<u>EXPERT TESTIMONY OF ADRIAN BROWN, PE IN SUPPORT OF THE NEW MEXICO ENVIRONMENT DEPARTMENT PROPOSED COPPER MINE RULE</u>

1 QUALIFICATIONS OF ADRIAN BROWN, P.E.

Adrian Brown P.E. is the Principal Engineer and President of Adrian Brown Consultants, Inc.

I received a Bachelor of Engineering in Civil Engineering, a Master of Science in Engineering, and a Master of Administration from Monash University, Australia. I have over 40 years of experience in mining and industrial projects in groundwater, geotechnical, and remedial engineering. I have investigated, evaluated, analyzed, designed, and supervised construction for over 400 mining and industrial projects world-wide. In addition, I have served as a technical expert in regulatory rulemaking and implementation for the U.S. Nuclear Regulatory Commission, the Government of Australia, the Government of Canada, the Government of Victoria, and the Wek'èezhii First Nation of Canada. I have over 35 publications in groundwater and earth science, and have served as an adjunct professor in groundwater engineering at the Colorado School of Mines. I have been admitted as an expert and have testified in more than 20 courts in the fields of geohydrology, geochemistry, mining, and geotechnical engineering.

A copy of my Professional Profile is provided as Exhibit 8.

2 THE COPPER MINE RULE

Title 20, Chapter 6, Part 7 of the New Mexico Administrative Code, entitled "Ground Water Protection - Supplemental Permitting Requirements for Copper Mine Facilities", designated the "Copper Mine Rule", is proposed by the New Mexico Environment Department ("NMED").

The scope of the Rule extends to "[a]ll persons subject to the Water Quality Act, NMSA 1978, Sections 74-6-1 et seq. and specifically copper mine facilities and their operations" [§2] [1]. To be enacted, the Rule will be adopted by the New Mexico Water Quality Control Commission ("NMWQCC") under the authority of the Water Quality Act, NMSA 1978, Sections 74-6-1 through 74-6-17. It is the standards set out in that act and regulations promulgated under it which are used as a basis for the technical evaluation set out in this testimony.

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[1] In the following testimony, references to sections of the Proposed Copper Rule, 20.6.7 NMAC, will be shortened to the section number indicated by the symbol "§", followed by the section and subsection numbers, enclosed in square braces where it is a reference. For example 20.6.7.17 C(1)(b)(ii) NMAC becomes [§17 C(1)(b)(ii)]. All references to other statutes remain in the standard form.

3 PURPOSE OF THE COPPER MINE RULE

The purpose of the Rule is “to supplement the general permitting requirements of 20.6.2.3000 through 20.6.2.3114 NMAC to control discharges of water contaminants specific to copper mine facilities and their operations to prevent water pollution” [20.6.7.6 NMAC].

The purpose of Sections 20.6.2.3000 through 20.6.2.3114 NMAC in controlling discharges onto or below the surface of the ground is “to protect all ground water of the state of New Mexico which has an existing concentration of 10,000 mg/l or less TDS, for present and potential future use as domestic and agricultural water supply, and to protect those segments of surface waters which are gaining because of ground water inflow, for uses designated in the New Mexico (Surface) Water Quality Standards 20.6.4 NMAC [20.6.2.3101 A NMAC].

Thus the purpose of the Copper Mine Rule can be stated as “to control discharges of water contaminants specific to copper mine facilities and their operations to prevent water pollution so as to protect all ground water of the state of New Mexico for present and potential future use as domestic and agricultural water supply and surface water recharge.”

More specifically, the purpose of the Copper Miner Rule can be stated in terms of regulated water quality standards as “to control discharges of water contaminants specific to copper mine facilities and their operations to prevent water pollution so that groundwater meets the quality standards of Section 20.6.2.3103 NMAC at locations of present and potential future use.”

The technical evaluation set out in this testimony evaluates the effectiveness of the proposed Rule to achieve this purpose.

4 DISCHARGE CONTROL UNDER THE RULE AT NEW MEXICO COPPER MINES

Discharge control at New Mexico copper mine facilities under the Rule is regulated separately for each mining unit within the facility, such as each mine, each waste rock pile, each tailings pile, and each leach pad. During mine operation, discharge control at each unit is achieved by containment:

1. By locating the materials in the unit in impermeable tanks, pipes and ponds.
2. By locating a liner system beneath some units to substantially prevent discharge of the liquids in the unit to the underlying soil or bedrock; or
3. By collecting any discharge to groundwater as close as practicable to the unit such that it does not impact present and potential future groundwater use external to the mine unit.

The effectiveness of the discharge control at each unit is determined by monitoring wells, located on the perimeter of the unit: upgradient, side gradient, and downgradient. In the event that a monitor well identifies concentrations rising towards exceedence of the standards, or an actual exceedence of the standards occurs, a contingency process is triggered. The contingency process generally comprises emergency repair of any breach or failure, corrective action, and, if appropriate, abatement of the impact.

During mine operation, under the Rule the method required for protection varies, dependent on the materials contained within the unit of the mine, and the threat which those contents present of exceeding standards in groundwater by each unit. The units containing highly concentrated process waters and intended for long-term storage of impacted stormwater are double lined; the units intended for short-term storage of impacted stormwater are single lined; and the units containing waste rock and tailings may be unlined but would have active groundwater capture systems. In all cases, the mine water management system controls discharges of water contaminants from the copper mine units, prevents water pollution, and protects the groundwater of the state of New Mexico for present use (during the mining period) as domestic and agricultural water supply and surface water recharge.

After operation, the copper mine closes. Under the Rule, the operational features are dismantled, piping systems are removed or abandoned in place, and impoundments are emptied and where the foundation materials are contaminated, reclaimed with a store-and-release soil cover. The large scale materials storage units - leach stockpiles, waste rock piles, and tailings impoundments - are all reclaimed the same way: any water on the piles is removed and water within the units allowed to drain, the sides are regraded to environmentally sustainable slopes, and the top and sides of each pile are enclosed in a three-foot thick store-and-release soil cover. The entire site is then revegetated.

The store-and-release soil cover system largely prevents infiltration of precipitation through the ground surface, by intercepting and storing precipitation that infiltrates, and slowly releasing it to the atmosphere via evaporation and plant transpiration. In this way, after mine closure there is very little seepage through the soil cover to the underlying ore, waste rock, and tailings materials, and there is correspondingly little seepage through the rock and tailings materials into the underlying groundwater system. This limits the transport of any contaminants that may be contained within, or released from, the materials in the units. The amounts of contaminants being released from beneath the units are sufficiently small that the impact on the underlying groundwater is also small, and is expected to prevent water pollution. As a result, the store-and-release soil cover protects the groundwater of the state of New Mexico for potential future use as domestic and agricultural water supply and surface water recharge.

5 EFFECTIVENESS OF GENERAL GROUNDWATER PROTECTION REQUIREMENTS AND PROCEDURES

The Rule codifies some general practices and responses that are applied to all copper mine units. This portion of my testimony presents and evaluates the effectiveness of these common requirements and procedures.

5.1 Stormwater Management

5.1.1 Requirements

Stormwater run-on shall be diverted and/or contained to minimize contact between stormwater run-on and any copper mine material that could generate or release water contaminants [§18 D].

5.1.2 Other State Requirements[2]

Stormwater control requirements are included in the mining regulations and guidance:

- Arizona: Surface water run-on from upstream watershed areas should be diverted around mining units unless it will be beneficially used and the facility is designed to accommodate it[3]. This is functionally the same as the requirement of the Rule.
- Nevada: Mine water quality regulation [NAC 445A] does not directly address stormwater. General guidance prohibits surface water degradation [NAC 445A.424], and requires all process components to "withstand" the runoff from a storm event [NAC 445A.432].

5.1.3 Technical evaluation

The stormwater management requirement of the Rule protects groundwater by minimizing the mobilization of contaminants by precipitation, and by maximizing the availability of unimpacted stormwater for infiltration to groundwater in uncontaminated locations.

5.2 Monitoring

5.2.1 Requirements

Groundwater monitoring is required under the Rule for the following purposes:

1. To detect an exceedance or a trend towards exceedance of ground water standards at the earliest possible occurrence, so that investigation of the extent of contamination and actions to address the source of contamination may be implemented as soon as possible [§28 B].
2. To determine the hydraulic gradient and direction of groundwater flow [§28 B(4)]
3. To ensure that groundwater hydraulic containment is being achieved [§29 H(3)].

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[2] "Other States" considered are those that are located in comparable climatic and geohydrologic conditions to New Mexico, and that have prescriptive mine water protection regulations and guidance.

[3] ADEQ, 2004, "Arizona Mining Guidance Manual – BADCT", Publication #TB 04-01, Arizona Department of Environmental Quality, p.2-18. Download: http://www.azdeq.gov/environ/water/wastewater/mines.html#badct

To achieve these objectives, the Rule requires that the Permittee proposes monitoring locations for each copper mine unit that has the potential to cause an exceedance of applicable standards, for NMED approval. Monitoring wells are to be located proximal to each copper mine unit, as follows [§28 B]:

1. Monitoring wells - required locations: Upgradient, around and downgradient of the perimeter and downgradient of any unit of a copper mine facility that has the potential to cause an exceedance of applicable standards as additional permit conditions in accordance with Subsection I of 20.6.7.10 NMAC.
2. Additional Wells: The department may require additional wells around the perimeter of mine units that are underlain by areas where ground water flow directions are uncertain, including fracture flow systems, and around copper mine units that have the potential to cause ground water mounding.
3. Leach stockpiles, waste rock stockpiles, tailings impoundments: Install a sufficient number of monitoring wells around and downgradient of the perimeter of each unit to adequately monitor ground water that may be impacted by water contaminants from those units. Each monitoring well shall be installed as close as practicable to the unit.
4. Process water and impacted stormwater impoundments: Install a minimum of one monitoring well upgradient and two monitoring wells downgradient of each unit. Each monitoring well shall be within 75 feet or as close as practicable to the unit.
5. Open pit: Install a sufficient number of monitoring wells around the perimeter of an open pit to adequately monitor ground water quality and the hydrologic gradient around the pit.

Monitoring wells are required to be constructed consistent with the rules of the State Engineer [19.27.4 NMAC[4]], The Rule sets out the design requirements of the monitoring wells in detail, for which the principal elements are:

1. Casing: Minimum 2 inch diameter Schedule 40 PVC, stainless steel, or carbon steel; compatible with chemistry of the ground water; appropriate for the contaminants of interest [§28 D(4)].
2. Well Screen: Maximum 20 feet for water table wells, 10 feet for deep wells [§28 D(7)(a)].
3. Filter Pack: Clean silica sand placed around screen 2 feet above the screen [§28 D(10)].
4. Seal: Bentonite seal placed in the annulus and hydrated [§28 D(11)].
5. Well Identification Tag: All monitoring wells require a permanent tag [§28 C].

Groundwater sampling is conducted at copper mines to ensure environmental compliance, both with respect to hydraulic containment and chemical compliance. Groundwater sampling is a complex process, involving water level measurement, field parameter measurement, sampling extraction, filtration, decanting, preservation, and analysis. The Rule provides prescriptive direction for sampling, for which the principal elements are:

[4] New Mexico Administrative Code – Title 19: Natural Resources and Wildlife; Chapter 27: Underground Water; Part 4: Well Driller Licensing; Construction, Repair and Plugging of Wells. Rules issued by the Office of the (New Mexico) State Engineer. “These rules also apply to mine drill holes that encounter water” [19.27.4.2 NMAC].

Depth to Groundwater: Measured from the top of well casing [§28 F(1)]
Purging Method: Three well volumes; low-flow method; or purge dry [§28 F)(2)].
Sampling and Analysis: Pursuant to Subsection B of 20.6.2.3107 NMAC [§28 D].
Timing: Quarterly sampling [§28 I].
Field Parameters: Before sampling measure: pH, specific conductance, temperature [§28 F)(3)].
Analytes: Analytes from 20.6.2.3103 NMAC based on the solution or material in the facility, include constituents generated by degradation, oxidation, decay or any other process [§28 I].

The permittee may request reduction of the analyte list, which may be granted provided:

1. Analyte is not present in the facility being monitored [§28 H], and
2. Analyte cannot be generated from the materials present [§28 H].

5.2.2 Technical Evaluation

The Rule provides prescriptive direction for the construction of monitor wells. This is necessary, because the monitor wells provide the primary information on the protection of groundwater against releases from each copper mine facility, and the performance of the quality and reliability of the water level measurements and the water quality data collected from water wells is strongly dependent on the method of construction of the wells. The key aspects of the Rule construction methods are:

- Exact location and length of the well sampling interval
- Physically stable well construction
- Chemically inert well construction
- Proven sampling methods that reflect actual water quality in the test formation
- Permanent identification of the well

The well installation meets or exceeds relevant standards:

- ASTM D 5092: Practice for Design and Installation of Ground Water Monitoring Wells in Aquifers.
- EPA 600/4-89/034: Handbook of Suggested Practices for the Design and installation of Ground- Water Monitoring Wells[5].

