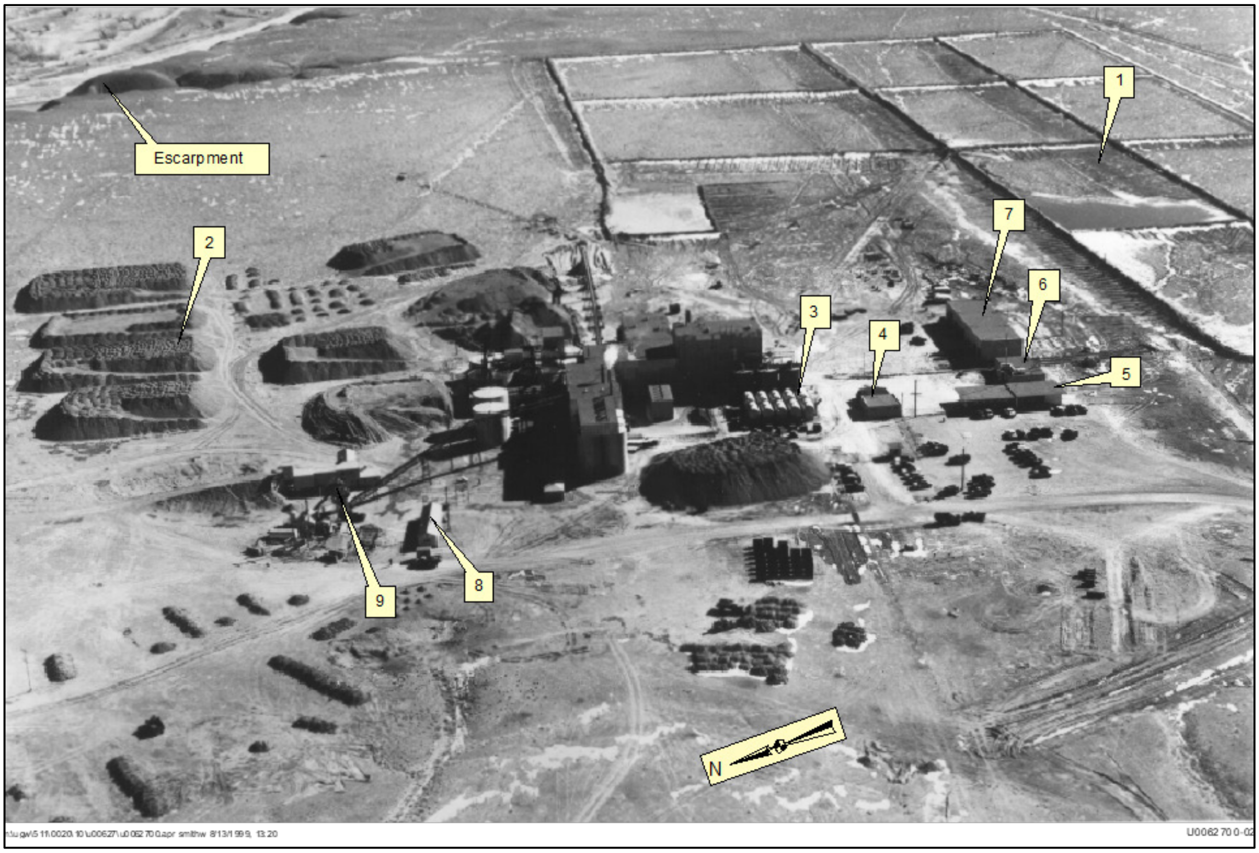
Time Periods	Active Milling 1954−1968	Mill Abandoned 1969−1984	Surface Remediation 1985−1986	Maximum Postclosure Period 1987−2987
Water Infiltration Sources	Slurry and mill process liquid in tailings impoundments and raffinate pond Precipitation on tailings impoundments and raffinate pond	Precipitation on tailings impoundments and raffinate pond	Dust suppression water during cell construction Precipitation on exposed tailings during cell construction	Residual drainage from covered tailings Precipitation infiltration through disposal cell cover

Natural evaporation removes water from surface features through all periods and is accounted for in the conceptual water balance.



Source: NAIP, ESRI, USGS

Figure 1. Shiprock, New Mexico, Disposal Site, Location Map



Notes: (1) Tailings impoundment and raffinate pond; (2) Ore piles; (3) Sulfuric acid storage; (4) Change house; (5) Office; (6) Control lab; (7) Warehouse and shops; (8) Sampling plant; (9) Ore crusher.

Figure 2. Aerial Photo of Shiprock Mill Site, Late 1954 or Early 1955

Note: Graphic from A Summary of the Engineering Assessment of Inactive Uranium Mill Tailings (DOE 1981).

Figure 3. Undated Aerial Photo of Shiprock Mill Site After Closure

Milling, 1954–1968. Components of the water balance during milling operations are schematically depicted in Figure 4 and include the water used in slurrying tailings to the ponds and the natural hydrologic components (evaporation, precipitation, and infiltration). Water was supplied to the mill from the San Juan River located east of the site. In addition to the tailings slurry use, water was also used in the chemical processes to extract uranium from ore. Excess water from the uranium extraction process is called raffinate. Both the tailings slurry and raffinate contained residuals of unrecovered uranium and process chemicals.

Upon reaching the unlined tailings impoundments, the solids settled out of the slurry. Some of the residual liquid would have evaporated while some liquid infiltrated through the bottom of the tailings impoundments into the subsurface. The raffinate pond was unlined and, thus, was also a source of infiltration to the subsurface. Precipitation contributed additional water to the tailings impoundments and raffinate pond. Upon reaching the water table, the infiltrating liquid mixed with groundwater to form a plume that exceeds groundwater standards (40 CFR 192.04, DOE 2000).

During most of the milling period, standing liquid was likely present in the tailings impoundments and raffinate pond, providing a constant driving force for infiltration and potentially resulting in mounding of the water table. The contaminant concentrations reaching groundwater during this period were also likely higher than at any other point in the site's timeline, as the water was in direct contact with the mill tailings. Additionally, the standing liquids in the tailings impoundments and raffinate pond likely contained oxygen, which would favor high uranium solubility. Thus, the infiltrating flow would have carried uranium in solution into the subsurface until geochemical processes could reduce its mobility.

Mill Idled and Abandoned, 1969–1984. In 1969, milling operations ceased, and the buildings, tailings impoundments, and raffinate pond were abandoned. The site water balance in this period includes natural processes (evaporation, precipitation, and infiltration) as schematically depicted in Figure 5. In the 16-year time frame of mill abandonment, pooled, mill-related water on the surface of the tailings impoundments and raffinate pond either evaporated or infiltrated. Precipitation on the tailings impoundments and raffinate pond could have infiltrated through residual material, potentially adding contaminant mass to the unsaturated subsurface and to the existing groundwater plume. The concentrations of contaminants in the water that infiltrated to the subsurface in this period are unknown and would have been affected by geochemical characteristics of the tailings material and the underlying subsurface.

Infiltration during this period would have been driven by gravity but would not have had the additional pressure from a standing liquid level in the tailings impoundments and the raffinate pond, as existed during the milling period. On an annual basis, the site has a net positive evaporation potential, which would limit infiltration to times of intense storm events (rapidly saturating and possibly pooling on the ground surface) or storm events when the natural evaporation rate is at its seasonal low.

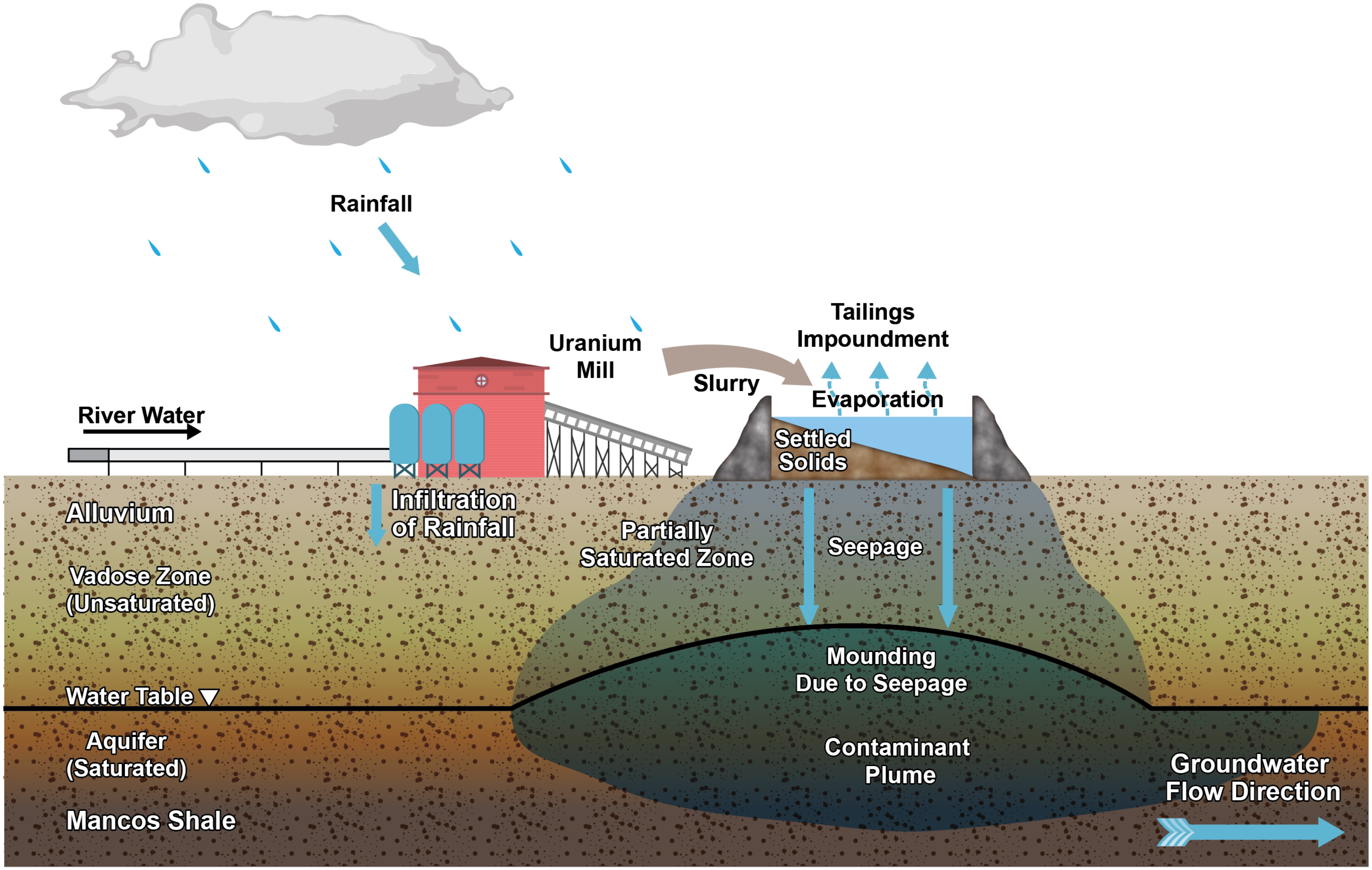


Figure 4. Shiprock Site Schematic Water Balance During Milling Operations (1954–1968)

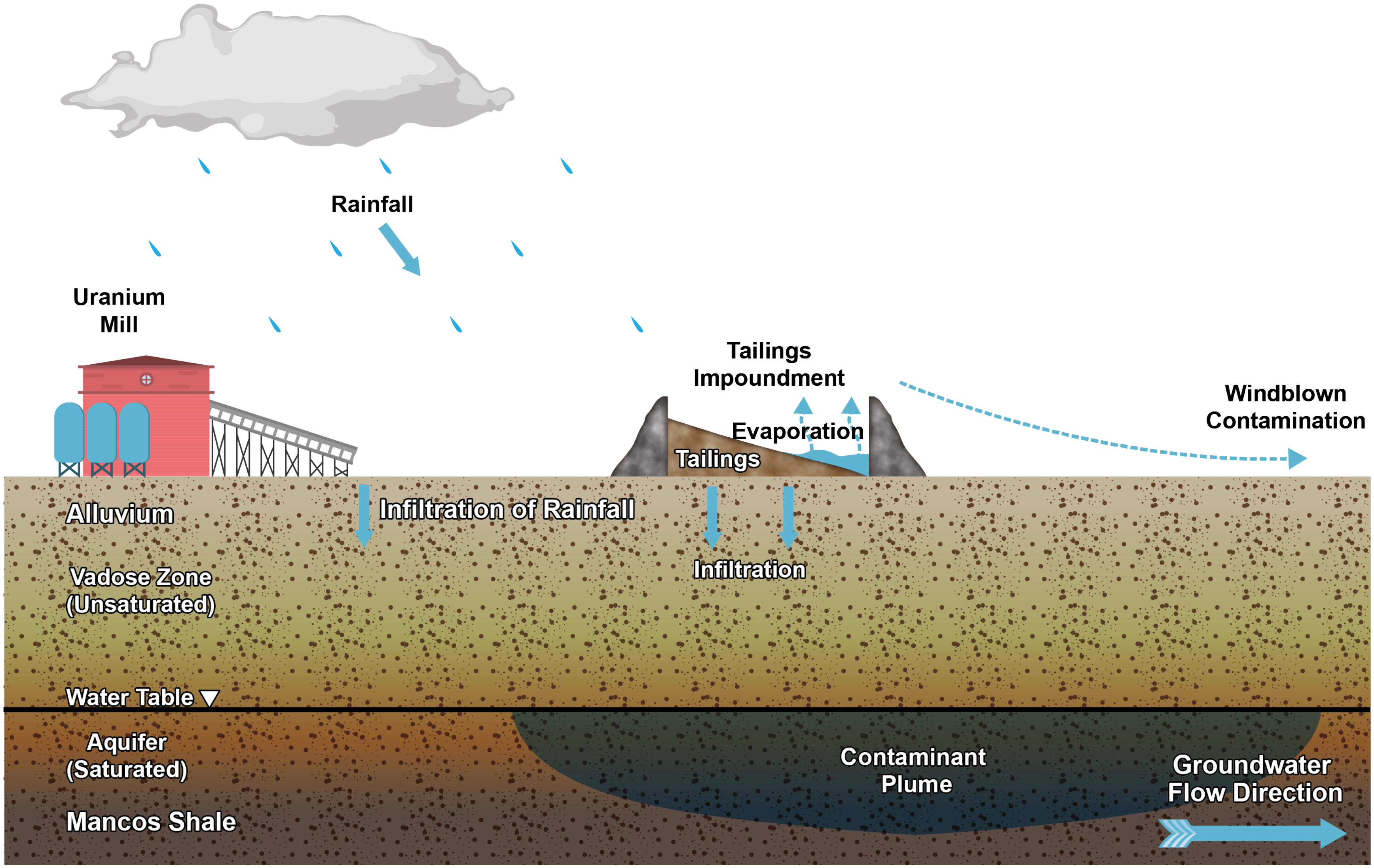


Figure 5. Schematic Water Balance When the Mill Was Abandoned (1969–1984)

Surface Remediation, 1985–1986. Surface remedial activities started in 1985 and continued through 1986. The site water-balance concept during surface remediation is schematically depicted in Figure 6. Surface activities included demolition of the abandoned buildings and excavation of soil from the surrounding area that was impacted by windblown contamination. Tailings were consolidated in place, with building debris and the excavated contaminated soils placed over them. Waste material with lower levels of contamination (i.e., windblown) was placed on top of more highly contaminated material before the cover was constructed. The raffinate pond was excavated, and this contaminated material was also moved to the stabilized tailings pile. During excavation and disposal cell construction, water was routinely sprayed on the waste material and the surrounding area to minimize windblown dust transport. In addition to water used for dust suppression, local precipitation would have contributed to infiltration and potential contaminant transport. The contaminant concentrations in the water that infiltrated during surface remediation are unknown, for similar reasons as described above for the period when the site was abandoned.

Maximum Postclosure Design Period, 1987–2987. Surface remedial activities, including construction of the disposal cell cover, were completed by 1987. The site water-balance concept for the 1000-year disposal cell life span includes natural processes (precipitation, evaporation, and infiltration) and is schematically depicted in Figure 7.

In accordance with UMTRCA regulations, the design for control of “residual radioactive materials and their listed constituents” is required to “be effective for up to 1000 years, to the extent reasonably achievable, and, in any case, for at least 200 years” (40 CFR 192.02(a)). In accordance with these standards the engineered cover at the Shiprock site is composed of three layers: a 77-inch CSL, a 6-inch bedding layer, a 12-inch riprap layer on sideslopes and on top (DOE 1996). The CSL serves as the radon barrier; its low permeability also limits meteoric precipitation such as rainfall from infiltrating into and through the contaminated materials. The cell is designed to shed rainfall, with a 2%–4% slope across the top of the cell and sideslopes pitched at 20% (DOE 1996).

Over time, the CSL will gradually lose compaction, and its permeability will increase (Waugh et al. 2015). Some portion of the precipitation that falls on the cell will infiltrate through the cover and contaminated material and into the subsurface. The water held within the tailings material at the time of disposal cell construction will also drain into the subsurface under the force of gravity (transient drainage).

