ARIZONA MINING GUIDANCE MANUAL BADCT

ADEQ
Arizona Department of Environmental Quality

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Publication # TB 04-01

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ARIZONA MINING BADCT GUIDANCE MANUAL

Aquifer Protection Program

ACKNOWLEDGMENTS

The publication of Arizona's new mining BADCT (Best Available Demonstrated Control Technology) document represents a milestone in protecting groundwater under the state's Aquifer Protection Permit (APP) program. Its successful completion combined the efforts of ADEQ staff and members of the mining community in an unprecedented cooperative venture to develop guidance for protecting groundwater for future uses. ADEQ is greatly indebted to the "Small BADCT Committee" for the thousands of hours its members invested in the preceding 18 months to produce this guidance manual. Without their patience, cooperation and perseverance, this project could not have been completed.

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This document also greatly benefited from an independent technical review performed by TRC Environmental Solutions, Inc., lead by Dr. Ian Hutchison. Dr. Hutchison, along with Dr. Richard D. Ellison, edited "Mine Waste Management," a publication sponsored by the California Mining Association. Drs. Hutchison and Ellison are internationally recognized water quality management experts and designers of mine waste management units, as well as authorities in developing mine waste regulations appropriate to those issues. The technical editorial team consisted of:

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USE OF MANUAL

At a minimum, readers are encouraged to read the following sections:

- Introduction
- Part 1 - General BADCT Information

Thereafter, if they intend to submit a *Prescriptive BADCT* design they should review:

- Part 2 - Prescriptive BADCT Criteria
- Section 2.1 - Introduction
- The sections that apply to their facilities selected from 2.2 to 2.5

If they intend to submit an *Individual BADCT* design they should review:

- Part 3 - Individual BADCT Guidance
- Section 3.1 - Introduction
- The sections that apply to their facilities selected from 3.2 to 3.6.

The Appendices are available for further detailed review. The more important are:

- Appendix B: Solution Ore and Waste Characterization
- Appendix C: Liner Design, Principals and Practice
- Appendix E: Engineering Design Guidance

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INTRODUCTION

INTRODUCTION

Purpose and Scope

This guidance manual describes the process that an Aquifer Protection Permit (APP) applicant should follow in selecting the Best Available Demonstrated Control Technology (BADCT) for a specific mining facility[(1)] and site[(1)] in accordance with Arizona Revised Statute (A.R.S) 49-243.B.1.

This statute requires all permitted facilities to utilize BADCT in their design, construction and operation while considering various factors depending on whether the facility is new or existing. The requirements of BADCT are met, according to A.R.S. 49-243.B.1, if it is demonstrated:

> "*That the facility will be so designed, constructed and operated as to ensure the greatest degree of discharge reduction achievable through application of the best available demonstrated control technology, processes, operating methods or other alternatives, including, where practicable, a technology permitting no discharge of pollutants. In determining best available demonstrated control technology, processes, operating methods or other alternatives the director shall take into account site specific hydrologic and geologic characteristics and other environmental factors, the opportunity for water conservation or augmentation and economic impacts of the use of alternative technologies, processes or operating methods on an industry-wide basis. However, a discharge reduction to an aquifer achievable solely by means of site specific characteristics does not, in itself, constitute compliance with this paragraph. In addition, the director shall consider the following factors for existing facilities:*
>
> *(a) Toxicity, concentrations and quantities of discharge likely to reach an aquifer from various types of control technologies.*
> *(b) The total costs of the application of the technology in relation to the discharge reduction to be achieved from such application.*
> *(c) The age of equipment and facilities involved.*
> *(d) The industrial and control process employed.*
> *(e) The engineering aspects of the application of various types of control techniques.*
> *(f) Process changes.*
> *(g) Non-water quality environmental impacts.*
> *(h) The extent to which water available for beneficial uses will be conserved by a particular type of control technology."*

Arizona Administrative Code (A.A.C.) R18-9-A202(A)(5) requires that an application for an APP include a description of the BADCT to be employed at the facility. The procedures and information presented in this guidance manual are intended for use in determining the appropriate BADCT, and to assist the applicant's development and the Arizona Department of Environmental Quality's (ADEQ's) review of permit applications.

Demonstrating that a facility will be designed, constructed, and operated in accordance with BADCT requirements is one of five demonstrations required for obtaining an APP permit. Other required demonstrations include:

- The facility will not cause or contribute to an exceedance of Aquifer Water Quality Standards (AWQS) at the point of compliance or, if AWQS for a pollutant has been exceeded in an aquifer, that no additional degradation will occur (A.A.C. R18-9-A202(A)(8)(a and b));
- The person applying for the APP is technically capable of carrying out the conditions of the permit (A.A.C. R18-9-A202(B));
- The person applying for the APP is financially capable of constructing, operating, closing, and assuring proper post-closure care of the facility (A.A.C. R18-9-A203); and
- The facility complies with applicable municipal or county zoning ordinances and regulations (A.A.C. R18-9-A201(A)(2)(c)).

The above four demonstrations are outside the scope of BADCT and are not further addressed. Additional information on these demonstrations is available from the referenced rules and statutes, and the ADEQ's "Aquifer Protection Permits Application Guidance Manual." The ADEQ will use both this "Mining BADCT Guidance Manual" and the "Aquifer Protection Permits Application Guidance Manual" to evaluate APP applications. In the event of an inconsistency between this manual and applicable rules and/or statutes, provisions from rules and/or statutes will prevail.

The "Aquifer Protection Permits Application Guidance Manual" provides procedures for pre-application meetings and coordination between the ADEQ and the applicant, at the applicant's request. This early coordination is strongly encouraged by ADEQ to provide assurance that the applicant's efforts are focused on relevant issues and necessary data collection, including those requirements related to the determination of appropriate BADCT.

BADCT Selection Process Overview

To achieve BADCT, mining facility owners and operators should use demonstrated discharge control elements utilized on an industry wide basis to limit or, where practicable, eliminate discharge to aquifers. When considering technologies, processes, operating methods and other alternatives for purposes of demonstrating BADCT, a facility must be evaluated in terms of 1) siting, 2) design, construction, and operation, and 3) closure/post-closure. A range of considerations must be taken into account in demonstrating BADCT for a facility, including characteristics, water conservation and augmentation, and economic impacts associated with the implementation of the various design elements being considered.

Key concepts reflected in this manual regarding determining BADCT for a facility are that:

- BADCT must be determined on a site specific basis by evaluating the degree that alternative discharge control systems minimize the addition of pollutants to the protected aquifer;
- Negotiation between the applicant and ADEQ is usually necessary because of subjective judgments inherent in some BADCT analyses. This means that no single technology or group of technologies can be mandated as appropriate for all discharge control systems. Rather, multiple DCTs (Demonstrated Control Technologies) may be appropriately used to arrive at a BADCT design for a specific facility at a given site. Then, based on a facility's status as new or existing, the criteria described in A.R.S. 49-243.B.1 must be applied to that particular site to determine which DCTs are appropriate for that facility. It is, however, important to note that the DCTs presented in this manual are simply alternatives which may or may not be required at any specific facility; and
- Monitoring is generally not regarded as part of the BADCT design, unless it is performed as a specific feedback mechanism to adjust the design or operational aspects of the facility. The reader is referred to the "Aquifer Protection Permits Application Guidance Manual" for further discussion on monitoring.

A mining APP applicant may choose between two general approaches to demonstrate BADCT:

- Prescriptive BADCT criteria (provided the criteria have been developed and are included in this manual); or
- Individual BADCT criteria.

Either approach has merit and may be applied to different facilities at a given site. Only one of the approaches can be applied to a specific facility.

The following sections describe the general processes for developing a BADCT demonstration for a mining facility.

How To Use This Manual

The APP applicant should use this manual as guidance in developing BADCT for a mining facility for the purposes of fulfilling the application requirements in A.A.C. R18-9-A202(A)(5), and demonstrating compliance with A.R.S. 49-243.B.1. If any questions arise, do not hesitate to contact ADEQ Aquifer Protection Program. This manual will also be used by ADEQ personnel to review BADCT demonstrations and to draft permits.

This guidance manual is subdivided into four parts, each containing several sections to assist the applicant in selecting the best route to determining BADCT. The General BADCT Information

described in Part 1 should be read first, because the principles discussed apply to whichever process the applicant chooses to comply with the BADCT requirements.

After reading Part 1, and deciding which BADCT process to use, read Part 2 if you are using the Prescriptive BADCT process, or read Part 3 if you are using the Individual BADCT process.

Part 1, Section 1.1, broadly discusses the two BADCT processes which are available to the applicant; namely, the "Prescriptive" and "Individual" processes. The "Prescriptive" process is a prescribed approach that utilizes pre-approved DCTs and design criteria to obtain an APP permit, largely independent of site specific conditions. It should not be confused with "Presumptive" BADCT (as defined in A.R.S. 49-243.01). Pursuant to A.R.S. 49-243.01.A, the Director may only establish Presumptive BADCT by rule. The "Individual" process, on the other hand, is performance based, and allows the applicant to select from all available DCTs that constitute BADCT. This process considers site specific characteristics, operational controls, and other DCTs. The "Individual" process allows designs to be tailored to a specific facility and site, and allows for the distinction between BADCT for new and existing facilities.

Part 1, Section 1.2, describes how site, technical and economic considerations are applied, on an industry-wide basis, to a BADCT analysis for a specific facility, with discussions of waste types, process solution characteristics, water resource values, climatic conditions, site factors and passive containment. Such factors may affect the BADCT selection for a facility seeking an APP permit.

Part 2 discusses how to select control technologies for the Prescriptive BADCT process that results in a conservative BADCT, largely independent of its site specific characteristics. Part 2 contains individual sections for the different types of mining facilities (e.g., heap leach pads, process solution ponds) for which Prescriptive BADCT criteria have been developed. These sections have been prepared in a stand-alone format, each intended for use in conjunction with Part 1. For example, if information is required for applying Prescriptive BADCT criteria to a heap leach pad, the necessary information is contained within Part 1 and Section 2.4, and the other sections in Part 2 do not need to be consulted. Prescriptive BADCT criteria have been developed for the following types of mining facilities:

- Non-Storm Water Ponds (Section 2.2)
- Process Solution Ponds (Section 2.3)
- Heap Leach Pads (Section 2.4)
- Tailing Impoundments (Section 2.5)

Part 3 identifies the specific control strategies or designs that may be used for individual BADCT for new and existing facilities. Discharge control strategies are discussed in individual sections for each mine facility type (e.g., heap leach pads, tailing impoundments, etc.). These sections have also been prepared in a stand-alone format, each intended for use in conjunction with Part 1. For example, if information for applying individual BADCT to a heap leach pad is needed, the necessary information is contained within Part 1, and Section 3.2, and the other sections in Part 3 are not needed. This manual addresses individual BADCT development for the following types of mining facilities:

- Heap Leach Pads (Section 3.2)
- Dump Leaching Facilities (Section 3.3)
- In Situ Leaching Facilities (Section 3.4)
- Tailing Impoundments (Section 3.5)
- Surface Ponds (Section 3.6)

The fourth part of the manual is the appendices. These are intended as supplementary information in developing a BADCT demonstration. Appendix A (Comparison of Copper Leaching Facilities) discusses and compares the principal types of copper leaching methods practiced in the United States. Appendix B (Solution, Ore and Waste Characterization) provides guidance on the rationale and the extent of characterization required for solutions, ores and wastes. These requirements are dependent on the type of discharge being considered. Appendix B also discusses the various test methods available to the applicant (such as acid-base accounting, humidity cell tests and leach procedures). Appendix C (Liner Design Principles and Practice) presents details helpful to the applicant pertaining to liner system types, their design and maintenance for environmental protection. The customary and appropriate provisions for construction quality assurance/quality control required in a BADCT demonstration are discussed in Appendix D (Construction Quality Assurance and Quality Control). In Appendix E, (Engineering Design Guidance) the engineering design requirements including hydrologic and stability considerations are described as they may apply to any type of facility and especially as they relate to tailing impoundments. Finally, applicable federal, state and local permits and approvals are discussed in Appendix F (Federal, State and Local Environmental Permits).

Facilities Requiring BADCT

One of the fundamental assumptions utilized in developing this guidance manual is that an applicant has already determined that an APP is needed for the facility in question. The following facilities may be present at mining, processing, or smelting and refining operations and are considered, or deemed by A.R.S. 49-241.B, to be categorical discharging facilities requiring an APP, unless exempt pursuant to A.R.S. 49-250:

- *Surface impoundments*[(2)] including holding, storage settling, treatment or disposal pits, ponds and lagoons (A.R.S. 49-241.B.1);
- Solid waste disposal facilities except for mining overburden and wall rock that has not and will not be subject to mine leaching operations (A.R.S. 49-241.B.2);
- Injection wells (A.R.S. 49-241.B.3);
- *Mine tailing piles and ponds*[(2)] (A.R.S. 49-241.B.6);
- *Mine leaching operations*[(2)] (A.R.S. 49-241.B.7);
- Sewage or sludge ponds and wastewater treatment facilities (A.R.S. 49-241.B.11);
- Septic tank systems with a capacity of greater than two thousand gallons per day (A.R.S. 49-241.B.8);
- Facilities which add a pollutant to a salt dome formation, salt bed formation, dry well or underground cave or mine (A.R.S. 49-241.B.5); and
- Point source discharges to navigable waters (A.R.S. 49-241.B.10).

The APP and BADCT requirements apply to both new and existing mining operations. The designations "new," "existing," and "closed" are specifically defined in A.R.S. 49-201, as follows:

- New facilities began construction or entered into binding contracts after August 13, 1986. Facilities that have undergone major modifications after August 13, 1986 are also deemed new facilities.
- Existing facilities began construction or entered into binding contracts on or before August 13, 1986. Facilities which ceased operation after January 1, 1986 are also regarded as existing facilities; they must meet BADCT and other APP requirements, including notification to ADEQ of closure. Economic considerations are important to the BADCT process for existing facilities.
- Closed facilities are those which ceased operation before January 1, 1986 with no intent to resume operations for which they were intended. Closed facilities are exempt from the APP requirements; hence, they are not subject to BADCT requirements.

Some mining facilities may qualify for the following specific exemptions:

- "Mining overburden returned to the excavation site, including any common material which has been excavated and removed from the excavation site and has not been subjected to any chemical or leaching agent or process of any kind." (A.R.S. 49-250.B.5)
- "Leachate resulting from the direct, natural infiltration of precipitation through undisturbed regolith or bedrock if pollutants are not added to the leachate as a result of any material or activity placed or conducted by man on the ground surface." (A.R.S. 49-250.B.9)
- "Surface impoundments used solely to contain storm runoff, except for surface impoundments regulated by the federal clean water act." (A.R.S. 49-250.B.10)
- "Closed Facilities. However, if the facility ever resumes operation the facility shall obtain an aquifer protection permit and the facility shall be treated as a new facility for purposes of section 49-243." (A.R.S. 49-250.B.11)
- "Storage, treatment or disposal of inert material." (A.R.S. 49-250.B.20)
- "Structures designed and constructed not to discharge, which are built on an impermeable barrier that can be visually inspected for leakage." (A.R.S. 49-250.B.21)
- "Pipelines and tanks designed, constructed, operated and regularly maintained so as not to discharge." (A.R.S. 49-250.B.22)
- Other miscellaneous facilities as referenced in A.A.C. R18-9-102 and 103.

Some mining facilities may qualify for a general permit. The APP rules contain 42 general permits which replace individual permits for several classes of facilities in major industry groups, including mining and other industrial operations. These general permits rely on clear technical standards to ensure that a discharging facility does not violate aquifer water quality standards and that the facility employs BADCT in its design, construction, operation and maintenance. There are four types of general permits (Types 1, 2, 3 and 4) for which facilities may qualify. Consult the following rules for the detailed technical requirements: A.A.C. R18-9-A301 through R18-9-A316 (General Provisions); R18-9-B301 (Type 1); R18-9-C301 through R18-9-C303 (Type 2); R18-9-D301 through R18-9-D307 (Type 3); and R18-9-E301 through R18-9-E323 (Type 4).

And, some types of facilities are not required to obtain an APP because they are not considered a discharging facility under the APP program. A "discharge" is defined by A.R.S. 49-201.11 as:

> "*the addition of a pollutant from a facility either directly to an aquifer or to the land surface or the vadose zone in such a manner that there is a reasonable probability that the pollutant will reach an aquifer.*"

Mining operations with activities that are neither categorical, exempt, or general permitted may be judged to be discharging in accordance with A.R.S. 49-241.A. All facilities that discharge are required to obtain an APP with BADCT incorporated into their design. If it is uncertain if a facility needs an APP, ADEQ can be requested, in accordance with A.A.C. R18-9-106, to determine the applicability of the APP program to the operation or activity. A non-refundable flat rate fee, in accordance with A.A.C. R18-14-102(C)(3), will be charged for each determination requested. ADEQ expects, however, that determinations of applicability will be rare. Applicants are urged to consult the APP rules first, because in almost all cases, the APP rules clarify whether coverage is required.

In evaluating a determination of applicability, ADEQ may request that the waste be characterized. Appendix B, Solution, Ore and Waste Characterization, includes guidance that will be useful for this purpose. If the facility does not discharge, then the facility need not comply with the APP requirements and no further design or analysis is necessary. If the facility does discharge, the characterization will be used to properly design the facility to satisfy the BADCT requirements. The burden of proof lies with the applicant to show that the facility is not a discharging facility.

PART I

General BADCT Information

PART 1 GENERAL BADCT INFORMATION

1.1 THE BADCT PROCESS

When considering technologies, processes, operating methods and other alternatives for purposes of a BADCT design, a facility must be evaluated in terms of 1) siting; 2) design, construction, and operation; and 3) closure and post-closure.