The sampling and analysis methods prescribed in Subsection B of 20.6.2.3107 NMAC are consistent with relevant standards:

- D 6232: Standard Guide for Selection of Sampling Equipment for Waste and Contaminated Media Data Collection Activities.
- EPA 542-S-02-001: Ground-Water Sampling Guidelines for Superfund and RCRA Project Managers[6].

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[5] Aller L, Bennett TW, Hackett G, Petty RJ, Lehr JH, Sedoris H, Nielsen DM, Denne JE, Handbook of Suggested Practices for the Design and Installation of Ground-Water Monitoring Wells, Environmental Monitoring Systems Laboratory, Office of Research and Development, U.S. Environmental Protection Agency, March 1991. Download from: http://www.epa.gov/oust/cat/monitor.htm

Based on this evaluation, the Rule's monitor well location, construction, and sampling requirements meet or exceed relevant and applicable standards. Water levels and samples obtained from these wells and by these methods will be reliable for use in copper mine regulation and control.

The location of the monitoring wells in the Rule is comprehensive. The requirement of (generally) a minimum of 2 downgradient wells, supported by upgradient and perimeter wells where the flow direction is unclear provides for complete protection of the surrounding groundwater environment immediately adjacent to each copper mine unit. The requirement that NMED must approve the monitoring locations for each copper mine unit, and may require additional wells to ensure that the monitoring system is comprehensive provides a high level of assurance that all discharge pathways are monitored. These location requirements are the most intensive and localized monitoring system that is required in any state.

5.3 Contingencies

5.3.1 Requirements

The Rule includes contingencies for each requirement, in the event that it fails [§30]. Contingency requirements are triggered when performance of the unit is observed to fail or approach failure of the requirements of the Rule. Contingencies are specified for the following:

- Exceedance of ground water standards [§30 B]
- Monitoring well replacement [§30 C]
- Exceedance of permitted maximum daily discharge volume [§30 D]
- Insufficient impoundment capacity [§30 E]
- Inability to preserve required freeboard [§30 F]
- Compromised structural integrity of an impoundment [§30 G]
- Unauthorized discharge [§30 H]
- Unstable slopes [§30 I]
- Compromised stormwater conveyance structure [§30 J]
- Water management and water treatment system failure [§30 K]

Contingency actions in each case comprise some or all of the following:

- Notify: Report to NMED, generally within 24 hours
- Confirm: Repeat monitoring sample or test
- Repair: Take emergency action to prevent further discharge
- Correct: Prepare a corrective action plan, and implement on approval by NMED
- Abate: Prepare abatement plan, and implement on approval

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[6] Yeskis D, Zavala B, 2002. Ground-Water Sampling Guidelines for Superfund and RCRA Project Managers. Report Number EPA 542-S-02-001, Office of Solid Waste and Emergency Response, USEPA, May 2002, 53 pp. Download from: www.epa.gov/superfund/remedytech/tsp/download/gw_sampling_guide.pdf

5.3.2 Technical Evaluation

The contingencies that are covered in the Rule cover the full range of failures and compliance exceedances of Rule-mandated groundwater protections. The range of options for contingency response and actions is comprehensive, with response times commensurate with the severity of the potential impact to groundwater of the state.

Abatement is included in the contingency actions for those failures and exceedances where remediable damage results. The selection of abatement opportunities is appropriate and comprehensive.

6 EFFECTIVENESS OF OPERATIONAL GROUNDWATER PROTECTION

The Rule defines minimum requirements for the design, construction, operation, closure, and post-closure care of copper mine units on a mining unit basis.,

Capture and containment systems are at the heart of the protection of groundwater from pollution by discharges from the operating mine system. In this section of my testimony I will examine the effectiveness of the groundwater protection systems required in the Rule, considering each class of operational facility.

6.1 Open Pit Mines

6.1.1 Operation

The open pit mine(s) at a Copper Mine facility will act as a sink for surface water and for groundwater. Water will collect in the open pit from many sources including direct precipitation, stormwater, seepage, dewatering wells, and water pressure control wells.

The Rule defines an "Open Pit Surface Drainage Area" ("OPSDA") which is the area in which [§7 (42)]:

a. Storm water drains into an open pit and cannot feasibly be diverted by gravity outside the pit perimeter; and
b. The underlying ground water is hydrologically contained by pumping or evaporation of water from the pit bottom.

The Rule also defines an "Area of Open Pit Hydrologic Containment" ("AOPHC") which comprises the area where groundwater drains to the open pit and is removed by evaporation and/or pumping, and is [also] interior to the monitoring well network installed around the perimeter of the open pit. Within this area of open pit hydrologic containment the water quality standards of 20.6.2.3103 NMAC do not apply [§24 A(4)].

The Rule requires that open pits will be operated with the following controls for water discharge:

1. Stormwater shall be diverted away from the open pit and shall not be directed into the open pit [§24 A(2)].
2. Groundwater underlying or adjacent to the pit will drain to the pit, and will be removed by evaporation or pumping [§24 A(3)].
3. Other regulated mine facilities shall be located to facilitate the drainage of water away from the open pit to the extent practicable [§24 A(5)].

6.1.2 Technical Evaluation

The walls of the open pit and the materials located within the OPSDA typically have the potential to cause groundwater pollution. The system of control in the Rule allows flow to the open pit of these waters, from which there is in general no gravitational escape. The Rule requires collection and appropriate management of the water influent to the open pit, pursuant to a NMED-approved water management plan, which by law does not allow of discharge of water in excess of the standards of Section 20.6.2.3103 NMAC at locations of present and potential future use.

Accordingly, it meets technical requirements for groundwater protection.

6.2 Underground Mines

6.2.1 Operation

The Rule regulates the operation of underground mines to be protective of groundwater quality as follows:

1. All waste rock removed from an underground mine and taken to the surface shall be characterized and managed pursuant to the Rule [§25 A].
2. Any waste rock, tailings or other waste that is intended to be deposited in the mine shall be evaluated for its potential to generate acid and/or to release water contaminants that would cause an exceedance of the applicable standards following placement in the underground mine [§25 A].

Further, deposition of material in an underground copper mine is restricted. In particular, a mine operator may not deposit in an underground mine any waste rock or tailings that may generate a leachate after deposition that may cause an exceedance of applicable groundwater standards [§25 B(1)]. Deposition of any other wastes in an underground mine requires a discharge permit approved by the department [§25 B(2)].

6.2.2 Technical Evaluation

Underground mines are likely to be below the water table, and when developed will act as a sink for local groundwater. This water will come under the ambit of the Water Management Plan, which prohibits discharge of water in excess of the quality standards of Section 20.6.2.3103 NMAC at locations of present and potential future use. Accordingly, the Plan is protective with respect to water entering underground mines. Further, ground water flowing into conventional mine workings is exempt from a discharge permit requirement (20.6.2.3105.K NMAC).

The Rule's allowance of deposition of (particularly) potentially acid-generating tailings or waste rock in an underground mine providing it does not generate a leachate after placement is important for minimization of impact of such wastes on the groundwater of the state. If oxidation of the sulfides in the deposited material can be prevented when placed, by such strategies as cementation, placement below the water level in the mine, or isolation, this method of this disposal minimizes release of contaminants from the waste, and is preferred over all other methods of disposal.

6.3 Copper Crushing, Milling, Concentrator, Smelting, and SX/EW Units

6.3.1 Operation

The operation of the processing systems of a Copper Mine is required in the Rule to comply with the following requirements to avoid exceedance of applicable standards at locations of present and potential future use:

(1) Crushing and Milling Units. Crusher and mills handle raw ore and add chemicals to aid in separation. The resulting process liquid may contain water contaminants that have the potential to migrate to ground water and cause an exceedance of applicable standards. These materials are to be contained and managed on concrete or low permeability surfaces [§22 A(1)][7].

(2) Concentrator Units. Tailing and concentrate thickener tanks handle fine milled ore and tailings fluids which have the potential to migrate to ground water and cause an exceedance of applicable standards [§22 A(2)]. These tanks may be constructed with concrete or low permeability bottoms consisting of a minimum of 12 inches of soil that has a minimum re-compacted in-place coefficient of permeability of $1x10^{-6}$ cm/sec to minimize infiltration.

(3) Smelter Units. Smelting facilities handle and produce materials including concentrate, fuels, metals, slag and flue dust that contain contaminants that have the potential to migrate to ground water and cause an exceedance of applicable standards [§22 A(3)]. Smelter units shall be designed to contain and manage all such materials on impermeable surfaces.

(4) SX/EW Units. Copper production in general takes place from leach stockpile liquor by solution extraction and electrowinning (SX/EW). Solution extraction involves contacting the leach stockpile liquor with an organic solvent (e.g. kerosene); extracting the copper to the organic phase; separating the organic phase from the water phase; and then contacting the copper-bearing organic phase with concentrated sulfuric acid, releasing the copper to the acid. Electrowinning involves passing electric current through the copper-bearing acid to plate out the copper on the cathode. The copper metal is then stripped off the cathode and shipped. The liquors involved in the SX/EW process have high concentrations of metals, sulfuric acid, and organics, which exceed the standards of 20.6.2.3103 NMAC, and so have the potential to impact groundwater or surface water if allowed to escape from the facility. To prevent or limit escape of waters that have the potential to impact water resources, the Rule requires the following for all SX/EW facilities:
   a. Primary containment using impermeable pipelines and tanks {§20 A (2)].
   b. Secondary containment using double synthetically lined impoundment system with leak collection [§20 A (2)].
   c. Disposal of sludge and spent electrolyte on a leach stockpile for leaching or at an approved disposal facility.

6.3.2 Technical Evaluation

The groundwater protection scheme for all process units is to locate the component equipment, pipes, and tanks on impermeable or low permeability surfaces. The protectiveness of this approach can be checked by consideration of the fluid losses that are possible through the low permeability surfaces that form the base of typically-sized units

[7] Except when located within the open pit surface drainage area [§22 A(1)]

Table 1 – Representative Seepage from Copper Mine Processing Units

Unit:	Crusher	Mill	Concentrator	Smelter	SX/EW
Component	Crusher slab	Mill basin	Thickener	Smelter	EW tanks
Area (sq.ft.)	2,500	10,000	8,000	160,000	1,000,000
Depth of water (ft)	1	1	30	0.5	5
Thickness of base (ft)	1	1	1	1	0.005
Base material	Concrete	Concrete	Soil	Impermeable	Tank+Liner
Hydraulic Conductivity (cm/s)	1.00E-06	1.00E-06	3.00E-06	1.00E-07	1.00E-14
Seepage flow (gpm)	0.07	0.29	10.76	0.35	1E-04
Liquid Concentration	Low	Low	Low	Moderate	High
Sulfate (mg/L)	1000	1000	1000	1500	5000
Sulfate flux (lb/day)	1	4	129	6	0.009

(1) Seepage flow computed from Darcy's Law: Q = K I A where Q = flow, K = hydraulic conductivity, I = hydraulic gradient, and A = Cross-sectional flow area.

Based on Table 1, the processing system may lose in the order of 10 gpm of low concentration (tailings) water, 1/3 gpm of moderately concentrated smelter wash-down water, and 0.2 gallons per day of acidic leach water from the double lined tank system of the SX/EW processing area. The total mass flux of (for example) sulfate from the processing system is estimated to be 140 lb/day, which is sufficient to impact 23 gpm of groundwater to the sulfate standard of 500 mg/L. This is not considered likely to create an exceedance of standards at any present or potential future use as domestic and agricultural water supply and surface water recharge.

6.4 Impoundments, Pipelines and Tanks

6.4.1 Operation

Waters that contain or may contain contaminants are present in large quantities in copper mine facilities, in particular associated with impacted stormwater, process water, leaching, electrowinning, tailings and waste rock. This water is stored within the mine facility in impoundments and tanks, transported within the facility by conveyances and pipes, and may be treated and discharged, or retained within the mine system (for use as process water and ultimately retained as interstitial tailings moisture).

The quality of copper mine related water is highly variable, from precipitation quality stormwater to high concentration pregnant leach solution. Most of the water in the mining facility has concentrations of one or more constituents which exceed the standards of 20.6.2.3103 NMED, and so has the potential to impact groundwater or surface water if allowed to discharge from the facility.

To prevent or limit release, the Rule requires the following design and operation for all impoundments which contain leach or process water:

1. Capacity: Normal operating capacity, plus allowance for upset conditions plus runoff and direct precipitation from a 100 year, 24 hour storm event [§17 D(2)].
2. Freeboard: Minimum of two feet during all normal operating conditions and at peak capacity [§17 D(2)].