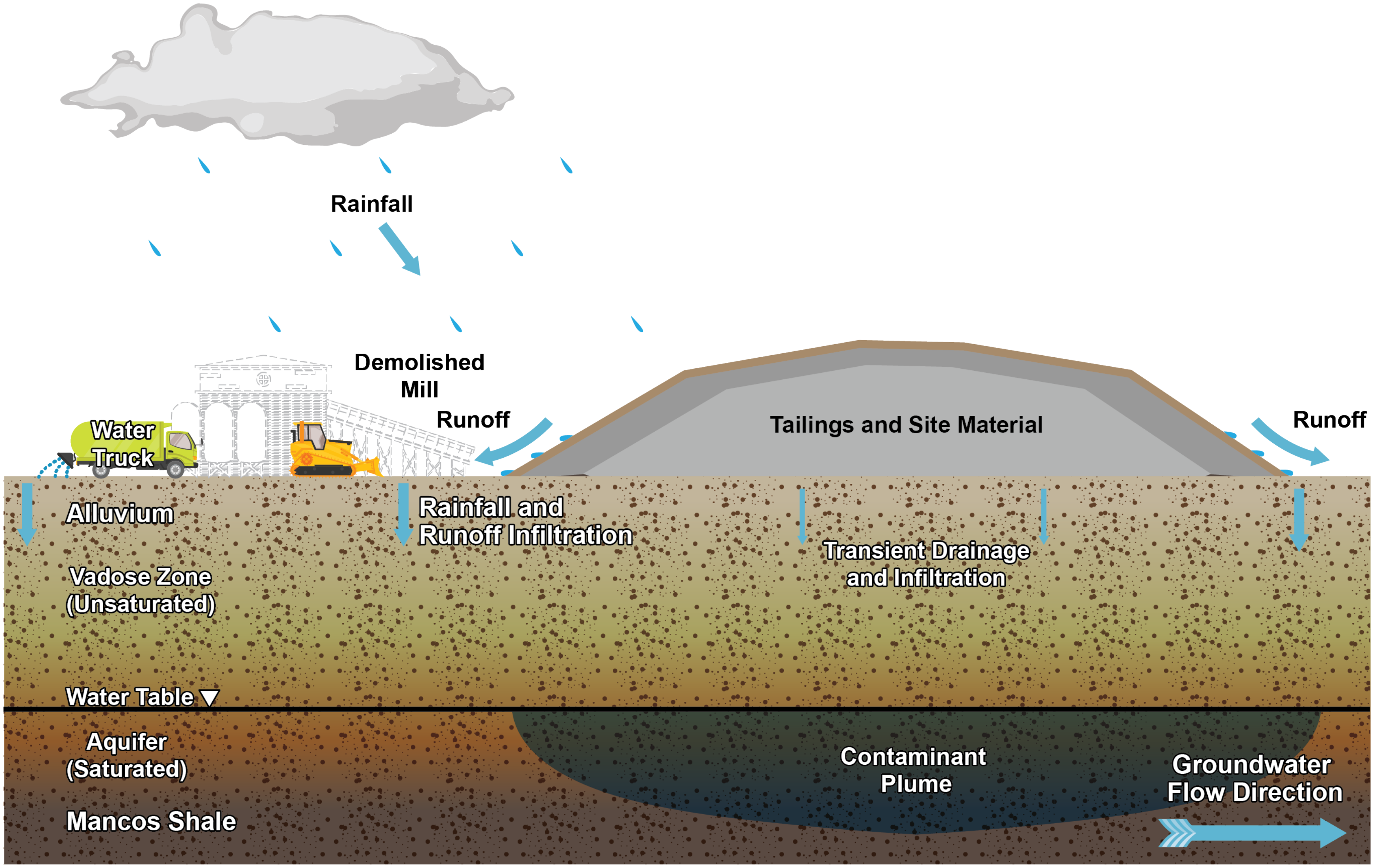


Figure 6. Shiprock Site Schematic Water Balance During Surface Remediation (1985–1986)

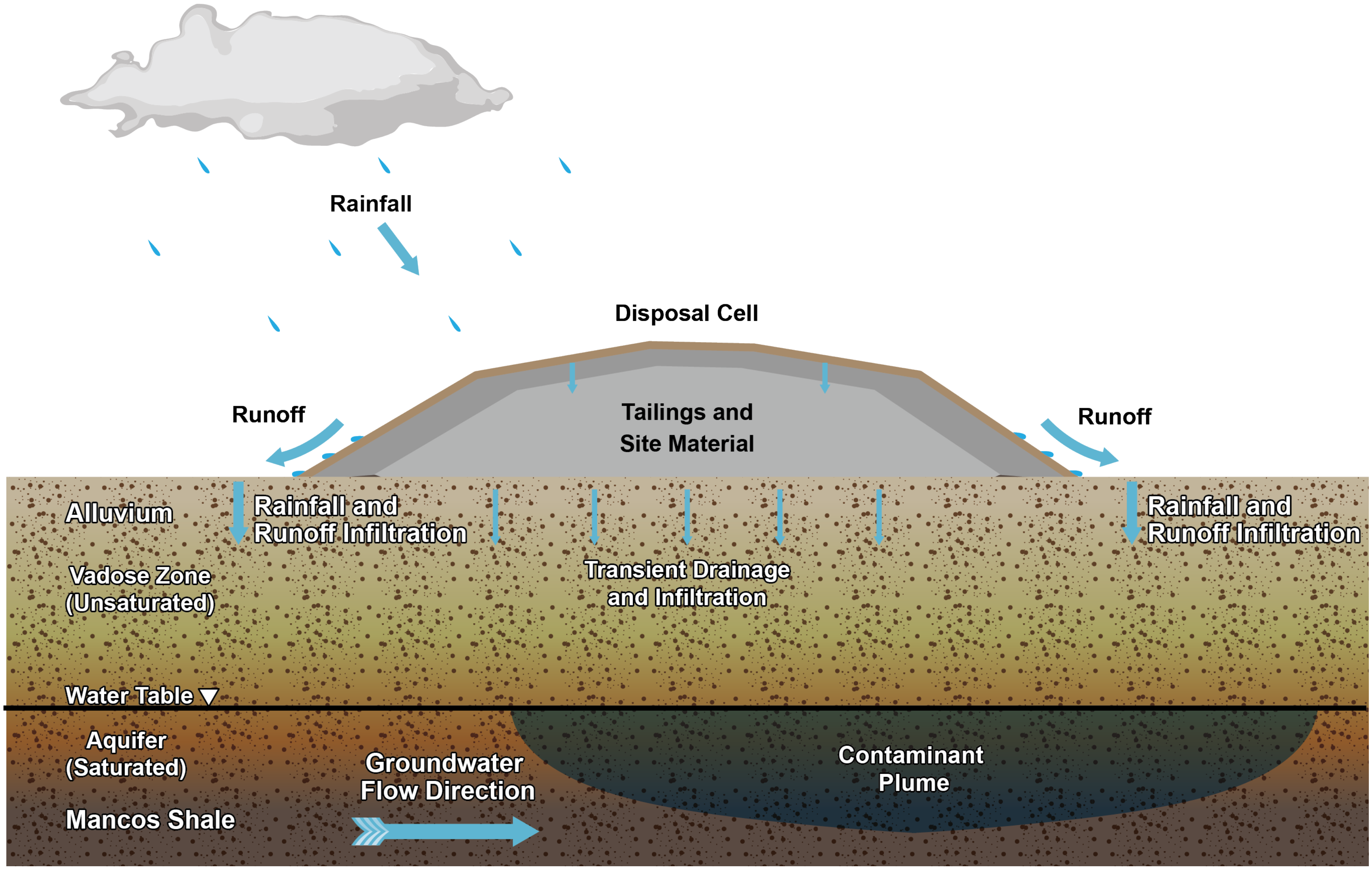


Figure 7. Schematic Water Balance for the 1000-Year Disposal Cell Design Life Span (1987–2987)

The contaminant concentrations in the water that infiltrates through the cell cover and tailings during the life span are unknown and will depend on the hydrogeochemical conditions within the tailings and the cover. Contaminant mass loading to the subsurface will likely decrease over time after the transient drainage subsides, if the transport of oxygen and water through the cover is limited. If the cover's low permeability is retained for hundreds of years, infiltration to the subsurface could essentially be limited to the transient drainage. Conversely, if the cover is assumed to lose compaction (increasing its permeability) within a relatively short period, infiltration through the cover and through tailings into the subsurface would occur at a higher rate and over a longer duration. The development or construction of an evapotranspiration (ET) cover may mitigate infiltration into the disposal cell if the cover loses compaction.

3.0 Water Infiltration Volumes

The estimated volumes of water infiltrating to the subsurface through the footprint area of the tailings impoundments and raffinate pond and disposal cell were calculated for the three periods in the past (milling, mill idled and abandoned, and surface remediation) and the current-through-future period covering a 1000-year design life span of the disposal cell. The estimated volume of water entering the subsurface for each period was compared to the other period volumes to better understand the relative impacts to groundwater resulting from each discrete period.

3.1 Milling Operations: 1954–1968

As previously described in the "Site Background" and "Site Conceptual Model" sections, the mill operated from 1954 through 1968. The calculations and results for the site water balance in this period are presented below.

3.1.1 Estimated Range for Water Infiltration During Milling

During the active milling period, the estimated volume of water that infiltrated the subsurface ranged between 43 and 163 million gallons (gal), equivalent to infiltration rates between 6 and 22 gallons per minute (gpm). Calculations and justification for variables supporting the estimate are presented in Appendix A. Infiltration estimates for the tailings impoundments and raffinate pond are summarized in Table 2. Calculation basis and assumptions are presented below.

- The mill operated 24 hours per day, 365 days per year.
- Water use while the mill operated (1954–1968) was between 100 and 160 gpm.
- Water evaporated to produce the final dry uranium product is assumed to be negligible in relation to the amount of water required to slurry tailings to the impoundments.
- Long-term regional average monthly precipitation and natural evaporation rates provide reasonable estimates for these components of the water balance.
- The 38.8-acre lower tailings impoundment was present at mill inception. The 30.6-acre upper tailings impoundment was constructed sometime prior to 1960; for this evaluation, the impoundment was assumed to have been constructed in 1957.
- The raffinate pond was 4.3 acres in size.
- Total infiltration area was 73.6 acres.

- The minimum estimate of infiltration volume assumes milling utilized 100 gpm of water.
- The maximum estimate of infiltration volume assumes milling utilized 160 gpm of water.
- All liquid contained in the tailings impoundments and raffinate pond either evaporates or infiltrates into the subsurface.

Table 2. Estimated Volumes and Rates of Water Infiltration During Milling 1954–1968 (15 years) Shiprock Site

Site Features	Minimum Cumulative Infiltration (million gal)	Minimum Infiltration Rate (gpm)	Maximum Cumulative Infiltration (million gal)	Maximum Infiltration Rate (gpm)
Tailings impoundments and raffinate pond	43	6	163	22

3.1.2 Uncertainties Affecting the Estimation of Infiltration During Milling

The uncertainties associated with the estimation of water infiltration to the water table during the milling period are primarily associated with the lack of information about mill operations.

Operations Efficiency. While it is logical to assume that near-continuous operation would have been planned, there may have been routine maintenance shutdowns that would have resulted in reduced water use. Mechanical failures may also have led to intermittent production interruptions of unknown durations. A reasonable assumption of runtime efficiency of 90% can be made based on engineering judgment that the mill would have been shut down for routine maintenance for 1 full day every 2 weeks and that unscheduled breakdowns would account for an additional half day of downtime in 2 weeks as a long-term average. Under this scenario, the estimate of minimum and maximum cumulative infiltration volumes would be 10% less than that listed in Table 2.

Nonroutine Operational Releases. An accidental release of an unknown volume occurred in 1960. While described as a relatively large release (HEW 1962), the released volume would have equaled at most the storage capacity of the lower tailings impoundment. Given that many times that volume of water was added to the lower tailings impoundment during mill operation, the released volume is assumed to be inconsequential to the estimated infiltration volumes.

3.2 Mill Inactive and Site Abandoned: 1969–1984

In 1969, the mill was idled and eventually abandoned due to the reduction in mining activity. The tailings impoundments and raffinate pond (covering 73.6 acres) were abandoned in place, and standing liquid associated with milling infiltrated and evaporated, leaving the features dry. When it rained or snowed, some of the water falling on the dry tailings impoundments and raffinate pond likely infiltrated and was a potential source of contaminant transport to the subsurface.

3.2.1 Estimated Range for Water Infiltration: 1969–1984

Infiltration estimates for when the site was inactive range from 0 to 64 million gallons, equivalent to infiltration rates between 0 and 8 gpm (Table 3). Calculations and justification for variables supporting the estimates are presented in Appendix B.

Table 3. Estimated Volumes of Water Infiltration When Mill Was Inactive 1969–1984 (16 years) Shiprock Site

Site Features	Minimum Cumulative Infiltration (million gal)	Minimum Infiltration Rate (gpm)	Maximum Cumulative Infiltration (million gal)	Maximum Infiltration Rate (gpm)
Tailings impoundments and raffinate pond	0	0	64	8

The minimum infiltration volume assumes that all precipitation falling on the 73.6-acre footprint of potentially contaminated material (tailings impoundments and raffinate pond) is transpired and infiltration is zero. This scenario is possible if native plants were to revegetate the former tailings impoundments and raffinate pond. Waugh et al. (2015) found that allowing native plants to grow on disposal cells effectively halts infiltration by transpiring precipitation infiltration before the water leaves the root zone. By extension, plants growing in the former tailings impoundments and raffinate pond could also limit or halt precipitation infiltration.

The Tuba City, Arizona, Disposal Site evapotranspiration (ET) study found that areas where surface soils had been excavated and reworked had less established plant communities, which allowed 2 inches of annual precipitation to infiltrate the subsurface (DOE 2016). Surface material within the tailings impoundment and raffinate pond, while not reworked, was not optimal for plant growth. This evaluation assumed, similar to that for the Tuba City disposal site, that soil conditions at the inactive Shiprock Mill site within the impoundments and raffinate pond yielded less healthy plant communities, which decreased ET and allowed 2 inches of annual precipitation to infiltrate and reach the water table.

3.2.2 Uncertainties Affecting the Estimation of Infiltration: 1969–1984

Plant growth on the abandoned mill site would not be instantaneous and, as such, transpiration rates would start at zero and increase with time. It is uncertain whether plant transpiration rates would have reached the maximum possible rates in the 16 years the mill site was abandoned.

3.3 Surface Remediation: 1985–1986

Demolition debris, windblown surface contamination, and sediments from the evaporation ponds were collected and consolidated in and around the tailings impoundment in 1985 and 1986. An engineered disposal cell was constructed to control radon emissions emanating from the tailings. During surface remediation, water was intermittently sprayed (usually during hot and windy weather) on the material and surrounding ground surface for dust suppression. An infiltration area of 76 acres was assumed for the evaluation, which corresponds to the footprint of the disposal cell.

In addition to infiltration associated with water sprayed for dust suppression, some transient drainage from emplaced tailings would also have occurred. However, when evaluating this period, transient drainage of tailings pore water was assumed to be minimal compared to the drainage that occurred after the disposal cell was completed. On the basis of this premise, the evaluation assumes that all of the transient drainage of tailings pore fluids occurs following disposal cell construction.

The components of the water balance in the period of surface remediation include the water used for dust suppression, natural precipitation, evaporation, and infiltration.

3.3.1 Estimated Range for Water Infiltration During Surface Remediation

The estimates of infiltration during surface remediation range from 0 to 41 million gallons, equivalent to infiltration rates between 0 and 39 gpm, as summarized in Table 4. Supporting calculations and justification for variables are provided in Appendix C.

Table 4. Estimated Volumes and Rates of Water Infiltration During Surface Remediation 1985–1986 (2 years) Shiprock Site

Activity	Minimum Cumulative Infiltration (million gal)	Minimum Infiltration Rate (gpm)	Maximum Cumulative Infiltration (million gal)	Maximum Infiltration Rate (gpm)
Dust suppression	0	0	12	11
Precipitation infiltrating through the footprint of consolidated materials	0	0	29	28
Total	**0**	**0**	**41**	**39**

There is no record of water usage to control dust during surface remediation of the Shiprock Mill site. The estimated volume of water used for dust suppression at the Tuba City disposal site during surface remediation and construction of the 55-acre disposal cell is 9 million gallons (DOE 1986). The 76-acre Shiprock disposal cell is 1.4 times larger than the Tuba City disposal cell. On the basis of size differential, the volume of water used for dust suppression during Shiprock site surface remediation and disposal cell construction was assumed to be 12 million gallons, equivalent to an infiltration rate of 11 gpm. A portion of the 12 million gallons likely infiltrated to the subsurface after passing through contaminated material. Bounding conditions for the estimate of dust suppression water available for infiltration are 0 (all evaporation, no infiltration) and 12 million gallons (all infiltration, no evaporation).

On the basis of average annual precipitation occurring throughout the 2-year duration of surface remediation and the 76-acre footprint of surface remediation, a total of 29 million gallons of water would have been available for evaporation or infiltration, or both. The proportional amount of evaporation was likely greater than infiltration but is unknown. Therefore, the bounding range for infiltration volume is 0–29 million gallons (0–28 gpm).

3.3.2 Uncertainties Affecting the Estimation of Infiltration During Surface Remediation

Uncertainty is introduced by the timing of construction activities. Putting construction activities temporarily on hold to minimize seasonal challenges (cold temperatures or heavy rains) would reduce the period over which dust suppression water may have been utilized. So the rate of use may have had seasonal peaks and valleys, and this would have affected the infiltration rate. Use of dust suppression water would have likely been greatest during the seasons when natural evaporation would also have been greatest (high temperatures and high winds).

Without construction records specific to the remediation period, defensible assumptions to reduce the uncertainties cannot be made. However, the estimated total volume of infiltration, even at the maximum case for this activity and period, is less than the infiltration rate for the milling period. Reducing the uncertainties in this relatively small time segment would have minimal impact and benefit to the accuracy of the overall water balance.

3.4 Maximum Postclosure Design Period: 1987–2987

In 1987, the disposal cell cover was in place and the site was in the postclosure period. The cover primarily serves as a radon barrier, but the CSL also prevents precipitation from infiltrating the contaminated material and going into the subsurface.

The water-balance components for the 1000-year design life span of the disposal cell include transient drainage of tailings-bound water, meteoric precipitation, evaporation, and infiltration. Supporting calculations and justification for variables for the minimum and maximum infiltration volumes are provided in Appendix D.

3.4.1 Estimated Range for Water Infiltration During Cover Life Span

The disposal cell cover's layer of compacted soil is designed to have low permeability. Assuming the cover prevents precipitation infiltration, the minimum volume of infiltrated water is zero (Table 5). Research of disposal cell cover performance has shown that soil-forming processes increase the permeability of covers over time, potentially allowing up to 20% of precipitation to infiltrate through the cover (Albright et al. 2004). The estimate of maximum infiltration through the cover is therefore based on 20% (1.41 inches/year) of the long-term average annual precipitation (7.06 inches/year, DOE 2000) infiltrating through the 76-acre cover, which results in an infiltrated volume of 3.0 billion gallons over 1000 years, equivalent to an infiltration rate of 5.7 gpm (Table 5).

The estimated range of water bound in the tailings during emplacement is 102–139 million gallons (Table 5). This is the maximum volume of water (average 0.2 to 0.3 gpm over the 1000-year performance period) that could enter the subsurface as a result of transient drainage from the tailings. It should be noted that the majority of gravity drainage will occur in a few decades or less following disposal cell construction. Correspondingly, gravity drainage rates will be greatest following cell construction and decline with time.

Table 5. Estimated Volumes and Rates of Water Infiltration During Maximum Postclosure Design Period 1987–2987 (1000 years) Shiprock Site

Activity	Minimum Cumulative Infiltration (million gal)	Minimum Infiltration Rate (gpm)	Maximum Cumulative Infiltration (million gal)	Maximum Infiltration Rate (gpm)
Infiltration through cover	0	0.0	2972	5.7
Transient drainage from tailings (pore water)	102	0.2	139	0.3
Total	**102**	**0.2**	**3111**	**6.0**

Disposal cell cover research has also shown that vegetated covers can limit infiltration to 1% of annual precipitation in locations with arid and semiarid climate conditions. Infiltration is limited by water uptake through root systems and release by transpiration to the atmosphere. The uptake and release processes are referred to as ET, and disposal cell covers that are designed with vegetation are referred to as ET or water-balance covers (Albright et al. 2004, Waugh et al. 2015).