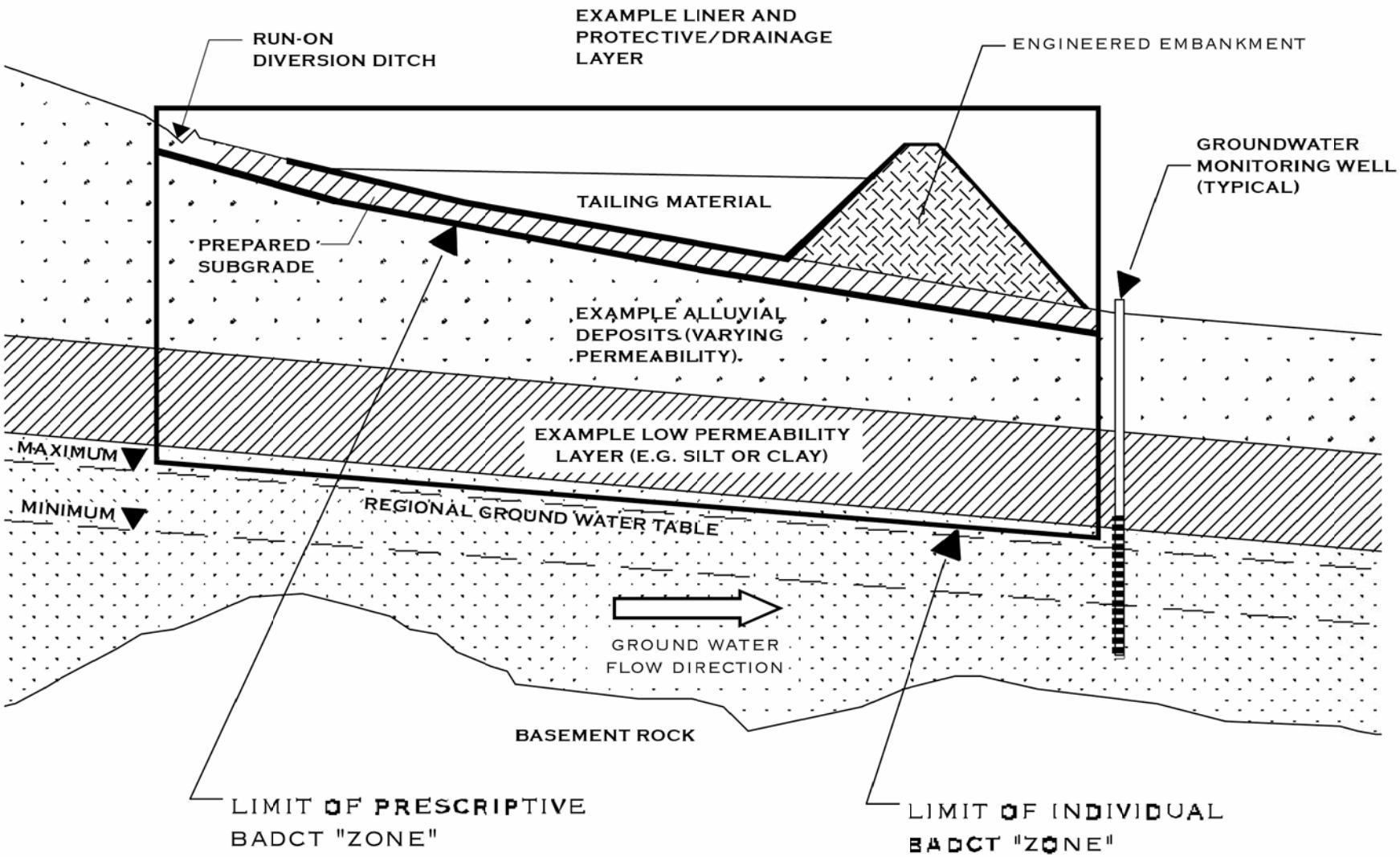
Part of the BADCT determination process involves deciding whether to use a "Prescriptive" approach or a site specific "Individual" approach for determining BADCT pursuant to A.R.S. 49-243.B.1. Both approaches have merit and either may be appropriate for the applicant's facility.

- The "Prescriptive" approach requires evaluating and selecting a predetermined discharge control technology as the BADCT design. This approach provides a simplified method for an APP applicant to propose BADCT that will be acceptable to the ADEQ. The prescriptive criteria provided in this manual are designed to be generally conservative, and to minimize the level of site investigation and engineering evaluations that the applicant will be responsible for completing. The Prescriptive BADCT criteria are based on the premise of minimizing any discharge beyond the engineered containment. Therefore, this approach cannot incorporate any natural discharge attenuation that may occur in the vadose zone below engineered containment systems.
- The "Individual" approach allows the applicant to evaluate and compare alternatives (alternative discharge control systems) which combine site characteristics with demonstrated control technologies (DCTs) that can be applied to arrive at a BADCT design. This approach provides a method for an APP applicant to utilize a site specific BADCT design that can incorporate water quality protection characteristics that may occur due to the climate, vadose zone conditions beneath the facility, operational procedures, and other factors. While this approach allows the BADCT design to be optimized compared to the generally conservative Prescriptive BADCT criteria, the applicant should realize an increased effort will likely be required for site characterization, facility design, APP application review, etc.

In the following sections, general processes for performing a BADCT evaluation for a facility are described. Both the Prescriptive and Individual BADCT approaches can be utilized for different facilities at a given site. For example, an applicant may elect to utilize Prescriptive BADCT for some site facilities such as ponds and Individual BADCT for other facilities such as heap leach pads or a tailing impoundment.

Both the Prescriptive and Individual BADCT approaches are based on preventing, or minimizing to the extent practicable, the loading of pollutants to an aquifer. Attenuation of pollutant concentrations within the aquifer itself, the point of compliance for water quality standards and water quality monitoring, and other aspects related to discharge after it encounters the aquifer, are outside the scope of BADCT for most types of facilities. Figure 1-1 schematically illustrates the "zones" typically encompassed by Prescriptive and Individual BADCT designs. Exceptions occur where the aquifer may be part of the BADCT design in the cases of in-situ leaching and passive containment.

FIGURE 1-1 - EXAMPLE ILLUSTRATION OF PRESCRIPTIVE AND INDIVIDUAL BADCT "ZONES"
(TAILING IMPOINDMENT EXAMPLE)



[NOT TO SCALE]

1.1.1 Prescriptive BADCT

Prescriptive BADCT, which is an expedited approach to determining BADCT, allows the applicant to select specific demonstrated control technologies for certain facilities or facility types which ADEQ considers to comply with the BADCT requirements. The objective of this approach is to simplify and expedite the permitting of conventional facilities by minimizing required information gathering, information review, and negotiations, compared to the site specific Individual BADCT approach. The Prescriptive BADCT criteria are defined in Part 2 of this manual.

The following facility types are eligible to utilize the Prescriptive approach:

- Non-Storm Water Ponds;
- Process Solution Ponds;
- Heap Leach Pads; and
- Tailing Impoundments.

If the applicant demonstrates that the design, construction, technology, process, operating method or other elements meet the prescriptive criteria, or an engineering equivalent, and the application incorporates these prescriptive criteria, or equivalents, then the applicant will meet the requirements of A.R.S. 49-243.B.1.

The use of Prescriptive BADCT in an APP application is typically more applicable to small and medium size mining operations, existing operations undergoing expansion, or existing operations intending to add facilities.

1.1.2 Prescriptive BADCT Review Process

An application for an APP utilizing Prescriptive BADCT must include a proposal of what BADCT is at the facility. This proposal should meet the appropriate prescriptive design criteria for the facility described in Part 2 of this manual. An example Table of Contents for describing in the APP application how the design meets BADCT requirements is provided in Table 1-1.

Shallow groundwater conditions, if present, must be documented for design considerations, and may prohibit the use of the Prescriptive BADCT approach.

The presence of certain site specific geologic hazards may also prohibit the use of Prescriptive BADCT. When process facilities are intended to be located: 1) in areas known to be prone to excessive subsidence; 2) in the vicinity of active faults; 3) in landslide prone terrain, or 4) in other locations of known geologic instability, ADEQ may request that an application using Prescriptive BADCT include studies specific to the hazard(s) present, to assist in determination of whether or not Prescriptive BADCT is appropriately applied. Provided that the hazard(s) present will not have a significant potential to impact the effectiveness of the Prescriptive BADCT design, it will be considered appropriately applied.

ADEQ's review begins with an applicability check of the proposed design, and the following questions are considered: Does this facility qualify for a Prescriptive BADCT approach? Is the proposed design correctly chosen from the guidance manual and is it correctly applied? If ADEQ determines that any of the answers are no, the applicant will be notified of the need to make the appropriate corrections, and resubmit the application. Depending on the degree of deficiency, this notification and re-submittal process will vary in the degree of formality but in all cases any final determination must be documented in ADEQ's files.

TABLE 1-1
Example Table of Contents - Prescriptive BADCT Demonstration(1)

1. Introduction

2. Site Criteria

   2.1 Relevant Site Characteristics
   2.2 Surface Water Controls
   2.3 Geologic Hazards

3. Design Construction and Operational Criteria

   3.1 Relevant Solution/Effluent Characteristics
   3.2 Storage Components
   3.3 Site Preparation
   3.4 Liner System Specifications
   3.5 Stability Considerations
   3.6 Facility Operation and Monitoring

4. Relevant Facility Inspection Criteria

5. Relevant Closure and Post-Closure Criteria

Example Appendices:

- Solution, Ore and Waste Characterization Data
- Groundwater Data
- Geologic Hazards Evaluation
- Geotechnical Data
- Surface Water Evaluations
- Construction Procedures and QA/QC
- Slope Stability Evaluations
- Water Balance and Storage Capacity Evaluations
- Equivalent Engineering Evaluations

(1) All applicable sections should clearly state the manner in which Prescriptive BADCT criteria are satisfied by the proposed design.

If the APP application and supporting documentation show that the prescriptive criteria are met and appropriately applied, BADCT demonstration in accordance with A.R.S. 49-243.B.1 and the APP application requirement of A.A.C. R18-9-A202(A)(5) are deemed satisfied. ADEQ then proceeds with the processing of the permit application, unless new information warrants an additional applicability check. This processing includes a determination of completeness for other parts of the APP application that are not part of BADCT, such as whether or not applicable water quality standards (AWQS) will be met at the Point of Compliance, and the technical and financial capability of the applicant.

1.1.2.1 Determination of Prescriptive BADCT

The determination of BADCT using prescriptive criteria for an APP application is based on meeting the prescribed design, construction, and operating criteria defined in Part 2 of this manual, or where applicable, by rule (A.R.S. 49-243.01). Since the objective of the Prescriptive BADCT determination is to simplify and expedite the BADCT review process and therefore the APP process, the prescriptive criteria are designed to be generally conservative for most site conditions in order to minimize the need for collection and evaluation of site specific data. Some site evaluations, however, are still required to provide enough information for determination that the Prescriptive BADCT is appropriate. As discussed further in Part 2, these include evaluations of key issues related to site conditions such as identification of flood plains and geologic hazards.

While the Prescriptive BADCT criteria, in part, include specific design criteria for many of the BADCT elements, engineering equivalents to specific elements are also acceptable. Examples of engineering equivalents, and supporting information that may be required by ADEQ for each, are provided in Part 2 (Table 2-1). The ADEQ may require specific supporting evaluations to demonstrate that the proposed element is at least as protective as the specific Prescriptive BADCT element it replaces. Engineering equivalents cannot rely on seepage attenuation or other geologic properties of the vadose zone as part of minimizing aquifer loading.

1.1.3 Individual BADCT Review Process For New Facilities

When submitting an individual application for an APP, an applicant must include a proposed BADCT design to be used at the facility. A.A.C. R18-9-A202(A)(5) requires that the applicant submit, in support of the proposed BADCT, a statement of the technology which will be employed to meet the requirements of A.R.S. 49-243.B.1. This statement shall describe alternative discharge control measures considered, the technical and economic advantages and disadvantages of each alternative, and the justification for selection or rejection of each alternative. The applicant shall evaluate each alternative discharge control technology, relative to the amount of discharge reduction achievable, site specific hydrologic and geologic characteristics, other environmental impacts, and water conservation or augmentation considerations. The economic impact of implementation of Individual BADCT design is further discussed in Section 1.1.3.7.

The development of an Individual BADCT design follows the general principles of engineering design. Engineering principles are adhered to during the design process involving the designer's professional judgment of contingencies, risks and uncertainties based on education and experience. It is therefore only possible to provide general guidance for the process to be followed.

Important aspects of developing an Individual BADCT design are:

- Discharge control technologies ordinarily constitute a discharge control system incorporating engineering features, operational measures and site characteristics to achieve BADCT; and,
- Alternative designs must be considered to arrive at a BADCT design.

Discharge control technologies are those design elements which can be included to reduce loading (discharge of pollutants) to an aquifer (e.g., design aspects such as liners, operational aspects such as desaturated tailing disposal for small projects, and closure aspects such as rinsing gold and silver ore residue on heap leach pads after leaching is completed).

Alternative designs can include consideration of alternative technologies or alternative design elements as discussed below, and in some cases, alternative sites. In principle, an Individual BADCT design is developed through the following approach:

- Development of a range of alternative discharge control systems which may or may not include different sites on a conceptual basis;
- Screening these alternative systems by estimating the relative degree of discharge control;
- Selection of the most promising alternative systems for more detailed analysis;
- Refinement of designs for the selected alternative systems;
- Comprehensive estimates of discharge control for the selected alternative systems; and,
- Selection of BADCT design.

In conducting these analyses, the following steps are required:

- Site selection;
- Development of individual site design ("Reference Design") based on demonstrated control technologies and site conditions;
- Estimation of aquifer loading for the Reference Design;
- Alternative design(s) selection as outlined above;
- Estimation of aquifer loading for the promising alternative design(s); and,
- Selection of BADCT design.

Figure 1-2 provides a schematic representation of the process. Each of the steps are described below. An example Table of Contents for describing in the APP application how the design meets Individual BADCT requirements is provided in Table 1-2.

1.1.3.1 Site Selection

Site selection is a powerful tool in developing a protective design. It is sometimes possible to select a site with outstanding characteristics which will enhance the containment of stored materials. Maximum advantage should be taken of site selection in development of a BADCT design.

Site selection can be conducted by the applicant in a formal or informal manner. The formal process will typically consider sites in areas surrounding the mine and the preferred site will be selected through a process of fatal flaw screening, site evaluation and ranking, and in some cases, also limited site investigations and final ranking. Informal site selection is often necessary because of limited availability of suitable sites in the vicinity of the ore body.

TABLE 1-2
Example Table of Contents - Individual BADCT Demonstration(1)

1. Introduction
2. Relevant Site Factors
   - 2.1 Solution, Ore and Waste Characteristics
   - 2.2 Site Characteristics
     - 2.2.1 Surface Hydrology
     - 2.2.2 Hydrogeology
     - 2.2.3 Geologic Hazards
3. Site Selection
   - 3.1 Alternatives
   - 3.2 Evaluation of Alternatives
   - 3.3 Recommended Site
4. Reference Design
   - 4.1 Design
   - 4.2 Construction Considerations
   - 4.3 Operations and Operational Monitoring
   - 4.4 Closure and Post-Closure Considerations
   - 4.5 Estimated Aquifer Loading
     - 4.5.1 Potential Release
     - 4.5.2 Estimated Travel Times to Groundwater Table
     - 4.5.3 Estimated Attenuation of Pollutants
     - 4.5.4 Estimated Aquifer Load
   - 4.6 Estimated Cost of Reference Design
5. Alternative Designs
   - 5.1 Selection of Alternatives
   - 5.2 Screening of Alternatives
   - 5.3 Description of Most Promising Alternative Systems
   - 5.4 Aquifer Loading of Most Promising Alternative Systems
   - 5.5 Estimated Cost of Most Promising Alternative Systems
6. Selection of BADCT Design
   - 6.1 Selection Criteria
   - 6.2 Evaluation of Reference Design and Alternative Systems
   - 6.3 Selected BADCT Design

Example Appendices:
- Solution Ore and Waste Characterization Data
- Groundwater Data
- Geologic Hazards Evaluation

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(1) All applicable sections should clearly state the manner in which Individual BADCT requirements are satisfied by the proposed BADCT design.

- Geotechnical Data
- Surface Water Evaluations
- Construction Procedures and QA/QC
- Slope Stability Evaluations
- Water Balance and Storage Capacity Evaluations

The design documents submitted for APP permitting must describe the site selection process. It is the applicant's responsibility to develop this information; ADEQ can only give guidance in this regard.

1.1.3.2 Development of Reference Design

The development of an individual site design must consider: 1) industry-wide DCTs taking into account differences in industry sectors; 2) the type and size of the operation; 3) the reasonableness of applying controls considering the site climatic conditions; and 4) other site specific conditions. In developing this design, a systems approach should be used. This systems approach should consider all phases of the project including:

- Site characterization;
- Design, construction and operations; and
- Closure and post-closure.

The demonstrated control technologies for various facilities are described further in Part 3 of this manual. Table 1-3 provides a "menu" of typical DCTs for each of the above phases.

A Reference Design will typically include DCTs selected from the Table 1-3 menu. For example, in developing a Reference Design, site specific DCTs will be included such as selection of a site with low permeability geologic formations, specific design elements such as single synthetic liners, specific operational technologies such as maintaining the low hydraulic head on a leach pad, specific operational monitoring proposals such as regular inspections by the facility operator, and specific closure and post-closure technologies such as bacterial rinsing for a gold heap leach pad.

In considering the systems approach to development of a Reference Design it is important to include site characteristics. While it may be important to select a high level of engineered containment for sites underlain by alluvium and shallow groundwater, the same may not be the case when the site is underlain by low permeability bedrock and/or deep groundwater (i.e., a demonstrated geologic barrier). The individual designer will include these considerations in the systems design based on experience as well as industry wide demonstrated control technologies which have been applied for similar site conditions. In developing an individual site design the designer must therefore be encouraged to use creativity to provide the greatest degree of discharge reduction achievable through application of DCTs and, where practicable, an approach permitting no discharge of pollutants.

1.1.3.3 Estimation of Aquifer Loading

An evaluation must next be performed to estimate the potential loading of pollutants to the aquifer as a result of implementing the Reference Design. Loading to the aquifer is used as a basis for evaluating the impacts of discharge from a facility. This evaluation can be done at

various levels of sophistication but at a minimum must include the steps outlined below. It is important that this evaluation should consider the total life cycle of the facility (i.e., operations as well as closure/post-closure). For example, during operations a slurry deposited tailing impoundment will contain free water. After closure and during the post-closure period, this free water may be removed and therefore the driving head for pollutant migration will be eliminated.

TABLE 1-3

Examples of Demonstrated Control Technologies			
Project Phase	Element	Demonstrated Control Technologies (DCT)	Evaluation Procedures to be Selected From
Site Characterization	Solution, Ore and Waste Characterization	1) These characterizations are required to determine the DCTs for other elements.	1) Procedures to differentiate between oxide and sulfide materials. 2) 1312 Leach Procedure. 3) Meteoric Water Mobility. 4) Acid Base Accounting. 5) Humidity Cell Tests.
	Geotechnical, Surface Hydrology, Hydrogeologic, and Geologic Hazards Characterizations	1) Siting DCT incorporates selection of locations with: • Low permeability geologic formation • Deep groundwater tables • Naturally poor groundwater quality • Small contributory watershed. 2) Selection of sites which avoid or mitigate geologic hazards. 3) These characterizations are required to determine the DCTs for other elements.	1) Test pitting, drilling, trenching, sampling and testing. 2) In-situ tests of, for example, hydraulic conductivity. 3) Geophysical methods. 4) Water level monitoring. 5) Remote sensing methods. 6) Aerial photography mapping and interpretation. 7) Site reconnaissance. 8) Other standard hydrologic and geotechnical field investigation and data evaluation methods.
Design, Construction, and Operations	Site Preparation	1) Strip vegetation. 2) Excavate and replace weak foundation materials.	1) Standard construction QA/QC methods.
	Surface Water Control	1) Diversion ditches. 2) Retention structures.	1) Standard hydrologic design methods.

Examples of Demonstrated Control Technologies			
Project Phase	Element	Demonstrated Control Technologies (DCT)	Evaluation Procedures to be Selected From
	Discharge Control	1) DCTs for discharge control vary significantly depending on the type and size of the operation and the reasonableness of applying controls in arid or semi-arid settings, but may include: • Liners for containment. • Natural containment. • Leachate collection and hydrostatic head control systems consisting of: - Manufactured or imported drain rock and perforated pipes. - Ore materials satisfying drainage requirements. - Granular or synthetic leak collection layers for pond liner systems. • Solution conveyance pipes or lined channels and storage capacity.	1) Systems approach to liner system design (Appendix C). 2) Standard engineering measures for surface containment.
	Stability	1) Specified ultimate slope height. 2) Stability benches. 3) Design to withstand shear forces, e.g., by compaction, use of geosynthetics, etc. 4) Control of pore pressures by drainage. 5) Buttressing.	1) Shear strength analysis. 2) Static stability analysis. 3) Seismic deformation analyses.