3. Embankment: Slopes less than 2 horizontal to 1 vertical, with a minimum static factor of safety against failure of 1.3 [§17 D(1)(a)].
4. Liner: Double synthetically lined system with leak collection from between liners. Liners shall be 60 mil HDPE or equal. Short term stormwater impoundments require only a single synthetic liner and no leak collection system [§17 D(3)].
5. Groundwater Separation: Any liner shall be located more than 4 feet above high ground water level [§17 D(6)].
6. Spillway: No spillway that discharges to ground surface is allowed for primary containment impoundments of process water. Short term stormwater impoundments may have a spillway to handle flow from a 25 year/24 hour storm [§17 D(7)].
7. Setbacks: Domestic water well or spring - greater than 500 feet; public water supply well or spring - greater than 1000 feet.
8. Dam Safety: Compliant with the requirements of the Dam Safety Bureau of the New Mexico Office of the State Engineer unless exempt [§17 C(1)(d)].
9. Maintenance: Prevent conditions which could affect structural integrity of the impoundments and associated liners [§18 F(3)].
10. Inspection: Quarterly [§18 F(3)]

6.4.2 Technical Evaluation

The Rule requires a conservative design for a water storage impoundment, and ensures that there will be no detectable impact on the groundwater resulting from escape of process water from any impoundment meeting these specifications.

This conclusion is based on consideration of the methods of failure of the impoundment system considered below:

1. Leakage. Leakage from the double lined impoundment can occur by water leaving the pond through the upper liner, pooling above the lower liner, and then seeping through the lower liner. The rate of leakage can be estimated from the known effective hydraulic conductivity of a 60 mil HDPE liner (10^{-11} cm/sec, with a range of 10^{-10} cm/sec to 10^{-12} cm/sec)[8,9]. The design of a leakage collection system between liners is such that the hydraulic head on the lower liner is minimized under normal operating conditions. However, if the upper liner fails or the leakage is not collected, the secondary liner will be subjected to the full pressure of liquid stored in the impoundment. For a 30 feet pond water depth the theoretical flow through the liner system under this failure mechanism is computed to be in the order of 0.05 gallons per minute per acre

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[8] Koerner, R.M., 1990, "Designing with Geosynthetics," 2nd Edition, Prentice-Hall, Englewood Cliffs, New Jersey, 652 pp., cited in ADEQ, 2004, "Arizona Mining Guidance Manual – BADCT", Publication #TB 04-01, Arizona Department of Environmental Quality, Phoenix, Arizona, 298 pp., in Appendix C, p. C-14. Download from: http://www.azdeq.gov/environ/water/wastewater/mines.html#badct

[9] Workman, J., and Keeble, R., Design and Construction of Liner Systems," Chapter 5.1 in Christensen et al. (eds), Sanitary Landfilling: Process, Technology and Environmental Impact, Academic Press, New York, pp. 301-309 (1989), p.303. [Exhibit 10]

(equivalent to a seepage rate of 1 inch per year). For a normally operating dual liner system the flow out of the lower liner is much less, close to zero.

2. Overtopping. The capacity requirements prevent overtopping release of the ponds except under extreme conditions: a storm with a probability of occurrence of less than once in 100 years ($p \leq 3x10-5$ on any given day), at the same time that the impoundment is full (estimated to be no more than one day a week, $p \leq 0.142$ on any given day), and the water management system is in an upset condition (estimated to be one day a year, $p = 0.003$ on any given day). The probability of them all occurring together on the same day is $p \leq 10^{-8}$, so for a 30 year mine life (10,000 days) the probability of overtopping is 1 in 10,000. The consequences of such an event are also minor with respect to impact to groundwater. Any release that would occur would be heavily diluted by the flooding caused by the design basis storm, and almost all of the release would be directed into stream channels under that flood condition. Very little of the diluted release would be transported to the groundwater system, and there would be no detectable change in groundwater quality resulting from that transport.

3. Embankment failure. Collapse of the engineered embankment represents a possible method of failure of an impoundment. For the slopes on a double-lined impoundment constructed under the Rule, the following conditions will apply:

    a. Dry slopes, as the liners will prevent fluid ingress to the slope material.

    b. Compacted granular construction material, with effective stress friction angle (ø) of 35° expected.

    c. Outboard slope required to be no steeper than 2:1 horizontal to vertical (26.6°).

    d. Full water load on the upstream bank of the embankment.

    e. Minimum Static Factor of Safety (FOS) = 1.3.

    Analysis of the stability of this slope using the slip circle method of Hoek and Bray[10] provides the following result for a dry slope at an angle of 26.6°:

    $$\text{Tan } ø / \text{FOS} = 0.47 \text{ and FOS} = \text{Tan}(26.6°) / 0.47 = 1.5$$

    A Factor of Safety of 1.5 is considered to provide a high probability of stability for civil engineering and mining slopes, so impoundment slopes designed in accordance with the Rule will be stable.

The monitoring requirements are reasonable. For most water impoundments, the area of the pond is typically less than a few acres. Two downgradient wells would be spaced approximately 100 feet apart at the third points of the impoundment wall in that situation. The wells are to be completed in the top of the saturated water table, which is the first receptor of impacted water. This should be adequate, based on experience, to identify any escape from the facility. In the event of bigger ponds, the Department may require more wells [§28 B(3)].

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[10] Hoek E, Bray J, 1977. *Rock Slope Engineering*. Institution of Mining and Metallurgy, London, 1977. [Exhibit 19]

6.4.3 Other State Regulation

The containment approach to impoundments for process, impacted, and stormwater in other similar jurisdictions, and the comparison with the requirements of the Rule, are as follows:

1. Arizona. The Arizona Best Available Demonstrated Control Technology ("BADCT") guidance "Prescriptive Criterion" for process water impoundments specifies double geomembrane liner with leak collection and removal system ("LCRS") between the two liners[11]. BADCT also allows "Individual BADCT Guidance", where a permittee may select and defend an alternate design. In the case of impoundments, alternate designs include a single liner on low permeability clay under-liner[12]. The Arizona regulations closely parallel the requirements and approach of the Rule.
2. Nevada. All ponds which are intended to contain process fluids must have a primary synthetic liner and a secondary liner, with a permeable leach collection layer between them [NAC 445A.435][13]. Ponds which are primarily designed to contain excess quantities of process fluids that result from storm events for limited periods may be constructed with a single liner if approved. The Nevada regulations closely parallel the requirements and approach of the Rule.

6.5 Leach Stockpiles

6.5.1 Operation

Leach stockpiles are used to extract copper from ore in general by the addition of sulfuric acid. The pregnant leach solution resulting from leaching has metal, sulfate and other constituent concentrations at high concentrations which exceed the groundwater quality standards of 20.6.2.3103 NMAC, and so have the potential to impact groundwater or surface water if allowed to escape from the unit.

To prevent or limit escape, the Rule requires the following general design and operation for all leach stockpile facilities:

1. Liner System: Stable subgrade overlain by a 12 inch thick compacted earthen liner with permeability of $1x10^{-6}$ cm/sec, overlain by a synthetic liner providing the same or greater level of containment as a 60 mil HDPE geomembrane liner [§20 A(1)(b) and §20 A(1)(c)].
2. Solution Collection: Liner protection and drainage system that will transmit fluids out of the drainage layer of the leach stockpile [§20 A (1)(d)].
3. Setbacks: Domestic water well or spring: greater than 500 feet [§19 E (1)]; public water supply well or spring: greater than 1000 feet [§19 E (1)].

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[11] ADEQ, 2004, BADCT, op.cit., p.2-19.

[12] ADEQ, 2004, BADCT, op.cit., p.3-74 – p.3-76, "Discharge Control".

[13] Nevada Administrative Code Section 445A in material parts is included in Exhibit 9.

6.5.2 Technical Evaluation

Under the Rule groundwater protection is provided for leach stockpiles by a 60 mil HDPE liner laid directly over a 12 inch compacted clay liner with a minimum hydraulic conductivity of 1×10^{-6} centimeter per second. The seepage through this system is presented in Table 2, for a range of conditions of the HDPE liner.

Table 2 – Representative Seepage from Leach Stockpiles in Operation

Liner Material		**HDPE without Defects**	**HDPE with Defects**	**HDPE Liner Failure**
Thickness	inch	0.06	0.06	12
Hydraulic Conductivity(1)	cm/sec	1×10^{-11}	1×10^{-10}	1×10^{-6}
Depth of water over liner	feet	1	1	1
Gradient over liner	feet/foot	200	200	1
Seepage rate(2)	in/year	0.025	0.25	12
Area of facility	sq.mile	1	1	1
Flow through liner(2)	gpm	0.82	8.2	410

(1) HDPE hydraulic conductivity from Workman and Keeble, 1989[14]; defects increase value to upper end of stated range.
(2) Seepage flow computed from Darcy's Law: Q = K I A where Q = flow, K = hydraulic conductivity, I = hydraulic gradient, and A = Cross-sectional flow area.

The liner system required by the Rule provides excellent groundwater protection if there are no defects in the liner, transmitting the equivalent of 0.03 inches per year of high concentration leachate solution through the liner system to the underlying material. For one square mile of leachate stockpile, this is equivalent to a leakage rate of approximately 1 gallon per minute. This leakage will blend with natural groundwater under the pile, and the resulting groundwater concentrations will likely not be in excess of the quality standards of Section 20.6.2.3103 NMAC when monitored at the downgradient toe of the leach stockpile.

However synthetic liners have defects, from manufacturing, seam leaks, and puncturing during construction, even with the construction quality assurance requirements of the Rule [§17 C(1)(b)]. Assuming that such defects increase the hydraulic conductivity of the liner to the upper end of the literature range (1×10^{-10} centimeters per second[15]), the leakage rate increases to 0.25 inches per year of high concentration leachate, or 8 gallons per minute for one square mile of leach stockpile. This will blend with water present and flowing beneath the leach stockpile. Provided that flow is more than approximately 10 gallons per minute (which it in general will be if the catchment upgradient of the leach stockpile exceeds half the size of the unit) then the groundwater beneath will meet the quality standards of Section 20.6.2.3103 NMAC when monitored at the downgradient toe of the leach stockpile. If there is no upgradient flow beneath the leach stockpile, it is likely because it is within the open pit surface drainage area, and any releases will be captured within the open pit.

[14] Workman, J., and Keeble, R., Design and Construction of Liner Systems," Chapter 5.1 in Christensen et al. (eds), Sanitary Landfilling: Process, Technology and Environmental Impact, Academic Press, New York, pp. 301-309 (1989).

[15] Workman and Keeble, 1989, op.cit., p.303.

Finally, if the HDPE liner fails, the flow through the liner system (now reduced to just the clay liner) increases towards a limit of about 12 inches per year for total failure, releasing approximately 400 gallons per minute of leach solution to the substrate underlying each square mile of leach stockpile. This would be rapidly evident to the operators of the leach system, due to the loss of product solution. It would also be rapidly evident as exceedances at the downgradient monitor wells, triggering contingency actions likely including repair, containment, abatement, and possibly removal of the leach stockpile from service.

It is noted that the purpose of the clay liner is not to prevent the effects of such a failure. Its hydraulic function is to limit the amount off flow that can occur through the HDPE liner as a result of small defects. If the material immediately beneath the HDPE liner were highly permeable, then a single small defect (say 1 inch in diameter or a 1 foot long seam failure) could conduct flows in the order of 1 gpm of leach solution to the subsurface. With a clay underliner in contact with the HDPE the maximum flow from such a defect drops to less than 0.0001 gpm.

6.5.3 Other State Regulation

The containment approach to leach stockpiles in other similar jurisdictions, and the comparison with the requirements of the Rule, are as follows:

1. Arizona. The BADCT guidance "Prescriptive Criterion" for leach stockpiles specifies a composite liner consisting of a single geomembrane of at least 30 mil thickness (60 mil if HDPE) over, a minimum, twelve inches (placed in two 6-inch lifts) of 3/8 inch minus native or natural materials compacted to achieve a saturated hydraulic conductivity of no greater than 10^{-6} cm/sec.[16]. BADCT also allows "Individual BADCT Guidance", where a permittee may select and defend an alternate design, including natural containment, leachate collection, and hydrostatic head control[17]. The Arizona regulations closely parallel the requirements and approach of the Rule.
2. Nevada. Containment of process fluids for leach stockpiles must consist of an engineered liner system which provides containment equal to or greater than that provided by a synthetic liner placed on top of a prepared sub-base of 12 inches of native, imported or amended soil, which has a maximum re-compacted in place coefficient of permeability of 1x10-6 cm/sec [NAC 445A.434]. The Nevada regulations closely parallel the requirements and approach of the Rule.
3. New Mexico. New Mexico permitted Chino Mine's Lampbright leach unit in 2010[18]. The requirements of the renewal for leach solution containment included groundwater containment using groundwater extraction wells, and seepage collection from the toe of

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[16] ADEQ, 2004, BADCT, op.cit., p.2-33.