Compacted soil covers can be converted to ET covers by establishing root-zone soil density and seedbed soil texture conditions that are conducive to propagation of natural vegetation (Waugh et al. 2015). ET covers, when fully developed, have been shown at a test facility located on the Grand Junction disposal cell site to reduce precipitation infiltration through disposal cell covers to 1% of the precipitation rate by the processes of vegetative uptake of water from the cover material and release of water to the atmosphere. The test facility consists of two, small-scale disposal cells that are located adjacent to one other. One cell is sprayed with herbicide to keep the cover weed free. The other disposal cell is not spayed with herbicides, allowing native vegetation to grow on the cover. The current LM weed spraying policy for the Shiprock disposal cell is to only spray noxious weeds and plants having deep roots that potentially could penetrate the CSL. All other native plants grow unfettered. Under the current LM weed spraying policy, with time, as windblown soil collects between the rocks of the cover, the current Shiprock disposal cell rock cover will become covered with native plants, which will reduce infiltration rates into the disposal cell. Assuming an ET cover does develop at Shiprock and performs similar to the test facility ET cover, infiltration into the disposal cell could be reduced to as little as 144 million gal (0.3 gpm) over the 1000-year performance period (Appendix D). Because ET cover effectiveness is a function of climate, plant types, and the water storage capabilities of the cover material, an evaluation will be required to determine the ultimate effectiveness of the native plants in mitigating precipitation infiltration into the Shiprock disposal cell.

3.4.2 Uncertainties Affecting the Estimation of Infiltration During Cover Life Span

Cover performance is the primary uncertainty in estimating infiltration throughout the cell cover's life span. If the cover exhibits low permeability throughout the maximum postclosure period, then minimum infiltration to the subsurface will occur, with the only source being transient drainage of tailings pore water. If the cover becomes increasingly permeable due to soil-forming processes but is not vegetated, the maximum infiltration could occur. Both the minimum and maximum infiltration scenarios are unlikely: It is unlikely that the cell cover's low permeability will remain constant over time, and it is also unlikely that the cover will remain unvegetated. That being said, the estimated cover infiltration in the 1996 Transient Drainage Summary Report was 1.24 inches/year (DOE 1996), which is almost equal to 20% of annual precipitation. Thus, infiltration through the disposal cell will likely be closer to the maximum than the minimum estimation. An ET cover that develops naturally or is constructed has the potential to reduce precipitation infiltration into the disposal cell. The ultimate performance of an ET cover is uncertain because performance is a function of climate, plant types, and the water storage capabilities of the cover material, which have not been evaluated in the context of an ET cover.

While tailings characterization has been performed and the distribution of sands to slimes has been estimated (CSU 1985), the limited number of boreholes drilled during characterization yields uncertain estimates of sand to slime proportions. For simplicity, this evaluation assumed complete drainage of the sands and slimes and the range of tailings drainage infiltration estimates assumes either sands or slimes but not both are present. The reality is that both tailings types are present and the tailings gravity drainage volume is somewhere between the two estimates (102–139 million gallons).

3.5 Summary of Water Infiltration Volumes

Calculated estimates of the volume of water infiltrating to the subsurface through the footprint of the mill tailings impoundments and raffinate pond range from 145 million to 3.4 billion gallons (Table 6).

Table 6. Summary of Shiprock Site Total Water Infiltration Volumes and Rates

Activity	Minimum Cumulative Infiltration (million gal)	Minimum Infiltration Rate (gpm)	Maximum Cumulative Infiltration (million gal)	Maximum Infiltration Rate (gpm)
Milling: 1954–1968	43	6	163	22
Mill inactive and abandoned: 1969–1984	0	0	64	8
Surface remediation: 1985–1986	0	0	41	39
Maximum postclosure design period: 1987−2987	102	0.2	3111	6
Total	**145**	**NA**	**3379**	**NA**

Abbreviation:
NA = not applicable

The relative amounts of water potentially infiltrating through the disposal cell cover throughout the four periods are reflected in pie charts (Figure 8 for minimum infiltration and Figure 9 for maximum infiltration). For both the minimum and maximum infiltration scenarios, because of the 1000-year performance period, postclosure infiltration through the disposal cell is the greatest contributor of water to the subsurface even though the infiltration rates are lowest for this period.

Figure 10 shows the infiltration percentages when infiltration is assumed to be equal to the average of the minimum and maximum calculated volumes for milling, inactive mill, and surface remediation time frames and native vegetation (ET cover) is allowed to develop on the disposal cell. For this scenario, infiltration through the cover for the 1000-year performance period at a rate of 0.3 gpm accounts for 48% of the total infiltration volume from 1954 to 2987.

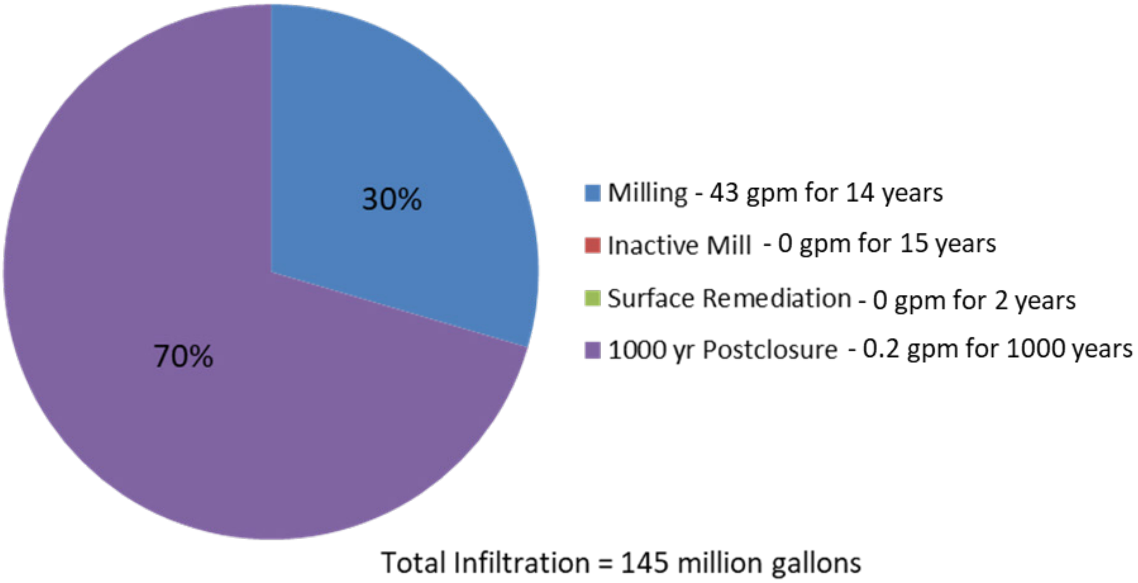


Figure 8. Minimum Water Infiltration Volume Percentages

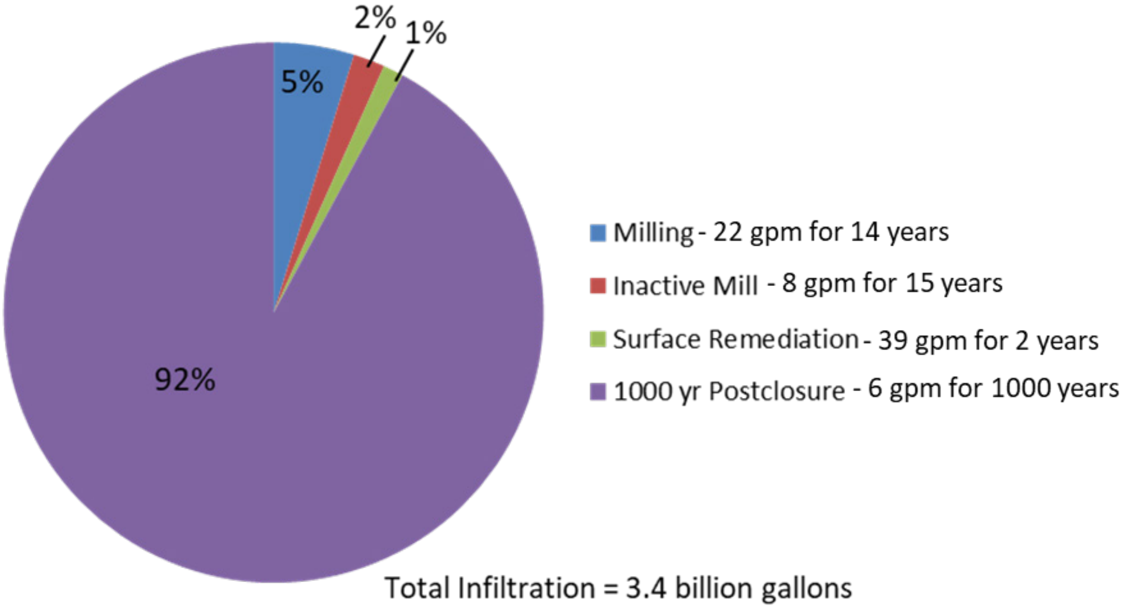


Figure 9. Maximum Water Infiltration Volume Percentages

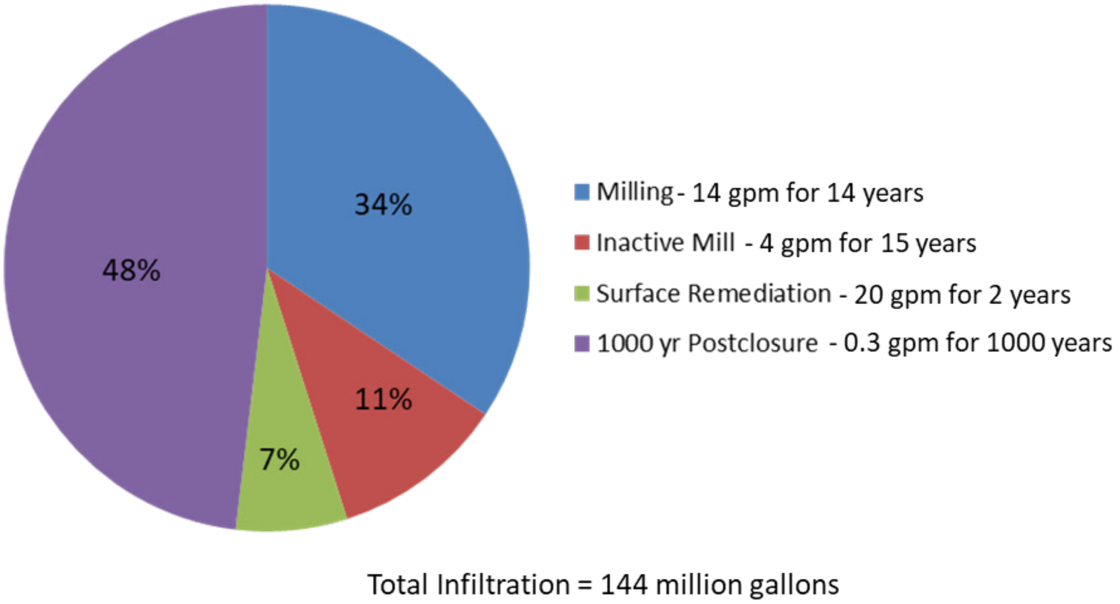


Figure 10. Average Water Infiltration Percentages with ET Cover

While the volumes of water infiltrating to the subsurface may appear quite large, it is important to keep the numbers in perspective. For example, the maximum estimate of 3.0 billion gallons of infiltration over the 1000-year life span of the cell cover equates to a flow rate of 5.7 gpm applied over the 76-acre footprint of the cell—or less than 0.07 gpm per acre. An ET cover has the potential to reduce the infiltration rates to 0.3 gpm, a nearly 20 times reduction in infiltration relative to the maximum infiltration scenario. Lastly, for comparison purposes, artesian well 648 flows continuously at a rate of 60 to 70 gpm (water that ultimately infiltrates the subsurface), a rate much greater than the estimated infiltration rates for the milling, inactive mill, surface remediation, and postclosure periods.

4.0 Conclusions

The estimate of water infiltration to the subsurface in the area of the Shiprock site disposal cell consists of four discrete periods: (1) during milling, (2) when the mill site was inactive, (3) during surface remediation, and (4) throughout the maximum postclosure design period (1000 years). In sum, the estimate of water infiltration from the start of uranium milling in 1954 through the end of the design life of the disposal cell (2987) is between 145 million and 3.4 billion gallons. Between 43 and 268 million gallons of water entered the subsurface at the footprint of the tailings impoundments and raffinate pond prior to completion of the disposal cell.

During the mill's operation, as a result of standing water in the unlined tailing impoundments and raffinate pond, there was essentially a constant supply of water for infiltration to the subsurface. This is also the period in which the infiltrating water would have carried the highest (although currently unquantified) mass of dissolved uranium and other contaminants.

Gravity drainage of tailings pore fluid (transient drainage) is expected to contribute as much as 139 million gallons of infiltration from the disposal cell. Because the rate of gravity drainage normally decreases exponentially over time, it is expected that most of the tailings pore water has already drained during the roughly 32-year period since cell construction was completed. Some pore water may be permanently held in the physical matrix of the tailings by capillary forces.

The disposal cell construction contributed a relatively small volume of infiltration. This is due to the relatively short 2-year duration of this period relative to the other time frames (15 years of mill operation, 16 years of site inactivity, and 1000 years of disposal cell design life span).

Because the design life span of the disposal cell cover is 1000 years, the greatest potential for water infiltration is likely to occur during this period. This period also contributes the greatest degree of uncertainty, because a defensible assumption of cover performance over such a long duration cannot be made. The uncertainties in the other three periods (active milling, site abandoned and inactive, surface remediation) become negligible in comparison to the long-term future performance of the cell cover.

As designed, the cover should effectively prevent precipitation from infiltrating the disposal cell. Research has shown that natural soil-forming processes can increase the permeability of disposal cell covers over time, allowing for greater infiltration. Soil-forming processes occur slowly, and in the future there is no way of knowing explicitly to what extent the cell cover permeability will be altered. Thus, over the 1000-year design life of the disposal cell, infiltration through the disposal cell cover could be minimal (near 0 gallons) or could be the largest source of infiltration (3.1 billion gallons). Although the cumulative maximum infiltration volume is 3.1 billion gallons, the maximum infiltration rate for the 1000-year design life is 6 gpm, which is smaller by almost a factor of 4 relative to the maximum estimated infiltration rate (22 gpm) that could have occurred during milling. For the minimum and ET cover infiltration scenarios, the infiltration rates through the disposal cell cover are 0.2 and 0.3 gpm, respectively, rates that are significantly less than those associated with milling.

While the cover is designed to require minimal maintenance over the long term, it is possible that a major maintenance activity could be undertaken if cover permeability is known to be increasing over time. An ET vegetative cover could be allowed to naturally develop over time or could be constructed. When vegetation is established, infiltration through tailings to the subsurface could be greatly reduced, potentially by more than an order of magnitude relative to that of the maximum infiltration scenario. Because ET cover effectiveness is a function of climate, plant types, and the water storage capabilities of the cover material, an evaluation will be required to determine the ultimate effectiveness of the native plants in mitigating precipitation infiltration into the Shiprock disposal cell.

5.0 References

40 CFR 192. U.S. Environmental Protection Agency, “Health and Environmental Protection Standards for Uranium and Thorium Mill Tailings,” *Code of Federal Regulations.*

Albright, W.H., C.H. Benson, G.W. Gee, A.C. Roesler, T. Abichou, P. Apiwantragoon, B.F. Lyles, and S.A. Rock, 2004. “Field Water Balance of Landfill Final Covers,” *Journal of Environmental Quality* 33:2317–2332.

Cooley, K.R., 1970. *Evaporation from Open Water Surfaces in Arizona*, USDA Agricultural Experiment Station and Cooperative Extension Service, University of Arizona, Tucson, Arizona.

CSU (Colorado State University), 1985. *Characterization of Inactive Uranium Mill Tailings Sites: Shiprock, New Mexico*, prepared by the CSU Geotechnical Engineering Program, Fort Collins, Colorado, for the U.S. Department of Energy, Albuquerque, New Mexico.

DOE (U.S. Department of Energy), 1981. *A Summary of the Engineering Assessment of Inactive Uranium Mill Tailings*, Shiprock Site, Shiprock, New Mexico, DOE/UMT-0104S, July.

DOE (U.S. Department of Energy), 1986. *Remedial Action at the Tuba City Uranium Mill Tailings Site, Tuba City, Arizona*, DOE/EA-0317, November.

DOE (U.S. Department of Energy), 1996. *Transient Drainage Summary Report, Final*, DOE/AL/62350-224, Rev. 2, September.

DOE (U.S. Department of Energy), 2000. *Final Site Observational Work Plan for the Shiprock, New Mexico, UMTRA Project Site*, GJO-2000-169-TAR, November.

DOE (U.S. Department of Energy), 2016. *Draft Groundwater Flow Model for the Tuba City, Arizona, Disposal Site*, LMS/TUB/S12512, February.

HEW (U.S. Department of Health, Education, and Welfare), 1962. Colorado River Basin Water Quality Control Project, *Stream Surveys in Vicinity of Uranium Mills. IV. Area of Shiprock, New Mexico – November 1960.*

Merritt, R.C., 1971. *The Extractive Metallurgy of Uranium*, Colorado School of Mines Research Institute.

Stone & Webster (Stone & Webster Engineering Corporation), 1978. *Uranium Mining & Milling: The Need, The Processes, The Impacts, The Choices; Administrator’s Guide*, prepared for Western Interstate Energy Board, for U.S. Environmental Protection Agency, Contract No. 68-01-4490, May.

Waugh, W.J., C.H. Benson, W.H. Albright, G.M. Smith, and R.P. Bush, 2015. “Evaluation of Soil Manipulation to Prepare Engineered Earthen Waste Covers for Revegetation,” *Journal of Environmental Quality* 44:1911–1922.