Examples of Demonstrated Control Technologies			
Project Phase	Element	Demonstrated Control Technologies (DCT)	Evaluation Procedures to be Selected From
	Operations	1) Conduct operations to minimize potential for damage to liners at heap leach sites: • •Geosynthetic and/or gravel protective layers. • •Low ground pressure equipment. • •Limit equipment traffic. • •Load in uphill direction. • •Limit rate of rise. • •Limit maximum height. 2) Control solution applications at heap leach sites: • •Avoid excessive reagent concentrations. • •Avoid application rates or storage conditions that result in excessive hydraulic head. • Sequence leaching activities. 3) Managed tailing deposition: • •Layered or subareal deposition. • •Limit size of water pond. 4) Operational monitoring to allow early detection and correction of problems. 5) Facility maintenance to assure performance is consistent with the design.	1) Consider operational conditions during design of facility. 2) Visual observations. 3) Survey monuments. 4) Instrumentation.
Closure and Post-Closure	Physical Stability	1) Surface Water Control to reduce erosion. 2) Recontouring to control surface flow. 3) Cover placement (e.g., vegetation or rock armor) to reduce erosion. 4) Erosion protection of ditches.	1) Stability evaluations. 2) Long-term erosion evaluations.

Examples of Demonstrated Control Technologies			
Project Phase	Element	Demonstrated Control Technologies (DCT)	Evaluation Procedures to be Selected From
	Chemical Stability	1) Source control: • •Ore residue rinsing and/or detoxification. • •Ore residue removal. 2) Migration control: • •Surface grading to enhance run-off. • •Surface grading to minimize run-on. • •Design cover to minimize infiltration and enhance moisture removal (e.g., increased evapo-transpiration by fine-grained soils and/or vegetation). • •Cap with low permeability cover. 3) Interception (e.g., using shallow trenches; cutoff walls) and water treatment.	1) Column leach tests. 2) Fate and transport evaluations. 3) Cover water balance evaluations.

The steps which should be followed to estimate aquifer loading for the total life cycle of the facility are as follows:

- Estimate the potential release from the facility by using empirical equations or other appropriate approximate methods.
- Estimate the travel time to the water table beneath the facility by vertical migration using groundwater flow calculation methods such as described in Appendix C of Hutchison and Ellison (1992).
- Estimate attenuation of pollutants in the foundation based on published values or laboratory test results.
- Estimate the load added to the aquifer of constituents that have the potential to impact water quality, particularly those for which there are water quality standards.

The purpose of the load estimation to the aquifer is to provide a consistent method to compare the potential impacts of various designs. It is therefore not intended that this evaluation should turn into a research project or an advancement of the state-of-the-art. However, consistent and realistic approaches should be followed.

1.1.3.4 Alternative Design(s) Selection

Alternative design(s) should next be developed and can include the evaluation of alternative control technologies or design elements for each applicable type of facility (Part 3 summarizes various demonstrated control technologies for different types of facilities) or, as may be appropriate, the evaluation of alternative sites. The selection of the alternative design(s) should be based on the systems approach where control technologies as well as realistic site conditions are considered.

1.1.3.5 Estimation of Aquifer Loading for Alternative Design(s)

Estimating the aquifer loading for the alternative design(s) follows the same approach as described above for estimation of aquifer loading for the Reference Design. By following the same procedures, comparative aquifer loadings from the Reference Design as well as the alternative design(s) can be developed.

1.1.3.6 Selection of BADCT Design

The final step in developing an individual BADCT design is to make a selection from the Reference Design and the alternative design(s). The basis for this selection is loading to the aquifer. The BADCT design will be that design which results in the least amount of pollutant loading (discharge) to the aquifer. For example if an alternative design results in a lower pollutant loading to the aquifer, then that design will be selected as the BADCT design instead of the Reference Design.

In cases where the Reference Design and/or the alternative design result in similar loadings to the aquifer, and discharges do not contain materials listed in A.R.S. 49-243.I, the design with the

lowest costs (i.e., capital, operations, closure, post-closure and other applicable costs) may be selected as the BADCT design. In such cases, negligible loadings can be considered similar even if the relative difference between loadings is significant (e.g., where loadings from alternatives are small compared to the highest loading that could still comply with aquifer water quality standards, the fact that the loading from one alternative may be up to orders of magnitude smaller may not preclude these loadings from being considered similar). If the discharge contains materials listed in A.R.S. 49-243.I, the applicant must limit discharges to the maximum extent practicable regardless of cost.

The BADCT design is therefore selected based on DCTs, a systems approach including site conditions, and the estimation of aquifer loadings for alternative designs.

The requirement for this individual BADCT evaluation process to be demonstrated in APP applications is described in regulation as follows (A.A.C. R18-9-A202(A)(5)):

> *"The applicant shall submit in support of the proposed BADCT a statement of the technology which will be employed to meet the requirements of A.R.S. 49-243.B. This statement shall describe the alternative discharge control measures considered, the technical and economic advantages and disadvantages of each alternative, and the justification for selection or rejection of each alternative. The application shall evaluate each alternative discharge control technology, relative to the amount of discharge reduction achievable, site specific hydrologic and geologic characteristics, other environmental impacts, and water conservation or augmentation. The economic impact of implementation of each alternative control technology shall be evaluated on an industry-wide basis. In addition, a statement for a facility in existence on the effective date of this Article shall reflect consideration of the factors listed in A.R.S. 49-243.B.1(a) through (h)."*

A.R.S. 49-243B.1(a) through (h) includes the following:

(a) *"Toxicity, concentrations and quantities of discharge likely to reach an aquifer from various types of control technologies.*
(b) *The total costs of the application of the technology in relation to the discharge reduction to be achieved from such application.*
(c) *The age of equipment and facilities involved.*
(d) *The industrial and control process employed.*
(e) *The engineering aspects of the application of various types of control techniques.*
(f) *Process changes.*
(g) *Non-water quality environmental impacts.*
(h) *The extent to which water available for beneficial uses will be conserved by a particular type of control technology."*

As discussed in Section 1.1.2, the BADCT demonstration portion of the application can be deemed complete, and A.A.C. R18-9-A202(A)(5) deemed satisfied without this evaluation where facilities utilize Prescriptive BADCT.

1.1.3.7 Economic Considerations

In regard to new facilities, A.R.S. 49-243.B.1. directs ADEQ to consider economic impacts of the application of BADCT with other factors on an industry-wide basis. The determination of economic impact on an industry-wide basis shall take into account differences in industry sectors

(i.e., Copper Sector, Gold Sector, Uranium Sector, etc.), the facility type (i.e., heap leaching, dump leaching, in-situ, copper oxide leaching, copper sulfide leaching, etc.), the size of the operation, and the reasonableness of applying controls in an arid or semi-arid setting (gold mining in Northern California vs. gold mining in Arizona, copper mining in Michigan vs. copper mining in Arizona, etc.). ADEQ considers that use of a technology at many other similar facilities in the same industry sector, same type and size, and in the same climatic setting indicates financial feasibility. As indicated above, if a new facility discharges the pollutants identified in A.R.S 49-243.I, then that facility must meet the criteria of A.R.S. 49-243.B.1 (BADCT) to limit discharges to the maximum extent practicable regardless of cost.

1.1.3.8 Discussion

It may be beneficial from a design point of view to include elements which are innovative and therefore may not satisfy the requirement of an industry-wide DCT. In this case, the designer must demonstrate that such technologies will perform as intended. Such demonstration can be based on literature reviews, engineering analyses, laboratory and pilot scale testing, or by providing case histories of analogous applications of the technology.

1.1.4 Individual BADCT Review Process for Existing Facilities

An existing facility is defined in A.R.S. 49-201.14. as one that is neither a new or closed facility and at which construction began before August 13, 1986. According to A.R.S. 49-201.18, a closed facility that is reopened does not constitute an existing facility, but is regarded as a new facility. The distinction between existing and new facilities is important in determining BADCT for the following two basic reasons:

1) At an existing facility, determining BADCT requires ADEQ and the applicant to consider potential upgrades to the facility design, and
2) Additional factors for existing facilities apply as listed in A.R.S. 49-243.B.1(a) through (h), such as, weighing cost vs. discharge reduction, the age of equipment, and the engineering aspects of the application of various types of industrial and control processes. Also, the requirement of A.R.S. 49-243.I that a new facility limit discharges of certain listed organic pollutants to the maximum extent practicable regardless of cost does not apply to existing facilities.

Note that the option of Prescriptive BADCT also applies to an existing facility. If the facility meets the prescriptive criteria identified for the specific type of facility in Part 2, no further demonstration is necessary. Most existing facilities, however, warrant the individual evaluation process.

There are two major differences in approach mandated for determining BADCT for an existing facility, compared to that for a new facility. First, existing design and site conditions offer constraints on what can be achieved with the final BADCT configuration. Second, analysis of cost vs. discharge reduction applies in determining BADCT. To arrive at a BADCT, the existing design and its performance become the basis of comparison for judgments about whether or not to upgrade the design. Possible upgrades must, of course, be limited to those that are feasible from an engineering standpoint given the age, design, and operational controls of the facility.

Complicating matters at an existing facility may be the groundwater impact of past operations. While remedial or mitigative efforts may be needed in areas where groundwater quality does not conform to Aquifer Water Quality Standards downgradient of a facility (see A.R.S. 49-243.L), these activities do not constitute part of BADCT for the facility. The reason for this distinction is that BADCT does not include actions or design features which affect groundwater after pollutants have been released into it, since discharge has already occurred in those instances. Thus, while existing groundwater quality may be an indicator of the performance of the current design, remedial or mitigative technologies do not reduce discharge and should not be considered in the BADCT evaluation.

There are five basic steps in the existing facility process. Similar to the new facility process outlined previously, the applicant develops a Reference Design. However, here, the existing configuration of a facility and site represents its Reference Design. Alternatives to the Reference Design are then developed and evaluated as outlined by the following five basic steps:

Step 1 Identify current DCTs and site factors;
Step 2 Estimate performance (determine aquifer loading);
Step 3 Identify technically feasible alternative DCTs and assemble them on a candidate list. Consider water conservation and other environmental factors to reduce or adjust the list;
Step 4 Use the candidate list to arrive at one or more alternative systems;
Step 5 Weigh cost vs. discharge reduction for each alternative system to arrive at BADCT:
- Calculate improvements in aquifer loading expected from one or more alternative systems with new DCTs, and
- Determine costs to implement alternative system(s).

1.1.4.1 Steps 1 & 2: Identifying Current Discharge Controls and Assessing Their Performance - The Reference Design

As with new facilities, BADCT determination for existing facilities depends on an adequate characterization of the discharge quantity and type. To establish the Reference Design for an existing facility, the applicant should inventory the discharge controls used in the facility's current design. The control processes and technologies can be identified according to the design elements and site characteristics described in Part 3. Discharge control technologies to consider include process solution controls in conjunction with: solution, ore and waste characterization; site preparation; surface water controls; liners; leachate collection systems; stability design; operational monitoring; closure/post-closure; and site factors. Where original design plans are lacking, the applicant should develop as-built design information for those aspects of the facility which have some bearing on discharge rates and characteristics. To save time and effort, and to promote efficiency, the applicant is encouraged to discuss the level of detail needed with ADEQ prior to developing as-built drawings.

Once existing control processes are identified, the applicant should evaluate the overall discharge control performance of the facility. As for the approach for new facilities, the applicant may assess site factors and their performance for pollutant reduction in the manner presented in Section 1.2. Where practicable, this step should involve direct measurement of discharge quantity and quality. Otherwise, the applicant may calculate expected performance based on

industry standards for the engineered controls, test data for components, and site specific characteristics determined from field or laboratory testing. Aquifer loading from the facility for the existing configuration can be estimated by the same methods used in Section 1.1.3. This aquifer loading analysis constitutes the performance of the Reference Design.

1.1.4.2 Step 3: Identifying Technically Feasible DCTs for Improvement

The BADCT design for an existing facility may involve instituting additional control technologies to those in current use. This step in the process involves developing a list of alternative DCTs that are technically feasible for application at the facility. In many situations, new controls may not be feasible. For instance, adding a liner to an existing dump leach system is beyond the realm of normal mine design and operation. In such cases an applicant should consider other design elements or operational controls discussed below to achieve discharge reduction.

Working with only technically feasible technologies, the applicant should assemble a focused, yet complete, list of candidate DCTs for improvement of the existing facility. Ideas for candidate DCTs may be gained from reviewing the lists of DCTs presented in Part 3. However, many DCTs identified in Part 3 may not work as "retrofitted technologies." The following are types of DCTs which are often easily implemented and may, depending on the facility design and site, offer considerable improvement in facility performance to control discharge:

- Operational controls - physical and chemical (This includes physical controls such as modifying solution application cycles and the amount of solution inventory in the heap or pond storage, and chemical controls such as altering the reagents or reagent dose rates);
- Run-on and other storm water management controls;
- Closure elements such as removal of free liquids, grading, covering, etc.;
- Containment systems for process solution and other potential pollutant sources; and
- Stability improvements by, for example, berming, benching or regrading.

Aside from technical feasibility, certain other factors may disqualify particular DCTs from making the candidate list. Water conservation may be a factor for deciding whether or not a change in discharge control technology is favorable. Simple dilution of a pollutant to achieve lower discharge concentrations, in itself, may not meet BADCT, nor will technologies that consume or alter the quality of large quantities of water. However, there may be extenuating circumstances in which dilution is desirable, such as to facilitate beneficial use of the water or achieve an environment which could enhance natural treatment.

The applicant should also consider other environmental factors. The use of a new discharge control technology at an existing facility may have environmental impacts that are not directly related to aquifer water quality. An example of such a technology is air stripping to remove volatile organic substances from water and mobilize them in air. These environmental tradeoffs must be assessed on a case-by-case basis, and judgments about whether they outweigh discharge reduction are likely to be subjective. Some other common environmental factors that may require consideration are air quality, noise levels, land use, aesthetics, environmentally sensitive areas, endangered species, and the potential for disease transmission.

1.1.4.3 Step 4: Use Candidate List to Arrive at One or More Alternative Discharge Control Systems

The selection of alternative design(s) should be based on a systems approach where technologies, as well as site conditions, are considered. The list of alternative DCTs should be used to identify components that may be incorporated alone or in combination in the existing reference design to arrive at the alternative design(s). This step in the process involves considerable professional judgment and the justification for the selected DCTs may require formal exchange of data, and discussion and negotiation between the applicant and ADEQ, depending upon how obvious the available choices are.

1.1.4.4 Step 5: Weigh Cost vs. Discharge Reduction by Calculating Aquifer Loading for Alternative System(s) and Calculating Cost for New DCTs

After selecting alternative design(s) in Step 4, an applicant should prepare additional aquifer loading calculation(s) using the same considerations as for the Reference Design. Where additional DCTs are used, their contribution to discharge reduction should be factored into the aquifer loading calculation(s). Where new DCTs are substituted for existing ones, the estimated performance of the new DCT should be used in the calculation. The aquifer loading(s) of the alternative system(s) need to be compared to the Reference Design.

For cost evaluations, the applicant shall compare the total cost/benefit of the application of the technology with the discharge reduction to be achieved from such application, as noted in A.R.S. 49-243.B.1(b). When calculating the total cost/benefit, the applicant may apply acceptable discounting methods used for other accounting purposes within the industry.

1.2 USING SITE CHARACTERISTICS AS A PART OF THE BADCT DESIGN

This section, together with Appendix B (Solution, Ore and Waste Characterization), describes site, technical and economic considerations, on an industry-wide basis, applicable to BADCT analysis for a specific facility. It includes discussions on waste types and process solution characteristics, water resource values, climatic conditions, site factors, and passive containment. Such factors may affect the BADCT selection for a facility seeking an Individual APP.

1.2.1 Waste Types and Process Solution Characteristics

A.A.C. R18-9-A202(A)(4) requires that a person applying for an APP provide a summary of the known past facility discharge activities and the proposed facility discharge activities indicating:

- The chemical, physical and biological characteristics of the discharge;
- The rates, volumes, and the frequency of the discharge for each facility; and
- The location of the discharge.

All applications should include the characterizations necessary to satisfy the requirements described above. In some cases (e.g., new facilities), the applicant may not be able to adequately define the characteristics of the material to be discharged until the facility becomes operational.

In such cases, the applicant must design the facility to be compatible with the characteristics of discharge from similar types of mining facilities. Then, upon start-up, the applicant shall be required to characterize the discharge. However, a discharge containing organic substances referenced in A.R.S. 49-243.I must be identified and characterized in order to design the facility to meet BADCT regardless of cost.

ADEQ will use this information to determine if the proposed facility BADCT is compatible with the materials to be contained in the facility. This need for compatibility between the DCT and the waste characteristics is one of the reasons that detailed design specifications for liners and other elements cannot be uniformly prescribed in this manual. The characterization information will also be used to evaluate the quality and quantity of the discharge.

In characterizing waste, ore or process solutions that may be discharged, the applicant must define the waste type or mix of types (solutions, wastewater, sludges, tailing, leached ore, waste rock, etc.) including the projected or actual leachate composition that will discharge. Discharges that are not identified will not be incorporated into the permit and will be subject to compliance actions under APP regulations. ADEQ should be contacted to review the required type and frequency of characterization for all materials at the facility.

While waste characterization may be appropriate in the case of waste rock or spent ore from a precious metal leach operation, it is not clear that such characterization is beneficial for copper leach ore. In acidic copper leach solutions, high acidity and metals concentrations will be produced (for both oxide and sulfide leach operations) throughout the period of operation, as well as after operations. In the case of a sulfide leach project, it is difficult to predict how long it will take to eliminate all the potential for metal and acid leachate because of the ongoing bacterial action. As a result, characterization of materials to be leached with acidic solutions may be deferred until closure of the leach facility. Proposals for deferring material characterization should be presented to ADEQ during the pre-application period.

Below is a tiered list of tests commonly used to characterize materials that may discharge. Other tests may also be proposed by the applicant or required by ADEQ. When characterizing tailing or waste rock that may discharge, or “produce” a leachate that may discharge, the applicant should conduct the appropriate tests listed in Tier #1 (Part A) with additional testing from Tier #2 (Part A) and Part B as necessary to adequately characterize the material. Similarly, if process solutions or waste waters may be discharged, then the applicant should submit the information requested in Part C below. Where necessary, the ore may be characterized in order to assist in characterizing the potential discharge. Further guidance on waste characterization testing is provided in Appendix B. Pre-application coordination with ADEQ is strongly encouraged to finalize characterization testing requirements.

PART A:
CHARACTERIZATION OF TAILING, SPENT ORE AND WASTE ROCK

TIER #1 Primary Analytical Procedures For Waste Characterization

- Description of mineralogy and lithology of the waste and leached ore;
- Leach Testing (Leach testing should be performed on all materials which may discharge in order to determine the quality of leachate that may be formed.) Types of leach testing include:
  - SPLP (Synthetic Precipitation Leaching Potential EPA Method 1312),
  - Nevada Meteoric Water Mobility Procedure,
  - Leachable sulfates and soluble solids,
  - Bottle Roll Tests.
- Acid Base Accounting (ABA):
  - Predictive Static Tests.
- Physical Characteristic Tests:
  - Grain Size Analysis,
  - Density,
  - Shear Strength.

TIER #2 Miscellaneous Analytical Procedures For Additional Waste Characterization

- Predictive Kinetic Tests for prediction and acid generating characteristics;
- Analysis of Metals (Total and/or Soluble);
- Analysis of Radionuclides;
- TCLP;
- Miscellaneous Physical Analyses (e.g., Hydraulic Conductivity, Moisture Retention Capacity).

PART B:
CHARACTERIZATION OF ORGANIC WASTES OR WASTES CONTAINING ORGANICS

- Organic Analyses:
  - Total Petroleum Hydrocarbons,
  - Polynuclear Aromatic Hydrocarbons,
  - Phenol Analyses,
  - Volatile Organic Compounds and Carbon Disulfide.
- Hazardous waste determination testing for wastes not exempted by the Resource Conservation and Recovery Act (RCRA), where applicable.