[17] ADEQ, 2004, BADCT, op.cit., p.3-8 – p.3-11, "Discharge Control".

[18] NMED, 2010. *Discharge Permit Renewal and Modification, Lampbright Leach System, DP-376*. New Mexico Environment Department, June 17, 2010 [Exhibit 17]

the unit. The requirements of the Rule are more restrictive, and provide a greater degree of containment than the Lampbright permit.

6.6 Waste Rock Stockpiles

6.6.1 Operation

Mine waste rock stockpiles are created when material is extracted from the mine that does not contain sufficient mineral value to warrant processing through the mill or leaching. Under the Rule this is placed in one or more waste rock stockpiles, which may be unlined, provided the permittee can demonstrate that groundwater of the State of New Mexico will be protected for present and potential future use as domestic and agricultural water supply and surface water recharge.

The Rule considers the design, construction, and operation of copper mine waste rock stockpiles to be controlled by two factors:

1. Rock Type. Material that may generate acid and/or to release water contaminants at levels in excess of the standards of 20.6.2.3103 NMAC must be stored, deposited or disposed of according to the requirements of the Rule; material that does not is not regulated by the Rule.
2. Location. A waste rock stockpile located outside the open pit surface water drainage area is required to meet the conditions of the Rule, while a waste rock stockpile within that area is regulated by the seepage collection requirements of the open pit surface water drainage area[19].

The determination as to whether waste rock may generate acid and/or to release water contaminants at levels in excess of the standards of 20.6.2.3103 NMAC is conducted using the following sampling and testing of the waste rock [§21 A(1)]:

1. Geological, mineralogical, physical, and geochemical characterization.
2. Representative sampling of the waste rock material.
3. Static testing using acid/base accounting or equal to determine acid generating potential; and meteoric water mobility procedure or equal to determine water contaminant leaching potential[20].
4. Kinetic testing to evaluate acidification, neutralization and drainage quality (only if static testing indicates contaminant leaching potential).

This characterization will identify whether waste rock may generate acid or release regulated groundwater contaminants.

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[19] The only regulation of waste rock within the open pit surface water area under the Rule is adoption of the same stormwater run-on requirements as for potentially impactful waste rock piles located outside the open pit surface water drainage area [§21 B(2)].

[20] The Rule allows “a department approved equivalent testing method”; the words “or equal” are used here to indicate this option.

The minimum groundwater protection requirements for waste rock stockpiles that may generate water contaminants that may cause an exceedance of applicable standards are:

1. Stormwater Diversion: Stormwater run-on shall be diverted and/or contained to minimize contact between stormwater run-on and the stockpiled material [§21 B(1)(a)].
2. Seepage Capture: Seepage from the base of a waste rock stockpile shall be captured and contained [§21 B(1)(b)], or if not feasible, shall require additional controls including but not limited to lining [§21 B(1)(e)].
3. Ground Water Capture: Ground water impacted by waste rock stockpiles in excess of applicable standards shall be captured and contained [§21 B(1)(c)], or if not feasible, shall require additional controls including but not limited to lining [§21 B(1)(e)].
4. Setbacks: Domestic water well or spring: greater than 500 feet. Public water supply well or spring: greater than 1000 feet [§19 E].

6.6.2 Technical Evaluation

6.6.2.1 Seepage from the waste rock stockpile during operation

The operational requirements of the Rule for waste rock stockpile management prevents water pollution so that groundwater will meet the quality standards of Section 20.6.2.3103 NMAC at locations of present and potential future use. This conclusion is based on consideration of the protection afforded the groundwater against impact in excess of the standards during operation.

The source term for potential impact to groundwater resources from waste rock stockpiles is incident precipitation which impinges on or melts on the waste rock stockpile during operation. As the surfaces of the stockpile are open, incident precipitation infiltrates at relatively high rates, with little ponding or surface runoff due to the high permeability rockmass.

The infiltrating water is initially captured by the waste rock, raising its moisture content from the as-mined value of less than 1% by weight to the field capacity typically in the vicinity of 7% by weight. When the waste rock in the stockpile has reached its field capacity moisture content, the infiltration rate is typically in the range of 25% to 50% of the precipitation. Average annual precipitation in New Mexico ranges from 8 inches per year to 30 inches per year, with the copper mining areas of the state receiving close to the average of 13.85 inches per year[21]. Accordingly, the seepage rate through New Mexico copper mine waste rock stockpiles during operation is expected to average in the order of 4.5 inches per year, with a range from 3.5 to 7 inches per year. For a 1 square mile waste rock stockpile, this results in an average seepage flow in the order of 150 gallons per minute. The instantaneous seepage outflow is expected to vary significantly over time with precipitation.

During the transit through the waste rock stockpile, the infiltrating water contacts any leachable material that is present in, or has been generated within, the waste rock. As the transit rate is slow, and the mass of water is small compared with the mass of waste rock

[21] National Atlas of the United States of America, New Mexico Precipitation, pageprecip_nm3.pdf, downloaded from http://www.maps.com/ref_map.aspx?pid=12601 on 2/16/2013. [Exhibit 11]

contacted, the concentration of soluble constituents in the seepage water will increase, limited by the available mass of soluble constituents or by their solubility in the seepage water.

Accordingly, the outflow of water from waste rock piles during operation is the equivalent of about 4.5 inches per year of potentially contaminated water.

6.6.2.2 Control of seepage from waste rock stockpiles located on bedrock

When seepage exits the base of a waste rock stockpile located on bedrock, it can enter the bedrock if the vertical hydraulic conductivity of the bedrock is greater than the infiltration rate. In the case of waste rock piles in New Mexico, the seepage rate is in the order of 4.5 inches per year, which can pass by gravity flow into the underlying bedrock if the vertical hydraulic conductivity is greater than 4×10^{-7} centimeters per second (i.e. 4.5 inches per year)[22]. This condition is almost invariably met for bedrock types encountered in New Mexico, so infiltration into the bedrock is assured.

For that portion of the flow that proceeds into the underlying materials, flow continues vertically downward until it intercepts the existing water table. At that point the flow joins the regional groundwater flow system, and flow becomes substantially horizontal, at much lower head gradient than the prior vertical flow. When the underlying material is bedrock, the carrying capacity is usually sufficiently low that the additional water will cause saturation of the underlying material back up to bedrock surface at the base of the waste rock facility, causing most of the exfiltrating water to flow through any overlying colluvium or through the base of the waste rock stockpile, and emerge at low points at the toe of the stockpile.

Consider typical conditions beneath a one mile square waste rock stockpile located on bedrock. Assume, as is typically the case, that groundwater circulates in approximately the upper 3,000 feet of the bedrock, with the upper few hundred feet stress relieved and weathered, resulting in higher permeability[23]. Finally, assume that the ground and the water table both slope at 5%, typical for most side-hill waste rock stockpile locations in New Mexico. The bedrock groundwater flow beneath the hypothetical waste rock pile in this system is summarized in Table 3, calculated with Darcy's Law and using typical bedrock hydraulic conductivity ranges observed in mining projects in New Mexico and world-wide.

Table 3 - Typical groundwater flow capacity of bedrock beneath a waste rock stockpile

Bedrock flow zone:	**Shallow**	**Deep**	**Total**
Depth of bedrock (ft)	200	2800	3000
Width of waste rock pile (ft)	5280	5280	5280
Hydraulic conductivity (cm/sec)[(1)]	10^{-4}-10^{-5}	10^{-5}-10^{-6}	~5×10^{-6}
Slope of water table (ft/ft)	5%	5%	5%
Flow capacity (gpm)	**25**	**34**	**59**

(1) Geometric mean of range used in Darcy flow computation

[22] For vertical gravity flow at saturation, the vertical hydraulic gradient is unity, and Darcy's Law becomes $Q/A = q = K_v$, where Q = flow, A = area, q = flow per unit area, and K_v = vertical hydraulic conductivity.

[23] Freeze RA, Cherry JA, 1979. *Groundwater*, Prentice Hall, p.29.

Note that the bedrock flow carrying capacity depends on the slope of the water table, which is why bedrock springs emerge in locations where the surface and bedrock slope flattens, at the base of mountain ranges and in incised bedrock valleys.

In general, most or all of the carrying capacity of the bedrock is taken up draining natural groundwater that has infiltrated into the system upgradient of the location of the waste rock stockpile. When the infiltration from the operating waste rock stockpile (150 gpm in the hypothetical case) is added to the upper surface of this groundwater flow system, it "floods" it, mounding the head in the system, and rejecting the excess seepage above the carrying capacity of the bedrock (between 100 gpm and 150 gpm in the hypothetical case). The rejected seepage proceeds to flow downhill in the base of the waste rock pile, emerging at the toe of the pile.

During operation under the Rule any seepage that would cause exceedance of groundwater standards at locations of present and potential future use is captured by one or more of three methods:

1. Drainage to the open pit. If the waste rock stockpile is located within the OPSDA, any seepage from the toe of the waste rock stockpile is captured by direct flow into the open pit, and any vertical seepage is captured by the groundwater containment system of the OPSDA, generally saturated gravity flow in the bedrock towards the open pit [§21 B(2)].
2. Capture of surface seepage. If the waste rock stockpile is located outside the OPSDA, surface seepage will be captured and contained by headwalls, impoundments and diversion structures at or near the toe of the stockpile. These features capture the waste rock stockpile seepage that exceeds the carrying capacity of the groundwater system, and contain it with in the mine water management system for use or treatment and discharge [§21 B(1)(b)].
3. Capture of impacted groundwater. If the waste rock stockpile is located outside the OPSDA, the Rule requires that "groundwater impacted by waste rock stockpiles in excess of applicable standards shall be captured and contained through the construction of interceptor systems" [§21 B(1)(c)]. This capture is generally not feasible in the following locations:
    a. Beneath the waste rock stockpile footprint, due to lack of accessibility during operation and due to the general infeasibility of completing in water wells through the dump materials.
    b. In bedrock downgradient of the waste rock stockpile, due to low permeability and ineffectiveness of extraction well systems to capture a significant proportion of the groundwater.

   Accordingly, capture is in general first feasible at locations where any impacted bedrock seepage exits the bedrock, and enters the overlying alluvium/colluvium, which is also where points of use are practicable, so where required, this capture is protective of groundwater use.

Thus when the operating waste rock stockpile is located over bedrock, the seepage management system of the Rule contains water pollution so that groundwater meets the quality standards at locations of present and potential future groundwater use.

6.6.2.3 Control of seepage for waste rock stockpiles located over alluvium

When a waste rock stockpile is located over alluvium[24], leachate seepage from the stockpile readily passes into the underlying materials, and continues vertically downward through the granular materials until it intercepts the existing water table, provided the vertical hydraulic conductivity of the alluvial materials is greater than approximately 4×10^{-7} centimeters per second (i.e. 4.5 inches per year)[25]. This condition is invariably met for alluvium and colluvium encountered in New Mexico, so infiltration is assured.

At the water table the flow joins the regional groundwater flow system, and flow becomes substantially horizontal, at much lower head gradient than the prior vertical flow. As the underlying material is alluvium, the carrying capacity is usually sufficiently high that the additional water from the waste rock stockpile seepage will cause little change in the saturation of the underlying aquifer, and the water levels in the aquifer beneath the stockpile will be largely unchanged.

During operation under the Rule any seepage that would cause exceedance of groundwater standards at locations of present and potential future use is captured from the alluvium by one or more of three methods:

1. Drainage to the open pit. If the waste rock stockpile is located within the OPSDA, any seepage from the waste rock stockpile is captured by direct (alluvial) flow into the open pit, or is captured by the groundwater containment system of the OPSDA [§21 B(2)].
2. Capture of surface seepage. In general, there will be no surface seepage from a waste rock pile located over alluvium. However, if the waste rock stockpile is located outside the OPSDA, any surface seepage is required to be captured and contained by headwalls, impoundments and diversion structures at or near the toe of the stockpile, and returned to the mine water management system for use or treatment and discharge [§21 B(1)(b)].
3. Capture of impacted groundwater. If the waste rock stockpile is located outside the OPSDA, the Rule requires that "groundwater impacted by waste rock stockpiles in excess of applicable standards shall be captured and contained through the construction of interceptor systems" [§21 B(1)(c)]. This capture is generally first feasible using a pumped interceptor system in the alluvium at the toe of the waste rock stockpile, as it is usually difficult or impossible to establish pumping wells in the footprint of an active waste rock pile. Capture of water from alluvial aquifers is a well-established technology, and is practiced widely in the mining industry. In addition, the Rule requires that the permittee demonstrate that the capture system will be effective and approved by the department [§21 B(1)(d)(vii)].

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[24] The reference to "alluvium" here is intended to be generic, to include any non-indurated material that is present as valley fill in New Mexico. It includes the Santa Fe group and the Gila Conglomerate.