Appendix A

Estimate of Water Volume That Infiltrated the Subsurface During Milling Operations (1954–1968)

This page intentionally left blank

Basis of Estimate for Infiltration Volume, 1954–1968

The volume of water that potentially infiltrated the subsurface during milling can be estimated using the expected daily water requirements for processing ore and measured evaporation rates from open surface water bodies in New Mexico. The concept is that all the water used during milling is conveyed with the tailings to the tailings impoundment where the solids settle out, leaving behind pooled liquid. Precipitation on the tailings impoundment and raffinate pond is included in the water balance for these features. The surface area of the tailings impoundment and raffinate pond is multiplied by the monthly evaporation rates (depth per time) from open surface water bodies (Cooley 1970) to calculate the volume of water expected to evaporate monthly during milling operations. Monthly production water in excess of the calculated evaporation volume is assumed to have infiltrated into the subsurface.

This method assumes that milling wastewater either evaporates or infiltrates into the subsurface. Evaporation and infiltration occur simultaneously, so even in the months when evaporation exceeds mill water usage, some infiltration would occur. Documentation of how the evaporation pond water levels were maintained and measured values for hydraulic conductivity in the subsurface would improve the accuracy of the infiltration volume estimate, but the infiltration volume calculations represent the best estimates possible given available data.

The evaluation also assumes that the mill operated 365 days per year. While not specifically mentioning the Shiprock Mill, Merritt (1971) states that other uranium mills in the Four Corners area operated year-round.

Water usage during milling was reported to be 130 gpm (HEW 1962). Milling capacity was reported to be between 300 and 500 tons per day (TPD). For the evaluation it was assumed that the reported water usage corresponded to a 400 ton per day production rate. Water usage estimates for the minimum (300 TPD) and maximum (500 TPD) mill production rates were scaled up or down relative to 400 TPD water usage to determine minimum (100 gpm) and maximum (160 gpm) potential usage rates.

The upper and lower tailings impoundments had footprints of 30.6 acres (1,332,936 square feet [ft^2]) and 38.7 acres (1,685,772 ft^2), respectively. The raffinate pond was 4.3 acres (187,308 ft^2) in size. Cumulatively, the three features have a footprint of 73.6 acres (3,206,016 ft^2). Based on aerial photos, the upper tailings impoundment was constructed sometime between 1954 and 1960. The evaluation assumed that the upper tailings pond became operational in 1957.

Minimum and maximum water infiltration scenarios during milling were evaluated with water usage rates of 100 and 160 gpm, respectively.

Scenario 1: Minimum infiltration volume for tailings impoundments and raffinate pond when mill water usage was 100 gpm (Table A-1)

≈43 million gallons

Minimum infiltration rate for tailings impoundments and raffinate pond when mill water usage was 100 gpm

~6 gpm

Scenario 2: Maximum infiltration volume for tailings impoundments and raffinate pond when mill water usage was 160 gpm (Table A-1)

≈163 million gallons

Maximum infiltration rate for tailings impoundments and raffinate pond when mill water usage was 160 gpm

~22 gpm

The infiltration rates were determined from infiltration volumes using the following conversion:
Infiltration volume × 1/14 years × 1 year/365.25 days × 1 day/24 hour × 1 hr/60 min

Table A-1. Minimum Water Volume Available Annually for Infiltration, from Impoundments and Pond, 1954–1968

Column	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18
Month	Days in Month	Cooley Net Evaporation[a]		Raffinate Pond	Upper Tailings	Lower Tailings	Raffinate Pond	Upper Tailings	Lower Tailings	Evaporation from Raffinate Pond and Tailings Impoundments		Monthly Mill Water Usage	Monthly Precipitation		Monthly Precipitation Volume		Total Inflow	Surplus Available to Infiltrate
					Impoundment			Impoundment										
		in	ft	ac	ac	Ac	ft^2	ft^2	ft^2	ft^3	gal	gal	in	ft	ft^3	gal	gal	gal
Nov-54	30	3.30	0.28	4.30	-	38.70	187,308	0	1,685,772	515,097	3,853,441	4,320,000	0.53	0.04	82,728	618,886	4,938,886	1,085,445
Dec-54	31	2.20	0.18	4.30	-	38.70	187,308	0	1,685,772	343,398	2,568,960	4,464,000	0.57	0.05	88,971	665,594	5,129,594	2,560,634
Jan-55	31	2.20	0.18	4.30	-	38.70	187,308	0	1,685,772	343,398	2,568,960	4,464,000	0.46	0.04	71,801	537,146	5,001,146	2,432,186
Feb-55	28	3.10	0.26	4.30	-	38.70	187,308	0	1,685,772	483,879	3,619,899	4,032,000	0.47	0.04	73,362	548,823	4,580,823	960,925
Mar-55	31	5.00	0.42	4.30	-	38.70	187,308	0	1,685,772	780,450	5,838,546	4,464,000	0.54	0.05	84,289	630,563	5,094,563	−743,983
Apr-55	30	6.60	0.55	4.30	-	38.70	187,308	0	1,685,772	1,030,194	7,706,881	4,320,000	0.41	0.03	63,997	478,761	4,798,761	−2,908,121
May-55	31	9.00	0.75	4.30	-	38.70	187,308	0	1,685,772	1,404,810	10,509,384	4,464,000	0.53	0.04	82,728	618,886	5,082,886	−5,426,498
Jun-55	30	9.90	0.83	4.30	-	38.70	187,308	0	1,685,772	1,545,291	11,560,322	4,320,000	0.29	0.02	45,266	338,636	4,658,636	−6,901,686
Jul-55	31	9.90	0.83	4.30	-	38.70	187,308	0	1,685,772	1,545,291	11,560,322	4,464,000	0.68	0.06	106,141	794,042	5,258,042	−6,302,280
Aug-55	31	9.00	0.75	4.30	-	38.70	187,308	0	1,685,772	1,404,810	10,509,384	4,464,000	1.01	0.08	157,651	1,179,386	5,643,386	−4,865,997
Sep-55	30	6.90	0.58	4.30	-	38.70	187,308	0	1,685,772	1,077,021	8,057,194	4,320,000	0.80	0.07	124,872	934,167	5,254,167	−2,803,027
Oct-55	31	5.30	0.44	4.30	-	38.70	187,308	0	1,685,772	827,277	6,188,859	4,464,000	0.77	0.06	120,189	899,136	5,363,136	−825,723
Nov-55	30	3.30	0.28	4.30	-	38.70	187,308	0	1,685,772	515,097	3,853,441	4,320,000	0.53	0.04	82,728	618,886	4,938,886	1,085,445
Dec-55	31	2.20	0.18	4.30	-	38.70	187,308	0	1,685,772	343,398	2,568,960	4,464,000	0.57	0.05	88,971	665,594	5,129,594	2,560,634
Jan-56	31	2.20	0.18	4.30	-	38.70	187,308	0	1,685,772	343,398	2,568,960	4,464,000	0.46	0.04	71,801	537,146	5,001,146	2,432,186
Feb-56	29	3.10	0.26	4.30	-	38.70	187,308	0	1,685,772	483,879	3,619,899	4,176,000	0.47	0.04	73,362	548,823	4,724,823	1,104,925
Mar-56	31	5.00	0.42	4.30	-	38.70	187,308	0	1,685,772	780,450	5,838,546	4,464,000	0.54	0.05	84,289	630,563	5,094,563	−743,983
Apr-56	30	6.60	0.55	4.30	-	38.70	187,308	0	1,685,772	1,030,194	7,706,881	4,320,000	0.41	0.03	63,997	478,761	4,798,761	−2,908,121
May-56	31	9.00	0.75	4.30	-	38.70	187,308	0	1,685,772	1,404,810	10,509,384	4,464,000	0.53	0.04	82,728	618,886	5,082,886	−5,426,498
Jun-56	30	9.90	0.83	4.30	-	38.70	187,308	0	1,685,772	1,545,291	11,560,322	4,320,000	0.29	0.02	45,266	338,636	4,658,636	−6,901,686
Jul-56	31	9.90	0.83	4.30	-	38.70	187,308	0	1,685,772	1,545,291	11,560,322	4,464,000	0.68	0.06	106,141	794,042	5,258,042	−6,302,280
Aug-56	31	9.00	0.75	4.30	-	38.70	187,308	0	1,685,772	1,404,810	10,509,384	4,464,000	1.01	0.08	157,651	1,179,386	5,643,386	−4,865,997
Sep-56	30	6.90	0.58	4.30	-	38.70	187,308	0	1,685,772	1,077,021	8,057,194	4,320,000	0.80	0.07	124,872	934,167	5,254,167	−2,803,027
Oct-56	31	5.30	0.44	4.30	-	38.70	187,308	0	1,685,772	827,277	6,188,859	4,464,000	0.77	0.06	120,189	899,136	5,363,136	−825,723
Nov-56	30	3.30	0.28	4.30	-	38.70	187,308	0	1,685,772	515,097	3,853,441	4,320,000	0.53	0.04	82,728	618,886	4,938,886	1,085,445
Dec-56	31	2.20	0.18	4.30	-	38.70	187,308	0	1,685,772	343,398	2,568,960	4,464,000	0.57	0.05	88,971	665,594	5,129,594	2,560,634
Jan-57	31	2.20	0.18	4.30	30.60	38.70	187,308	1,332,936	1,685,772	587,770	4,397,104	4,464,000	0.46	0.04	122,897	919,395	5,383,395	986,290
Feb-57	28	3.10	0.26	4.30	30.60	38.70	187,308	1,332,936	1,685,772	828,221	6,195,920	4,032,000	0.47	0.04	125,569	939,381	4,971,381	−1,224,538
Mar-57	31	5.00	0.42	4.30	30.60	38.70	187,308	1,332,936	1,685,772	1,335,840	9,993,419	4,464,000	0.54	0.05	144,271	1,079,289	5,543,289	−4,450,130
Apr-57	30	6.60	0.55	4.30	30.60	38.70	187,308	1,332,936	1,685,772	1,763,309	13,191,313	4,320,000	0.41	0.03	109,539	819,460	5,139,460	−8,051,853
May-57	31	9.00	0.75	4.30	30.60	38.70	187,308	1,332,936	1,685,772	2,404,512	17,988,154	4,464,000	0.53	0.04	141,599	1,059,302	5,523,302	−12,464,852
Jun-57	30	9.90	0.83	4.30	30.60	38.70	187,308	1,332,936	1,685,772	2,644,963	19,786,970	4,320,000	0.29	0.02	77,479	579,618	4,899,618	−14,887,351
Jul-57	31	9.90	0.83	4.30	30.60	38.70	187,308	1,332,936	1,685,772	2,644,963	19,786,970	4,464,000	0.68	0.06	181,674	1,359,105	5,823,105	−13,963,865
Aug-57	31	9.00	0.75	4.30	30.60	38.70	187,308	1,332,936	1,685,772	2,404,512	17,988,154	4,464,000	1.01	0.08	269,840	2,018,671	6,482,671	−11,505,484
Sep-57	30	6.90	0.58	4.30	30.60	38.70	187,308	1,332,936	1,685,772	1,843,459	13,790,918	4,320,000	0.80	0.07	213,734	1,598,947	5,918,947	−7,871,971
Oct-57	31	5.30	0.44	4.30	30.60	38.70	187,308	1,332,936	1,685,772	1,415,990	10,593,024	4,464,000	0.77	0.06	205,719	1,538,987	6,002,987	−4,590,038
Nov-57	30	3.30	0.28	4.30	30.60	38.70	187,308	1,332,936	1,685,772	881,654	6,595,657	4,320,000	0.53	0.04	141,599	1,059,302	5,379,302	−1,216,354
Dec-57	31	2.20	0.18	4.30	30.60	38.70	187,308	1,332,936	1,685,772	587,770	4,397,104	4,464,000	0.57	0.05	152,286	1,139,250	5,603,250	1,206,145
Jan-58	31	2.20	0.18	4.30	30.60	38.70	187,308	1,332,936	1,685,772	587,770	4,397,104	4,464,000	0.46	0.04	122,897	919,395	5,383,395	986,290
Feb-58	28	3.10	0.26	4.30	30.60	38.70	187,308	1,332,936	1,685,772	828,221	6,195,920	4,032,000	0.47	0.04	125,569	939,381	4,971,381	−1,224,538
Mar-58	31	5.00	0.42	4.30	30.60	38.70	187,308	1,332,936	1,685,772	1,335,840	9,993,419	4,464,000	0.54	0.05	144,271	1,079,289	5,543,289	−4,450,130
Apr-58	30	6.60	0.55	4.30	30.60	38.70	187,308	1,332,936	1,685,772	1,763,309	13,191,313	4,320,000	0.41	0.03	109,539	819,460	5,139,460	−8,051,853
May-58	31	9.00	0.75	4.30	30.60	38.70	187,308	1,332,936	1,685,772	2,404,512	17,988,154	4,464,000	0.53	0.04	141,599	1,059,302	5,523,302	−12,464,852
Jun-58	30	9.90	0.83	4.30	30.60	38.70	187,308	1,332,936	1,685,772	2,644,963	19,786,970	4,320,000	0.29	0.02	77,479	579,618	4,899,618	−14,887,351
Jul-58	31	9.90	0.83	4.30	30.60	38.70	187,308	1,332,936	1,685,772	2,644,963	19,786,970	4,464,000	0.68	0.06	181,674	1,359,105	5,823,105	−13,963,865
Aug-58	31	9.00	0.75	4.30	30.60	38.70	187,308	1,332,936	1,685,772	2,404,512	17,988,154	4,464,000	1.01	0.08	269,840	2,018,671	6,482,671	−11,505,484
Sep-58	30	6.90	0.58	4.30	30.60	38.70	187,308	1,332,936	1,685,772	1,843,459	13,790,918	4,320,000	0.80	0.07	213,734	1,598,947	5,918,947	−7,871,971
Oct-58	31	5.30	0.44	4.30	30.60	38.70	187,308	1,332,936	1,685,772	1,415,990	10,593,024	4,464,000	0.77	0.06	205,719	1,538,987	6,002,987	−4,590,038
Nov-58	30	3.30	0.28	4.30	30.60	38.70	187,308	1,332,936	1,685,772	881,654	6,595,657	4,320,000	0.53	0.04	141,599	1,059,302	5,379,302	−1,216,354
Dec-58	31	2.20	0.18	4.30	30.60	38.70	187,308	1,332,936	1,685,772	587,770	4,397,104	4,464,000	0.57	0.05	152,286	1,139,250	5,603,250	1,206,145
Jan-59	31	2.20	0.18	4.30	30.60	38.70	187,308	1,332,936	1,685,772	587,770	4,397,104	4,464,000	0.46	0.04	122,897	919,395	5,383,395	986,290
Feb-59	28	3.10	0.26	4.30	30.60	38.70	187,308	1,332,936	1,685,772	828,221	6,195,920	4,032,000	0.47	0.04	125,569	939,381	4,971,381	−1,224,538
Mar-59	31	5.00	0.42	4.30	30.60	38.70	187,308	1,332,936	1,685,772	1,335,840	9,993,419	4,464,000	0.54	0.05	144,271	1,079,289	5,543,289	−4,450,130
Apr-59	30	6.60	0.55	4.30	30.60	38.70	187,308	1,332,936	1,685,772	1,763,309	13,191,313	4,320,000	0.41	0.03	109,539	819,460	5,139,460	−8,051,853
May-59	31	9.00	0.75	4.30	30.60	38.70	187,308	1,332,936	1,685,772	2,404,512	17,988,154	4,464,000	0.53	0.04	141,599	1,059,302	5,523,302	−12,464,852
Jun-59	30	9.90	0.83	4.30	30.60	38.70	187,308	1,332,936	1,685,772	2,644,963	19,786,970	4,320,000	0.29	0.02	77,479	579,618	4,899,618	−14,887,351
Jul-59	31	9.90	0.83	4.30	30.60	38.70	187,308	1,332,936	1,685,772	2,644,963	19,786,970	4,464,000	0.68	0.06	181,674	1,359,105	5,823,105	−13,963,865
Aug-59	31	9.00	0.75	4.30	30.60	38.70	187,308	1,332,936	1,685,772	2,404,512	17,988,154	4,464,000	1.01	0.08	269,840	2,018,671	6,482,671	−11,505,484
Sep-59	30	6.90	0.58	4.30	30.60	38.70	187,308	1,332,936	1,685,772	1,843,459	13,790,918	4,320,000	0.80	0.07	213,734	1,598,947	5,918,947	−7,871,971
Oct-59	31	5.30	0.44	4.30	30.60	38.70	187,308	1,332,936	1,685,772	1,415,990	10,593,024	4,464,000	0.77	0.06	205,719	1,538,987	6,002,987	−4,590,038
Nov-59	30	3.30	0.28	4.30	30.60	38.70	187,308	1,332,936	1,685,772	881,654	6,595,657	4,320,000	0.53	0.04	141,599	1,059,302	5,379,302	−1,216,354
Dec-59	31	2.20	0.18	4.30	30.60	38.70	187,308	1,332,936	1,685,772	587,770	4,397,104	4,464,000	0.57	0.05	152,286	1,139,250	5,603,250	1,206,145
Jan-60	31	2.20	0.18	4.30	30.60	38.70	187,308	1,332,936	1,685,772	587,770	4,397,104	4,464,000	0.46	0.04	122,897	919,395	5,383,395	986,290
Feb-60	29	3.10	0.26	4.30	30.60	38.70	187,308	1,332,936	1,685,772	828,221	6,195,920	4,176,000	0.47	0.04	125,569	939,381	5,115,381	−1,080,538
Mar-60	31	5.00	0.42	4.30	30.60	38.70	187,308	1,332,936	1,685,772	1,335,840	9,993,419	4,464,000	0.54	0.05	144,271	1,079,289	5,543,289	−4,450,130
Apr-60	30	6.60	0.55	4.30	30.60	38.70	187,308	1,332,936	1,685,772	1,763,309	13,191,313	4,320,000	0.41	0.03	109,539	819,460	5,139,460	−8,051,853
May-60	31	9.00	0.75	4.30	30.60	38.70	187,308	1,332,936	1,685,772	2,404,512	17,988,154	4,464,000	0.53	0.04	141,599	1,059,302	5,523,302	−12,464,852
Jun-60	30	9.90	0.83	4.30	30.60	38.70	187,308	1,332,936	1,685,772	2,644,963	19,786,970	4,320,000	0.29	0.02	77,479	579,618	4,899,618	−14,887,351
Jul-60	31	9.90	0.83	4.30	30.60	38.70	187,308	1,332,936	1,685,772	2,644,963	19,786,970	4,464,000	0.68	0.06	181,674	1,359,105	5,823,105	−13,963,865
Aug-60	31	9.00	0.75	4.30	30.60	38.70	187,308	1,332,936	1,685,772	2,404,512	17,988,154	4,464,000	1.01	0.08	269,840	2,018,671	6,482,671	−11,505,484
Sep-60	30	6.90	0.58	4.30	30.60	38.70	187,308	1,332,936	1,685,772	1,843,459	13,790,918	4,320,000	0.80	0.07	213,734	1,598,947	5,918,947	−7,871,971
Oct-60	31	5.30	0.44	4.30	30.60	38.70	187,308	1,332,936	1,685,772	1,415,990	10,593,024	4,464,000	0.77	0.06	205,719	1,538,987	6,002,987	−4,590,038
Nov-60	30	3.30	0.28	4.30	30.60	38.70	187,308	1,332,936	1,685,772	881,654	6,595,657	4,320,000	0.53	0.04	141,599	1,059,302	5,379,302	−1,216,354
Dec-60	31	2.20	0.18	4.30	30.60	38.70	187,308	1,332,936	1,685,772	587,770	4,397,104	4,464,000	0.57	0.05	152,286	1,139,250	5,603,250	1,206,145