PART C:
CHARACTERIZATION OF PROCESS SOLUTIONS, WASTEWATERS AND MINE WATERS

- Metals;
- Major Cations and Anions;
- Physical/Indicator Parameters;
- Reagents and Organics;
- Radiochemicals;
- Cyanide Species;
- Nutrients and Bacteria;
- Miscellaneous; and,

1.2.2 Water Resource Values

As discussed in previous sections, the BADCT determination process is driven by A.R.S. 49-243.B.1 and A.A.C. R18-9-A202(A)(5) The BADCT for a site includes those components of facility siting, design, construction, operation and closure/post-closure that limit discharge to an aquifer. Dilution, attenuation, and other factors that effect discharges after reaching an aquifer are not part of BADCT. Demonstrations related to water quality at the point of compliance pursuant to A.R.S. 49-243.B.2 and B.3 are separate and in addition to BADCT, and are not covered in this manual.

Water resource considerations that play a role in BADCT determination are: (1) site surface water flow characteristics that can effect containment and migration of discharges through the vadose zone (e.g., surface water run-on and run-off); and (2) potential opportunities for water conservation or augmentation. The surface water hydrology aspects are discussed further in Section 1.2.4.4. This section provides the objectives and background to the water resource conservation considerations.

A.R.S. 243.B.1 states, in part:

> *"In determining best available demonstrated control technology, processes, operating methods or other alternatives the director shall take into account ... the opportunity for water conservation or augmentation ... ."*

A.A.C. R18-9-A202(A)(5)(b) states that an applicant shall submit,

> *"An evaluation of each alternative discharge control technology, relative to the amount of discharge reduction achievable, site specific hydrologic and geologic characteristics, other environmental impacts, and water conservation or augmentation."*

Because mining generally necessitates the use of large quantities of water, conservation plays a major role in the BADCT design. Water conservation is based on the efficient use of the available water and recycling of water used in processing. Recycling of process water should be maximized in the BADCT design. Pumped mine water should be beneficially used wherever possible.

1.2.3 Climatic Conditions

Precipitation rates and evaporation rates (a function of temperature, humidity, and wind) are the two primary climatic factors. An applicant wanting to make a demonstration that climatic factors can reduce potential for discharge should evaluate precipitation and evaporation rates in conjunction with other site characteristics.

In areas where precipitation rates are high and evaporation rates are low, there is a higher potential for discharge to impact groundwater. This is because precipitation that does not evaporate or run off, infiltrates into and then percolates through the mine waste. This infiltration may be a major transporter of pollutants to the aquifer where no engineered containment is provided. Generally in these conditions, percolation and subsequent leachate formation are important and must be accommodated in the design of the facility by incorporating leachate collection and containment features. Conversely, in arid and semi-arid environments, where precipitation is low and/or evaporation is high, the potential for surface discharge to impact groundwater is reduced. It is the applicant's responsibility to demonstrate what impacts, if any, climatic conditions will have on the containment provided by the facility.

When analyzing the effects and/or discharge reduction capabilities of climatic factors on a facility design, it is important that the applicant understands and considers the following site-specific conditions:

- Precipitation and evaporation rates at the site (or nearest comparable area with historic data). (A measurement that is relevant to standing water conditions is pan evaporation. Other methodologies can be applied to estimating soil moisture evaporation conditions.);
- Surface run-off: The applicant must estimate what percent of precipitation will run off the facility, and thereby be removed from water balance considerations for the material.

The percentage of run-off depends on several factors including amount, intensity and duration of storm events (consideration should be given to extended periods of precipitation events during periods of low evaporation, such as winter rains), surface slope, permeability of surface (e.g., bedrock conditions, compacted surface vs. ripped surface), etc. Values of run-off can be determined from existing facilities or obtained using the U.S. Department of Agriculture Soil Conservation Service SCS methodology ("Urban Hydrology for Small Watersheds", PB87-101580);

- Moisture storage condition of the material: Two common terms used to define moisture conditions are saturation (the moisture condition at which all pore spaces are completely filled with liquid) and specific retention (the volume of liquid remaining in the previously saturated material after allowing the liquid to drain out of the material by gravity). Specific retention depends primarily on material grain size, shape and distribution of pores and structure. For example, fine grained tailing piles may have a specific retention of as much as 30% moisture by dry weight, while waste rock may have a specific retention of between 10% (coarse rock with minimal fines) and 20% (coarse rock with fines and loam). An applicant considering arid climatic conditions as a demonstrated control technology must, at a minimum, demonstrate that the material deposited will be at a moisture content below specific retention, or that it will be deposited in a manner that will cause the material to dry to at least specific retention;

- Infiltration: The rate of infiltration depends on the grain size distribution, the texture and geometry of the ground surface, the moisture content of the waste material, and the amount and rate of rainfall. Coarser materials tend to have higher infiltration rates than fine-grained materials (or surfaces that are highly compacted);

- Percolation: Once fluids infiltrate a material and the moisture content reaches the specific retention capacity of the material, percolation occurs. Whether percolation occurs at the facility depends on several factors including material thickness, frequency and intensity of storm events, "drying" time in between storm events, the amount of layering and permeability of the material, the amount of vegetation (vegetation reduce the potential for percolation through evapotranspiration), grain and rock size, evaporative depth, etc. Methods such as the Hydrologic Evaluation of Landfill Performance (HELP) water balance model (Federal Environmental Protection Agency) and other approaches can be used as a guide to evaluate percolation rates;

- Evaporative depth: Evaporative depth is the depth to which evaporation can occur. Beyond this depth, evaporation cannot practicably remove moisture that has infiltrated. This depth is a function of material grain size and density (void space), extent and type of vegetation, and climatic conditions; and

- Wind: Wind should be considered in the design of a facility because wind increases the evaporation. The applicant must also take into account over-spray problems and freeboard design (wave action) when constructing a facility in an area prone to high speed winds.

If climatic factors are to be used in considering DCTs for a given facility, water balance calculations must be conducted. It is strongly recommended that water balance calculations be conducted with input from ADEQ to help assure that acceptable methods are used.

1.2.4 Site Factors

Site specific factors that may be considered part of the BADCT determination, along with their data requirements, are discussed in this section. The following discussions do not cover all site factors relevant to an APP application, but only those relative to BADCT determination. The applicant may need to gather additional site specific information under the hydrogeologic-study portion of an APP application to determine the point of compliance, likelihood of compliance with aquifer standards, alert levels, monitoring requirements, and the discharge impact area. The "Aquifer Protection Permits Application Guidance Manual" discusses these aspects in more detail. Applicants are strongly encouraged to meet early with ADEQ and submit a proposal for the hydrogeologic study. ADEQ's comments on the workplan and the negotiations with ADEQ will save much time and effort throughout the BADCT and APP application process.

For mining projects, siting is often dictated by the ore body configuration and local topography. However, for certain facets of the surface operation, such as location of tailing impoundments, dump leach and heap leach facilities, etc., limited alternative sites may be available. Site selection and site characteristics will greatly influence individual BADCT determination since it is site specific. To a great extent, the site will control the design of the facility.

Site selection influences the design of a facility in that each design element must be adapted, or fit, to the dimensions, layout and characteristics of the chosen site. The adaptation to the site affects the performance of the particular design component being used. In selecting a site, an investigation program needs to be developed and implemented. Much has been published on site investigation methods and there are numerous investigation approaches. General approaches available may include:

- Remote sensing;
- Geophysical methods;
- Drilling and sampling;
- Test pits and trenches;
- Laboratory testing;
- In-situ testing; and,
- Monitoring wells and groundwater sampling.

The designer must determine the appropriate investigative methods for selecting a site. The methods may vary from site to site but the following is a suggested approach.

- Conduct a preliminary study. Review existing geologic and hydrologic information (e.g., available through libraries, USGS, universities, project files, etc.) including reports, maps, aerial photos, etc.
- Conduct field reconnaissance of the area. Compare this information with any existing information.
- Conduct initial investigations and tests, as needed, to augment existing data. Initial investigations and tests may include: surface mapping; subsurface geotechnical, geologic and hydrogeologic investigations using test pits or trenches, soil or rock borings, geophysics, etc.; laboratory testing of soil and rock samples for physical and geochemical properties; and other efforts, as required to develop the facility design and supporting evaluations.

- Review results of initial investigations and tests, determine if additional work is required to support the development of the design and supporting evaluations (e.g., a higher level of field mapping, additional site specific tests, etc.), and conduct additional investigations and tests, as needed.

Examples of site characteristics which may be considered in the ultimate design are summarized below. These examples are not intended to cover all site aspects of a permit application.

1.2.4.1 Topography

Identifying the topography and surface characteristics of a site is a crucial step in designing a facility to minimize potential discharge, and to protect human health and the environment.

Tailing, dump leach and heap leach facilities, for example, located on relatively steep topography underlain by low permeability geologic formations, may benefit from a natural high rate of drainage that can occur under the tailing, dump leach or heap leach material. This is because of the presence of steep slopes and limited potential for infiltration into the underlying geologic formations. Steep topographic terrain is also generally associated with outcropping bedrock and/or shallow alluvium.

Lining of slopes steeper than 2(H):1(V) has not been practiced on an industry wide basis, especially for high slopes, due to high induced shear stresses and the possibility of failure of the underlying geologic materials. Liners can be safely designed for slightly flatter slopes ranging from 2:1 to 2.5:1 for landfills and on embankment faces. Lining of slopes steeper than 2.5:1 can be considered provided the applicant has considered the above factors, amongst others, and can demonstrate the adequacy of the design. However, at larger mining facilities, the height and steepness of the slope may be limited by 1) allowable tensile stresses in the liner, 2) the capacity of anchor trenches at the top of the slopes, and 3) the stability of any LCRS system or liners placed on top of the primary liner.

Stability can be improved by constructing a “buttress” on a flatter slope, benching or the application of fill materials to reduce the slope. Textured or sprayed-on liners may also be applicable.

Facilities located on relatively flat terrain do not, on their own, benefit from higher drainage rates and generally encounter greater soil depths to bedrock. This type of topography is generally suitable for liner application and such sites may benefit from the presence of naturally occurring, low permeability material within the vadose zone beneath the facility.

Other topographic factors to consider include the existing containment offered at the site (e.g., valley fills, canyons, within existing pits), the characteristics of the natural soils (e.g., low permeability clay, high permeability gravel), and availability of low permeability borrow soils for liner construction.

Information to evaluate topography and surface characteristics can be obtained from topographic maps, field surveys, aerial photos, USGS, Soil Conservation Service reports, etc.

1.2.4.2 Geology/Stability

To determine how geologic conditions may affect the Individual BADCT design for a facility, the applicant should extensively evaluate the associated physical, hydraulic and geochemical properties.

Specific information that may be appropriate to address, and that may be required for an APP application utilizing Individual BADCT, includes:

- Structural Geology: The degree to which geologic structures may affect the Individual BADCT design depends on the amount of reliance being placed on geologic containment. Information on major geologic structures can be identified using geologic maps, aerial photographs, and existing geologic reports, etc. Detailed onsite geologic mapping or field investigation programs are required to evaluate site specific structures. The types of structures that need to be considered include:
  - Faults must be considered in the design of any facility because they affect stability.
  - Other structures, such as anticlines and synclines which affect rock strata orientation, can influence the rate and direction of liquid migration through the vadose zone and may be important in designing leak detection systems.
  - Fracture systems in bedrock can be important in determining seepage rates and velocities, and the location of monitoring systems.
  - Various other geologic structures or discontinuities can affect the areal continuity of low permeability layers.
- Lithology: Lithology is the physical and mineralogic makeup of geologic materials, including both unconsolidated deposits (e.g., alluvium) and bedrock. Important lithologic considerations include:
  - Horizontal and vertical variations in lithology that cause permeability to vary and which can affect the degree of natural containment provided by the site.
  - Subsurface strength properties that can affect the long-term integrity of the facility (e.g., settlement potential) and seismic stability.
  - The depth to bedrock, degree of subsurface stratification, and variations in strata characteristics, can be important to the design of a facility.
  - Certain alluvial materials and rock types may, by themselves or possibly in combination with planned facility operations, possess geochemical characteristics that contribute to a reduction of discharge and/or limit pollutant migration by attenuation.

The following are representative methods for determining permeability; site specifics will determine which methodologies are applicable:

- Soil and rock classification based on subsurface lithologic logs and the use of literature or other available information to determine approximate permeability values;
- Field permeability testing, including pump tests, packer tests, and other in-situ tests;
- Laboratory grain size analyses and permeability tests;
- Borehole and surface geophysical surveys to define lithologic boundaries, and to characterize the distribution of permeability.

The effects of scale should be considered in interpreting results of permeability testing. The permeability measured in isolated borehole packer tests (e.g., local permeability) may vary from the permeability of the larger scale rock or soil mass (bulk permeability). This is due to differences in the persistence, character and interconnectivity of the fractures near the boreholes as compared to the rock mass or due to heterogeneity in soil masses. It is also important to consider possible horizontal and vertical variations in permeability (i.e., does permeability decrease or increase between varying lithologies or with depth) and how the local and regional groundwater regimes at the site are affected.

1.2.4.3 Soil Properties

Soil is generally characterized by relatively high organic content, biologic activity by roots and microorganisms, and concentration of weathering products left by leaching, evaporation or transportation. Soil properties may affect discharge from a facility by physical, chemical and biologic interaction with a pollutant(s).

Soil properties with potential to affect discharge include: type, distribution and thickness, structure, grain-size distribution, organic carbon content, chemical composition, mineralogy, cation exchange capacity, specific surface area and permeability. The applicant should evaluate any changes to soil characteristics that may result from interaction with the discharge. If soil characteristics are to be used for attenuation, the attenuation capacity of the material must be predicted using literature data, or laboratory or field tests.

In addition to analyzing the ability of soil properties to affect the quantity and/or quality of a potential discharge, shear strength must be analyzed to support stability analyses.

Soil tests and data which may be useful in an Individual BADCT determination include:

- Studies of degradation of pollutants in the soils;
- Batch or column tests to react a simulated discharge with site soils to determine attenuation capacity;
- Infiltration tests;
- Permeability tests;
- Chemical analyses (pH, EC, inorganic analyses, organic analyses);
- Material property tests (grain size analyses, moisture content, bulk density, Atterberg Limits);
- Maps of soil distribution and depth;
- Soil boring logs;
- Other pertinent soil information including reference to pollutant attenuation research.

1.2.4.4 Surface Hydrology

If surface water enters waste or processing facilities, leachate can be generated. A key to controlling leachate generation is to design, construct, operate and close facilities in a manner that minimizes the potential for contact of surface water with pollutants and excludes surface water from areas where infiltration may affect groundwater quality. The configuration of surface

water control systems for a mining facility depends on the climate and topography of the site area. Computer models may guide the assessment of surface water effects and the need for surface water control systems. County flood maps may also be helpful.

In general, surface water should be diverted around and drained from areas where facilities are located using engineered features such as diversions and/or retention structures. Diversions and/or retention structures are usually designed to minimize run-on to the facility. This preserves containment integrity and limits the amount of water that may contact process reagents or other sources of potential pollutants. In some cases, drainage controls may also be necessary to protect against inundation of the facility and nearby low areas where infiltration may contribute to pollutant transport in the vadose zone. This can typically be achieved by providing protective berms or dikes.

The design of surface water control systems is influenced by: precipitation (amount, intensity, duration, distribution), watershed characteristics (size, shape, topography, geology, vegetation), run-off (peak rate, volumes, time distribution) and degree of protection warranted.

Timely maintenance is necessary for the continued satisfactory operation of surface water control systems. The principal causes of failure of surface water diversions and/or retention structures are inadequate design peak flow capacity, channel and bank erosion, sedimentation, and excessive growth of vegetation reducing the flow capacity. It is recommended that free-draining features (e.g., ditches and dikes) be capable of handling the design peak flow and that impounding features be designed to handle the design storm volume which occurs over a duration resulting in the maximum storage requirement (ADEQ may approve other design criteria). Evaluation of these design peak flows and storm volumes is discussed in Appendix E (Engineering Design Guidance).

Data that may be presented to evaluate the need for surface water control include:

- Location of any perennial or ephemeral surface water bodies;
- Rates, volumes, and directions of surface water flow, including hydrographs, if available;
- Location of 100-year flood plain;
- Site topography;
- Historical precipitation data.

Any activities in, or discharges to, waters of the United States require 401 Certification with ADEQ, and may require notification to the Army Corps of Engineers for a 404 Permit, the EPA for a 402 Permit, and/or the respective County Flood Control District. Additional information regarding these permits and certifications is presented in Appendix F (Federal, State and Local Environmental Permits).

1.2.4.5 Hydrogeology

Site characteristics are a part of BADCT insofar as they control the quality and/or quantity of discharge before it reaches groundwater. Potentially important hydrogeologic characteristics include vadose zone properties that may help to limit discharge to the aquifer. Dilution,

attenuation and other factors that affect discharges after reaching an aquifer are not normally an inherent part of BADCT.

The exceptions, where characteristics within the aquifer may be an inherent part of BADCT, are the case of in-situ leaching of an ore body and passive containment. In-situ leaching is defined as the underground injection of solutions into an ore body in-place for the purpose of extracting the mineral commodity. In-situ leaching is discussed in Section 3.4. Passive containment is defined by regulation and is discussed in Section 1.2.5.

The remainder of this section addresses vadose zone hydrogeology that may be important to BADCT for mining operations.

Properties of the vadose zone, the unsaturated zone between the land surface and the saturated zone or maximum groundwater table (Figure 1-1), may affect the behavior of a discharge in a number of ways. For example, physical properties of the vadose zone, like the presence of high permeability layers and geologic structures (e.g., faults, fracture zones), may increase movement of a discharge to groundwater. Conversely, the presence of impervious layers and geologic structures (e.g., clay seams, strata boundaries) may retard the movement of a discharge to groundwater or cause the presence of perched water tables; fine grained layers within the zone may physically remove some types of pollutants; and the decrease in bedrock permeability with depth may reduce the possibility of discharge reaching groundwater. Also, chemical and/or geochemical reactions between the discharge and materials in the vadose zone may alter or remove some pollutants; or biodegradation due to microbial interaction with the pollutant may degrade the pollutant.

If the vadose zone consists of layers or lenses of different materials, such as stratified soil horizons or rock units, the properties of each unit must be considered separately in addition to describing the general properties of the vadose zone. The applicant should identify lateral and vertical extent of the geologic units and the type of contacts between the units (e.g., gradational, fault, unconformity, facies change). Perched water tables within the vadose zone may be a consideration.

The attenuation of chemical constituents in soil and rock is a valid consideration that can be factored into site specific evaluations. If vadose materials are to be used for attenuation, the attenuation capacity of the material must be predicted. Below is a brief description of the four major types of attenuation mechanisms. This is further explained in “Mine Waste Management,” Chapter 5 (Hutchison and Ellison, 1992).

- Physical Mechanisms: Physical mechanisms include filtration, dispersion, dilution and volatilization.

- Physiochemical Mechanisms: Physiochemical mechanisms are dependent on both physical and chemical conditions and can include adsorption and fixation.

- Chemical Mechanisms: Chemical mechanisms are dependent on the chemical interaction of an element or mineral with the soil or pore water and includes solution/precipitation of compounds or the increase/reduction in toxicity of a constituent by changing its valence state, or the removal/addition of ions by cation exchange.

- Biological Mechanisms: Biological mechanisms include biodegradation of a chemical into the basic oxidation product, bacterial consumption of the chemical or cellular uptake.