[25] For vertical gravity flow at saturation, the vertical hydraulic gradient is unity, and Darcy's Law becomes $Q/A = q = K_v$, where Q = flow, A = area, q = flow per unit area, and K_v = vertical hydraulic conductivity.

Thus when the operating waste rock stockpile is located over alluvium, the seepage management system of the Rule prevents water pollution so that groundwater meets the quality standards at monitoring well locations required by the Rule.

6.6.3 Other State Regulation

The containment approach to waste rock stockpiles in other similar jurisdictions, and the comparison with the requirements of the Rule, are as follows:

1. Arizona. The BADCT guidance "Prescriptive Criterion" does not provide specific guidance for waste rock stockpiles. The Arizona guidelines are therefore less protective than the requirements and approach of the Rule.
2. Nevada. Nevada does not have specific requirements for containment of waste rock stockpile water. The regulation is through the general requirement that: "All sources must be designed to minimize releases of contaminants into groundwater or subsurface migration pathways so that any release from the facility will not degrade waters of the State [NAC 445A.433 (1)(b)]. The Nevada regulations are less specific, and therefore likely less protective, than the requirements and approach of the Rule.

6.7 Tailings Impoundments

6.7.1 Operations

Tailings impoundments contain the ground residue of metal production from ore. The impoundments are generally constructed from the coarse fraction of the tailings themselves, or use a rock dam behind which tailings are deposited. The tailings are in general transported to the tailings impoundment as a slurry and excess water is decanted from the tailings by settlement and is pumped back to the process for re-use.

Tailings may also be handled "dry", where the excess water is removed at the mill, and the resulting moist tailings (at either paste or solid constituency) are transported by truck to the tailings facility and deposited there.

Tailings impoundments (including dry stack tailings piles [§22 A(5)]) shall meet the following requirements of the Rule [§22 A(4)] or equal[26]:

1. Setbacks: Minimum 500 feet from domestic water well or spring; minimum 1000 feet from public water supply well or spring.
2. Stormwater: Stormwater run-on shall be diverted and/or contained to minimize contact between stormwater and tailings [§22 A(4)(a)].
3. Seepage: Basal seepage shall be captured and contained through the construction of headwalls, impoundments and/or diversion structures [§22 A(4)(b)].
4. Ground water: Groundwater impacted by tailings seepage in excess of applicable standards will be captured and contained by interceptor systems [§22 A(4)(c)].

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[26] If the permittee or the department determines that the proposed facility when constructed and operated under the Rule would cause ground water to exceed applicable standards, the permittee may propose or the department may require additional controls including but not limited to a liner system [§22 A(4)(e)]

5. Dam Safety: Tailings dams shall be compliant with the requirements of the Dam Safety Bureau of the New Mexico State Engineer unless exempt [§17 C(1)(d)].

6.7.2 Monitoring

Tailings impoundments shall be monitored as follows:

1. Upgradient: 1 minimum [§28 B(5)]
2. Perimeter: Adequately monitor [§28 B(2)].
3. Downgradient: Adequately monitor [§28 B(2)].
4. Distance: As close as practicable to the proposed facility [§28 B(2)]
5. Limitation: Outside of the open pit surface drainage area [§28 B(2)].

6.7.3 Technical Evaluation

The key issue with respect to tailings dam operation is the protectiveness of the Rule-required minimum design. This can be assessed by consideration of the typical tailings storage facility in the New Mexico copper mine setting. There are two general tailings deposition locations: tailings over bedrock and tailings over alluvial aquifers; due to the constraints of tailings management, the latter has been and will continue to be more likely to be used in New Mexico.

The operational requirements of the Rule for tailings impoundment management prevents water pollution so that groundwater will meet the quality standards of Section 20.6.2.3103 NMAC at locations of present and potential future use. This conclusion is based on consideration of the protection afforded the groundwater against impact in excess of the standards during operation.

6.7.3.1 Seepage from an unlined tailings impoundments during operation

The source term for potential impact to groundwater resources from conventional tailings impoundments is seepage of tailings supernatant water from the impoundment surface during operation. The amount of water that enters the tailings mass and passes through the system is dependent on the vertical hydraulic conductivity of the tailings, and of the materials onto which they are deposited. It is observed that tailings ponds contain water when constructed by spigotting. The amount of flow through an unlined tailings pile to a free-draining foundation can be computed using Darcy's Law, as shown in Table 4 for a range of possible vertical hydraulic conductivity values.

Table 4 - Seepage flow through operating unlined tailings impoundment

Tailings slimes material:		**Fine sand**	**Silty sand**	**Sandy silt**	**Silt**	**Silty clay**	**Clay**
Hydraulic conductivity	cm/sec	10^{-3}	10^{-4}	10^{-5}	10^{-6}	10^{-7}	10^{-8}
10% finer grainsize[1]	mm	0.03	0.01	0.003	0.001	0.0003	0.0001
Hydraulic gradient	ft/ft	1	1	1	1	1	1
Flow per unit area[2]	in/yr	12,000	1,200	120	12	1.2	0.12
Area of pond	sq. mi.	1	1	1	1	1	1
Flow through base[2]	gpm	400,000	40,000	4,000	400	40	4

[1] 10% finer grainsize estimated from Hazen's Formula: D_{10} (mm) = √[K (cm/sec)], where K = hydraulic conductivity
[2] Seepage flow from Darcy's Law: Q = K I A where Q = flow, K = hydraulic conductivity, I = hydraulic gradient, and A = cross-sectional flow area.

The circulating flow for large tailings ponds are in the order of 5,000 gpm, which indicates that a loss of 4,000 gpm would render a typical 1 square mile pond close to dry, which does not occur during operation. Conversely, after operation ceases, most New Mexico tailings ponds dry up, indicating that the vertical flow rate is greater than the rate of infiltration, which is some large fraction of the 13.85 inches per year of precipitation received on average in New Mexico. Thus, a maximum infiltration rate of 12 inches per year through tailings impoundments is consistent with the operational and post-operational behavior of the impoundments.

In summary, a typical seepage loss from an operating unlined tailings impoundment in New Mexico is in the order of 12 inches per year, for a flow loss in the order of 400 gpm per square mile of pond.

6.7.3.2 Seepage from a lined tailings impoundments during operation

The source term for a tailings pond lined in the same way as is required for leach stockpiles (single 60 mil HDPE liner over a 12 inch compacted clay liner) is presented in Table 5. Two liner arrangements are considered:

1. Undrained liner. In this arrangement, the tailings are placed directly on the HDPE liner. This has the effect of not allowing significant drainage of the tailings above the liner, which remains saturated to the upper tailings surface, and causes an equivalent head on the liner.
2. Drained liner. In this arrangement, a drainage layer (usually with piping) is placed on top of the HDPE liner, and the piping passed through the liner to allow removal of water from the base of the tailings. This arrangement causes a reduced head on the liner while the drainage system is effective.

Table 5 - Seepage flow through opererating lined tailings impoundment

Liner System Type:		Undrained Liner	Drained Liner
Pile thickness	ft	100	100
Primary liner thickness	ft	0.005	0.005
Primary liner hydraulic conductivity	cm/sec	1.00E-11	1.00E-11
Head loss[1]	ft	100	10
Hydraulic gradient	ft/ft	20000	2000
Flow per unit area	in/yr	2.5	0.25
Area of pond	sq. mi.	1	1
Flow through base	gpm	82	8

[1] All head loss is assumed to occur across the HDPE liner; the small head loss across the clay liner is ignored

The result of the evaluation is that seepage loss from a typical lined tailings impoundment ranges from 0.25 inches per year and 8 gpm per square mile for a liner with an overdrain system; to 2.5 inches per year and 80 gpm/square mile for liner with no overdrain.

It is noted that there is a stability penalty for placing a liner under a tailings impoundment. The water pressure in the tailings is higher than for unlined tailings, with the result that the tailings is less stable, and less able to resist liquefaction under earthquake loading.

6.7.3.3 Control of seepage for operating unlined tailings impoundments located over alluvium

When an unlined tailings impoundment is located over alluvium, seepage flow from the stockpile readily passes into the underlying alluvium, and continues vertically downward until it reaches the existing water table, provided the vertical hydraulic conductivity of the alluvial materials is greater than the expected vertical hydraulic conductivity of the tailings, or approximately 1×10^{-6} centimeters per second as identified above. This condition is invariably met for alluvium and colluvium encountered in New Mexico, so infiltration to the water table is assured.

At the water table the flow joins the regional groundwater flow system, and flow becomes substantially horizontal, at much lower head gradient than the prior vertical flow. As the underlying material is alluvium, the carrying capacity is usually sufficiently high that the additional water from the waste rock stockpile seepage will cause little change in the saturation of the underlying aquifer, and the water levels in the aquifer beneath the stockpile will be largely unchanged. This is illustrated in Table 6, which shows the hydraulic gradient change in a one-mile wide strip of a typical New Mexico alluvial aquifer when 400 gallons per minute of seepage is introduced into it from an unlined tailings pond.

Table 6 – Flow carrying capacity of a typical New Mexico alluvial aquifer

Aquifer material		**Gravel**	**Coarse sand**	**Sand**	**Fine sand**	**Silty sand**
Hydraulic conductivity	cm/sec	1.00E+00	1.00E-01	1.00E-02	1.00E-03	1.00E-04
Aquifer Thickness[1]	ft	200	200	200	200	200
Aquifer width	ft	5280	5280	5280	5280	5280
Flow rate	gpm	400	400	400	400	400
Hydraulic gradient[2]	ft/ft	0.003%	0.03%	0.3%	3%	30%

[1] Aquifer thickness chosen to approximate relatively thin saturated alluvial section in New Mexico basin-fill aquifers

[2] Hydraulic gradient from Darcy's Law: I = Q / [K A] where Q = flow, K = hydraulic conductivity, I = hydraulic gradient, and A = flow area.

As can be seen, any aquifer with sand or coarser material can carry this flow without significant change in hydraulic gradient. New Mexico basin-fill alluvial materials are typically mostly sand and gravel, so there is generally sufficient capacity for valley aquifers to readily accommodate seepage flow of this magnitude[27,28].

During operation under the Rule any tailings pond seepage that could cause exceedance of groundwater standards at locations of present and potential future use is to be captured by the following methods:

1. Capture of surface seepage. In general, there will be no surface seepage from a tailings impoundment located over alluvium. However, any surface seepage is required to be

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[27] Bexfield, L.M., 2010, *Section 11. Conceptual Understanding and Groundwater Quality of the Basin-Fill Aquifer, Middle Rio Grande Basin, NM*, in Thiros, S.A., Bexfield, L.M., Anning, D.W., and Huntington, J.M., eds., 2010, Conceptual understanding and groundwater quality of selected basin-fill aquifers in the Southwestern United States: U.S. Geological Survey Professional Paper 1781, p. 198-218. [Exhibit 12]

[28] NMONRT, 2012. *Final Groundwater Restoration Plan for the Chino, Cobre, and Tyrone Mine Facilities*, New Mexico Office of Natural Resources Trustee, January 4, 2012. Download: www.onrt.state.nm.us. [Exhibit 13]

captured and contained by headwalls, impoundments and diversion structures [§22 A(4)(b)].

2. Capture of impacted groundwater. The Rule requires that "groundwater impacted by the tailing impoundment in excess of applicable standards shall be captured and contained [by] … interceptor systems" [§22 A(4)(c)]. This capture is generally first feasible using a pumped interceptor system in the alluvium at the toe of the tailings impoundment, as it is usually difficult or impossible to establish pumping wells in the footprint of an active tailings pile. Capture of water from alluvial aquifers is a well-established technology, and is practiced widely in the mining industry. In addition, the Rule requires that the permittee demonstrate that the capture system will be effective [§22 B(4)(d)(viii)].

Thus when the operating tailings impoundment is located over alluvium, the seepage management system of the Rule prevents water pollution so that groundwater meets the quality standards at the Rule-required monitoring wells at the toe of the unit, and therefore it will protect groundwater standards at locations of present and potential future groundwater use.

6.7.3.4 Control of seepage from waste rock stockpiles located on bedrock

When seepage exits the base of a tailings impoundment stockpile located on bedrock, it can enter the bedrock if the vertical hydraulic conductivity of the bedrock is greater than the infiltration rate. In the case of an operating unlined tailings impoundment in New Mexico, the seepage rate is expected to be in the order of 12 inches per year, as shown in Section 6.7.3.1 above. This seepage can pass by gravity flow into the underlying bedrock if the vertical hydraulic conductivity in the bedrock is greater than 1×10^{-6} centimeters per second (i.e. 12 inches per year)[29]. This condition is generally met for bedrock types encountered in New Mexico, so infiltration into the bedrock is expected.

For that portion of the flow that proceeds into the underlying materials, flow continues vertically downward until it intercepts the existing water table. At that point the flow joins the regional groundwater flow system, and flow becomes substantially horizontal, at much lower head gradient than the prior vertical flow. When the underlying material is bedrock, the carrying capacity is usually sufficiently low that the additional water will cause saturation of the underlying material back up to bedrock surface at the base of the waste rock facility, causing most of the exfiltrating water to flow through any overlying colluvium or through the lower portion of the tailings, and emerge at low points at the toe of the tailings impoundment.