Table A-1. Minimum Water Volume Available Annually for Infiltration, from Impoundments and Pond, 1954–1968 (continued)

Column	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18
Month	Days in Month	Cooley Net Evaporation[a]		Raffinate Pond	Upper Tailings	Lower Tailings	Raffinate Pond	Upper Tailings	Lower Tailings	Evaporation from Raffinate Pond and Tailings Impoundments		Monthly Mill Water Usage	Monthly Precipitation		Monthly Precipitation Volume		Total Inflow	Surplus Available to Infiltrate
					Impoundment			Impoundment										
		in	ft	ac	ac	Ac	ft^2	ft^2	ft^2	ft^3	gal	gal	in	ft	ft^3	gal	gal	gal
Jan-61	31	2.20	0.18	4.30	30.60	38.70	187,308	1,332,936	1,685,772	587,770	4,397,104	4,464,000	0.46	0.04	122,897	919,395	5,383,395	986,290
Feb-61	28	3.10	0.26	4.30	30.60	38.70	187,308	1,332,936	1,685,772	828,221	6,195,920	4,032,000	0.47	0.04	125,569	939,381	4,971,381	−1,224,538
Mar-61	31	5.00	0.42	4.30	30.60	38.70	187,308	1,332,936	1,685,772	1,335,840	9,993,419	4,464,000	0.54	0.05	144,271	1,079,289	5,543,289	−4,450,130
Apr-61	30	6.60	0.55	4.30	30.60	38.70	187,308	1,332,936	1,685,772	1,763,309	13,191,313	4,320,000	0.41	0.03	109,539	819,460	5,139,460	−8,051,853
May-61	31	9.00	0.75	4.30	30.60	38.70	187,308	1,332,936	1,685,772	2,404,512	17,988,154	4,464,000	0.53	0.04	141,599	1,059,302	5,523,302	−12,464,852
Jun-61	30	9.90	0.83	4.30	30.60	38.70	187,308	1,332,936	1,685,772	2,644,963	19,786,970	4,320,000	0.29	0.02	77,479	579,618	4,899,618	−14,887,351
Jul-61	31	9.90	0.83	4.30	30.60	38.70	187,308	1,332,936	1,685,772	2,644,963	19,786,970	4,464,000	0.68	0.06	181,674	1,359,105	5,823,105	−13,963,865
Aug-61	31	9.00	0.75	4.30	30.60	38.70	187,308	1,332,936	1,685,772	2,404,512	17,988,154	4,464,000	1.01	0.08	269,840	2,018,671	6,482,671	−11,505,484
Sep-61	30	6.90	0.58	4.30	30.60	38.70	187,308	1,332,936	1,685,772	1,843,459	13,790,918	4,320,000	0.80	0.07	213,734	1,598,947	5,918,947	−7,871,971
Oct-61	31	5.30	0.44	4.30	30.60	38.70	187,308	1,332,936	1,685,772	1,415,990	10,593,024	4,464,000	0.77	0.06	205,719	1,538,987	6,002,987	−4,590,038
Nov-61	30	3.30	0.28	4.30	30.60	38.70	187,308	1,332,936	1,685,772	881,654	6,595,657	4,320,000	0.53	0.04	141,599	1,059,302	5,379,302	−1,216,354
Dec-61	31	2.20	0.18	4.30	30.60	38.70	187,308	1,332,936	1,685,772	587,770	4,397,104	4,464,000	0.57	0.05	152,286	1,139,250	5,603,250	1,206,145
Jan-62	31	2.20	0.18	4.30	30.60	38.70	187,308	1,332,936	1,685,772	587,770	4,397,104	4,464,000	0.46	0.04	122,897	919,395	5,383,395	986,290
Feb-62	28	3.10	0.26	4.30	30.60	38.70	187,308	1,332,936	1,685,772	828,221	6,195,920	4,032,000	0.47	0.04	125,569	939,381	4,971,381	−1,224,538
Mar-62	31	5.00	0.42	4.30	30.60	38.70	187,308	1,332,936	1,685,772	1,335,840	9,993,419	4,464,000	0.54	0.05	144,271	1,079,289	5,543,289	−4,450,130
Apr-62	30	6.60	0.55	4.30	30.60	38.70	187,308	1,332,936	1,685,772	1,763,309	13,191,313	4,320,000	0.41	0.03	109,539	819,460	5,139,460	−8,051,853
May-62	31	9.00	0.75	4.30	30.60	38.70	187,308	1,332,936	1,685,772	2,404,512	17,988,154	4,464,000	0.53	0.04	141,599	1,059,302	5,523,302	−12,464,852
Jun-62	30	9.90	0.83	4.30	30.60	38.70	187,308	1,332,936	1,685,772	2,644,963	19,786,970	4,320,000	0.29	0.02	77,479	579,618	4,899,618	−14,887,351
Jul-62	31	9.90	0.83	4.30	30.60	38.70	187,308	1,332,936	1,685,772	2,644,963	19,786,970	4,464,000	0.68	0.06	181,674	1,359,105	5,823,105	−13,963,865
Aug-62	31	9.00	0.75	4.30	30.60	38.70	187,308	1,332,936	1,685,772	2,404,512	17,988,154	4,464,000	1.01	0.08	269,840	2,018,671	6,482,671	−11,505,484
Sep-62	30	6.90	0.58	4.30	30.60	38.70	187,308	1,332,936	1,685,772	1,843,459	13,790,918	4,320,000	0.80	0.07	213,734	1,598,947	5,918,947	−7,871,971
Oct-62	31	5.30	0.44	4.30	30.60	38.70	187,308	1,332,936	1,685,772	1,415,990	10,593,024	4,464,000	0.77	0.06	205,719	1,538,987	6,002,987	−4,590,038
Nov-62	30	3.30	0.28	4.30	30.60	38.70	187,308	1,332,936	1,685,772	881,654	6,595,657	4,320,000	0.53	0.04	141,599	1,059,302	5,379,302	−1,216,354
Dec-62	31	2.20	0.18	4.30	30.60	38.70	187,308	1,332,936	1,685,772	587,770	4,397,104	4,464,000	0.57	0.05	152,286	1,139,250	5,603,250	1,206,145
Jan-63	31	2.20	0.18	4.30	30.60	38.70	187,308	1,332,936	1,685,772	587,770	4,397,104	4,464,000	0.46	0.04	122,897	919,395	5,383,395	986,290
Feb-63	28	3.10	0.26	4.30	30.60	38.70	187,308	1,332,936	1,685,772	828,221	6,195,920	4,032,000	0.47	0.04	125,569	939,381	4,971,381	−1,224,538
Mar-63	31	5.00	0.42	4.30	30.60	38.70	187,308	1,332,936	1,685,772	1,335,840	9,993,419	4,464,000	0.54	0.05	144,271	1,079,289	5,543,289	−4,450,130
Apr-63	30	6.60	0.55	4.30	30.60	38.70	187,308	1,332,936	1,685,772	1,763,309	13,191,313	4,320,000	0.41	0.03	109,539	819,460	5,139,460	−8,051,853
May-63	31	9.00	0.75	4.30	30.60	38.70	187,308	1,332,936	1,685,772	2,404,512	17,988,154	4,464,000	0.53	0.04	141,599	1,059,302	5,523,302	−12,464,852
Jun-63	30	9.90	0.83	4.30	30.60	38.70	187,308	1,332,936	1,685,772	2,644,963	19,786,970	4,320,000	0.29	0.02	77,479	579,618	4,899,618	−14,887,351
Jul-63	31	9.90	0.83	4.30	30.60	38.70	187,308	1,332,936	1,685,772	2,644,963	19,786,970	4,464,000	0.68	0.06	181,674	1,359,105	5,823,105	−13,963,865
Aug-63	31	9.00	0.75	4.30	30.60	38.70	187,308	1,332,936	1,685,772	2,404,512	17,988,154	4,464,000	1.01	0.08	269,840	2,018,671	6,482,671	−11,505,484
Sep-63	30	6.90	0.58	4.30	30.60	38.70	187,308	1,332,936	1,685,772	1,843,459	13,790,918	4,320,000	0.80	0.07	213,734	1,598,947	5,918,947	−7,871,971
Oct-63	31	5.30	0.44	4.30	30.60	38.70	187,308	1,332,936	1,685,772	1,415,990	10,593,024	4,464,000	0.77	0.06	205,719	1,538,987	6,002,987	−4,590,038
Nov-63	30	3.30	0.28	4.30	30.60	38.70	187,308	1,332,936	1,685,772	881,654	6,595,657	4,320,000	0.53	0.04	141,599	1,059,302	5,379,302	−1,216,354
Dec-63	31	2.20	0.18	4.30	30.60	38.70	187,308	1,332,936	1,685,772	587,770	4,397,104	4,464,000	0.57	0.05	152,286	1,139,250	5,603,250	1,206,145
Jan-64	31	2.20	0.18	4.30	30.60	38.70	187,308	1,332,936	1,685,772	587,770	4,397,104	4,464,000	0.46	0.04	122,897	919,395	5,383,395	986,290
Feb-64	29	3.10	0.26	4.30	30.60	38.70	187,308	1,332,936	1,685,772	828,221	6,195,920	4,176,000	0.47	0.04	125,569	939,381	5,115,381	−1,080,538
Mar-64	31	5.00	0.42	4.30	30.60	38.70	187,308	1,332,936	1,685,772	1,335,840	9,993,419	4,464,000	0.54	0.05	144,271	1,079,289	5,543,289	−4,450,130
Apr-64	30	6.60	0.55	4.30	30.60	38.70	187,308	1,332,936	1,685,772	1,763,309	13,191,313	4,320,000	0.41	0.03	109,539	819,460	5,139,460	−8,051,853
May-64	31	9.00	0.75	4.30	30.60	38.70	187,308	1,332,936	1,685,772	2,404,512	17,988,154	4,464,000	0.53	0.04	141,599	1,059,302	5,523,302	−12,464,852
Jun-64	30	9.90	0.83	4.30	30.60	38.70	187,308	1,332,936	1,685,772	2,644,963	19,786,970	4,320,000	0.29	0.02	77,479	579,618	4,899,618	−14,887,351
Jul-64	31	9.90	0.83	4.30	30.60	38.70	187,308	1,332,936	1,685,772	2,644,963	19,786,970	4,464,000	0.68	0.06	181,674	1,359,105	5,823,105	−13,963,865
Aug-64	31	9.00	0.75	4.30	30.60	38.70	187,308	1,332,936	1,685,772	2,404,512	17,988,154	4,464,000	1.01	0.08	269,840	2,018,671	6,482,671	−11,505,484
Sep-64	30	6.90	0.58	4.30	30.60	38.70	187,308	1,332,936	1,685,772	1,843,459	13,790,918	4,320,000	0.80	0.07	213,734	1,598,947	5,918,947	−7,871,971
Oct-64	31	5.30	0.44	4.30	30.60	38.70	187,308	1,332,936	1,685,772	1,415,990	10,593,024	4,464,000	0.77	0.06	205,719	1,538,987	6,002,987	−4,590,038
Nov-64	30	5.30	0.44	4.30	30.60	38.70	187,308	1,332,936	1,685,772	1,415,990	10,593,024	4,320,000	0.53	0.04	141,599	1,059,302	5,379,302	−5,213,722
Dec-64	31	2.20	0.18	4.30	30.60	38.70	187,308	1,332,936	1,685,772	587,770	4,397,104	4,464,000	0.57	0.05	152,286	1,139,250	5,603,250	1,206,145
Jan-65	31	2.20	0.18	4.30	30.60	38.70	187,308	1,332,936	1,685,772	587,770	4,397,104	4,464,000	0.46	0.04	122,897	919,395	5,383,395	986,290
Feb-65	28	3.10	0.26	4.30	30.60	38.70	187,308	1,332,936	1,685,772	828,221	6,195,920	4,032,000	0.47	0.04	125,569	939,381	4,971,381	−1,224,538
Mar-65	31	5.00	0.42	4.30	30.60	38.70	187,308	1,332,936	1,685,772	1,335,840	9,993,419	4,464,000	0.54	0.05	144,271	1,079,289	5,543,289	−4,450,130
Apr-65	30	6.60	0.55	4.30	30.60	38.70	187,308	1,332,936	1,685,772	1,763,309	13,191,313	4,320,000	0.41	0.03	109,539	819,460	5,139,460	−8,051,853
May-65	31	9.00	0.75	4.30	30.60	38.70	187,308	1,332,936	1,685,772	2,404,512	17,988,154	4,464,000	0.53	0.04	141,599	1,059,302	5,523,302	−12,464,852
Jun-65	30	9.90	0.83	4.30	30.60	38.70	187,308	1,332,936	1,685,772	2,644,963	19,786,970	4,320,000	0.29	0.02	77,479	579,618	4,899,618	−14,887,351
Jul-65	31	9.90	0.83	4.30	30.60	38.70	187,308	1,332,936	1,685,772	2,644,963	19,786,970	4,464,000	0.68	0.06	181,674	1,359,105	5,823,105	−13,963,865
Aug-65	31	9.00	0.75	4.30	30.60	38.70	187,308	1,332,936	1,685,772	2,404,512	17,988,154	4,464,000	1.01	0.08	269,840	2,018,671	6,482,671	−11,505,484
Sep-65	30	6.90	0.58	4.30	30.60	38.70	187,308	1,332,936	1,685,772	1,843,459	13,790,918	4,320,000	0.80	0.07	213,734	1,598,947	5,918,947	−7,871,971
Oct-65	31	5.30	0.44	4.30	30.60	38.70	187,308	1,332,936	1,685,772	1,415,990	10,593,024	4,464,000	0.77	0.06	205,719	1,538,987	6,002,987	−4,590,038
Nov-65	30	5.30	0.44	4.30	30.60	38.70	187,308	1,332,936	1,685,772	1,415,990	10,593,024	4,320,000	0.53	0.04	141,599	1,059,302	5,379,302	−5,213,722
Dec-65	31	2.20	0.18	4.30	30.60	38.70	187,308	1,332,936	1,685,772	587,770	4,397,104	4,464,000	0.57	0.05	152,286	1,139,250	5,603,250	1,206,145
Jan-66	31	2.20	0.18	4.30	30.60	38.70	187,308	1,332,936	1,685,772	587,770	4,397,104	4,464,000	0.46	0.04	122,897	919,395	5,383,395	986,290
Feb-66	28	3.10	0.26	4.30	30.60	38.70	187,308	1,332,936	1,685,772	828,221	6,195,920	4,032,000	0.47	0.04	125,569	939,381	4,971,381	−1,224,538
Mar-66	31	5.00	0.42	4.30	30.60	38.70	187,308	1,332,936	1,685,772	1,335,840	9,993,419	4,464,000	0.54	0.05	144,271	1,079,289	5,543,289	−4,450,130
Apr-66	30	6.60	0.55	4.30	30.60	38.70	187,308	1,332,936	1,685,772	1,763,309	13,191,313	4,320,000	0.41	0.03	109,539	819,460	5,139,460	−8,051,853
May-66	31	9.00	0.75	4.30	30.60	38.70	187,308	1,332,936	1,685,772	2,404,512	17,988,154	4,464,000	0.53	0.04	141,599	1,059,302	5,523,302	−12,464,852
Jun-66	30	9.90	0.83	4.30	30.60	38.70	187,308	1,332,936	1,685,772	2,644,963	19,786,970	4,320,000	0.29	0.02	77,479	579,618	4,899,618	−14,887,351
Jul-66	31	9.90	0.83	4.30	30.60	38.70	187,308	1,332,936	1,685,772	2,644,963	19,786,970	4,464,000	0.68	0.06	181,674	1,359,105	5,823,105	−13,963,865
Aug-66	31	9.00	0.75	4.30	30.60	38.70	187,308	1,332,936	1,685,772	2,404,512	17,988,154	4,464,000	1.01	0.08	269,840	2,018,671	6,482,671	−11,505,484
Sep-66	30	6.90	0.58	4.30	30.60	38.70	187,308	1,332,936	1,685,772	1,843,459	13,790,918	4,320,000	0.80	0.07	213,734	1,598,947	5,918,947	−7,871,971
Oct-66	31	5.30	0.44	4.30	30.60	38.70	187,308	1,332,936	1,685,772	1,415,990	10,593,024	4,464,000	0.77	0.06	205,719	1,538,987	6,002,987	−4,590,038
Nov-66	30	5.30	0.44	4.30	30.60	38.70	187,308	1,332,936	1,685,772	1,415,990	10,593,024	4,320,000	0.53	0.04	141,599	1,059,302	5,379,302	−5,213,722
Dec-66	31	2.20	0.18	4.30	30.60	38.70	187,308	1,332,936	1,685,772	587,770	4,397,104	4,464,000	0.57	0.05	152,286	1,139,250	5,603,250	1,206,145
Jan-67	31	2.20	0.18	4.30	30.60	38.70	187,308	1,332,936	1,685,772	587,770	4,397,104	4,464,000	0.46	0.04	122,897	919,395	5,383,395	986,290
Feb-67	28	3.10	0.26	4.30	30.60	38.70	187,308	1,332,936	1,685,772	828,221	6,195,920	4,032,000	0.47	0.04	125,569	939,381	4,971,381	−1,224,538

Table A-1. Minimum Water Volume Available Annually for Infiltration, from Impoundments and Pond, 1954–1968 (continued)