Additional data which may be submitted to characterize the vadose zone or any unit of the vadose zone for consideration as a part of BADCT design may include:

- Detailed lithologic logs of borings and/or well logs that describe:
  - rock type,
  - grain-size distribution,
  - stratigraphy,
  - type and degree of cementation, and
  - thickness of units;
- Description of the structural geology including:
  - faults,
  - fractures,
  - joints,
  - folds, and
  - bedding orientation;
- Geologic maps and cross-sections which identify:
  - stratigraphic or formation contacts, and
  - structural geology;
- Borehole geophysical logs;
- Surface geophysical surveys;
- Physical properties including:
  - horizontal and vertical permeability,
  - dispersivity,
  - porosity (primary and secondary),
- Chemical analyses (pH, EC, neutralization potential, inorganic and/or organic analyses);
- Results of batch or column tests showing quality of discharge after reacting with vadose zone material and quality of vadose zone material after reacting with discharge;
- Material property tests (grain size analyses, moisture content, Atterberg Limits, maximum density);
- Analyses of fluid movement and/or chemical transport through the vadose zone. Supportive data may be obtained from:
  - lysimeters,
  - neutron log measurements,
  - observation wells,
  - packer tests, and/or
  - analytical or numeric simulations.

Depth to groundwater or the thickness of the vadose zone may be a factor in determining BADCT. The degree of discharge reduction provided by depth will depend on several variables including: depth to the anticipated maximum groundwater elevation, the volume and rate of discharge, the properties of the pollutants in the discharge, the properties of the vadose zone, and the length of time a discharge may continue. Any considerations of depth to water as a part of BADCT will have to show how the hydrologic and geochemical characteristics of the vadose zone in conjunction with its thickness will affect discharge.

Data for evaluating depth to water may include:

- Static water elevation measurements (including date of measurement, location of well, and elevation of measuring point);
- Well hydrographs to document long term and seasonal trends;
- Location of pumping wells in vicinity of measured well;
- Well construction data (including total depth and location of perforations);
- Geophysical surveys such as seismic and resistivity.

1.2.4.6 Barriers

Hydraulic barriers (e.g., dewatered open pits, or quarries) and physical barriers (e.g., pit walls, quarries, subsidence zones, or slurry walls) can function as downgradient interceptors of groundwater flows, seepage in the unsaturated zone and/or surface flows. For example, steeply sloping surfaces, depressions or openings created by open pit or underground mining can function as downgradient interceptors of lateral seepage from a facility. Cones of depressions in groundwater or slurry walls can be used to contain in-situ leach solutions.

Except for in-situ leaching, the use of a hydraulic or physical barrier as a consideration in BADCT design is appropriate only in the context of discharge reduction prior to a pollutant reaching an aquifer. For facilities other than in-situ leaching, use of barriers to control pollutants after reaching the aquifer or to control impacted groundwater may not be used as a part of BADCT unless the physical barrier also functions as passive containment (see Section 1.2.5).

1.2.5 Passive Containment

A discharging facility at an open pit mining operation shall be deemed to satisfy BADCT requirements of A.R.S. 49-243.B.1. if the ADEQ determines that both of the following conditions are satisfied (A.R.S. 49-243.G):

1. *"The mine pit creates a passive containment that is sufficient to capture the pollutants discharged and that is hydrologically isolated to the extent that it does not allow pollutant migration from the capture zone. For purposes of this paragraph, "passive containment" means natural or engineered topographical, geological or hydrological control measures that can operate without continuous maintenance. Monitoring and inspections to confirm performance of the passive containment do not constitute maintenance.*
2. *The discharging facility employs additional processes, operating methods or other alternatives to minimize discharge."*

1.3 USING LINERS AS A PART OF THE BADCT DESIGN

A liner system may be an integral part of BADCT for a facility. Site characterization is necessary to evaluate the performance of the proposed facility both from a geotechnical and geohydrological perspective. The availability of borrow materials (e.g., low permeability materials which could be used for liner construction) and other site specific conditions, such as geologic containment, are important in developing a site specific BADCT design. The selection of liner materials should match with discharged material characteristics and impoundment design.

Geomembrane manufacturers typically provide product specifications for a product's physical properties, such as tensile properties, tear resistance, puncture resistance and others. These properties may change when a liner is exposed to different chemical and physical environments, such as when used in a pond to contain wastes.

EPA Method 9090 can be used to determine the effects chemicals in a pond will have on the physical properties of synthetic liner materials. Data from 9090 tests may be used to assist in deciding whether a given liner material is acceptable for the intended application. In the 9090 test, the liner material is immersed in the chemical environment for different time periods and at different temperatures. Comparisons of measurements of the liner's physical properties, taken periodically before and after contact with the fluid, are used to estimate the compatibility of the liner with the discharged material over time.

Geomembrane material and thickness should be selected to provide resistance to chemical action and ultraviolet radiation. The liner should also provide retention of tensile strength and maintenance of low permeability through time. The facility design should specify a liner of appropriate mechanical strength to maintain integrity of the liner system during the design life of the facility. If the expected liner life is shorter than the design life of the facility, appropriate liner replacement, repair or other contingency plans must be included. Seams of geomembranes should be routinely inspected and tested for quality control during installation. Additional information is contained in Appendix D (Construction Quality Assurance and Quality Control).

Soil liners used in ponds must also be evaluated to determine if the liner will be compatible with the discharged materials to be contained. Some organic, acidic and caustic solutions have been found to adversely affect the permeability of soil liners. Clay minerals in soil liners are subject to dissolution or may adsorb depending on the chemical environment. These reactions can lead to increased liner permeability compared to field and laboratory measurements which use water as the permeant. If the chemical environment of the pond could adversely affect a soil liner, an evaluation of these effects, which may include permeability testing using the discharged material as the permeant, should be conducted.

The applicant should explain how the material composition has guided selection of compatible control design elements. For example, an applicant should choose a liner material that resists acidic attack if a highly acidic material is anticipated. The BADCT proposal should include manufacturer's data or EPA 9090 data that confirm this feature. The life expectancy of the liner under expected leachate conditions should also be taken into account.

PART II

Prescriptive BADCT Criteria

PART 2 PRESCRIPTIVE BADCT CRITERIA

2.1 INTRODUCTION

The following design requirements (Prescriptive BADCT criteria) provide a basis for satisfying the BADCT demonstration requirement of an APP application pursuant to A.A.C. R18-9-A202(A)(5) and ARS 49-243.B.1. The concept of Prescriptive BADCT criteria involves the utilization of specific design requirements such that when an applicant submits a permit application with a design meeting the prescriptive requirements, BADCT is deemed demonstrated pending ADEQ approval. ADEQ's review typically focuses on the design plans, specifications and quality assurance/quality control documents. The major advantage in utilizing Prescriptive BADCT criteria is that potential application costs and permitting time frames can be reduced.

This part specifies design requirements for the following facility categories:

- Section 2.2 - Non-Storm Water Ponds;
- Section 2.3 - Process Solution Ponds;
- Section 2.4 - Heap Leach Pads;
- Section 2.5 - Tailing Impoundments.

Accompanying each section is an example cross section (Figures 2-1 through 2-4) showing an example of prescriptive BADCT design for each facility.

Prescriptive BADCT criteria for the subject facility categories without consideration of size restrictions include Siting; Design, Construction, and Operations; Facility Inspection; and Closure/Post-Closure. These criteria are further defined in the following sections and summarized in Tables 2-1 through 2-5.

Site specific hydrologic and vadose zone characteristics that may aid in limiting aquifer loading at a mining operation are not to be considered part of BADCT under the Prescriptive process. If site hydrologic or vadose zone characteristics are to be considered part of the system used to minimize aquifer loading, then the applicant must adhere to requirements discussed in Section 1.2, Site Characteristics, and Part 3, Individual BADCT Guidance.

The Prescriptive BADCT criteria include specific designs for many of the BADCT components such as liners, overliner drainage and protection layers, and leak collection and removal systems. As discussed in Section 1.1.2.1, engineering equivalents that provide a level of protection equal or superior to specific component designs are also acceptable. The ADEQ may require specific supporting evaluations where required, to demonstrate that the proposed component is at least as protective as the specific Prescriptive BADCT component it is replacing.

TABLE 2-1

Examples of Engineering Equivalents[1] for Various Prescriptive BADCT Design Components			
Perscriptive BADCT Component	Prescriptive BADCT Design Criteria	Example Engineering Equivalents	Potential Evaluations That May be Required to Demonstrate Engineering Equivalence
• Heap Leach Pad overliner protective/ drainage layer.	• 3/4-inch minus, well draining material with a minimum thickness of 18 inches, and corrugated perforated HDPE pipe of 3 inches or larger diameter at 20-foot spacings.	• Larger-sized drainage material may be suitable if underlain by a suitable geotextile or other geomembrane protection.	• Hydraulic calculations may be required to demonstrate expected hydraulic head. If the prescriptive liner configuration is used, the maximum and average hydraulic head over the leach pad liner must not exceed 5 and 2 feet, respectively. Greater hydraulic head may be acceptable if a more conservative liner configuration is used. • Particle size compatibility calculation may be required to demonstrate that ore will not clog the protective drainage layer and impair drainage capacity.
		• Piping configurations may be varied to suit specific slope and drainage conditions.	• Hydraulic calculations may be required to demonstrate expected hydraulic head. If the prescriptive liner configuration is used, the maximum and average hydraulic head over the leach pad liner must not exceed 5 and 2 feet, respectively. Greater hydraulic head may be acceptable if a more conservative liner configuration is used.
• Lower composite liner of a Process Solution Pond.	• Geomembrane at least 30 mils thick (60 mils for HDPE) underlain by at least 6 inches of 3/8-inch minus native or natural materials compacted to achieve a saturated hydraulic conductivity no greater than 10^{-6} cm/sec.	• Geotextile/clay geocomposite may be suitable to replace 6 inches of native or natural materials.	• Subgrade preparation must be suitable for geocomposite use. • Interface strength properties must be suitable for static and seismic loading. • Geocomposite longevity and construction issues must be addressed.
		• Geomembrane/ clay geocomposite may be suitable to replace prescriptive composite liner.	• Subgrade preparation must be suitable for geocomposite use. • Interface strength properties must be suitable for static and seismic loading. • Geocomposite longevity and construction issues must be addressed.

Examples of Engineering Equivalents[1] for Various Prescriptive BADCT Design Components			
Perscriptive BADCT Component	Prescriptive BADCT Design Criteria	Example Engineering Equivalents	Potential Evaluations That May be Required to Demonstrate Engineering Equivalence
• Process Solution Pond LCRS sump and seepage pumpback system.	• LCRS sump should be equipped with a dedicated, fluid-level activated pump large enough and capable of pumping the flow rate necessary to maintain minimal head on the bottom liner.	• LCRS sump may be designed so that it is capable of accepting an appropriate pump, with frequent monitoring utilized to determine if and when a pump is required.	• LCRS system must provide a means to remove liquid from between the upper and lower liners and maintain minimal hydraulic head on the lower liner.
		• LCRS sump may be designed to empty by gravity flow.	• LCRS system must provide a means to remove liquid from between the upper and lower liners and maintain minimal hydraulic head on the lower liner.
• Process solution transport ditch composite liner.	• Geomembrane at least 30 mils thick (60 mils for HDPE) underlain by at least 6 inches of 3/8-inch minus native or natural materials compacted to achieve a saturated hydraulic conductivity no greater than 10^{-5} cm/sec.	• Geomembrane/clay geocomposite.	• Subgrade preparation must be suitable for geocomposite use. • Geocomposite longevity and construction issues must be addressed.
		• Double geomembrane liner with sand or geosynthetic LCRS.	• Subgrade preparation must be suitable for geomembrane placement.
		• Solution transport in piping.	• None. Piping is not regulated under the APP Program.
• Heap Leach Pad or tailing facility composite liner.	• Geomembrane at least 30 mils thick (60 mils for HDPE) underlain by at least 12 inches of native or natural 3/8-inch minus materials compacted in two 6-inch lifts to achieve a saturated hydraulic conductivity no greater than 10^{-6} cm/sec.	• Double geomembrane liner with sand or geosynthetic LCRS over all or portions of the facility.	• Subgrade preparation must be suitable for geomembrane placement. • Interface strength properties must be suitable for static and seismic loading. • Drainage calculations for sand or geonet drains.

Examples of Engineering Equivalents[1] for Various Prescriptive BADCT Design Components			
Perscriptive BADCT Component	Prescriptive BADCT Design Criteria	Example Engineering Equivalents	Potential Evaluations That May be Required to Demonstrate Engineering Equivalence
• Tailing layer to limit infiltration to tailing facility protective/drainage layer.	• Tailing material should be deposited in the impoundment to form a continuous layer that limits the rate of infiltration to the protective/drainage layer. • After the deposition of a continuous layer of tailing over the protective/drainage layer, the rate of infiltration into the protective/ drainage layer and the flow capacity thereof must be adequate to limit the average and maximum hydraulic head over the liner to less than 2 and less than 5 feet, respectively. Lower heads should be maintained, where practicable.	• Compacted fine-grained soil may be placed over the protective/drainage layer prior to deposition of tailing material.	• Hydraulic calculations may be required to demonstrate expected hydraulic head over the liner. If the prescriptive liner configuration is used, head shall not exceed that specified. Greater hydraulic head may be acceptable if a more conservative liner configuration is used.
• Subgrade compaction for ponds, Heap Leach Pads, or Tailing Impoundments.	• Minimum six inches native or natural materials compacted to 95 percent maximum dry density (standard Proctor; ASTM Method D-698) within 3 percent of optimum moisture content.	• Alternative subgrade compaction specification may be suitable.	• Strength properties must be suitable for bearing load and required seismic design, and to prevent significant differential settlement.

(1) This table provides examples only. It is not intended to be all-inclusive of potential engineering equivalents or to dictate requirements for equivalency demonstrations.

2.2 NON-STORM WATER PONDS

Prescriptive BADCT criteria for Non-Storm Water Ponds include: siting considerations; design, construction and operations; facility inspection; and closure/post-closure. Non-Storm Water Ponds include lined ponds that receive seepage from tailing impoundment, waste dump and/or process areas where potential pollutant constituents in the seepage have concentrations that are relatively low (e.g., compared to process solutions) but exceed Arizona Surface Water Quality Standards. Non-Storm Water Ponds also include secondary containment structures and overflow ponds that contain process solution for short periods of time due to process upsets or rainfall events.

Ponds that continually contain process solution as a normal function of facility operations are considered Process Solution Ponds and shall be designed in accordance with criteria discussed in Section 2.3.

2.2.1 Siting Criteria

The Prescriptive BADCT criteria are designed to eliminate the need for considering site hydrogeology and vadose zone characteristics, and minimize the need for consideration of other site factors. Therefore, design and operational components of Prescriptive BADCT described in this part are intended to be conservative so that they are protective at most sites. Even though the Prescriptive BADCT process does not require full site characterization, certain siting criteria must be addressed as part of the application to confirm that conditions unsuitable for Prescriptive BADCT do not occur. Basic siting criteria are identified in the following sections.

The prescriptive design appropriately applied is expected to result in an aquifer loading that will result in conformance with AWQS or will not further degrade the quality of any aquifer that already violates the AWQS at the point of compliance (A.R.S. 49-243.B.3). By law, demonstration of conformance with AWQS at the point of compliance, or demonstration of no further degradation in the quality of any aquifer that already violates an AWQS, is still required to obtain an APP permit, but a simplified approach to this demonstration may be used.

2.2.1.1 Site Characterization

Site characterization information can be gathered from data obtained during the initial site evaluation, exploration or development. Site reconnaissance, test pits and exploration drilling may serve, where possible, a dual role of reserve evaluation and also identification and evaluation of foundation materials and potential areas for borrow materials. Site characterization must: 1) provide surface water drainage information; and 2) delineate areas unsuitable for facility location based on surface and groundwater conditions or potential geologic hazards. Shallow groundwater conditions, if present, must be documented for design consideration, and may prohibit the use of Prescriptive BADCT.

2.2.1.2 Surface Water Control

The control of surface water is a design factor for the Prescriptive BADCT process. Surface water run-on from upstream watershed areas that the Non-Storm Water Pond is not designed to capture should be diverted around the pond area. The minimum design storm is the 100-year, 24-hour storm event unless another regulatory program requires a larger design storm or other hydrologic criteria due to potential threat to human life (Appendix E, Engineering Design Guidance).

Erosion of diversion structures should be controlled by placing rip-rap at ditch entrances, exits and other erosion sensitive points. Alternative acceptable methods of erosion control include suitable channel geometry, soil cementation, limiting watershed areas (e.g., through the use of additional diversion trenches and dikes), slope down-drain pipes, energy dissipaters (e.g., gabions, rip-rap), retention basins to attenuate peak flows, etc.

If facilities are proposed within the 100-year flood plain, drainage controls must in addition to the above, be designed to protect the facilities from damage or flooding for 100-year peak streamflows.

Lakes, wetlands, springs and other surface waters must be identified in order to safely design the facility (minimize run-on) and minimize any unnecessary discharge to surface waters. Knowing the location of surface waters also will inform the applicant if other agencies must be contacted (see Appendix F, Federal, State and Local Environmental Permits).

2.2.1.3 Geologic Hazards

Potential geologic hazards should be considered present if conditions prone to the following occur at the proposed facility location:

- Excessive or differential subsidence;
- Collapsing soils;
- Landslides;
- Strong seismic shaking;
- Other potential ground instability.

If present, conditions prone to these hazards must be documented for consideration in facility design. Geologic hazards will not preclude the use of Prescriptive BADCT provided that such hazards do not have a significant potential to impact the effectiveness of the Prescriptive BADCT design (considering mitigating engineering measures, if any).

2.2.2 Design, Construction and Operations Criteria

2.2.2.1 Solution/Effluent Characterization

Liner selection is determined in part by the chemical compatibility of the liner material and the nature of the liquids/solids to be contained. An analysis is to be made of all potential contained constituents, including organic compounds. Characteristics of importance are outlined in Section 1.2.1.

2.2.2.2 Capacity and Storage Design

Capacity design for Non-Storm Water Ponds must include: 1) the volume of precipitation that may inflow to the pond as a result of the design storm (discussed in Section 2.2.1.2); 2) the estimated volume of other inflows such as seepage; and 3) additional volume adequate to result in two (2) feet

of freeboard while containing these inflows. Ponds should be designed so that there will not be excessive erosion at the low point of the freeboard if the storage capacity is ever exceeded. The applicant must minimize the storage time of process solutions in a Non-Storm Water Pond.

2.2.2.3 Site Preparation

Site preparation includes clearing the area of vegetation, grubbing and grading as well as embankment and subgrade preparation. Supporting surface slopes and foundation are to be stable and structurally sound. Subsurface materials that affect the integrity and/or stability of the final pond design are to be excavated and replaced with appropriately compacted fill. Side slopes are to be no steeper than two (2) feet horizontal run to one (1) foot vertical rise (2:1 slope). Side slopes and bottoms are to consist of, at a minimum, six inches 3/8 inch minus native or natural materials compacted to 95% maximum dry density (standard Proctor; ASTM Method D-698) within 3% of the optimum moisture content. The compacted subgrade surface should be finished flat and smooth (e.g., by rolling) and inspected prior to geomembrane installation to remove protruding particles, if present.

2.2.2.4 Liner Specifications

Non-Storm Water Ponds will be designed with a single geomembrane of at least 30 mil thickness (exception - 60 mil if proposing HDPE). Geomembranes are to be selected based on a compatibility analysis considering liner composition and thickness, depth of fluid stored, chemical composition of solutions to be stored and foundation conditions. In areas that are exposed to the sun, the geomembrane must be certified UV resistant. The geomembrane is to be

secured in an engineered anchor trench. The anchor trench is to be at least two feet deep and two feet wide. The geomembrane must extend across the bottom of the trench and at least one foot up the outside trench wall. The anchor trench backfill must consist of minus 1/2 inch material compacted in 6-inch lifts at 95% of maximum dry density according to the standard Proctor compaction effort (ASTM Method D-698).