Consider typical conditions beneath a one mile tailings impoundment located on bedrock. Assume, as is typically the case, that groundwater circulates in approximately the upper 3,000 feet of the bedrock, with the upper few hundred feet stress relieved and weathered, resulting in higher permeability[30]. Finally, assume that the ground and the water table both slope at 5%,

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[29] For vertical gravity flow at saturation, the vertical hydraulic gradient is unity, and Darcy's Law becomes $Q/A = q = K_v$, where Q = flow, A = area, q = flow per unit area, and K_v = vertical hydraulic conductivity.

[30] Freeze RA, Cherry JA , *Groundwater*. Prentice Hall, 1979, p.29.

typical for most side-hill slopes in mining locations in New Mexico. The bedrock groundwater flow beneath the hypothetical tailings impoundment in this system is summarized in Table 3, calculated with Darcy's Law and using typical bedrock hydraulic conductivity ranges observed in mining projects in New Mexico and world-wide.

Table 7 - Typical groundwater flow capacity of bedrock beneath a tailings impoundment

Bedrock flow zone:	**Shallow**	**Deep**	**Total**
Depth of bedrock (ft)	200	2800	3000
Width of tailings impoundment (ft)	5280	5280	5280
Hydraulic conductivity (cm/sec)(1)	10^{-4}-10^{-5}	10^{-5}-10^{-6}	~$5x10^{-6}$
Slope of water table (ft/ft)	5%	5%	5%
Flow capacity (gpm)	**25**	**34**	**59**

[1] Geometric mean of range used in Darcy flow computation

In general, most or all of the carrying capacity of the bedrock is taken up draining natural groundwater that has infiltrated into the system upgradient of the location of the tailings impoundment. When the infiltration from the operating tailings impoundment (400 gpm in the hypothetical case) is added to the upper surface of this groundwater flow system, it "floods" it, mounding the head in the system, and rejecting the excess seepage above the carrying capacity of the bedrock (between 350 gpm and 400 gpm in the hypothetical case). The rejected seepage proceeds to flow downhill in the base of the tailings, emerging at the toe of the impoundment.

It should be noted that preventing the discharge of tailings seepage from the base of the impoundment is potentially problematic for the stability of the tailings impoundment. The carrying capacity of the tailings for horizontal flow is quite limited, and significant water pressure would likely build up in the tailings, reducing the effective stress friction and the factor of safety of the tailings slopes.

During operation under the Rule any seepage that would cause exceedance of groundwater standards at locations of present and potential future use is captured by one of the following methods:

1. Capture of surface seepage. The great majority of the tailings seepage will exit the tailings impoundment at the toe of the pile. The Rule requires this surface seepage to be captured and contained by headwalls, impoundments and diversion structures [§22 A(4)(b)].
2. Capture of impacted groundwater. The Rule requires that "groundwater impacted by tailings impoundments [at point of use] in excess of applicable standards shall be captured and contained through the construction of interceptor systems" [§22 A(4)(c)]. This capture is generally not feasible in the following locations:
    a. Within the operating tailings impoundment footprint, due to lack of accessibility during operation and due to the general infeasibility of completing water wells through the tailings materials.
    b. In bedrock downgradient of the tailings impoundment, due to low permeability and ineffectiveness of extraction well systems to capture a significant proportion of the groundwater.

Accordingly, capture is in general first feasible at locations where any impacted bedrock seepage exits the bedrock, and enters alluvium, which is also where points of use are practicable, so where required, this capture is protective of groundwater use. Whatever the method of capture, the Rule also requires that the permittee demonstrates that the capture system will be effective [§22 B(4)(d)(viii)].

Thus the when the operating tailings impoundment is located over bedrock, the seepage management system of the Rule prevents water pollution so that groundwater meets the quality standards at locations of present and potential future groundwater use.

6.7.4 Other State Regulation

The containment approach to tailings impoundments in other similar jurisdictions, and the comparison with the requirements of the Rule, are as follows:

1. Arizona. The BADCT guidance "Prescriptive Criterion" for leach stockpiles specifies a composite liner consisting of a single geomembrane of at least 30 mil thickness (60 mil if HDPE) over, a minimum, twelve inches (placed in two 6-inch lifts) of 3/8 inch minus native or natural materials compacted to achieve a saturated hydraulic conductivity of no greater than 10^{-6} cm/sec.[31]. However, the guidelines state that "this design is not representative of base metal operations". The "Individual BADCT Guidance" allows an unlined tailings facility, with discharge control essentially identical to those required by the Rule[32].
2. Nevada. Containment of process fluids for tailings impoundments must utilize a system of containment equivalent to a) twelve inches of recompacted native, imported, or amended soils which have an in place recompacted coefficient of permeability of no more than 1x10-6 cm/sec; or b) competent bedrock or other geologic formations underlying the site which has been demonstrated to provide an equivalent degree of containment [NAC 445A.437]. An alternate level of containment may be allowed by the Department for all of the tailings impoundment or for a portion thereof after considering alternate containment methods. The Arizona requirements appear to be equivalent to those in the Rule, although arrived at by a somewhat different method.
3. New Mexico. New Mexico renewed the permit for Chino Mine's tailing pond 7 in 2005[33]. The conditions of the permit were substantially the same as the requirements for containment of impacted groundwater and seepage in the Rule.

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[31] ADEQ, 2004, BADCT, op.cit., p.2-43 – 2-49.

[32] ADEQ, 2004, BADCT, op.cit., p.3-50 – 3-62.

[33] NMED, 2010. *Discharge Permit Renewal and Modification, Tailings Pond 7 DP-484*. New Mexico Environment Department, January 14, 2005 [Exhibit 18]

7 EFFECTIVENESS OF POST-OPERATIONAL GROUNDWATER PROTECTION

After mine operations are completed, the minesite undergoes closure. In this section of my testimony I will examine the effectiveness of the Rule-required closure actions in achieving post-operational groundwater protection.

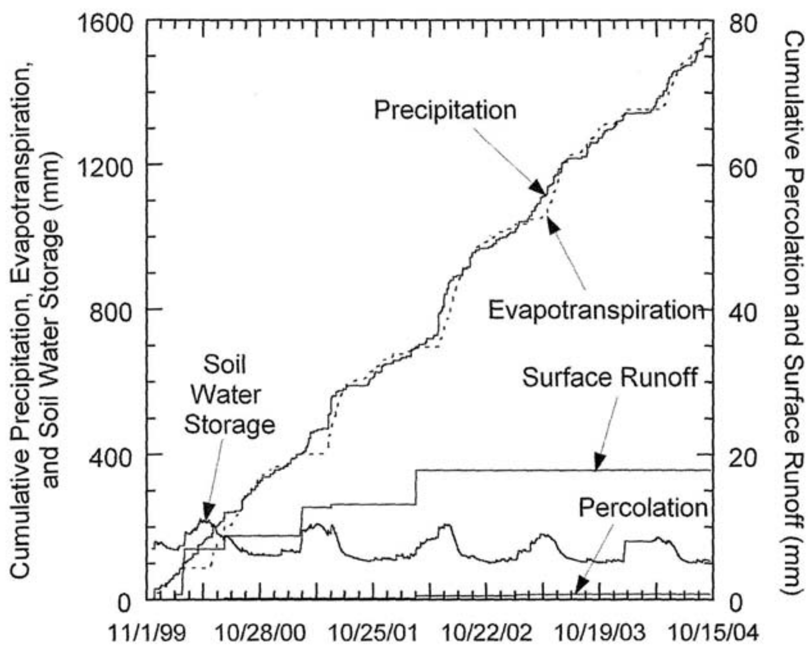
7.1 Effectiveness of store-and-release covers for seepage control

Seepage control is at the heart of the Rule's post-closure groundwater protection system by limiting discharge from the closed mine facilities to rates that protect groundwater of the state of New Mexico for potential future use as domestic and agricultural water supply and surface water recharge. This portion of my testimony examines the effectiveness of the seepage control systems that are allowed in the Rule.

7.1.1 Method of operation of Store-and-Release Covers

Store-and-release cover systems achieve seepage control by storing infiltrating precipitation water after storms, snowmelt, and sustained rainfall, and then releasing the stored water over time to the atmosphere by evaporation and plant evapotranspiration. This process is illustrated in the recorded performance of a cover in Polson, Montana[34], shown as Figure 1.

Figure 1 – Performance of Store-and-Release Cover[35]



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[34] Albright WH, Benson CH, Waugh WJ, 2010. *Water Balance Covers for Waste Containment - Principles and Practice.* ASCE Press, Reston, Virginia, 2010, Figure 7-3, p.112. [Exhibit 16]

[35] Albright et al., op.cit., Figure 7-3.

The figure shows five years of performance of a store-and-release cover, with the following features of the water balance:

1. The cumulative precipitation that impinges on the site is the driving force for the system. It increases over time, with (in this case) more precipitation in the summer than the winter.
2. A small amount of the precipitation runs off during periods of heavy or sustained precipitation, as shown cumulatively on the (expanded) right scale.
3. Water is removed from the system by evapotranspiration to the atmosphere, shown cumulatively, closely approximating precipitation, sometimes higher (when water is being released from storage), and sometimes lower (when water is being stored in the soil).
4. Percolation vertically out of the system is the residual flow, shown here at the very bottom of the figure, with the expanded right hand scale (for visibility).
5. The balance of the water (precipitation minus runoff, evapotranspiration, and percolation) reports to soil water storage; sometimes increasing it, sometimes decreasing it, depending mostly on whether it's raining. Storage is shown as the oscillating trace at the base of the figure.

In this case, the overall performance of the cover is as follows, on an annual basis:

- Precipitation: 15 inches/year (349 mm/year)
- Active Soil Storage: 4 inches of water (100 mm)
- Percolation: 0.01 inches/year (0.2 mm/year)

7.1.2 Rule-Required Store-and-Release Covers

The Rule requires the following design for all store-and-release covers:

Material: Earthen, sustain plant growth, erosion resistant [§33 F(1)].

Thickness: Minimum 36 inches [§33 F(1)].

Storage: Store water within the fine fraction the greater of [§33 F(2)]:
≥95% of long-term average winter precipitation (Dec, Jan and Feb)
≥35% of long-term average summer precipitation (Jun, Jul, Aug)

7.1.3 Cover Thickness and Material

The storage specification in the Rule requires sufficient water storage to intercept most of the snowmelt and summer storm water that impinges on the site. Storage is required for essentially all the winter precipitation water, as little of it is lost to evapotranspiration. Storage is required for approximately 1/3 of the summer precipitation, as in New Mexico the summer heat evaporates and transpires water rapidly, emptying the storage more rapidly than in winter.

Typical values of the water storage requirement for typical copper mining areas of New Mexico are presented in Table 8. As can be seen, the winter period is the critical storage requirement, requiring 2.6 inches of storage to accommodate 95% of the average long-term winter precipitation.

Table 8 – Store-and-Release Cover Storage Requirements

Weather Station Location:	**Fort Bayard**	**Red River**	**Hills-boro**	**Average**	**Storage (%)**	**Storage (in)**
Winter = Dec., Jan., and Feb.	**2.71**	**3.55**	**1.96**	**2.74**	**95%**	**2.60**
Spring = Mar., Apr., and May	1.6	5.35	1.22	2.72		
Summer = Jun., Jul., and Aug.	7.25	7.52	5.43	6.73	35%	2.36
Fall = Sep., Oct., and Nov.	4.05	4.53	3.8	4.13		
Average annual precipitation	15.61	20.95	12.41	16.32		
Period of Record	1897-2011	1906-2012	1893-2012	114 yr		

The cover thickness required to provide that storage depends on the type of material that the cover is made of. The general choices are summarized in Table 9, using estimates of the water contents at field capacity (gravity drained water content) and wilting point (water content below which the soil will no longer give up water to plants)[36].

Table 9 - Soil Cover Thickness to Provide Required Storage

Cover Material[1]:	**Loamy Sand**	**Silty Sand & Gravel**	**Coarse Sand & Gravel**	**Rationale**
Fine fraction storage (inches)	2.6	2.6	2.6	Rule requirement
Volumetric water content (sat)	40%	40%	40%	Estimate, from ACAP
Field capacity water content	30%	20%	10%	Estimate, from ACAP
Wilting point water content	10%	7.5%	5%	Estimate, from ACAP
Storage available by volume	20%	12.5%	5%	FC - WP
Thickness required (inches)	13	21	52	Required storage (in) / available storage (%)

[1] Cover material descriptions relate to particle sizing; the material may derive from alluvium or crushed rock or a combination of both.