Column	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18
Month	Days in Month	Cooley Net Evaporation[a]		Raffinate Pond	Upper Tailings	Lower Tailings	Raffinate Pond	Upper Tailings	Lower Tailings	Evaporation from Raffinate Pond and Tailings Impoundments		Monthly Mill Water Usage	Monthly Precipitation		Monthly Precipitation Volume		Total Inflow	Surplus Available to Infiltrate
					Impoundment			Impoundment										
		in	ft	ac	ac	Ac	ft^2	ft^2	ft^2	ft^3	gal	gal	in	ft	ft^3	gal	gal	gal
Mar-67	31	5.00	0.42	4.30	30.60	38.70	187,308	1,332,936	1,685,772	1,335,840	9,993,419	4,464,000	0.54	0.05	144,271	1,079,289	5,543,289	−4,450,130
Apr-67	30	6.60	0.55	4.30	30.60	38.70	187,308	1,332,936	1,685,772	1,763,309	13,191,313	4,320,000	0.41	0.03	109,539	819,460	5,139,460	−8,051,853
May-67	31	9.00	0.75	4.30	30.60	38.70	187,308	1,332,936	1,685,772	2,404,512	17,988,154	4,464,000	0.53	0.04	141,599	1,059,302	5,523,302	−12,464,852
Jun-67	30	9.90	0.83	4.30	30.60	38.70	187,308	1,332,936	1,685,772	2,644,963	19,786,970	4,320,000	0.29	0.02	77,479	579,618	4,899,618	−14,887,351
Jul-67	31	9.90	0.83	4.30	30.60	38.70	187,308	1,332,936	1,685,772	2,644,963	19,786,970	4,464,000	0.68	0.06	181,674	1,359,105	5,823,105	−13,963,865
Aug-67	31	9.00	0.75	4.30	30.60	38.70	187,308	1,332,936	1,685,772	2,404,512	17,988,154	4,464,000	1.01	0.08	269,840	2,018,671	6,482,671	−11,505,484
Sep-67	30	6.90	0.58	4.30	30.60	38.70	187,308	1,332,936	1,685,772	1,843,459	13,790,918	4,320,000	0.80	0.07	213,734	1,598,947	5,918,947	−7,871,971
Oct-67	31	5.30	0.44	4.30	30.60	38.70	187,308	1,332,936	1,685,772	1,415,990	10,593,024	4,464,000	0.77	0.06	205,719	1,538,987	6,002,987	−4,590,038
Nov-67	30	5.30	0.44	4.30	30.60	38.70	187,308	1,332,936	1,685,772	1,415,990	10,593,024	4,320,000	0.53	0.04	141,599	1,059,302	5,379,302	−5,213,722
Dec-67	31	2.20	0.18	4.30	30.60	38.70	187,308	1,332,936	1,685,772	587,770	4,397,104	4,464,000	0.57	0.05	152,286	1,139,250	5,603,250	1,206,145
Jan-68	31	2.20	0.18	4.30	30.60	38.70	187,308	1,332,936	1,685,772	587,770	4,397,104	4,464,000	0.46	0.04	122,897	919,395	5,383,395	986,290
Feb-68	29	3.10	0.26	4.30	30.60	38.70	187,308	1,332,936	1,685,772	828,221	6,195,920	4,176,000	0.47	0.04	125,569	939,381	5,115,381	−1,080,538
Mar-68	31	5.00	0.42	4.30	30.60	38.70	187,308	1,332,936	1,685,772	1,335,840	9,993,419	4,464,000	0.54	0.05	144,271	1,079,289	5,543,289	−4,450,130
Apr-68	30	6.60	0.55	4.30	30.60	38.70	187,308	1,332,936	1,685,772	1,763,309	13,191,313	4,320,000	0.41	0.03	109,539	819,460	5,139,460	−8,051,853
May-68	31	9.00	0.75	4.30	30.60	38.70	187,308	1,332,936	1,685,772	2,404,512	17,988,154	4,464,000	0.53	0.04	141,599	1,059,302	5,523,302	−12,464,852
																	Total, gal	42,971,540

Notes:

[a] The numbers represent evaporation rates from open surface water bodies (Cooley 1970).
Column 3: Convert inches (Column 2) to feet by dividing Column 2 values by 12 inches/ft.
Columns 7–9: Calculate area, ft^2, by multiplying columns 4–6 by 43,560 ft^2/acre.
Column 10: Sum columns 7, 8, and 9 and multiply by column 3.
Column 11: Convert monthly evaporation volume ft^3 to gal by multiplying ft^3 × 7.481 gal/ft^3.
Column 12: Multiply column 1 by 100 gpm × 1440 minutes/day to obtain monthly water usage.
Column 14: Convert precipitation (inches, Column 13) to feet by dividing by 12 inches/ft.
Column 15: Calculate monthly precipitation volume by multiplying Column 14 by sum of columns 7, 8, and 9.
Column 16: Convert monthly precipitation volume ft^3 to gal by multiplying ft^3 × 7.481 gal/ft^3.
Column 17: Calculate monthly inflow by summing Columns 12 and 16.
Column 18: Calculated surplus available for infiltration by subtracting Column 11 from Column 17; total only includes positive values.

Abbreviations:

ac = acre
ft^3 = cubic feet
in = inches

Table A-2. Maximum Water Volume Available Annually for Infiltration, from Impoundments and Pond, 1954–1968

Column	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18
Month	Days in Month	Cooley Net Evaporation[a]		Raffinate Pond	Upper Tailings	Lower Tailings	Raffinate Pond	Upper Tailings	Lower Tailings	Evaporation from Raffinate Pond and Tailings Impoundments		Monthly Mill Water Usage	Monthly Precipitation		Monthly Precipitation Volume		Total Inflow	Surplus Available to Infiltrate
					Impoundment			Impoundment										
		in	ft	ac	ac	ac	ft^2	ft^2	ft^2	ft^3	gal	gal	in	ft	ft^3	gal	gal	gal
Nov-54	30	3.30	0.28	4.30	-	38.70	187,308	0	1,685,772	515,097	3,853,441	6,912,000	0.53	0.04	82,728	618,886	7,530,886	3,677,445
Dec-54	31	2.20	0.18	4.30	-	38.70	187,308	0	1,685,772	343,398	2,568,960	7,142,400	0.57	0.05	88,971	665,594	7,807,994	5,239,034
Jan-55	31	2.20	0.18	4.30	-	38.70	187,308	0	1,685,772	343,398	2,568,960	7,142,400	0.46	0.04	71,801	537,146	7,679,546	5,110,586
Feb-55	28	3.10	0.26	4.30	-	38.70	187,308	0	1,685,772	483,879	3,619,899	6,451,200	0.47	0.04	73,362	548,823	7,000,023	3,380,125
Mar-55	31	5.00	0.42	4.30	-	38.70	187,308	0	1,685,772	780,450	5,838,546	7,142,400	0.54	0.05	84,289	630,563	7,772,963	1,934,417
Apr-55	30	6.60	0.55	4.30	-	38.70	187,308	0	1,685,772	1,030,194	7,706,881	6,912,000	0.41	0.03	63,997	478,761	7,390,761	−316,121
May-55	31	9.00	0.75	4.30	-	38.70	187,308	0	1,685,772	1,404,810	10,509,384	7,142,400	0.53	0.04	82,728	618,886	7,761,286	−2,748,098
Jun-55	30	9.90	0.83	4.30	-	38.70	187,308	0	1,685,772	1,545,291	11,560,322	6,912,000	0.29	0.02	45,266	338,636	7,250,636	−4,309,686
Jul-55	31	9.90	0.83	4.30	-	38.70	187,308	0	1,685,772	1,545,291	11,560,322	7,142,400	0.68	0.06	106,141	794,042	7,936,442	−3,623,880
Aug-55	31	9.00	0.75	4.30	-	38.70	187,308	0	1,685,772	1,404,810	10,509,384	7,142,400	1.01	0.08	157,651	1,179,386	8,321,786	−2,187,597
Sep-55	30	6.90	0.58	4.30	-	38.70	187,308	0	1,685,772	1,077,021	8,057,194	6,912,000	0.80	0.07	124,872	934,167	7,846,167	−211,027
Oct-55	31	5.30	0.44	4.30	-	38.70	187,308	0	1,685,772	827,277	6,188,859	7,142,400	0.77	0.06	120,189	899,136	8,041,536	1,852,677
Nov-55	30	3.30	0.28	4.30	-	38.70	187,308	0	1,685,772	515,097	3,853,441	6,912,000	0.53	0.04	82,728	618,886	7,530,886	3,677,445
Dec-55	31	2.20	0.18	4.30	-	38.70	187,308	0	1,685,772	343,398	2,568,960	7,142,400	0.57	0.05	88,971	665,594	7,807,994	5,239,034
Jan-56	31	2.20	0.18	4.30	-	38.70	187,308	0	1,685,772	343,398	2,568,960	7,142,400	0.46	0.04	71,801	537,146	7,679,546	5,110,586
Feb-56	29	3.10	0.26	4.30	-	38.70	187,308	0	1,685,772	483,879	3,619,899	6,681,600	0.47	0.04	73,362	548,823	7,230,423	3,610,525
Mar-56	31	5.00	0.42	4.30	-	38.70	187,308	0	1,685,772	780,450	5,838,546	7,142,400	0.54	0.05	84,289	630,563	7,772,963	1,934,417
Apr-56	30	6.60	0.55	4.30	-	38.70	187,308	0	1,685,772	1,030,194	7,706,881	6,912,000	0.41	0.03	63,997	478,761	7,390,761	−316,121
May-56	31	9.00	0.75	4.30	-	38.70	187,308	0	1,685,772	1,404,810	10,509,384	7,142,400	0.53	0.04	82,728	618,886	7,761,286	−2,748,098
Jun-56	30	9.90	0.83	4.30	-	38.70	187,308	0	1,685,772	1,545,291	11,560,322	6,912,000	0.29	0.02	45,266	338,636	7,250,636	−4,309,686
Jul-56	31	9.90	0.83	4.30	-	38.70	187,308	0	1,685,772	1,545,291	11,560,322	7,142,400	0.68	0.06	106,141	794,042	7,936,442	−3,623,880
Aug-56	31	9.00	0.75	4.30	-	38.70	187,308	0	1,685,772	1,404,810	10,509,384	7,142,400	1.01	0.08	157,651	1,179,386	8,321,786	−2,187,597
Sep-56	30	6.90	0.58	4.30	-	38.70	187,308	0	1,685,772	1,077,021	8,057,194	6,912,000	0.80	0.07	124,872	934,167	7,846,167	−211,027
Oct-56	31	5.30	0.44	4.30	-	38.70	187,308	0	1,685,772	827,277	6,188,859	7,142,400	0.77	0.06	120,189	899,136	8,041,536	1,852,677
Nov-56	30	3.30	0.28	4.30	-	38.70	187,308	0	1,685,772	515,097	3,853,441	6,912,000	0.53	0.04	82,728	618,886	7,530,886	3,677,445
Dec-56	31	2.20	0.18	4.30	-	38.70	187,308	0	1,685,772	343,398	2,568,960	7,142,400	0.57	0.05	88,971	665,594	7,807,994	5,239,034
Jan-57	31	2.20	0.18	4.30	30.60	38.70	187,308	1,332,936	1,685,772	587,770	4,397,104	7,142,400	0.46	0.04	122,897	919,395	8,061,795	3,664,690
Feb-57	28	3.10	0.26	4.30	30.60	38.70	187,308	1,332,936	1,685,772	828,221	6,195,920	6,451,200	0.47	0.04	125,569	939,381	7,390,581	1,194,662
Mar-57	31	5.00	0.42	4.30	30.60	38.70	187,308	1,332,936	1,685,772	1,335,840	9,993,419	7,142,400	0.54	0.05	144,271	1,079,289	8,221,689	−1,771,730
Apr-57	30	6.60	0.55	4.30	30.60	38.70	187,308	1,332,936	1,685,772	1,763,309	13,191,313	6,912,000	0.41	0.03	109,539	819,460	7,731,460	−5,459,853
May-57	31	9.00	0.75	4.30	30.60	38.70	187,308	1,332,936	1,685,772	2,404,512	17,988,154	7,142,400	0.53	0.04	141,599	1,059,302	8,201,702	−9,786,452
Jun-57	30	9.90	0.83	4.30	30.60	38.70	187,308	1,332,936	1,685,772	2,644,963	19,786,970	6,912,000	0.29	0.02	77,479	579,618	7,491,618	−12,295,351
Jul-57	31	9.90	0.83	4.30	30.60	38.70	187,308	1,332,936	1,685,772	2,644,963	19,786,970	7,142,400	0.68	0.06	181,674	1,359,105	8,501,505	−11,285,465
Aug-57	31	9.00	0.75	4.30	30.60	38.70	187,308	1,332,936	1,685,772	2,404,512	17,988,154	7,142,400	1.01	0.08	269,840	2,018,671	9,161,071	−8,827,084
Sep-57	30	6.90	0.58	4.30	30.60	38.70	187,308	1,332,936	1,685,772	1,843,459	13,790,918	6,912,000	0.80	0.07	213,734	1,598,947	8,510,947	−5,279,971
Oct-57	31	5.30	0.44	4.30	30.60	38.70	187,308	1,332,936	1,685,772	1,415,990	10,593,024	7,142,400	0.77	0.06	205,719	1,538,987	8,681,387	−1,911,638
Nov-57	30	3.30	0.28	4.30	30.60	38.70	187,308	1,332,936	1,685,772	881,654	6,595,657	6,912,000	0.53	0.04	141,599	1,059,302	7,971,302	1,375,646

Table A-2. Maximum Water Volume Available Annually for Infiltration, from Impoundments and Pond, 1954–1968 (continued)