Ditches that flow only to Non-Storm Water Ponds shall be lined with, at a minimum, a 30-mil geomembrane (except 60-mil if proposing HDPE) ponds over a minimum 6-inch layer of 3/8-inch minus native or natural material compacted to 95% maximum dry density (standard Proctor; ASTM Method D-698) within 3% of the optimum moisture content. The compacted soil layer should be finished flat and smooth (e.g., by rolling) and inspected prior to geosynthetic installation to remove protruding particles, if present. ADEQ may accept a lower level of compaction for the soil component of the ditch liner where 95% compaction is not practicably achievable and a lower level of compaction will satisfy performance goals. Piping is an alternative that can be used to transport leachate/solutions to Non-Storm Water Ponds. Piping is not regulated under the APP program.

Geomembranes are not to be used as a structural component in the design. Geomembranes are to be installed over a prepared subgrade. Operations must be conducted in a manner that does not result in unnecessary mechanical stress on the geomembrane.

Standard Number 54 (NSF, 1993), Flexible Membrane Liners, covers geomembranes used in the retention of water and containment of pollutants or chemicals in an environmentally acceptable manner. The successful application of geomembranes covered by this standard depend upon site evaluation, design, material selection, construction, operation and maintenance. The applicant shall refer and adhere to this standard for geomembranes as applicable to the subject facility. Other sources of information on geomembranes include ASTM standards and current technical journals.

A Quality Assurance/Quality Control Program must be developed and implemented that meets or exceeds the geomembrane manufacturer's minimum requirements including inspection procedures, field testing (including limits for test failure and a description of the corrective procedures to be used upon failure), laboratory testing and repair of seams during installation and final inspection of the completed liner for functional integrity. Geomembranes are to be installed in compliance with manufacturer's seaming and seam testing recommendations for installation. Quality assurance/ quality control programs must also address site and subgrade preparation. Additionally, guidelines for the operation and maintenance of the liner system are to be formulated and implemented for the life of the facility. Appendix D (Construction Quality Assurance and Quality Control) includes additional guidance on the development of a Quality Assurance/Quality Control Program.

2.2.2.5 Stability Design

Where the pond design includes a large embankment, the stability under static and seismic loading conditions must be considered and may need to be evaluated using quantitative stability analysis techniques.

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Appendix E provides additional guidance on stability design and the required factors of safety.

Static stability analyses should indicate a factor of safety of at least 1.3. Seismic stability analyses should be based on the Maximum Probable Earthquake (MPE) unless a larger design earthquake is warranted due to potential threat to human life (Appendix E). The MPE is the largest earthquake with a 100-year return interval. The MPE should be evaluated considering all known active faults within a distance of 200 kilometers. Seismic stability analyses may include pseudostatic and deformation analyses methods, as further discussed in Appendix E. When deformation analyses are required, the displacement predicted shall be within the following limits unless engineering evaluations are provided to demonstrate that larger displacements will not jeopardize containment integrity:

- Deformations not affecting geomembranes shall be less than or equal to 1 foot.
- Deformations affecting geomembranes shall be less than or equal to 6 inches.

The pond design shall incorporate necessary measures such that static and seismic stability criteria are achieved.

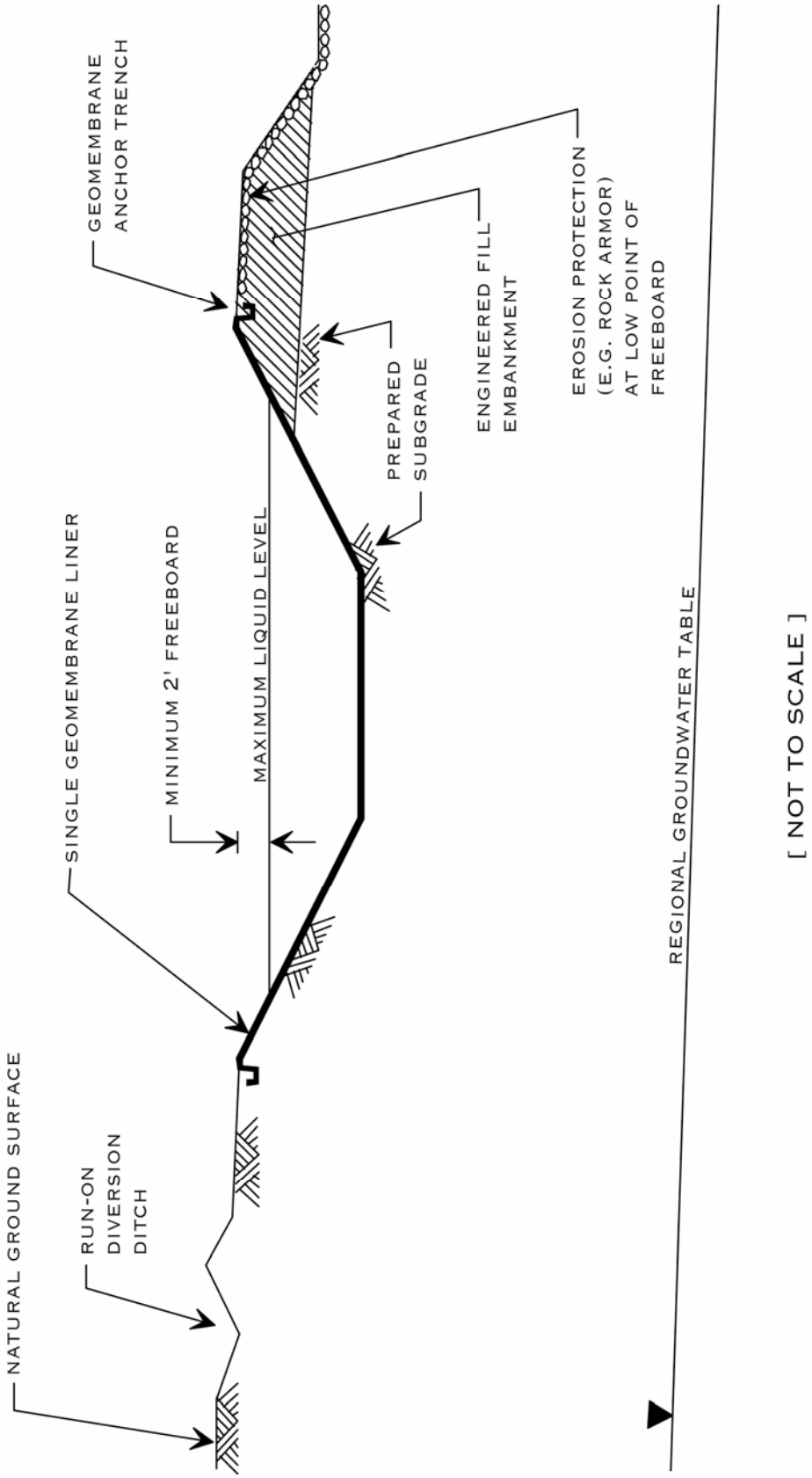
Figure 2-1 shows a cross section of an example non-storm water pond prescriptive BADCT design.

2.2.3 Facility Inspection Criteria

The objective of facility inspections by the permittee is early detection of component damage or degeneration and of potential discharges from the facility so that steps can be taken to prevent, reduce or stop discharges. Facility inspection is to be instituted at the time of pond construction. Thereafter, facility inspection is to be conducted on a quarterly basis and after major storm or surface water events. At a minimum, facility inspection will include: 1) a visual survey of the pond site to evaluate liner integrity, and 2) physical inspection of the pond to ensure the design capacity is not exceeded. Further detail regarding inspections that may be required can be obtained through pre-application consultation with ADEQ staff. Records of inspection shall remain on-site or at other approved locations for a period negotiated with ADEQ.

The applicant must propose and draft a Contingency Plan that will be approved by ADEQ. The plan shall be implemented in the event of an accidental discharge from the facility. The plan will identify the discharge discovery and notification procedure, the general clean-up procedures for chemical discharges, leaks, spills, or other releases from the solution management system, and reporting procedures. In the event of a discharge from a Non-Storm Water Pond, solutions contained within the pond are to be sampled to determine what has been discharged. At a minimum, sampled solutions are to be tested for pH, primary metals, and cyanide when present (Total and Weak Acid Dissociable). Liquids pumped from the pond shall be treated and disposed of in a manner consistent with all appropriate requirements, or recycled back into the facility operational system.

FIGURE 2-1 - EXAMPLE OF NON-STORM WATER POND CROSS-SECTION
(PRESCRIPTIVE BADCT DESIGN)



[NOT TO SCALE]

If a Non-Storm Water Pond is used for overflow protection, the contingency plan must include procedures to either neutralize leachate/solutions prior to discharge or pumpback overflow so that residence time in the Non-Storm Water Pond can be limited.

2.2.4 Closure/Post-Closure Criteria

A closure/post-closure strategy must be drafted and submitted to ADEQ for preliminary approval as part of the APP application. The applicant must still comply with the requirements of A.A.C. R18-9-A209(B) prior to formal closure. Ordinarily, for permanent closure of Non-Storm Water Ponds, contained solutions shall be disposed of by physical removal or containment and evaporation. If physical removal is the chosen option, and if the solution is to be discharged from a point source to "waters of the U.S." (which requires a NPDES Permit under the CWA), solutions must be treated or neutralized to meet surface water quality standards. Any residues or sludges remaining following discharge must be analyzed for applicable waste listing prior to disposal at an approved site.

The following are example elements of a closure strategy (A.R.S. 49-243.A.8) for a Prescriptive BADCT Non-Storm Water Pond:

- Excavated Ponds
  - Removal and appropriate disposal of solid residue(1) on the liner.
  - Inspection of synthetic liner for evidence of holes, tears or defective seams that could have leaked.
  - If there is no evidence of past leakage, the synthetic liner can be folded in place and covered by filling the excavation or removed for appropriate disposal elsewhere.
  - Where inspection reveals presence of one or more holes or tears or defective seams, the synthetic liner is to be removed, and the underlying surface inspected for visual signs of impact. The ADEQ may require sampling and analysis of the underlying material to determine whether it poses a threat to groundwater quality.
  - If required, conduct soil remediation to prevent groundwater impact.
  - After the residual soil conditions are approved by ADEQ, the synthetic liner material can be placed back into the excavation or be removed for appropriate disposal elsewhere, and the excavation backfilled.
  - The filled area will be graded to drain surface run-off and minimize precipitation infiltration.
  - Capping of the pond area with a low permeability cover may also be part of a closure strategy if it will achieve further discharge reduction that maintains compliance with AWQS at the point of compliance.
- Bermed Ponds

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(1) Residue is defined as any solids collected on the liner to a thickness of greater than 1/4-inch or which can readily be removed by physical means such as sweeping or high pressure water sprays.

- Closure as for excavated ponds with the following exception: the synthetic liner will not be buried within the pond area and must be appropriately disposed of elsewhere.

TABLE 2-2

NON-STORM WATER PONDS [1] Prescriptive BADCT		
Category	Element	Prescriptive Criteria
2.2.1 Siting Criteria	2.2.1.1 Site Characterization - Although Prescriptive BADCT does not require full site characterization prior to development of a mining area nor allow for site specific characteristics to be used as components of BADCT, certain siting considerations must be addressed. Obtain data during initial site evaluation, exploration, and/or development, as required to apply and implement the Prescriptive BADCT design.	1) Evaluate site characteristics such as surface water hydrology and general site suitability. 2) Determine if shallow groundwater conditions exist, and document if present. 3) Determine if geologic hazards exist.
	2.2.1.2 Surface Water Control - Identify and define floodplains, and need to protect the integrity of the pond from surface run-on/run-off.	1) Surface water run-on from upstream watershed areas that the pond is not designed to capture should be diverted around the pond. Minimum design storm is the 100-year, 24-hour storm event unless a larger design storm is required by another regulatory program or due to potential threat to human life (Appendix E). 2) The facility and related diversion structures must be designed to avoid excessive erosion. 3) If located within the 100-year floodplain, the facility must be protected from damage or flooding from 100-year peak streamflows.
	2.2.1.3 Geologic Hazards - Identify geologic hazards at the site. Potential geologic hazards should be considered present if conditions prone to the following occur: • Excessive or differential subsidence. • Collapsing soils. • Landslides. • Strong seismic shaking. • Other potential ground instability.	1) If present, conditions prone to geologic hazards must be documented for consideration in facility design. 2) Potential geologic hazards must be mitigated such that they do not have significant potential to impact the effectiveness of the Prescriptive BADCT design.
2.2.2 Design, Construction and Operations Criteria	2.2.2.1 Solution/Effluent Characterization - Identify expected chemical and physical characteristics of potential contents to ensure compatibility with the design.	1) Chemical characteristics of contained constituents, including organic compounds. 2) Physical characteristics of contained constituents. 3) Temperature of contained constituents. 4) Other parameters as needed for liner design.

NON-STORM WATER PONDS [1] Prescriptive BADCT		
Category	Element	Prescriptive Criteria
	2.2.2.2 Capacity and Storage Design - Determine the design flood event and estimated inflow seepage.	1) Pond must contain adequate volume for: • The design storm volume. • The estimated volume of other inflows. • Additional two (2) feet freeboard. 2) Applicant to operate pond to minimize duration of fluid storage.
	2.2.2.3 Site Preparation - Prepare site for pond and embankment construction.	1) Grub and grade the area. 2) Excavate and replace unsuitable material. 3) Subgrade to consist of, at a minimum, six inches of 3/8 minus native or natural materials compacted to 95% maximum dry density (standard Proctor; ASTM D-698). 4) Side slopes no steeper than 2:1. 5) Subgrade surface to be smoothed (e.g., rolled) and inspected prior to geomembrane liner installation.
	2.2.2.4 Liner Specifications - Design and install pond components.	1) Single geomembrane of at least 30 mil thickness or 60 mil if HDPE. 2) Geomembrane certified to be UV resistant for areas exposed to sunlight. 3) Geomembrane secured by an engineered trench. 4) Ditches that carry leachate/solution only to Non-Storm Water Ponds will be designed with a single geomembrane of at least 30 mil thickness, or 60 mil if proposing HDPE, over a minimum of 6 inches of 3/8-inch minus native or natural material compacted to 95% maximum dry density (Standard Proctor; ASTM D-698), unless such compaction is not practicable and a lower compaction is approved by ADEQ. Piping may be used as an alternative to ditches. Piping is not regulated under the APP Program. 5) Activities over geomembrane to be conducted in a manner that minimizes potential for damage. 6) Quality Assurance/Quality Control program developed and implemented for liner installation, operation and maintenance.
	2.2.2.5 Stability Design - Design to Provide Stability Under Static and Potential Seismic Loading Conditions	1) Stability analysis may be required for ponds that include a large embankment. 2) The minimum recommended static factor of safety is 1.3. 3) The MPE is the design earthquake for seismic stability analyses, where required, unless a larger design earthquake is warranted due to potential threat to human life (Appendix E).

NON-STORM WATER PONDS [1] Prescriptive BADCT		
Category	Element	Prescriptive Criteria
		4) When deformation analyses are required (Appendix E), the displacement predicted shall be within the following limits unless engineering evaluations are provided to demonstrate that larger displacement will not jeopardize containment integrity: • Deformations not affecting a geomembrane shall be less than or equal to 1 foot. • Deformations affecting a geomembrane shall be less than or equal to 6 inches.
2.2.3 Facility Inspection Criteria	Inspections to alert permittee of component damage or degeneration, and of potential discharges.	1) Inspections to be instituted at the time of pond construction and on a quarterly basis thereafter or after a major storm or surface water event. 2) Inspection to include visual survey to evaluate liner integrity and physical inspection to ensure pond design capacity is not exceeded. 3) Develop and implement Contingency Plan approved by ADEQ that specifies permittee courses of action to be taken in the event of an accidental discharge. 4) Inspection records are to remain on-site or at other approved locations for a period negotiated with ADEQ.
2.2.4 Closure/Post-Closure Criteria	Facility Closure/Post-Closure - Contain and control discharges after closure.	1) Closure/Post-Closure Plan to be submitted to ADEQ for approval. 2) The following are example elements of a closure strategy (A.R.S. 94-243.A.8) for a Prescriptive BADCT Non-Storm Water Pond: • Excavated Ponds: - Removal and appropriate disposal of solid residue on the geomembrane. - Geomembrane inspection for evidence of holes, tears or defective seams that could have leaked. - Where there is no evidence of leakage, the geomembrane can be folded in place and buried or removed for appropriate disposal elsewhere. - Where geomembrane inspection reveals potential leaks, inspect soil for visual signs of impact. The ADEQ may require soil sampling and analysis to determine the potential for threat to groundwater quality.

NON-STORM WATER PONDS [1] Prescriptive BADCT		
Category	Element	Prescriptive Criteria
		- Conduct soil remediation if required to prevent groundwater impact. - After the residual soil conditions are approved by ADEQ the geomembrane can be buried in the pond or be removed for appropriate disposal elsewhere, and the pond excavation backfilled. - The filled area will be graded to minimize infiltration. - Capping of the pond area with a low permeability cover may also be part of a closure strategy if it will achieve further discharge reduction that maintains compliance with AWQS at the point of compliance. • Bermed Ponds: - Same closure procedures as for excavated ponds, except geomembranes will not be buried in place and must be appropriately disposed of elsewhere.

(1) Non-Storm Water Ponds include ponds that receive seepage from tailing impoundments, waste dumps, and/or process areas where potential pollutant constituents in the seepage have concentrations that are relatively low (e.g., compared to process solutions) but exceed Arizona surface water quality standards. Non-Storm Water Ponds also include secondary containment structures and overflow ponds that contain process solution for short periods of time due to process upsets or rainfall events. Ponds that continually contain process solution as a normal function of facility operations shall be considered Process Solution Ponds and shall be designed in accordance with criteria discussed in Table 2-3.

2.3 PROCESS SOLUTION PONDS

Process Solution Ponds include pregnant or barren solution ponds and recycle ponds. Overflow ponds that contain process solution for short periods of time due to process upsets or rainfall events shall be considered Non-Storm Water Ponds and designed in accordance with criteria discussed in Section 2.2 of this manual. Overflow ponds that continually contain process solution as a normal function of facility operations are be considered Process Solution Ponds and designed in accordance with criteria discussed in this section.

2.3.1 Siting Criteria

The Prescriptive BADCT criteria are designed to eliminate the need for considering site hydrogeology and vadose zone characteristics and minimize the need for consideration of other site factors. Therefore, design and operational components of Prescriptive BADCT described in this part are intended to be conservative so that they are protective enough for most sites. Even though the Prescriptive BADCT process does not require full site characterization, certain siting criteria must be addressed as part of the application to confirm that conditions unsuitable for Prescriptive BADCT do not occur at the facility location. Basic siting criteria are identified in the following sections.

The prescriptive design appropriately applied is expected to result in an aquifer loading that will result in conformance with AWQS or will not further degrade the quality of any aquifer that already violates the AWQS at the point of compliance (A.R.S. 49-243.B.3). By law, demonstration of conformance with AWQS at the point of compliance, or demonstration of no further degradation in the quality of any aquifer that already violates an AWQS, is still required to obtain an APP permit, but a simplified approach to this demonstration may be used.

2.3.1.1 Site Characterization

Site characterization information can be gathered from data obtained during the initial site evaluation, exploration or development. Site reconnaissance, test pits and exploration drilling may serve, where possible, a dual role of reserve evaluation and also identification and evaluation of foundation materials and potential areas for borrow materials. Site characterization must: 1) provide surface water drainage information; and 2) delineate areas unsuitable for facility location based on surface and groundwater conditions or potential geologic hazards. Any shallow groundwater conditions must be documented for design consideration, and may prohibit the use of Prescriptive BADCT.