Based on this assessment, approximately 21 inches of material no coarser than silty sand and gravel is needed to provide the required water storage for typical New Mexico copper mine covers. The cover also requires some admixture of coarser material to ensure erosion protection. The combined material is consistent with the Rule's minimum requirement for 36 inches minimum total cover thickness.

7.1.4 Effectiveness of Store-and-Release Covers in New Mexico's Copper Mines

The extent to which infiltrating water will pass through the Rule's store-and-release cover can be most readily evaluated by reference to experience with similar covers. Performance of store-and-release covers has been evaluated in detail by the U.S. Environmental Protection Agency's Alternative Cover Assessment Program ("ACAP")[37]. This program conducted five-year tests of a total of 15 heavily instrumented "water balance covers", of which 11 are located in the western US (Figure 2). The results of the western US tests in this program are summarized in Table 10.

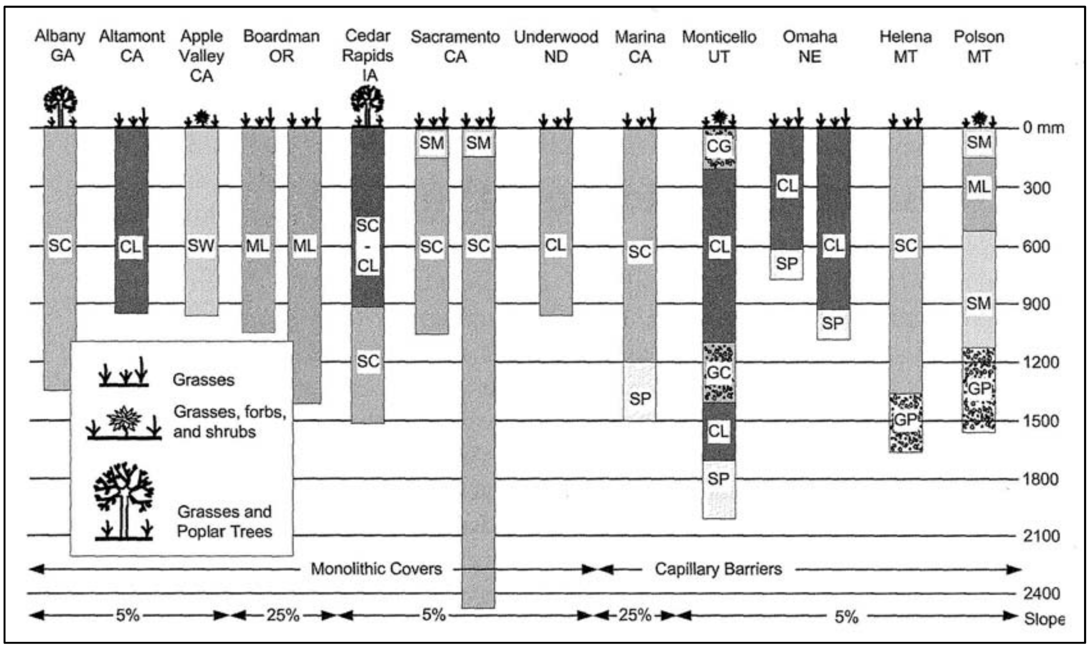
[36] Albright et al., op.cit.

[37] Albright et al., op. cit.

Figure 2 - Locations of the ACAP Field Sites[38]

Figure 7-2. Locations of the ACAP field sites.

Figure 3 – Cover Profiles Evaluated in ACAP



38 Albright et.al., op.cit., Figure 7-2.

Table 10 - Western US ACAP Cover Percolation Test Results[39]

	Site Location	Boardman OR	Boardman OR	Helena MT	Polson MT	Apple Valley CA	Monticello UT	Sacramento CA	Underwood ND	Altamont CA	Sacramento CA	Monterey CA
Cover Description	Cover Type	Monolithic	Monolithic	Capillary Barrier	Capillary Barrier	Monolithic	Capillary Barrier	Monolithic	Monolithic	Monolithic	Monolithic	Capillary Barrier
	Cover Depth (mm)	1250	1560	1350	1150	1000	1700	2500	950	1000	1070	1500
	Cover Soil Type	Silt	Silt	Clayey Sand	Silty Sand	Sand	Clay	Silty Sand	Clay	Clay	Silty Sand	Clayey Sand
	Capillary Barrier Thickness (mm)	--	--	200	450	--	300	--	--	--	--	300
	Capillary Barrier Soil Type	--	--	Gravel	Gravel	--	Sand	--	--	--	--	Sand
	Side Slope (%)	25%	25%	5%	5%	5%	5%	5%	5%	5%	5%	25%
	Vegetative Cover Type	Grass	Grass	Grass	Shrubs grass	Shrubs grass	Shrubs grass	Grass	Grass	Grass	Grass	Grass
Climate	Long Term Average Precipitation (mm/yr)	225	225	312	380	119	385	434	442	358	434	466
	Precipitation/ PET	0.23	0.23	0.44	0.58	0.06	0.34	0.33	0.47	0.31	0.33	0.46
	Climate Description	Arid	Arid	Semi-arid	Sub-humid	Arid	Semi-arid	Semi-arid	Semi-arid	Semi-arid	Semi-arid	Semi-arid
	Average Precipitation During Test (mm/yr)	181	181	273	349	172	410	422	420	378	422	463
Percolation	**Average Annual Percolation (mm/yr)**	**0**	**0**	**0**	**0.2**	**0.5**	**0.7**	**2.7**	**7.2**	**44.8**	**54.8**	**63.3**
	Average Annual Percolation (% precip)	**0%**	**0%**	**0%**	**0%**	**0.3%**	**0.2%**	**0.6%**	**0.9%**	**11.8%**	**13.0%**	**13.7%**

[39] Adapted from Albright et al., op.cit., Table 7-1 Summary of Climatic Conditions and Percolation Rates for ACAP WB Covers, and Figure 7-1 WB cover profiles evaluated in ACAP.

Of the 11 western sites investigated, a total of 8 sites experienced seepage through the cover of less than 0.25 inch per year. These sites had the following characteristics:

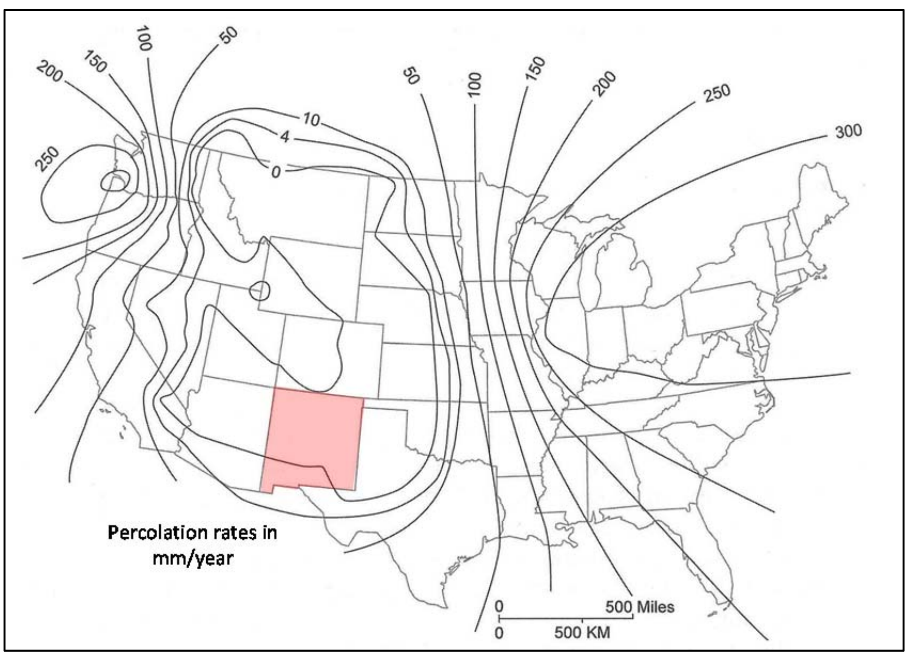
1. All were in locations where the total precipitation was less than 20 inches per year (500 mm per year).
2. All covers were 36 inches thick or greater.
3. All covers had substantial proportion of fine-grained material.
4. No covers had trees growing on them.
5. The presence of capillary barriers in some covers did not appear to affect performance.

Three of the western US sites showed significant seepage through the cover, in the order of 1.75 inches per year to 2.5 inches per year, representing approximately 13% of the incident precipitation. These sites had the following characteristics in common:

1. They were all in central California, which is characterized by receiving essentially all the annual precipitation in the cool winter months of December through February, when there is little evaporation or evapotranspiration, and little or no surface freezing to prevent ingress of precipitation to the cover.
2. They were 40 to 60 inches thick, so meet the thickness requirements of the Rule.
3. They all had significant fine-grained material within the covers, but would likely not have had sufficient storage capacity to hold the winter precipitation, which was when all of the seepage was recorded.

The results of the nation-wide testing of store-and-release covers have been generalized into a map presenting potential infiltration rates, presented here as Figure 4.

Figure 4 - Potential Percolation Rates for Store-and-Release Covers[40]



[40] Albright et al, op.cit., Figure 7-8, p.119, New Mexico shading and percolation rate units added for clarity.

From this figure most of New Mexico falls within the zero infiltration zone for store-and-release covers, with the southern portion of the state ranging up to approximately 0.1 inches per year (3 mm/year) seepage through store-and-release covers.

Based on all of these results, it is concluded that store-and-release covers applied to the top and sides of waste rock stockpiles provide good protection against infiltration in arid and semi-arid environments. When constructed in New Mexico in accordance with the requirements of the Rule, store-and-release covers will limit flow through waste rock piles to less than 0.2 inches per year (5 millimeters per year).

7.1.5 Cover Thickness

In one location tested by ACAP (Sacramento, CA) a 40 inch thick silty sand cover allowed 2.2 inches per year infiltration, while a companion 100 inch thick cover constructed at the same location with the same material allowed only 0.1 inches per year infiltration[41]. This paring offers a useful opportunity to evaluate the appropriateness of the Rule's thickness requirement, and the method of its computation.

The thickness computation has been conducted for each of the two covers, with the results shown in Table 11.

Table 11 - Soil Cover Thickness – Sacramento ACAP Test[42]

Parameter	1 m Cover	2.5 m Cover	Notes
Thickness of cover (inches)	40	100	From ACAP
Volumetric water content (sat)	40%	40%	Estimate, based on ACAP
Field capacity water content	20%	20%	Estimate, based on soil type (silty clayey sand)
Wilting point water content	7.5%	7.5%	Estimate, based on soil type (silty clayey sand)
Storage available	12.5%	12.5%	Field capacity WC – Wilting point WC
Storage capacity (inches)	5.0	12.5	Cover thickness (in) * Storage capacity
Winter precipitation (inches)	9.1		Sacramento climatic data for Dec, Jan, Feb[43]
Cover water storage capacity as a % of winter precipitation	55%	137%	Storage capacity (in) / Winter precipitation (in)
Seepage observed (inches/year)	2.2	0.1	From ACAP

A soil will store water up to the field capacity moisture content, which is the moisture content which occurs under gravity drainage. The soil will give up water down to the wilting point, below which neither plant transpiration, nor evaporation, can remove significant moisture from the soil. The 40 inch thick cover had storage capacity to accommodate and hold only 55% of the winter wet season precipitation at this site until it could be evapotranspired to the atmosphere

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[41] Albright et al., 2010, op.cit., Table 7-1, p.111, and Table 10 of this report.

[42] Data from Albright et al., 2010, op.cit.

[43] Sacramento CA climate data from http://www.climate-zone.com/climate/united-states/california/sacramento/ on February 17, 2013.

in the spring and summer. This was insufficient, so the cover saturated during the winter precipitation period, and an average of more than 2 inches per year of percolation occurred through the cover. However, the 100 inch cover had storage capacity to accommodate 137% of the entire winter precipitation, and stored it all without saturating, allowing removal of the water by evapotranspiration the following spring and summer, and limiting the average percolation to 0.1 inches per year.

This example verifies the method of determining the thickness requirement for the Rule.

7.2 Post-Closure Groundwater Protection at Leached Rock, Waste Rock, and Tailings Stockpiles

7.2.1 Closure

Under the Rule, all Copper Mine leached rock, waste rock, and tailings stockpiles will be closed consistent with the following requirements:

1. Slope stability. At closure, tailing impoundments (not regulated by the New Mexico State Engineer), leach piles, and waste rock piles shall be constructed to ensure the long-term stability of the structure, as expressed by the following factors of safety [§33 B]:

Long-term static factor of safety for critical structures:	1.5 or greater
Long-term static factor of safety for non-critical structures:	1.3 or greater
Pseudostatic factor of safety under earthquake loading:	1.1 or greater

2. Surface re-grading. Surfaces of all stockpiles shall be re-graded to a stable configuration that minimizes ponding and promotes the conveyance of surface water off the facility, as follows: [§33 C]

Top surfaces:	Tailings grade ≥0.5% [§33 C(1)]
	Leach stockpiles grade ≥1% [§33 C(2)]
	Waste rock stockpiles grade ≥1% [§33 C(2)]
Outslopes:	Interbench slope no steeper than 3H:1V or equal[44] [§33 C(3)].
Slope lengths:	<300 ft. for 4.0:1, <200 ft. for 3:1, <175 ft. for 2.5:1 [§33 C(4)][45].