Column	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18
Month	Days in Month	Cooley Net Evaporation[a]		Raffinate Pond	Upper Tailings	Lower Tailings	Raffinate Pond	Upper Tailings	Lower Tailings	Evaporation from Raffinate Pond and Tailings Impoundments		Monthly Mill Water Usage	Monthly Precipitation		Monthly Precipitation Volume		Total Inflow	Surplus Available to Infiltrate
					Impoundment			Impoundment										
		in	ft	ac	ac	ac	ft²	ft²	ft²	ft³	gal	gal	in	ft	ft³	gal	gal	gal
Dec-57	31	2.20	0.18	4.30	30.60	38.70	187,308	1,332,936	1,685,772	587,770	4,397,104	7,142,400	0.57	0.05	152,286	1,139,250	8,281,650	3,884,545
Jan-58	31	2.20	0.18	4.30	30.60	38.70	187,308	1,332,936	1,685,772	587,770	4,397,104	7,142,400	0.46	0.04	122,897	919,395	8,061,795	3,664,690
Feb-58	28	3.10	0.26	4.30	30.60	38.70	187,308	1,332,936	1,685,772	828,221	6,195,920	6,451,200	0.47	0.04	125,569	939,381	7,390,581	1,194,662
Mar-58	31	5.00	0.42	4.30	30.60	38.70	187,308	1,332,936	1,685,772	1,335,840	9,993,419	7,142,400	0.54	0.05	144,271	1,079,289	8,221,689	−1,771,730
Apr-58	30	6.60	0.55	4.30	30.60	38.70	187,308	1,332,936	1,685,772	1,763,309	13,191,313	6,912,000	0.41	0.03	109,539	819,460	7,731,460	−5,459,853
May-58	31	9.00	0.75	4.30	30.60	38.70	187,308	1,332,936	1,685,772	2,404,512	17,988,154	7,142,400	0.53	0.04	141,599	1,059,302	8,201,702	−9,786,452
Jun-58	30	9.90	0.83	4.30	30.60	38.70	187,308	1,332,936	1,685,772	2,644,963	19,786,970	6,912,000	0.29	0.02	77,479	579,618	7,491,618	−12,295,351
Jul-58	31	9.90	0.83	4.30	30.60	38.70	187,308	1,332,936	1,685,772	2,644,963	19,786,970	7,142,400	0.68	0.06	181,674	1,359,105	8,501,505	−11,285,465
Aug-58	31	9.00	0.75	4.30	30.60	38.70	187,308	1,332,936	1,685,772	2,404,512	17,988,154	7,142,400	1.01	0.08	269,840	2,018,671	9,161,071	−8,827,084
Sep-58	30	6.90	0.58	4.30	30.60	38.70	187,308	1,332,936	1,685,772	1,843,459	13,790,918	6,912,000	0.80	0.07	213,734	1,598,947	8,510,947	−5,279,971
Oct-58	31	5.30	0.44	4.30	30.60	38.70	187,308	1,332,936	1,685,772	1,415,990	10,593,024	7,142,400	0.77	0.06	205,719	1,538,987	8,681,387	−1,911,638
Nov-58	30	3.30	0.28	4.30	30.60	38.70	187,308	1,332,936	1,685,772	881,654	6,595,657	6,912,000	0.53	0.04	141,599	1,059,302	7,971,302	1,375,646
Dec-58	31	2.20	0.18	4.30	30.60	38.70	187,308	1,332,936	1,685,772	587,770	4,397,104	7,142,400	0.57	0.05	152,286	1,139,250	8,281,650	3,884,545
Jan-59	31	2.20	0.18	4.30	30.60	38.70	187,308	1,332,936	1,685,772	587,770	4,397,104	7,142,400	0.46	0.04	122,897	919,395	8,061,795	3,664,690
Feb-59	28	3.10	0.26	4.30	30.60	38.70	187,308	1,332,936	1,685,772	828,221	6,195,920	6,451,200	0.47	0.04	125,569	939,381	7,390,581	1,194,662
Mar-59	31	5.00	0.42	4.30	30.60	38.70	187,308	1,332,936	1,685,772	1,335,840	9,993,419	7,142,400	0.54	0.05	144,271	1,079,289	8,221,689	−1,771,730
Apr-59	30	6.60	0.55	4.30	30.60	38.70	187,308	1,332,936	1,685,772	1,763,309	13,191,313	6,912,000	0.41	0.03	109,539	819,460	7,731,460	−5,459,853
May-59	31	9.00	0.75	4.30	30.60	38.70	187,308	1,332,936	1,685,772	2,404,512	17,988,154	7,142,400	0.53	0.04	141,599	1,059,302	8,201,702	−9,786,452
Jun-59	30	9.90	0.83	4.30	30.60	38.70	187,308	1,332,936	1,685,772	2,644,963	19,786,970	6,912,000	0.29	0.02	77,479	579,618	7,491,618	−12,295,351
Jul-59	31	9.90	0.83	4.30	30.60	38.70	187,308	1,332,936	1,685,772	2,644,963	19,786,970	7,142,400	0.68	0.06	181,674	1,359,105	8,501,505	−11,285,465
Aug-59	31	9.00	0.75	4.30	30.60	38.70	187,308	1,332,936	1,685,772	2,404,512	17,988,154	7,142,400	1.01	0.08	269,840	2,018,671	9,161,071	−8,827,084
Sep-59	30	6.90	0.58	4.30	30.60	38.70	187,308	1,332,936	1,685,772	1,843,459	13,790,918	6,912,000	0.80	0.07	213,734	1,598,947	8,510,947	−5,279,971
Oct-59	31	5.30	0.44	4.30	30.60	38.70	187,308	1,332,936	1,685,772	1,415,990	10,593,024	7,142,400	0.77	0.06	205,719	1,538,987	8,681,387	−1,911,638
Nov-59	30	3.30	0.28	4.30	30.60	38.70	187,308	1,332,936	1,685,772	881,654	6,595,657	6,912,000	0.53	0.04	141,599	1,059,302	7,971,302	1,375,646
Dec-59	31	2.20	0.18	4.30	30.60	38.70	187,308	1,332,936	1,685,772	587,770	4,397,104	7,142,400	0.57	0.05	152,286	1,139,250	8,281,650	3,884,545
Jan-60	31	2.20	0.18	4.30	30.60	38.70	187,308	1,332,936	1,685,772	587,770	4,397,104	7,142,400	0.46	0.04	122,897	919,395	8,061,795	3,664,690
Feb-60	29	3.10	0.26	4.30	30.60	38.70	187,308	1,332,936	1,685,772	828,221	6,195,920	6,681,600	0.47	0.04	125,569	939,381	7,620,981	1,425,062
Mar-60	31	5.00	0.42	4.30	30.60	38.70	187,308	1,332,936	1,685,772	1,335,840	9,993,419	7,142,400	0.54	0.05	144,271	1,079,289	8,221,689	−1,771,730
Apr-60	30	6.60	0.55	4.30	30.60	38.70	187,308	1,332,936	1,685,772	1,763,309	13,191,313	6,912,000	0.41	0.03	109,539	819,460	7,731,460	−5,459,853
May-60	31	9.00	0.75	4.30	30.60	38.70	187,308	1,332,936	1,685,772	2,404,512	17,988,154	7,142,400	0.53	0.04	141,599	1,059,302	8,201,702	−9,786,452
Jun-60	30	9.90	0.83	4.30	30.60	38.70	187,308	1,332,936	1,685,772	2,644,963	19,786,970	6,912,000	0.29	0.02	77,479	579,618	7,491,618	−12,295,351
Jul-60	31	9.90	0.83	4.30	30.60	38.70	187,308	1,332,936	1,685,772	2,644,963	19,786,970	7,142,400	0.68	0.06	181,674	1,359,105	8,501,505	−11,285,465
Aug-60	31	9.00	0.75	4.30	30.60	38.70	187,308	1,332,936	1,685,772	2,404,512	17,988,154	7,142,400	1.01	0.08	269,840	2,018,671	9,161,071	−8,827,084
Sep-60	30	6.90	0.58	4.30	30.60	38.70	187,308	1,332,936	1,685,772	1,843,459	13,790,918	6,912,000	0.80	0.07	213,734	1,598,947	8,510,947	−5,279,971
Oct-60	31	5.30	0.44	4.30	30.60	38.70	187,308	1,332,936	1,685,772	1,415,990	10,593,024	7,142,400	0.77	0.06	205,719	1,538,987	8,681,387	−1,911,638
Nov-60	30	3.30	0.28	4.30	30.60	38.70	187,308	1,332,936	1,685,772	881,654	6,595,657	6,912,000	0.53	0.04	141,599	1,059,302	7,971,302	1,375,646
Dec-60	31	2.20	0.18	4.30	30.60	38.70	187,308	1,332,936	1,685,772	587,770	4,397,104	7,142,400	0.57	0.05	152,286	1,139,250	8,281,650	3,884,545
Jan-61	31	2.20	0.18	4.30	30.60	38.70	187,308	1,332,936	1,685,772	587,770	4,397,104	7,142,400	0.46	0.04	122,897	919,395	8,061,795	3,664,690
Feb-61	28	3.10	0.26	4.30	30.60	38.70	187,308	1,332,936	1,685,772	828,221	6,195,920	6,451,200	0.47	0.04	125,569	939,381	7,390,581	1,194,662
Mar-61	31	5.00	0.42	4.30	30.60	38.70	187,308	1,332,936	1,685,772	1,335,840	9,993,419	7,142,400	0.54	0.05	144,271	1,079,289	8,221,689	−1,771,730
Apr-61	30	6.60	0.55	4.30	30.60	38.70	187,308	1,332,936	1,685,772	1,763,309	13,191,313	6,912,000	0.41	0.03	109,539	819,460	7,731,460	−5,459,853
May-61	31	9.00	0.75	4.30	30.60	38.70	187,308	1,332,936	1,685,772	2,404,512	17,988,154	7,142,400	0.53	0.04	141,599	1,059,302	8,201,702	−9,786,452
Jun-61	30	9.90	0.83	4.30	30.60	38.70	187,308	1,332,936	1,685,772	2,644,963	19,786,970	6,912,000	0.29	0.02	77,479	579,618	7,491,618	−12,295,351
Jul-61	31	9.90	0.83	4.30	30.60	38.70	187,308	1,332,936	1,685,772	2,644,963	19,786,970	7,142,400	0.68	0.06	181,674	1,359,105	8,501,505	−11,285,465
Aug-61	31	9.00	0.75	4.30	30.60	38.70	187,308	1,332,936	1,685,772	2,404,512	17,988,154	7,142,400	1.01	0.08	269,840	2,018,671	9,161,071	−8,827,084
Sep-61	30	6.90	0.58	4.30	30.60	38.70	187,308	1,332,936	1,685,772	1,843,459	13,790,918	6,912,000	0.80	0.07	213,734	1,598,947	8,510,947	−5,279,971
Oct-61	31	5.30	0.44	4.30	30.60	38.70	187,308	1,332,936	1,685,772	1,415,990	10,593,024	7,142,400	0.77	0.06	205,719	1,538,987	8,681,387	−1,911,638
Nov-61	30	3.30	0.28	4.30	30.60	38.70	187,308	1,332,936	1,685,772	881,654	6,595,657	6,912,000	0.53	0.04	141,599	1,059,302	7,971,302	1,375,646
Dec-61	31	2.20	0.18	4.30	30.60	38.70	187,308	1,332,936	1,685,772	587,770	4,397,104	7,142,400	0.57	0.05	152,286	1,139,250	8,281,650	3,884,545
Jan-62	31	2.20	0.18	4.30	30.60	38.70	187,308	1,332,936	1,685,772	587,770	4,397,104	7,142,400	0.46	0.04	122,897	919,395	8,061,795	3,664,690
Feb-62	28	3.10	0.26	4.30	30.60	38.70	187,308	1,332,936	1,685,772	828,221	6,195,920	6,451,200	0.47	0.04	125,569	939,381	7,390,581	1,194,662
Mar-62	31	5.00	0.42	4.30	30.60	38.70	187,308	1,332,936	1,685,772	1,335,840	9,993,419	7,142,400	0.54	0.05	144,271	1,079,289	8,221,689	−1,771,730
Apr-62	30	6.60	0.55	4.30	30.60	38.70	187,308	1,332,936	1,685,772	1,763,309	13,191,313	6,912,000	0.41	0.03	109,539	819,460	7,731,460	−5,459,853
May-62	31	9.00	0.75	4.30	30.60	38.70	187,308	1,332,936	1,685,772	2,404,512	17,988,154	7,142,400	0.53	0.04	141,599	1,059,302	8,201,702	−9,786,452
Jun-62	30	9.90	0.83	4.30	30.60	38.70	187,308	1,332,936	1,685,772	2,644,963	19,786,970	6,912,000	0.29	0.02	77,479	579,618	7,491,618	−12,295,351
Jul-62	31	9.90	0.83	4.30	30.60	38.70	187,308	1,332,936	1,685,772	2,644,963	19,786,970	7,142,400	0.68	0.06	181,674	1,359,105	8,501,505	−11,285,465
Aug-62	31	9.00	0.75	4.30	30.60	38.70	187,308	1,332,936	1,685,772	2,404,512	17,988,154	7,142,400	1.01	0.08	269,840	2,018,671	9,161,071	−8,827,084
Sep-62	30	6.90	0.58	4.30	30.60	38.70	187,308	1,332,936	1,685,772	1,843,459	13,790,918	6,912,000	0.80	0.07	213,734	1,598,947	8,510,947	−5,279,971
Oct-62	31	5.30	0.44	4.30	30.60	38.70	187,308	1,332,936	1,685,772	1,415,990	10,593,024	7,142,400	0.77	0.06	205,719	1,538,987	8,681,387	−1,911,638
Nov-62	30	3.30	0.28	4.30	30.60	38.70	187,308	1,332,936	1,685,772	881,654	6,595,657	6,912,000	0.53	0.04	141,599	1,059,302	7,971,302	1,375,646
Dec-62	31	2.20	0.18	4.30	30.60	38.70	187,308	1,332,936	1,685,772	587,770	4,397,104	7,142,400	0.57	0.05	152,286	1,139,250	8,281,650	3,884,545
Jan-63	31	2.20	0.18	4.30	30.60	38.70	187,308	1,332,936	1,685,772	587,770	4,397,104	7,142,400	0.46	0.04	122,897	919,395	8,061,795	3,664,690
Feb-63	28	3.10	0.26	4.30	30.60	38.70	187,308	1,332,936	1,685,772	828,221	6,195,920	6,451,200	0.47	0.04	125,569	939,381	7,390,581	1,194,662
Mar-63	31	5.00	0.42	4.30	30.60	38.70	187,308	1,332,936	1,685,772	1,335,840	9,993,419	7,142,400	0.54	0.05	144,271	1,079,289	8,221,689	−1,771,730
Apr-63	30	6.60	0.55	4.30	30.60	38.70	187,308	1,332,936	1,685,772	1,763,309	13,191,313	6,912,000	0.41	0.03	109,539	819,460	7,731,460	−5,459,853
May-63	31	9.00	0.75	4.30	30.60	38.70	187,308	1,332,936	1,685,772	2,404,512	17,988,154	7,142,400	0.53	0.04	141,599	1,059,302	8,201,702	−9,786,452
Jun-63	30	9.90	0.83	4.30	30.60	38.70	187,308	1,332,936	1,685,772	2,644,963	19,786,970	6,912,000	0.29	0.02	77,479	579,618	7,491,618	−12,295,351
Jul-63	31	9.90	0.83	4.30	30.60	38.70	187,308	1,332,936	1,685,772	2,644,963	19,786,970	7,142,400	0.68	0.06	181,674	1,359,105	8,501,505	−11,285,465
Aug-63	31	9.00	0.75	4.30	30.60	38.70	187,308	1,332,936	1,685,772	2,404,512	17,988,154	7,142,400	1.01	0.08	269,840	2,018,671	9,161,071	−8,827,084
Sep-63	30	6.90	0.58	4.30	30.60	38.70	187,308	1,332,936	1,685,772	1,843,459	13,790,918	6,912,000	0.80	0.07	213,734	1,598,947	8,510,947	−5,279,971
Oct-63	31	5.30	0.44	4.30	30.60	38.70	187,308	1,332,936	1,685,772	1,415,990	10,593,024	7,142,400	0.77	0.06	205,719	1,538,987	8,681,387	−1,911,638
Nov-63	30	3.30	0.28	4.30	30.60	38.70	187,308	1,332,936	1,685,772	881,654	6,595,657	6,912,000	0.53	0.04	141,599	1,059,302	7,971,302	1,375,646
Dec-63	31	2.20	0.18	4.30	30.60	38.70	187,308	1,332,936	1,685,772	587,770	4,397,104	7,142,400	0.57	0.05	152,286	1,139,250	8,281,650	3,884,545
Jan-64	31	2.20	0.18	4.30	30.60	38.70	187,308	1,332,936	1,685,772	587,770	4,397,104	7,142,400	0.46	0.04	122,897	919,395	8,061,795	3,664,690

Table A-2. Maximum Water Volume Available Annually for Infiltration, from Impoundments and Pond, 1954–1968 (continued)

Column	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18
Month	Days in Month	Cooley Net Evaporation[a]		Raffinate Pond	Upper Tailings Impoundment	Lower Tailings Impoundment	Raffinate Pond	Upper Tailings Impoundment	Lower Tailings Impoundment	Evaporation from Raffinate Pond and Tailings Impoundments		Monthly Mill Water Usage	Monthly Precipitation		Monthly Precipitation Volume		Total Inflow	Surplus Available to Infiltrate
		in	ft	ac	ac	ac	ft^2	ft^2	ft^2	ft^3	gal	gal	in	ft	ft^3	gal	gal	gal
Feb-64	29	3.10	0.26	4.30	30.60	38.70	187,308	1,332,936	1,685,772	828,221	6,195,920	6,681,600	0.47	0.04	125,569	939,381	7,620,981	1,425,062
Mar-64	31	5.00	0.42	4.30	30.60	38.70	187,308	1,332,936	1,685,772	1,335,840	9,993,419	7,142,400	0.54	0.05	144,271	1,079,289	8,221,689	−1,771,730
Apr-64	30	6.60	0.55	4.30	30.60	38.70	187,308	1,332,936	1,685,772	1,763,309	13,191,313	6,912,000	0.41	0.03	109,539	819,460	7,731,460	−5,459,853
May-64	31	9.00	0.75	4.30	30.60	38.70	187,308	1,332,936	1,685,772	2,404,512	17,988,154	7,142,400	0.53	0.04	141,599	1,059,302	8,201,702	−9,786,452
Jun-64	30	9.90	0.83	4.30	30.60	38.70	187,308	1,332,936	1,685,772	2,644,963	19,786,970	6,912,000	0.29	0.02	77,479	579,618	7,491,618	−12,295,351
Jul-64	31	9.90	0.83	4.30	30.60	38.70	187,308	1,332,936	1,685,772	2,644,963	19,786,970	7,142,400	0.68	0.06	181,674	1,359,105	8,501,505	−11,285,465
Aug-64	31	9.00	0.75	4.30	30.60	38.70	187,308	1,332,936	1,685,772	2,404,512	17,988,154	7,142,400	1.01	0.08	269,840	2,018,671	9,161,071	−8,827,084
Sep-64	30	6.90	0.58	4.30	30.60	38.70	187,308	1,332,936	1,685,772	1,843,459	13,790,918	6,912,000	0.80	0.07	213,734	1,598,947	8,510,947	−5,279,971
Oct-64	31	5.30	0.44	4.30	30.60	38.70	187,308	1,332,936	1,685,772	1,415,990	10,593,024	7,142,400	0.77	0.06	205,719	1,538,987	8,681,387	−1,911,638
Nov-64	30	5.30	0.44	4.30	30.60	38.70	187,308	1,332,936	1,685,772	1,415,990	10,593,024	6,912,000	0.53	0.04	141,599	1,059,302	7,971,302	−2,621,722
Dec-64	31	2.20	0.18	4.30	30.60	38.70	187,308	1,332,936	1,685,772	587,770	4,397,104	7,142,400	0.57	0.05	152,286	1,139,250	8,281,650	3,884,545
Jan-65	31	2.20	0.18	4.30	30.60	38.70	187,308	1,332,936	1,685,772	587,770	4,397,104	7,142,400	0.46	0.04	122,897	919,395	8,061,795	3,664,690
Feb-65	28	3.10	0.26	4.30	30.60	38.70	187,308	1,332,936	1,685,772	828,221	6,195,920	6,451,200	0.47	0.04	125,569	939,381	7,390,581	1,194,662
Mar-65	31	5.00	0.42	4.30	30.60	38.70	187,308	1,332,936	1,685,772	1,335,840	9,993,419	7,142,400	0.54	0.05	144,271	1,079,289	8,221,689	−1,771,730
Apr-65	30	6.60	0.55	4.30	30.60	38.70	187,308	1,332,936	1,685,772	1,763,309	13,191,313	6,912,000	0.41	0.03	109,539	819,460	7,731,460	−5,459,853
May-65	31	9.00	0.75	4.30	30.60	38.70	187,308	1,332,936	1,685,772	2,404,512	17,988,154	7,142,400	0.53	0.04	141,599	1,059,302	8,201,702	−9,786,452
Jun-65	30	9.90	0.83	4.30	30.60	38.70	187,308	1,332,936	1,685,772	2,644,963	19,786,970	6,912,000	0.29	0.02	77,479	579,618	7,491,618	−12,295,351
Jul-65	31	9.90	0.83	4.30	30.60	38.70	187,308	1,332,936	1,685,772	2,644,963	19,786,970	7,142,400	0.68	0.06	181,674	1,359,105	8,501,505	−11,285,465
Aug-65	31	9.00	0.75	4.30	30.60	38.70	187,308	1,332,936	1,685,772	2,404,512	17,988,154	7,142,400	1.01	0.08	269,840	2,018,671	9,161,071	−8,827,084
Sep-65	30	6.90	0.58	4.30	30.60	38.70	187,308	1,332,936	1,685,772	1,843,459	13,790,918	6,912,000	0.80	0.07	213,734	1,598,947	8,510,947	−5,279,971
Oct-65	31	5.30	0.44	4.30	30.60	38.70	187,308	1,332,936	1,685,772	1,415,990	10,593,024	7,142,400	0.77	0.06	205,719	1,538,987	8,681,387	−1,911,638
Nov-65	30	5.30	0.44	4.30	30.60	38.70	187,308	1,332,936	1,685,772	1,415,990	10,593,024	6,912,000	0.53	0.04	141,599	1,059,302	7,971,302	−2,621,722
Dec-65	31	2.20	0.18	4.30	30.60	38.70	187,308	1,332,936	1,685,772	587,770	4,397,104	7,142,400	0.57	0.05	152,286	1,139,250	8,281,650	3,884,545
Jan-66	31	2.20	0.18	4.30	30.60	38.70	187,308	1,332,936	1,685,772	587,770	4,397,104	7,142,400	0.46	0.04	122,897	919,395	8,061,795	3,664,690
Feb-66	28	3.10	0.26	4.30	30.60	38.70	187,308	1,332,936	1,685,772	828,221	6,195,920	6,451,200	0.47	0.04	125,569	939,381	7,390,581	1,194,662
Mar-66	31	5.00	0.42	4.30	30.60	38.70	187,308	1,332,936	1,685,772	1,335,840	9,993,419	7,142,400	0.54	0.05	144,271	1,079,289	8,221,689	−1,771,730
Apr-66	30	6.60	0.55	4.30	30.60	38.70	187,308	1,332,936	1,685,772	1,763,309	13,191,313	6,912,000	0.41	0.03	109,539	819,460	7,731,460	−5,459,853
May-66	31	9.00	0.75	4.30	30.60	38.70	187,308	1,332,936	1,685,772	2,404,512	17,988,154	7,142,400	0.53	0.04	141,599	1,059,302	8,201,702	−9,786,452
Jun-66	30	9.90	0.83	4.30	30.60	38.70	187,308	1,332,936	1,685,772	2,644,963	19,786,970	6,912,000	0.29	0.02	77,479	579,618	7,491,618	−12,295,351
Jul-66	31	9.90	0.83	4.30	30.60	38.70	187,308	1,332,936	1,685,772	2,644,963	19,786,970	7,142,400	0.68	0.06	181,674	1,359,105	8,501,505	−11,285,465
Aug-66	31	9.00	0.75	4.30	30.60	38.70	187,308	1,332,936	1,685,772	2,404,512	17,988,154	7,142,400	1.01	0.08	269,840	2,018,671	9,161,071	−8,827,084
Sep-66	30	6.90	0.58	4.30	30.60	38.70	187,308	1,332,936	1,685,772	1,843,459	13,790,918	6,912,000	0.80	0.07	213,734	1,598,947	8,510,947	−5,279,971
Oct-66	31	5.30	0.44	4.30	30.60	38.70	187,308	1,332,936	1,685,772	1,415,990	10,593,024	7,142,400	0.77	0.06	205,719	1,538,987	8,681,387	−1,911,638
Nov-66	30	5.30	0.44	4.30	30.60	38.70	187,308	1,332,936	1,685,772	1,415,990	10,593,024	6,912,000	0.53	0.04	141,599	1,059,302	7,971,302	−2,621,722
Dec-66	31	2.20	0.18	4.30	30.60	38.70	187,308	1,332,936	1,685,772	587,770	4,397,104	7,142,400	0.57	0.05	152,286	1,139,250	8,281,650	3,884,545
Jan-67	31	2.20	0.18	4.30	30.60	38.70	187,308	1,332,936	1,685,772	587,770	4,397,104	7,142,400	0.46	0.04	122,897	919,395	8,061,795	3,664,690
Feb-67	28	3.10	0.26	4.30	30.60	38.70	187,308	1,332,936	1,685,772	828,221	6,195,920	6,451,200	0.47	0.04	125,569	939,381	7,390,581	1,194,662
Mar-67	31	5.00	0.42	4.30	30.60	38.70	187,308	1,332,936	1,685,772	1,335,840	9,993,419	7,142,400	0.54	0.05	144,271	1,079,289	8,221,689	−1,771,730
Apr-67	30	6.60	0.55	4.30	30.60	38.70	187,308	1,332,936	1,685,772	1,763,309	13,191,313	6,912,000	0.41	0.03	109,539	819,460	7,731,460	−5,459,853
May-67	31	9.00	0.75	4.30	30.60	38.70	187,308	1,332,936	1,685,772	2,404,512	17,988,154	7,142,400	0.53	0.04	141,599	1,059,302	8,201,702	−9,786,452
Jun-67	30	9.90	0.83	4.30	30.60	38.70	187,308	1,332,936	1,685,772	2,644,963	19,786,970	6,912,000	0.29	0.02	77,479	579,618	7,491,618	−12,295,351
Jul-67	31	9.90	0.83	4.30	30.60	38.70	187,308	1,332,936	1,685,772	2,644,963	19,786,970	7,142,400	0.68	0.06	181,674	1,359,105	8,501,505	−11,285,465
Aug-67	31	9.00	0.75	4.30	30.60	38.70	187,308	1,332,936	1,685,772	2,404,512	17,988,154	7,142,400	1.01	0.08	269,840	2,018,671	9,161,071	−8,827,084
Sep-67	30	6.90	0.58	4.30	30.60	38.70	187,308	1,332,936	1,685,772	1,843,459	13,790,918	6,912,000	0.80	0.07	213,734	1,598,947	8,510,947	−5,279,971
Oct-67	31	5.30	0.44	4.30	30.60	38.70	187,308	1,332,936	1,685,772	1,415,990	10,593,024	7,142,400	0.77	0.06	205,719	1,538,987	8,681,387	−1,911,638
Nov-67	30	5.30	0.44	4.30	30.60	38.70	187,308	1,332,936	1,685,772	1,415,990	10,593,024	6,912,000	0.53	0.04	141,599	1,059,302	7,971,302	−2,621,722
Dec-67	31	2.20	0.18	4.30	30.60	38.70	187,308	1,332,936	1,685,772	587,770	4,397,104	7,142,400	0.57	0.05	152,286	1,139,250	8,281,650	3,884,545
Jan-68	31	2.20	0.18	4.30	30.60	38.70	187,308	1,332,936	1,685,772	587,770	4,397,104	7,142,400	0.46	0.04	122,897	919,395	8,061,795	3,664,690
Feb-68	29	3.10	0.26	4.30	30.60	38.70	187,308	1,332,936	1,685,772	828,221	6,195,920	6,681,600	0.47	0.04	125,569	939,381	7,620,981	1,425,062
Mar-68	31	5.00	0.42	4.30	30.60	38.70	187,308	1,332,936	1,685,772	1,335,840	9,993,419	7,142,400	0.54	0.05	144,271	1,079,289	8,221,689	−1,771,730
Apr-68	30	6.60	0.55	4.30	30.60	38.70	187,308	1,332,936	1,685,772	1,763,309	13,191,313	6,912,000	0.41	0.03	109,539	819,460	7,731,460	−5,459,853
May-68	31	9.00	0.75	4.30	30.60	38.70	187,308	1,332,936	1,685,772	2,404,512	17,988,154	7,142,400	0.53	0.04	141,599	1,059,302	8,201,702	−9,786,452
																	Total, gal	162,898,387