2.3.1.2 Surface Water Control

The control of surface water is a design factor for the Prescriptive BADCT process. Surface water run-on from upstream watershed areas should be diverted around Process Solution Ponds unless it will be beneficially used and the facility is designed to accommodate it. The minimum design storm is the 100-year, 24-hour storm event unless another regulatory program requires a larger design storm or other hydrologic criteria due to potential threat to human life (Appendix E).

Erosion of diversion structures should be controlled by placing rip-rap at ditch entrances, exits and other erosion sensitive points. Alternative acceptable methods of erosion control include suitable channel geometry, soil cementation, limiting watershed areas (e.g., through the use of additional diversion trenches and dikes), slope down-drain pipes, energy dissipaters (e.g., gabions, rip-rap), retention basins to attenuate peak flows, etc.

If facilities are proposed within the 100-year flood plain, drainage controls must in addition to the above, be designed to protect the facilities from damage or flooding for 100-year peak streamflows.

Lakes, wetlands, springs and other surface waters must be identified to safely design the facility (minimize run-on) and minimize any unnecessary surface water discharge. Knowing the location of surface waters also will inform the applicant if other agencies must be contacted (see Appendix F).

2.3.1.3 Geologic Hazards

Potential geologic hazards should be considered present if conditions prone to the following occur at the proposed facility location:

- Excessive or differential subsidence;
- Collapsing soils;
- Landslides;
- Strong seismic shaking;
- Other potential ground instability.

If present, conditions prone to these hazards must be documented for consideration in facility design. Geologic hazards will not preclude the use of Prescriptive BADCT provided that such hazards do not have a significant potential to impact the effectiveness of the Prescriptive BADCT design (considering mitigating engineering measures, if any).

2.3.2 Design, Construction and Operations Criteria

2.3.2.1 Solution/Effluent Characterization

Chemical compatibility of the liner material and nature of the liquids/solids to be contained determine in part liner selection. An analysis is to be made of all potential contained constituents, including organic compounds. Characteristics of importance are outlined in Section 1.2.1.

2.3.2.2 Capacity and Storage Design

Capacity design for Process Solution Ponds must include: 1) design operating solution volume and other inflows such as seepage; 2) the volume of precipitation that may inflow to the pond as a result of the design storm (discussed in Section 2.3.1.2); and 3) additional volume adequate to result in two (2) feet of freeboard while containing these inflows. In addition, pond capacity must be such that, in the event of system failure or planned shut down, circulation can be reestablished using auxiliary power, or process solutions can be contained for the period of system failure or down time. Where an overflow pond is provided to contain excess solution (e.g., a Non-Storm Water Pond), the capacity of the overflow pond can be used in conjunction with the Process Solution Pond volume to satisfy the specified design capacity. Ponds should be designed so that there will not be excessive erosion at the low point of the freeboard in the event that the pond capacity is ever exceeded.

2.3.2.3 Site Preparation

Site preparation includes clearing the area of vegetation, grubbing and grading as well as embankment and subgrade preparation. Supporting surface slopes and foundation are to be stable and structurally sound. Subsurface materials that affect the integrity and/or stability of the final pond design are to be excavated and replaced with appropriately compacted fill. Side slopes are to be no steeper than two (2) feet horizontal run to one (1) foot vertical rise (2:1 slope). Subgrade is to consist of, at a minimum, six inches of native or natural materials compacted to 95% maximum dry density (standard Proctor; ASTM Method D-698) within 3% of the optimum moisture content. The six inches of subgrade is in addition to the low permeability soil component of the composite liner specified in Section 2.3.2.4, Liner Specifications, if the compacted subgrade material does not satisfy the liner hydraulic conductivity requirements.

2.3.2.4 Liner Specifications

Process Solution Ponds will be designed with a double liner system and leak collection and removal system (LCRS) between the two liners. Geomembranes are to be selected based on a compatibility analysis considering liner composition and thickness, depth of fluid stored, chemical composition of solutions to be contained and foundation conditions. The lower liner will be a composite liner consisting of a single geomembrane of at least 30 mil thickness (exception - 60 mil if proposing HDPE) over a minimum six inches of 3/8 inch minus native or

natural materials compacted to achieve a saturated hydraulic conductivity no greater than 10^{-6} cm/sec. This is typically achieved by compacting to over 90% maximum dry density (standard Proctor; ASTM Method D-698) within 3% of the optimum moisture content. The upper liner will be a single geomembrane of at least 30 mil thickness (exception - 60 mil if proposing HDPE). In areas exposed to the sun, the geomembrane must be certified UV resistant. The geomembranes are to be secured in an engineered anchor trench. All anchor trenches are to be at least two feet deep and two feet wide. The geomembrane must extend across the bottom of the trench and at least one foot up the outside trench wall. The anchor trench backfill must consist of minus 1/2 inch material compacted in 6-inch lifts at 95% of maximum dry density according to the standard Proctor compaction effort (ASTM Method D-698).

Liners for leachate/solution ditches that convey process/recycle solutions to and from Process Solution Ponds should be a composite consisting of a minimum 30-mil geomembrane (except 60-mil for HDPE) directly overlying a minimum of 6 inches of 3/8-inch minus native or natural materials compacted to achieve a saturated hydraulic conductivity no greater than 10^{-5} cm/sec except for ditches that flow only to Non-Storm Water Ponds. Ditches that flow only to Non-Storm Water Ponds are addressed in Section 2.2.2.4. The compacted soil component of the Process Solution Pond and ditch liners should be finished flat and smooth (e.g., by rolling) and inspected prior to geomembrane installation to remove protruding particles, if present. Piping is an alternative that can be used to transport solution to/from Process Solution Ponds. Piping is not regulated under the APP program.

Geomembranes are not to be used as a structural component in the design. Geomembranes are to be installed over a prepared subgrade. Operations must be conducted in a manner that does not result in unnecessary mechanical stress on the geomembrane.

Standard Number 54 (NSF, 1993), Flexible Membrane Liners, covers geomembranes used in the retention of water and containment of pollutants or chemicals in an environmentally acceptable manner. The successful application of geomembranes covered by this standard depend upon site evaluation, design, material selection, construction, operation and maintenance. The applicant shall refer and adhere to this standard for geomembranes as applicable to the subject facility. Other sources of information on geomembranes include ASTM standards and current technical journals.

A Quality Assurance/Quality Control Program must be developed and implemented that meets or exceeds the geomembrane manufacturer's minimum requirements including inspection procedures, field testing (including limits for test failure and a description of the corrective procedures to be used upon failure), laboratory testing, and repair of seams during installation and final inspection of the completed liner for functional integrity. Geomembranes are to be installed in compliance with manufacturer's seaming and seam testing recommendations for installation. Quality Assurance/Quality Control Programs must also address site and subgrade preparation, and installation and testing of the low permeability soil component of liners. Additionally, guidelines for the operation and maintenance of the liner system are to be formulated and implemented for the life of the facility. Appendix D includes additional guidance on the development of a Quality Assurance/Quality Control Program.

(2-20) PRESCRIPTIVE CRITERIA

2.3.2.5 Leak Collection and Removal System (LCRS)

The LCRS shall be designed to result in minimal hydraulic head on the lower liner and provide for the collection and removal of liquids from between the upper and lower liner. The LCRS shall consist of a layer of sand, gravel, geonet or other permeable material located between the two (2) geomembranes. Materials used as drainage media must achieve a flow capacity equivalent to a 1-foot-thick layer with a saturated hydraulic conductivity of 10^{-2} cm/sec or greater and 3 percent slope, and must be chemically compatible with the solutions stored in the pond. The LCRS must drain to a sump designed to facilitate liquid extraction and leak monitoring. A three (3) percent minimum slope is required to promote drainage to a collection sump. In the case of large ponds, a leak collection pipe system may be required as part of the LCRS. The leak collection system should be equipped with a dedicated, automatic, fluid-level activated pump large enough and capable of pumping the necessary flow rates in order to maintain minimal head on the bottom liner. An example engineering equivalent that may be acceptable is to design the sump with the ability to install a pump, and perform frequent monitoring to determine if and when a pump is necessary to maintain minimal head on the bottom liner.

2.3.2.6 Stability Design

Where the pond design includes a large embankment, the stability under static and seismic loading conditions is to be considered and possibly evaluated using quantitative stability analysis techniques.

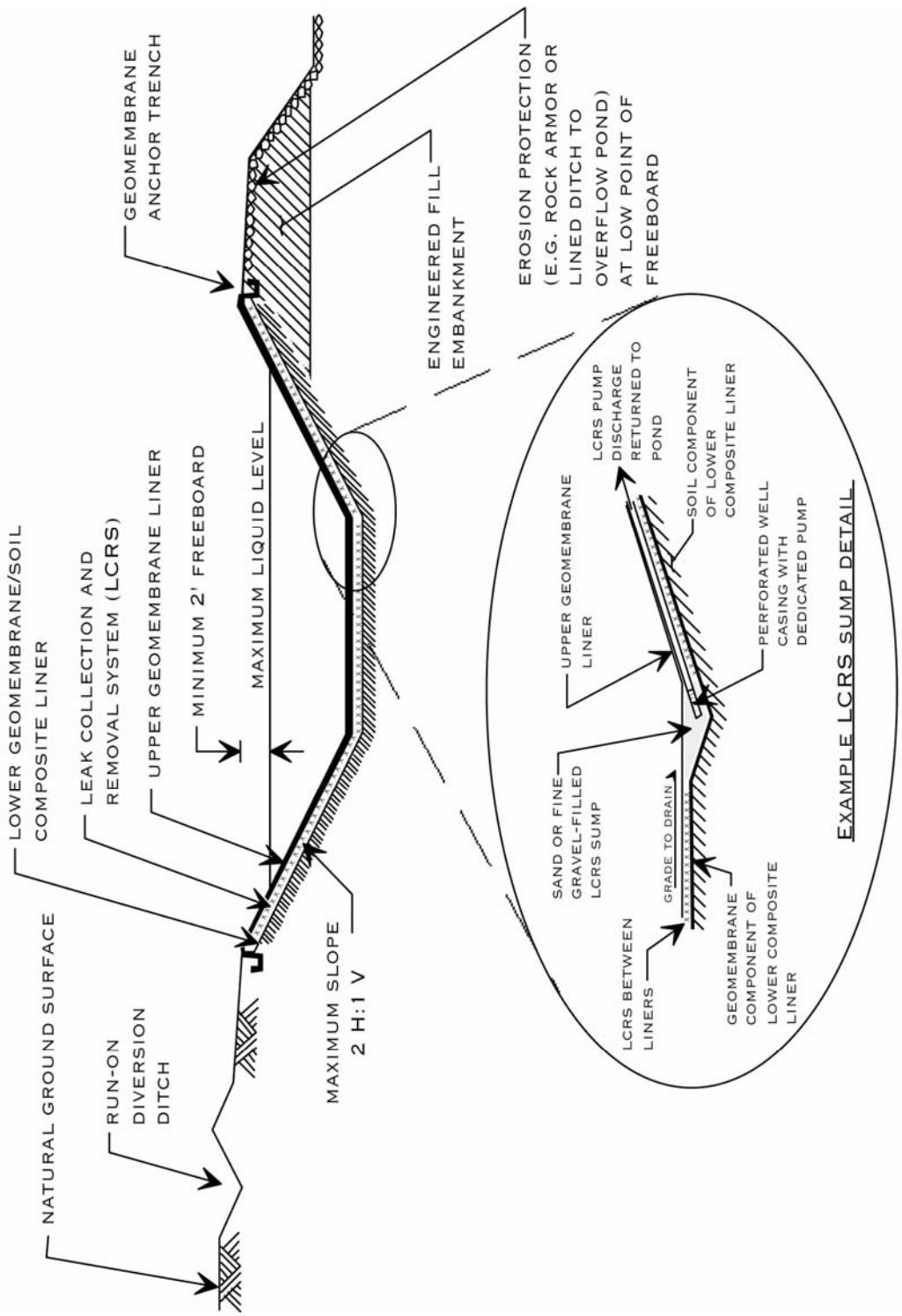
Appendix E provides additional guidance on stability design and the required factors of safety.

Static stability analyses should indicate a factor of safety of at least 1.3. Seismic stability analyses should be based on the Maximum Probable Earthquake (MPE) unless a larger design earthquake is warranted due to potential threat to human life (Appendix E). The MPE is the largest earthquake with a 100-year return interval. The MPE should be evaluated considering all known active faults
within a distance of 200 kilometers. Seismic stability analyses may include pseudostatic and deformation analysis methods as further discussed in Appendix E. When deformation analyses are required, the displacement predicted shall be within the following limits unless engineering evaluations are provided to demonstrate that larger displacements will not jeopardize containment integrity:

- Deformations not affecting a geomembrane shall be less than or equal to 1 foot.
- Deformations affecting a geomembrane shall be less than or equal to 6 inches.

The pond design shall incorporate necessary measures such that static and stability criteria are achieved.
Figure 2-2 shows an example cross section of a process solution pond prescriptive BADCT design.

FIGURE 2-2 - EXAMPLE OF PROCESS SOLUTION POND CROSS-SECTION
(PRESCRIPTIVE BADCT DESIGN)



[NOT TO SCALE]

2.3.3 Facility Inspection Criteria

The objective of facility inspections by the permittee is early detection of component damage or degeneration and of potential discharges from the facility so that steps can be taken to prevent, reduce or stop discharges. Facility inspection is to be instituted at the time of pond construction. Thereafter, facility inspection is to be conducted on a quarterly basis and after major storm or surface water events. At a minimum, facility inspection will include: 1) a visual survey of the pond site to evaluate liner integrity, and 2) physical inspection of the pond to ensure the design capacity is not exceeded. The LCRS pump and liquid level in the sump will be checked weekly. Further detail regarding inspections that may be required can be obtained through pre-application consultations with ADEQ staff. Records of inspection shall remain on-site or at other approved locations for a period negotiated with ADEQ.

The applicant must propose and draft a Contingency Plan that will be approved by ADEQ. The plan shall be implemented in the event of an accidental discharge from the facility. The plan will identify the discharge discovery and notification procedure, the general clean up procedures for chemical discharges, leaks, spills or other releases from the solution management system, and reporting procedures. In the event of leachate/solution discharge, leachate/solutions contained within the pond are to be sampled to determine what has been discharged. At a minimum, sampled leachate/solutions are to be tested for pH, metals contained within the process solution, and cyanide when present (Total and Weak Acid Dissociable). Solutions pumped from the LCRS shall be treated and disposed of in a manner consistent with all appropriate requirements or recycled back into the facility operational system.

2.3.4 Closure/Post-Closure Criteria

A closure/post-closure strategy must be drafted and submitted to ADEQ for preliminary approval as part of the APP application. The applicant must still comply with the requirements of A.A.C. R18-9-A209(B) prior to formal closure. Ordinarily, for permanent closure of Process Solution Ponds, contained solutions shall be disposed of by physical removal or containment and evaporation. If physical removal is the chosen option, and if the solution is to be discharged from a point source to“waters of the U.S.” (which requires a NPDES Permit) solutions must be treated or neutralized to meet surface water quality standard. Any residues or sludges remaining following discharge must be analyzed for applicable waste listing prior to disposal at an approved site.
The following are example elements of a closure strategy (A.R.S. 49-243.A.8) for a Prescriptive BADCT Process Solution Pond:

- Excavated Ponds
- Removal and appropriate disposal of solid residue(1) on the upper liner.

(1) Residue is defined as any solids collected on the liner to a thickness of greater than 1/4-inch or which can readily be removed by physical means such as sweeping or high pressure water sprays.

- Inspection of the lower liner and underlying soils for any visual signs of liner damage, liner defects, or impact by leakage through the lower liner. The ADEQ may require sampling and analysis to determine whether any of these soils pose a threat to groundwater quality.
    - If required, conduct soil remediation to prevent groundwater impact.
    - After the residual soil conditions are approved by ADEQ, the liner and LCRS can be placed back into the excavation or be removed for appropriate disposal elsewhere, and the excavation backfilled.
    - The filled area will be graded to drain surface run-off and minimize precipitation infiltration.
    - Capping of the pond area with a low permeability cover may also be part of a closure strategy if it will achieve further discharge reduction that maintains compliance with AWQS at the point of compliance.

- Bermed Ponds
    - Closure as for excavated ponds with the following exception: The liner and LCRS will not be buried within the impoundment area and must be appropriately disposed of elsewhere

TABLE 2-3

PROCESS SOLUTION PONDS(1) Prescriptive BADCT		
Category	Element	Prescriptive Criteria
2.3.1 Siting Criteria	2.3.1.1 Site Characterization - Although Prescriptive BADCT does not require full site characterization prior to development of a mining area nor allow for site specific characteristics to be used as components of BADCT, certain siting considerations must be addressed. Obtain data during initial site evaluation, exploration, and/or development, as required to apply and implement the Prescriptive BADCT design.	1) Evaluate site characteristics such as surface water hydrology and general site suitability. 2) Determine if shallow groundwater conditions exist, and document if present. 3) Determine if geologic hazards exist.
	2.3.1.2 Surface Water Control - Identify and define floodplains, and need to protect the integrity of the pond from surface run-on/run-off.	1) Surface water run-on from upstream watershed areas that the pond is not designed to capture should be diverted around the pond. Minimum design storm is the 100-year, 24-hour storm event unless a larger design storm is required by another regulatory program or due to potential threat to human life (Appendix E). 2) The facility and related diversion structures must be designed to avoid excessive erosion. 3) If located within the 100-year floodplain, the facility must be protected from damage or flooding from 100-year peak streamflows.
2.3.2 Design, Construction and Operations Criteria	2.3.1.3 Geologic Hazards - Identify geologic hazards at the site. Potential geologic hazards should be considered present if conditions prone to the following occur: • Excessive or differential subsidence. • Collapsing soils. • Landslides. • Strong seismic shaking. • Other potential ground instability.	1) If present, conditions prone to geologic hazards must be documented for consideration in facility design. 2) Potential geologic hazards must be mitigated such that they do not have significant potential to impact the effectiveness of the Prescriptive BADCT design.
	2.3.2.1 Solution/Effluent Characterization - Identify expected chemical and physical characteristics of potential contents to ensure compatibility with the design.	1) Chemical characteristics of contained constituents, including organic compounds. 2) Physical characteristics of contained constituents. 3) Temperature of contained constituents. 4) Other parameters as needed for liner design.

PROCESS SOLUTION PONDS(1) Prescriptive BADCT		
Category	Element	Prescriptive Criteria
	2.3.2.2 Capacity and Storage Design - Determine the design flood event and estimated inflow seepage.	1) Pond must contain adequate volume for: • The design storm volume. • The design operating solution volume of other inflows. • Additional capacity such that, in the event of system failure or planned shut-down, drained down solution can be contained for the period of shutdown until solution circulation can be re-established, using auxiliary power if necessary. • Additional two (2) feet freeboard. 2) Where an overflow pond (e.g., Non-Storm Water Pond) is provided, its capacity can be used in conjunction with the Process Solution Pond to satisfy the above volume criteria.
	2.3.2.3 Site Preparation - Prepare site for pond and embankment construction.	1) Grub and grade the area. 2) Excavate and replace unsuitable material. 3) Subgrade to consist of, at a minimum, six inches of native or natural materials compacted to 95% maximum dry density (standard Proctor; ASTM D-698). 4) Side slopes no steeper than 2:1.