3. Cover system. At closure a cover system will be constructed and maintained on potentially contaminating material storage piles as follows:

Type of cover:	Store-and-release earthen cover system
Application:	All surfaces for piles outside OPSDA [§33 F].
	Top surfaces only within OPSDA [§33 F].
Thickness:	36 inches [§33 F].

[44] Alternative slope gradients may be allowed within an open pit surface drainage area, or if the permittee provides information showing that the cover performance objectives in … §33 F … are met and the exception is approved by the department.

[45] Supported alternatives may be proposed.

Material:	Earthen, capable of sustaining plant growth, erosion resistant [§33 F(1)].
Storage:	Limit net-percolation by having the capacity to store within the fine fraction of the greater of [§33 F(2)]: Winter (Dec, Jan, Feb): ≥95% of long-term average precipitation Summer (Jun, Jul, Aug): ≥35% of long-term average precipitation.
Modification:	Cover design criteria may be modified if equal [§33 F(3)(a),(b)].

4. Closure water management and treatment. Water management and treatment will be required to manage water generated after closure that is not of sufficient quality to discharge [§33 H].
5. Closure monitoring and maintenance. During closure monitoring shall continue, with approved modifications as needed [§33 L].

7.2.2 Post-Closure Requirements

The post-closure period at a Copper Mine Facility unit shall commence upon completion and approval of regrading, covering, seeding, and construction of unit closure elements [§35]. The requirements are as follows:

1. Seepage interceptor system inspections. Quarterly inspections, annual evaluations, and maintenance of all seepage interceptor systems to ensure that the systems are performing to be protective of ground water quality [§35 A].
2. Water quality monitoring and reporting. Water quality monitoring and reporting will continue for all units during the post-closure period [§35 B]. Application for reduction in monitor well coverage may be made for monitoring wells where concentrations have been below the applicable standards for eight consecutive quarters [§35 B].
3. Reclamation monitoring, maintenance, and inspections. Post-closure reclamation monitoring, maintenance and inspections shall be conducted of vegetation, erosion, subsidence, slope instability, ponding, cover, drainage, and storm damage [§35 C(2)].
4. Cover maintenance. Maintenance shall be performed on all areas where a cover system was installed, including associated drainage channels and diversion structures [§35 C(4)].
5. Other inspection and maintenance. Inspection and maintenance shall be conducted on all structures, facilities, and equipment the failure of which may impact ground water quality [§35 C(5)].
6. Implementation of water management and treatment plan. The water management and treatment required for closure will be maintained during the post-closure period [§35 C(6)].
7. Post-closure Contingencies. The contingency requirements of 20.6.7.30 NMAC apply to any deficiencies in the implemented closure systems discovered during post-closure monitoring and inspections [§35 E].

7.2.3 Post-closure Groundwater Protection at Mine Waste Stockpiles

Mine waste stockpiles containing waste rock, leached ore, and tailings will remain at the minesite after closure of the copper mine facility. Closure of these features under the Rule requires re-grading to ecologically sustainable and free-draining slopes, and placement of a 36-inch thick earthen store-and-release cover over the regraded surfaces of the pile. This portion of my testimony provides a demonstration that this closure will prevent water pollution so that groundwater meets the quality standards of Section 20.6.2.3103 NMAC at locations of present and potential future use.

7.2.3.1 Post-closure seepage through closed copper mine waste stockpiles

Post-closure seepage of precipitation water through closed copper mine waste stockpiles is limited under the Rule by the required store-and-release cover. This cover method limits the infiltration of precipitation water to the closed copper mine waste stockpiles to less than 0.3 inches per year, which is equivalent to a seepage flow of less than 10 gallons per minute per square mile of stockpile (Table 12).

Table 12 - Post-closure seepage from copper mine waste material stockpiles

Method of seepage control:		**Store-and-Release Cover**	**Drained HDPE Liner**	**Undrained HDPE Liner**
Seepage flow per unit area	in/yr	<0.2[1]	0.25[2]	2.5[2]
Hydraulic conductivity needed for infiltration[3]	cm/sec	>2 x 10^{-8}	>2 x 10^{-8}	>2 x 10^{-7}
Area of stockpile	sq. mi.	1	1	1
Flow through base	gpm	<6	8	83

[1] From Section 7.1.4 above
[2] From Table 5 above
[3] The hydraulic conductivity of the underlying material has to be greater than these values to allow infiltration of the seepage flow.

The post-closure seepage from closed copper mine waste stockpiles achieved by the use of store-and-release covers is equal to or better than that achievable by any other demonstrated and available technology[46]. The best alternative practicable seepage control technology is installation of a synthetic liner, with pressure relief over-drains. This largely prevents discharge of seepage from the stockpile, with any infiltration to the pile surface being collected by the drainage system, or in the absence of an effective drainage system, discharge to the toe of the stockpile above the liner. As shown in Table 12, the store-and-release cover system is in general equal to or better than underliner systems in controlling seepage from closed copper mine waste material stockpiles.

7.2.3.2 Protection of groundwater from seepage through closed copper mine waste stockpiles

The seepage water that exits a stockpile will pass into the subsurface material beneath the pile provided that material has a vertical hydraulic conductivity of more than 0.2 inches per year (2 x 10^{-8} centimeters per second). The vertical hydraulic conductivity of all alluvial and bedrock materials in New Mexico's copper mining areas significantly exceed these values, so infiltration into the underlying material is assured.

[46] For demonstrated and available technologies, see BADCT Manual, ADEQ (2004), op.cit.

Upon entry of the stockpile seepage to the subsurface, it proceeds downward until it encounters the water table. At this point the seepage mixes with the groundwater in the upper portion of the saturated material beneath the stockpile. The mixed groundwater then flows with the natural groundwater until it emerges from beneath the closed waste stockpile, which is the first location at which the water will be available for extraction for present and potential future use. The underlying bedrock or alluvial groundwater system will have the capacity to accommodate this flow. This follows from consideration of the ability of the underlying material to accommodate the natural infiltration prior to construction of the waste stockpile. The natural infiltration of precipitation in the US west for areas with 12 to 15 inches of annual precipitation is approximately 7% of the total precipitation, or 1 inch per year[47]. Thus the infiltration to the groundwater system in the footprint of the stockpile after closure is one third of the flow than infiltrated prior to construction of the stockpile, and will be comfortably accommodated within the flow system.

The quality of the blended groundwater at this point of first access for domestic and agricultural use can be estimated by consideration of sulfate, which is present in essentially all copper mine stockpile water at concentrations in excess of the 600 mg/L standard of 26.6.2.3013 NMAC for domestic water supply, due to atmospheric oxidation of pyrite and other sulfides present in the stockpile materials. At source in the stockpile material, it is reasonable to expect that sulfate is present at concentrations up to gypsum solubility, which in oxic systems with abundant calcium and magnesium is approximately 1,450 mg/L[48]. The result of mixing of this source material with natural groundwater under typical groundwater systems beneath copper mine waste material stockpiles is presented in Table 13.

Table 13 - Computation of groundwater underflow required to meet sulfate groundwater standards downgradient of a closed copper mine waste stockpile

Computation	Value	Unit	Basis
Seepage rate through waste stockpile	0.30	in/yr	Store-and-release seepage evaluation
Area of waste stockpile	1.00	sq. mi.	Nominal waste material stockpile area
Seepage from base of waste stockpile	10	gpm	Flow through store-and-release cover
Sulfate concentration in seepage	1,450	mg/L	Gypsum solubility (Azimi et al, 2007)
Sulfate flux in waste stockpile seepage	173	lb/day	Flux = flow x concentration
Sulfate domestic water supply standard	600	mg/L	Standard from 26.6.2.3103 B(7) NMAC
Total flow to meet sulfate standard	24	gpm	Flow = Flux / Concentration
Upgradient flow required to meet sulfate standard	14	gpm	Upgradient flow = Total flow - stockpile seepage
Natural infiltration rate in upgradient area	1	in/yr	Maxey & Eakin value for 13.85 in/year precipitation
Upgradient infiltration area required to meet sulfate standard	0.43	sq. mi.	Area = Flow / infiltration rate

[47] Maxey GB and Eakin TE, 1949. Ground Water in White River Valley, White Pine, Nye, and Lincoln Counties, Nevada. Water Resources Bulletin No. 8, State of Nevada Office of the State Engineer, 1949, p.40. Download from http://images.water.nv.gov/images/publications/water%20resources%20bulletins/Bulletin8.pdf. [Exhibit 14]

[48] Azimi G, Papangelakis VG, J.E. Dutrizac JE, 2007. Modelling of calcium sulphate solubility in concentrated multi-component sulphate solutions. *Fluid Phase Equilibria* 260 (2007) 300–315. [Exhibit 15]

The finding the evaluation in Table 13 is that post-closure groundwater protection requires upgradient underflow from an infiltration area one half the area of the stockpile. This is almost always available, which demonstrates that the store-and-release closure technique is generally protective of groundwater, even in the most sensitive location at the downgradient toe of the stockpile.

7.3 Post-closure groundwater protection at open pit copper mines

7.3.1 <u>Closure</u>

At closure, water management in open pits will minimize the potential to cause an exceedance of applicable water quality standards using the following methods [§33 D]:

1. If, after closure, the pit will form an evaporative sink, the ground water quality standards of 26.6.2.3103 NMAC do not apply within the area of open pit hydrologic containment [§33 D(1)].
2. If, after closure, water within the pit is predicted to flow from the open pit into ground water and the discharge from an open pit may cause an exceedance of applicable standards at monitoring well locations, then the open pit shall be considered a flow-through pit and the open pit water quality must meet ground water standards of 20.6.2.3103 NMAC, or the open pit must be pumped in order to create an area of open pit hydrologic containment. [§33 D(2)].

7.3.2 <u>Post-closure groundwater protection</u>

Post-closure protection of groundwater is achieved by making the closed open pit a groundwater sink, either by evaporation or by pumping. This protection will be effective.

7.4 Post-closure groundwater protection for other copper mine units

7.4.1 <u>Closure</u>

All other copper mine units except leach stockpiles, waste rock stockpiles, tailings piles, and open pits will be closed by the following general steps [§33 K]:

1. <u>Site cleanup.</u> Any materials containing water contaminants that may cause an exceedance of the applicable standards shall be removed or disposed of.
2. <u>Cover.</u> The areas will be characterized for the presence of any remaining potential water contaminants. If water contaminants are present that may cause a groundwater exceedance of applicable standards, the area shall be covered with a 36-inch thick store-and-release cover.

7.4.2 <u>Technical Evaluation</u>

Closure of the remaining copper mine units by removal or covering of materials containing materials with the potential to cause a groundwater exceedence of applicable standards will be protective of the all ground water of the state of New Mexico for present and potential future use as domestic and agricultural water supply and surface water recharge.

7.4.3 Other State Regulation

The containment approach for closure of copper mine units in other similar jurisdictions, and the comparison with the requirements of the Rule, are as follows:

1. Arizona. The BADCT guidance "Prescriptive Criterion" for closure of mine units typically specifies fluid removal, regrading, and revegetation. The requirements for tailings piles are typical: "At closure, the Tailing Impoundment site will be stabilized and allowed to dry to permit safe access by heavy equipment. The surface will then be recontoured to eliminate ponding and limit infiltration utilizing an appropriately designed cover system."[49]. The requirements are similar to, but less protective than the Rule.
2. Nevada. Methods of permanent closure are not specified in Nevada's regulations [NAC 445A.447]. They are therefore less prescriptive than the Rule.
3. New Mexico. New Mexico issued DP-1340, the discharge permit for closure for the Chino mine, in 2003[50]. The renewed the permit for Chino Mine's tailing pond 7 in 2005. The conditions of the permit included regrading of top surfaces of waste ore and leach ore stockpiles at 1/2 % slope, side slopes at 2½:1; 2 feet of cover on the tailing impoundment; and no reclamation within the open pit. These permit conditions were less protective than the requirements of the Rule.

[49] ADEQ, 2004, BADCT, op.cit., p.2-49.

[50] NMED, 2003. *Supplemental Discharge Permit for Closure, Chino Mines Company, DP-1340.* New Mexico Environment Department, February 24, 2003

8 CERTIFICATION

I, Adrian Brown, do hereby certify that I prepared the testimony provided in this report, and that the work reported herein was performed to normal standards of professional care.

Signed and sealed this 22nd Day of February, 2013

Adrian Brown, P.E.

New Mexico Professional Engineer #12455