Notes:

[a] The numbers represent evaporation rates from open surface water bodies (Cooley 1970).

Column 3: Convert inches (Column 2) to feet by dividing Column 2 values by 12 inches/ft.

Columns 7–9: Calculate area, ft^2, by multiplying columns 4–6 by 43,560 ft^2/acre.

Column 10: Sum columns 7, 8, and 9 and multiply by Column 3.

Column 11: Convert monthly evaporation volume ft^3 to gal by multiplying ft^3 × 7.481 gal/ft^3.

Column 12: Multiply column 1 by 100 gpm × 1440 minutes/day to obtain monthly water usage.

Column 14: Convert precipitation (inches, Column 13) to feet by dividing by 12 inches/ft.

Column 15: Calculate monthly precipitation volume by multiplying Column 14 by sum of columns 7, 8, and 9.

Column 16: Convert monthly precipitation volume ft^3 to gal by multiplying ft^3 × 7.481 gal/ft^3.

Column 17: Calculate monthly inflow by summing Columns 12 and 16.

Column 18: Calculated surplus available for infiltration by subtracting Column 11 from Column 17; total only includes positive values.

Abbreviations:

ac = acre

ft^3 = cubic feet

in = inches

This page intentionally left blank

Appendix B

Estimate of Water Volume That Infiltrated the Subsurface When the Mill Was Inactive (1969–1984)

This page intentionally left blank

Basis of Estimate for Infiltration Volume, 1969–1984

Tailings Impoundments and Raffinate Pond

A plant ET study was conducted to quantify recharge rates from precipitation for various plant communities adjacent to the Tuba City, Arizona, Disposal Site (DOE 2016). The study found that, when healthy, the root systems of native plants currently growing in the vicinity of the former evaporation ponds capture the majority, if not all, of the shallow subsurface water derived from precipitation. The same study also found that the water usage of a native plant community growing in an area of disturbed soil east of the disposal cell was less than that of the native plants and allowed 2 inches of precipitation to infiltrate the subsurface and reach groundwater.

It is likely that some native vegetation was reestablished during the 16 years the Shiprock mill site was inactive. Assuming the Tuba City disposal site ET evaluation is applicable to the Shiprock site, depending on the degree of soil disturbance in the tailings impoundments and raffinate pond (a factor that controls plant community type and health), the naturally reestablished vegetation would allow between 0 and 2 inches of precipitation to infiltrate the subsurface annually.

Table B-1. Minimum and Maximum Infiltration Volumes When the Mill Was Inactive

Row	Description	Minimum	Maximum
1	Tailings impoundments and raffinate pond, acres	76	76
2	Tailings impoundments and raffinate pond, ft^2	3,206,016	3,206,016
3	Annual precipitation infiltration rate, inches	0	2
4	Annual precipitation infiltration rate, ft	0	1.67×10^{-1}
5	Volumetric infiltration, ft^3/year	0	534,336
6	Volumetric infiltration, gal/year	0	3,997,368
7	Total infiltration volume for 16 years	0	63,957,882

Notes:
Row 2 = Row 1 × 43,560 ft^2/acre.
Row 4 = Row 3 ÷ 12 inches/ft.
Row 5 = Row 2 × Row 4.
Row 6 = Row 5 × 7.481 gal/ft^3.
Row 7 = Row 6 × 16 years.

Abbreviations:
ft^2 = square feet
ft^3 = cubic feet

Minimum infiltration volume = 0 gal/year × 16 years = 0 gal
Minimum infiltration rate = 0 gpm

Maximum infiltration volume = 3,997,368 gal/year × 16 years = 63,957,882 ≈ 64 million gal
Maximum infiltration rate = 8 gpm

The infiltration rates were determined from infiltration volumes using the following conversion:
Infiltration volume × 1/15 year × 1 year/365.25 days × 1 day/24 hour × 1 hr/60 min

This page intentionally left blank

Appendix C

Estimate of Water Volume That Infiltrated the Subsurface During Surface Remediation (1985–1986)

This page intentionally left blank

Basis of Estimate for Infiltration Volume, 1985–1986

Surface remediation consisted, among other activities, of moving contaminated dirt and demolition rubble to the disposal cell, then under construction. Water was sprayed around the site as necessary to minimize airborne dust during remediation activities. In addition, precipitation could potentially infiltrate the subsurface.

Precipitation During Disposal Cell Construction

It is assumed that the infiltration associated with precipitation occurred within a 76-acre footprint corresponding to the final area of the disposal cell. The disposal cell was constructed directly over the original tailings impoundments.

In the absence of hydraulic data for material placed in the cell, bounding assumptions are that none or all of the average 7.06 inches of annual precipitation (DOE 2000) infiltrated the 76-acre disposal cell. The rationale for assuming that all the precipitation infiltrated is that heavy equipment operation would remove plants growing within the disposal cell footprint. For this evaluation, gravity drainage of tailings pore water was assumed to be minimal relative to what occurs after disposal cell construction and was assumed to all occur during the postclosure period.

Input Data and Results, 1985–1986

Row	Parameter	Minimum Infiltration	Maximum Infiltration
1	Infiltration rate, inches/year	0.0	7.06
2	Infiltration rate, ft/yr	0.0	0.59
3	Disposal cell area, acres	76	76
4	Disposal cell area, ft^2	3,310,560	3,310,560
5	Volumetric infiltration, ft^3/yr	0	1,947,713
6	Volumetric infiltration, gal/yr	0	14,570,839

Notes:
Row 2 = Row 1 ÷ 12 in/ft.
Row 4 = Row 3 × 43,560 ft^2/acre.
Row 5 = Row 2 × Row 4.
Row 6 = Row 5 × 7.481 gal/ft^3.

Abbreviations:
ft^3 = cubic feet
ft/yr = feet per year

Minimum infiltration volume = 0 gal/yr × 2 years = 0 gal
Minimum infiltration rate = 0 gpm

Maximum infiltration volume = 14,570,839 gal/yr × 2 years = 29,141,678 gal ≈ 29 million gal
Maximum infiltration rate = 28 gpm

The infiltration rates were determined from infiltration volumes using the following conversion:
Infiltration volume × 1/2 year × 1 year/365.25 days × 1 day/24 hour × 1 hr/60 min

Dust Control

No records of the volumes of water used for dust suppression during the Shiprock Mill site surface remediation were maintained. During remediation and construction activities of the Tuba City disposal cell, 8.5 million gal of water was sprayed for dust mitigation (DOE 1986). For this evaluation it was assumed that construction of the larger Shiprock disposal cell required a proportionally similar volume of water for dust suppression. The Tuba City disposal cell is 55 acres in size compared to the Shiprock disposal cell's 76 acres, a 38% size increase. On the basis of the increased size, the total volume of water sprayed for dust suppression during the 2-year Shiprock disposal cell construction period is 12 million gallons. To establish the minimum and maximum bounds for infiltration volumes associated with dust suppression, it was assumed that potentially none, or the entire 12 million gal, of the water sprayed for dust suppression infiltrated the subsurface.

Minimum infiltration volume = 0 gal
Minimum infiltration rate = 0 gpm

Maximum infiltration volume ≈ 12 million gal
Maximum infiltration rate = 11 gpm

Cumulative Infiltration (precipitation and dust suppression water)

Total minimum infiltration volume = 0 gal
Total minimum infiltration rate = 0 gpm

Total maximum infiltration volume = 29 million gal + 12 million gal = 41 million gal
Total minimum infiltration rate = 39 gpm

The infiltration rates were determined from infiltration volumes using the following conversion:
Infiltration volume × 1/2 year × 1 year/365.25 days × 1 day/24 hour × 1 hr/60 min

Appendix D

Estimate of Water Volume That Has Infiltrated and Will Infiltrate the Subsurface from the Disposal Cell (1987–2987)

This page intentionally left blank

Basis of Estimate for Infiltration Volume, 1987–2987

After completion of surface remediation, the disposal cell was capped with a low-permeability cover designed to minimize radon emissions. The combination of low permeability and evaporation of precipitation from the cover potentially could significantly limit infiltration, potentially to zero. While the cover's CSL is designed for low permeability over the long term (with minimal need for maintenance), research has shown that soil-forming processes act on the cover and increase permeability over time, which potentially allows infiltration of as much as 20% of precipitation, which is 1.41 inches per year (Waugh et al. 2015). The Shiprock site disposal cell cover was designed to allow 1.24 inches of precipitation infiltration annually, which is similar to the 20% infiltration volume. Allowing vegetation to grow on the cover can reduce infiltration to less than 1% of precipitation because plant roots uptake water and release water to the atmosphere through transpiration (Waugh et al. 2015). By regulation, the design life span of the disposal cell is 1000 years, with minimal maintenance.

Infiltration Through the Disposal Cell Cover

Input Data and Results, 1987–2987

Row	Parameter	Minimum	Maximum	ET Cover
1	Disposal cell area, acres	76	76	76
2	Disposal cell area, ft^2	3,310,560	3,310,560	3,310,560
3	Disposal cell infiltration rate, inches/yr	0	1.41	0.07
4	Disposal cell infiltration rate, ft/yr	0	0.12	5.83×10^{-3}
5	Volumetric infiltration, ft^3/yr	0	397,267	19,312
6	Volumetric infiltration, gal/yr	0	2,971,956	144,470

Notes:
Row 2 = Convert acres to ft^2 by multiplying Row 1 by 43,560 ft^2/acre.
Row 3 infiltration rates are based on the local annual average precipitation, and bounding conditions for cover performance. For the minimum infiltration rate, it is assumed that the cover permeability remains constant and in conformance with the original design specification and any precipitation infiltrating the cover following a storm event is evaporated. For the maximum infiltration rate, it is assumed that soil-forming processes occur, as reported in cited research, resulting in 20% of precipitation infiltrating the cover. Similarly, the infiltration rate reported for the ET cover is based on cited research (Waugh et al. 2015).
Row 4 = Convert inches/yr to ft/yr by dividing by 12.
Row 5 = Row 2 × Row 4.
Row 6 = Convert ft^3/yr to gal/yr by multiplying by 7.481 gal/ft^3.

Abbreviations: ft^3 = cubic feet; ft/yr = feet per year

Minimum infiltration volume = 0 gal/year × 1000 years = 0 gal
Minimum infiltration rate = 0 gpm

Maximum infiltration volume = 2,971,956 gal/year × 1000 years = 2,971,956,000 gal
≈ 2972 million gal
Maximum infiltration rate = 6 gpm

ET cover infiltration volume = 144,470 gal/year × 1000 years = 144,470,000 gal ~ 145 million gal
ET cover infiltration rate = 0.3 gpm

The infiltration rates were determined from infiltration volumes using the following conversion:
Infiltration volume × 1/1000 year × 1 year/365.25 days × 1 day/24 hour × 1 hr/60 min

Gravity Drainage of Tailings Pore Fluid

The tailings within the disposal cell contain residual moisture that is stored in the pores of the tailings material. Over time, gravity will drain the pores until equilibrium is reached between gravity and capillary forces. At that point, gravity drainage will halt, leaving behind permanent (irreducible) residual moisture. The drainage rate and volume of water released by gravity drainage will be a function of the tailings' hydraulic conductivity, porosity, and moisture content, none of which have been characterized within the disposal cell. Gravity drainage of the pore fluids is expected to be greatest immediately after material is placed in the disposal cell and will decline exponentially over time.

Reasonable estimates of the gravity drainage volumes of tailings pore fluid can be approximated based on the volume of tailings, tailings moisture content, and an assumption that all the tailings fluid is drainable. The assumption that all pore fluid is drainable results in an overestimation of the infiltration volume but provides a reasonable order of magnitude estimate of infiltration volumes.

The volume of tailings reported to be in place (contained within the tailings impoundments) was 1,079,000 cubic yards (DOE 1996). Another 928,000 cubic yards of tailings were collected at off-site locations and transported to the disposal cell (DOE 1996). It is assumed for this analysis that the relocated tailings, some associated with windblown material, were primarily dry with minimal pore water available for gravity drainage. It was also assumed that in-place tailings were sufficiently moist for gravity drainage to occur. Moisture content measurements performed on fine and coarse-grained tailings found tailings moisture content to range between 47% and 64% (CSU 1985).

Input Data and Results, Shiprock Site Tailings and Qualities

Row	Parameter	Minimum	Maximum
1	Volume of tailings, yd^3	1,079,000	1,079,000
2	Volume of tailings, ft^3	29,133,000	29,133,000
3	Percent moisture content	47	64
4	Volume pore fluid in tailings, ft^3	13,692,510	18,645,120
5	Volume pore fluid in tailings, gal	102,433,667	139,484,143

Notes:
Row 2 = Convert yd^3 to ft^3 by multiplying by 27 ft^3/yd^3.
Row 4 = Row 2 × Row 3/100.
Row 5 = Convert ft^3 to gal by multiplying by 7.481 gal/ft^3.

Abbreviations: ft^3 = cubic feet; yd^3 = cubic yard

Minimum infiltration volume = 102,433,667 ≈ 102 million gal
Minimum infiltration rate ~ 0 gpm; assumes infiltration occurs over the entire 1000-year performance period

Maximum infiltration volume = 139,484,143 gal ≈ 139 million gal
Maximum infiltration rate ~ 0 gpm; assumes infiltration occurs over the entire 1000-year performance period

Cumulative Infiltration (through cover and transient drainage of tailings pore fluid)

Total minimum infiltration volume = 0 gal + 102 million gal = 102 million gal
Total maximum infiltration volume = 2972 million gal + 139 million gal = 3111 million gal