PROCESS SOLUTION PONDS(1) Prescriptive BADCT		
Category	Element	Prescriptive Criteria
	2.3.2.4 Liner Specifications - Design and install pond components.	1) Double liner system and LCRS between the two liners. 2) Lower liner will be a composite liner consisting of a single geomembrane of at least 30 mil thickness or 60 mil if proposing HDPE over, a minimum, six inches of 3/8-inch minus native or natural materials compacted to achieve a saturated hydraulic conductivity no greater than 10^{-6} cm/sec. 3) Upper liner will be a single geomembrane of at least 30 mil thickness or 60 mil if proposing HDPE. 4) Geomembrane to be certified UV resistant for areas exposed to sunlight. 5) Geomembrane secured by an engineered trench. 6) Ditches that convey process/recycle solutions to the Process Solution Pond will be designed with a composite liner consisting of a single geomembrane of at least 30 mil minimal thickness or 60 mil if proposing HDPE over a minimum 6 inches of 3/8-inch minus native or natural materials compacted to achieve a saturated hydraulic conductivity no greater than 10^{-5} cm/sec. 7) Soil liner component surfaces to be smooth (e.g., rolled) and inspected prior to geomembrane installation.
		8) Activities over geomembrane to be conducted in a manner that minimizes potential for damage. 9) Quality Assurance/Quality Control program developed and implemented for liner installation, operation and maintenance.

PROCESS SOLUTION PONDS(1) Prescriptive BADCT		
Category	Element	Prescriptive Criteria
	2.3.2.5 Leachate Collection and Removal System (LCRS)	1) LCRS consists of a drainage layer of sand, gravel, geonet or other permeable material located between the two geomembranes. 2) The LCRS shall be designed to result in minimal hydraulic head on the lower liner and provide for removal of liquids between the upper and lower liners. 3) Drainage layer media must achieve a flow capacity equivalent to a 1-foot-thick layer with a 3 percent slope and hydraulic conductivity of 10^{-2} cm/sec or greater. Materials used must be chemically compatible with the solutions stored in the pond. 4) A three (3) percent minimum slope is required to promote drainage to a collection sump. 5) LCRS must be connected to a sump for solution extraction and leachate monitoring. 6) A leak collection pipe system will be required as part of the LCRS. 7) LCRS should be equipped with a dedicated, automatic, fluid-level activated pump capable of pumping the necessary flow rate in order to maintain minimal head on the bottom liner. The capability to install a pump, plus frequent monitoring to determine if and when a pump is necessary to maintain minimal head above the bottom liner, may also be acceptable.
	2.3.2.6 Stability Design - Design to provide stability under static and potential seismic loading conditions.	1) Stability analysis may be required for ponds that include a large embankment. 2) The minimum recommended static factor of safety is 1.3. 3) The MPE is the design earthquake for seismic stability analyses, where required, unless a larger design earthquake is warranted due to potential threat to human life (Appendix E).
		4) When deformation analyses are required (Appendix E), the displacement predicted shall be within the following limits unless engineering evaluations are provided to demonstrate that larger displacement will not jeopardize containment integrity: • Deformations not affecting a geomembrane shall be less than or equal to 1 foot. • Deformations affecting a geomembrane shall be less than or equal to 6 inches.

PROCESS SOLUTION PONDS(1) Prescriptive BADCT		
Category	Element	Prescriptive Criteria
2.3.3 Facility Inspection Criteria	Inspections to alert permittee of component damage or degeneration, and of potential discharges.	1) Inspections to be instituted at the time of pond construction and on a quarterly basis thereafter or after a major storm or surface water event. 2) Inspection to include visual survey to evaluate liner integrity and physical inspection to ensure pond design capacity is not exceeded. 3) LCRS pump and liquid level in the LCRS sump are to be checked weekly. 4) Develop and implement Contingency Plan approved by ADEQ that specifies permittee courses of action to be taken in the event of an accidental discharge from the facility. 5) Inspection records are to remain on-site or at other approved locations for a period negotiated with ADEQ.
2.3.4 Closure/Post-Closure Criteria	Facility Closure/Post-Closure - Contain and control discharges after closure	1) Closure/Post-Closure Plan to be submitted to ADEQ for approval. 2) The following are example elements of a closure strategy (A.R.S. 49-243.A.8) for a Prescriptive BADCT Process Solution Pond: • Excavated Ponds: - Removal and appropriate disposal of solid residue on the upper geomembrane. - Inspection of the lower geomembrane and underlying soils for any visual signs of liner damage, liner defects, or impact by leakage through the lower liner. The ADEQ may require soil sampling and analysis to determine the potential for threat to groundwater quality.

PROCESS SOLUTION PONDS(1) Prescriptive BADCT		
Category	Element	Prescriptive Criteria
		- Conduct soil remediation if required to prevent groundwater impact. - After the residual soil conditions are approved by ADEQ, the geomembranes can be buried or be removed for appropriate disposal elsewhere, and the pond excavation backfilled. - The filled area will be graded to minimize infiltration. - Capping of the pond area with a low permeability cover may also be part of a closure strategy if it will achieve further discharge reduction that maintains compliance with AWQS at the point of compliance. • Bermed Ponds: - Same closure procedures as for excavated ponds, except geomembranes will not be buried in place and must be appropriately disposed of elsewhere.

(1) Process Solution Ponds include pregnant or barren solution ponds and recycle ponds. Overflow ponds that contain process solution for short periods of time due to process upsets or rainfall events are considered Non-Storm Water Ponds and designed in accordance with criteria discussed in Table 2-2. Overflow ponds that continually contain process solution as a normal function of facility operations shall be considered Process Solution Ponds and designed in accordance with criteria discussed in this table.

2.4 HEAP LEACH PADS

Heap Leach Pads are lined leaching facilities utilized in both the base and precious metals industry. In heap leaching, ore is placed on pads for exposure to leaching solutions. The leaching solution is applied to the heap (e.g., sprayed or dripped) and a pregnant solution collected. The metal content is extracted from the pregnant solution through processing. The prescriptive criteria discussed below provide the minimum guidelines for the design, operation and closure of dedicated synthetically lined Heap Leach Pads for both base and precious metals. Prescriptive criteria for Process Solution Ponds associated with heap leach facilities are discussed in Section 2.3.

2.4.1 Siting Criteria

The Prescriptive BADCT criteria are designed to eliminate the need for considering site hydrogeology and vadose zone characteristics, and minimize the need for consideration of other site factors. Therefore, design and operational components of Prescriptive BADCT described in this part are intended to be conservative so that they are protective enough for most sites. Even though the Prescriptive BADCT process does not require full site characterization, certain siting criteria must be addressed as part of the application to confirm that conditions unsuitable for Prescriptive BADCT do not occur at the facility location. Basic siting criteria are identified in the following sections.

The prescriptive design appropriately applied is expected to result in an aquifer loading that will result in conformance with AWQS or will not further degrade the quality of any aquifer that already violates the AWQS at the point of compliance (A.R.S. 49-243.B.3). By law, demonstration of conformance with AWQS at the point of compliance, or demonstration of no further degradation in the quality of any aquifer that already violates an AWQS, is still required to obtain an APP permit, but a simplified approach to this demonstration may be used.

2.4.1.1 Site Characterization

Site characterization information can be gathered from data obtained during the initial site evaluation, exploration or development. Site reconnaissance, test pits and exploration drilling may serve, where possible, a dual role of reserve evaluation and also identification and evaluation of foundation materials and potential areas for borrow materials. Site characterization must: 1) provide surface water drainage information; and 2) delineate areas unsuitable for facility location based on surface and groundwater conditions or potential geologic hazards. Shallow groundwater conditions, if present, must be documented for design consideration, and may prohibit the use of Prescriptive BADCT.

2.4.1.2 Surface Water Control

The control of surface water is a design factor for the Prescriptive BADCT process. Surface water run-on from upstream watershed areas should be diverted around heap leach facilities. The minimum design storm is the 100-year, 24-hour storm event unless another regulatory program requires a larger design storm or other hydrologic criteria, or due to potential threat to human life (Appendix E).

Erosion of diversion structures should be controlled by placing rip-rap at ditch entrances, exits and other erosion sensitive points. Alternative acceptable methods of erosion control include suitable channel geometry, soil cementation, limiting watershed areas (e.g., through the use of additional diversion trenches and dikes), slope down-drain pipes, energy dissipaters (e.g., gabions, rip-rap), retention basins to attenuate peak flows, etc.

If facilities are proposed within the 100-year flood plain, drainage controls must in addition to the above, be designed to protect the facilities from damage or flooding for 100-year peak streamflows.

Lakes, wetlands, springs and other surface waters must be identified in order to safely design the facility (minimize run-on) and minimize any unnecessary discharge to surface waters. Knowing the location of surface waters also will inform the applicant if other agencies must be contacted (see Appendix F).

2.4.1.3 Geologic Hazards

Potential geologic hazards should be considered present if conditions prone to the following occur at the proposed facility location:

- Excessive or differential subsidence;
- Collapsing soils;
- Landslides;
- Strong seismic shaking;
- Other potential ground instability.

If present, conditions prone to these hazards must be documented for consideration in facility design. Geologic hazards will not preclude the use of Prescriptive BADCT provided that such hazards do not have a significant potential to impact the effectiveness of the Prescriptive BADCT design (considering mitigating engineering measures, if any).

2.4.2 Design, Construction and Operations Criteria

The extent of surface preparation required is dependent on the characteristics of the liner, the topography of the site and the height/weight of the ore which will be placed on the pad.

Topography and ore pile height can also effect Heap Leach Pad stability, solution drainage (and hydrostatic head) over the liner, and solution containment at the pad perimeter. The prescriptive design of some BADCT components discussed in the following sections may not be applicable for pile heights exceeding 200 feet, or leach pad locations that are very flat (i.e., less than 2% slope).

2.4.2.1 Solution and Waste Characterization

The nature of the liquids/solids to be contained determine in part the chemical compatibility of the liner material. An analysis is to be made of all potential leachate constituents, including organic compounds. Characteristics of importance are outlined in Section 1.2.1.

2.4.2.2 Site Preparation

Site preparation includes clearing the area of vegetation, grubbing and grading as well as embankment and subgrade preparation.

The leach pad foundation and perimeter and interior divider berms are to be stable and structurally sound. Subsurface materials that affect the integrity and/or stability of the final pad design are to be excavated and replaced with appropriately compacted fill. Subgrade is to consist of, at a minimum, six inches native or natural materials compacted to 95% maximum dry density (standard Proctor; ASTM Method D-698) within 3% of the optimum moisture content. The six inches of subgrade is in addition to the low permeability soil component of the composite liner specified in Section 2.4.2.3, Liner Specifications, if the compacted subgrade material does not satisfy the liner hydraulic conductivity requirements.

2.4.2.3 Liner Specifications

Heap Leach Pads will be designed with 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. This is typically achieved by compacting to over 90% maximum dry density (standard Proctor; ASTM Method D-698) within 3% of the optimum moisture content. The compacted low permeability soil surface should be finished flat and smooth (e.g., by rolling) and inspected prior to geomembrane installation to remove protruding particles, if present. In areas exposed to the sun, the geomembrane must be certified UV resistant. Geomembranes are to be selected based on a compatibility analysis using an evaluation of the liner composition and thickness, height of the heap, chemical composition of the solutions to be contained and foundation characteristics. The geomembrane is to be secured in an engineered anchor trench. The anchor trench is to be at least two feet deep and two feet wide. The geomembrane must extend across the bottom of the trench and at least one foot up the outside trench wall. The anchor trench backfill must consist of minus 1/2 inch material

compacted in 6-inch lifts at 95% of maximum dry density according to the standard Proctor compaction effort (ASTM Method D-698).

The geomembrane will be covered by a protective/drainage layer of 3/4 inch minus, well draining material with a minimum thickness of 18 inches, and corrugated perforated HDPE pipe of 3-inch or larger diameter at 20 foot spacing. Materials used in the protective drainage layer shall not deteriorate when in contact with leachate solutions. If the protective/drainage layer is installed separately, the entire thickness should be placed in a single lift with a track-dozer or other low ground pressure procedure, and precautions must be taken to prevent geomembrane damage. If an engineering equivalent is to be used for overliner drainage, the engineering equivalent shall provide for removal of solution from the base of the ore pile such that the maximum (midway between drainpipes) and average hydrostatic head over the geomembrane are less than 5 and 2 feet, respectively.

Liners for solution ditches that convey process solutions from the Heap Leach Pad should be a composite consisting of a minimum 30-mil geomembrane (except 60-mil if proposing HDPE) directly overlying a minimum of 6 inches of 3/8-inch minus native or natural materials compacted to achieve a saturated hydraulic conductivity no greater than 10^{-5} cm/sec. The compacted soil layer should be finished flat and smooth (e.g., by rolling) and inspected prior to geomembrane installation to remove protruding particles, if present.

Geomembranes are not to be used as structural components in the design. Geomembranes are to be installed over a prepared subgrade. Operations must be conducted in a manner that does not result in unnecessary mechanical stress on the geomembrane (e.g., piping should be adequately supported with liner protection beneath supports where geomembrane is exposed).

Standard Number 54 (NSF, 1993), Flexible Membrane Liners, covers geomembranes used in the retention of water and containment of pollutants or chemicals in an environmentally acceptable manner. The successful application of geomembranes covered by this standard depend upon site evaluation, design, material selection, construction and operation and maintenance. The applicant shall refer and adhere to this standard for geomembranes as applicable to the subject facility. Other sources of information on geomembranes include ASTM standards and current technical journals.

Quality Assurance/Quality Control Program must be developed and implemented that meets or exceeds the geomembrane manufacturer's requirements including inspection procedures, field testing (including limits for test failure and a description of the corrective procedures to be used upon failure), laboratory testing and inspection and repair of seams during installation and final inspection
of the completed liner for functional integrity. Liners are to be installed in compliance with manufacturers seaming and seam testing recommendations for installation. Quality Assurance/Quality Control Programs must also address site and subgrade preparation, and installation and testing of the low permeability soil component of liners. Additionally, guidelines for the operation and maintenance of the liner system are to be formulated and

implemented for the life of the heap leach facility. Appendix D includes additional guidance on the development of a Quality Assurance/Quality Control Program.

2.4.2.4 Perimeter Containment

Edges of the Heap Leach Pad with potential to receive precipitation run-off or solution drain down should be designed with a perimeter containment berm. The geomembrane liner should continue high enough onto the perimeter containment berm to safely contain the design storm. This can usually be accommodated by using a perimeter berm that is lined with geomembrane to a level that is 2 feet higher than the adjacent toe of the ore pile, provided the following ore pile setbacks are observed.

BOTTOM LIFT HEIGHT (feet)	REQUIRED MINIMUM SETBACK (TOE OF ORE TO TOP OF GEOMEMBRANE) (feet)
10	5
20	10
50	15

Actual capacity needs for perimeter containment usually vary with location on the pad. The pad design should specifically consider required capacity for operating flows plus storm flows at the lowest area of the pad perimeter and other representative locations along the pad perimeter. Where appropriate, leach pad perimeter capacity calculations should include conservative assumptions of potential for drainage constrictions due to talus or washouts at the ore pile toe.

Solution collection ditches in which the liner is contiguous with the leach pad may be used to satisfy perimeter containment requirements.

2.4.2.5 Stability Design

The heap shall be evaluated and designed to provide stability of the heap under static and potential seismic loading conditions. Shear strengths should be based on site-specific material evaluations and not on published values. Stability evaluations should be conducted for ultimate pile heights, intermediate construction stages, and maximum anticipated phreatic surfaces that may be critical with regard to stability.

Static stability analyses should indicate a factor of safety of at least 1.3. Seismic evaluations should be based on the Maximum Probable Earthquake (MPE). The MPE is the largest earthquake with a 100-year return interval. The MPE should be evaluated considering all known active faults within a distance of 200 kilometers. Seismic stability analyses may include

pseudostatic and deformation analysis methods, as further discussed in Appendix E. When deformation analyses are required, the displacement predicted shall be within the following limits unless engineering evaluations are provided to demonstrate that larger displacements will not jeopardize containment integrity:

- Deformations not affecting geomembranes shall be less than or equal to 1 foot.
- Deformations affecting geomembranes shall be less than or equal to 6 inches.

Analytical methodology and design considerations are further discussed in Appendix E, Stability Design Guidance.

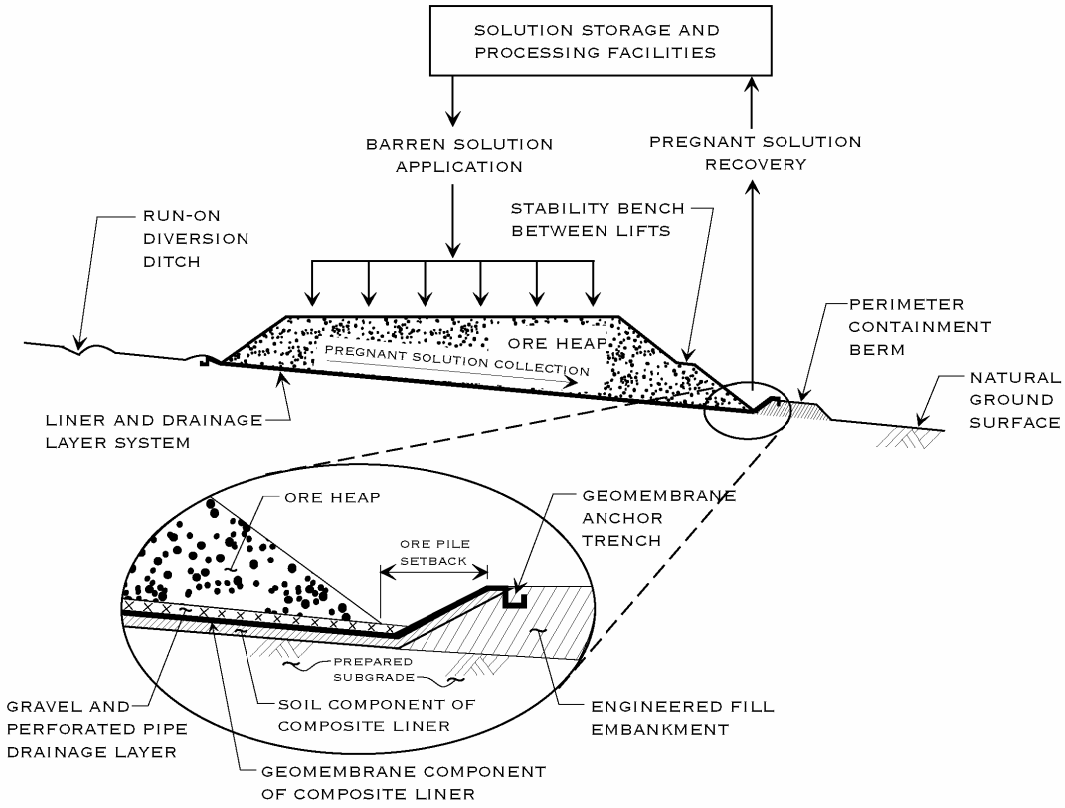
Figure 2-3 shows an example cross section of a heap leach pad prescriptive BADCT design.

2.4.3 Facility Inspection Criteria

The objective of facility inspections by the permittee is early detection of component damage or degeneration and of potential discharges from the facility so that steps can be taken to prevent, reduce or stop discharges. Facility inspection is to be instituted at the time of pad construction. Thereafter, facility inspection is to be conducted on a quarterly basis and after major storm or surface water events. At a minimum, facility inspection will include: 1) a visual survey of the facility to evaluate its overall integrity and 2) physical inspection of the facility to ensure pad design capacity and safety criteria are not exceeded. Additionally, all conveyance ditches that convey solutions from or to the Heap Leach Pad are to be included in the facility inspection to evaluate the integrity of the structures over time. Pre-application consultation with ADEQ staff and Section 3.2.4 of this manual can provide further detail regarding inspections that may be required. Records of inspection shall remain on-site or at other approved locations for a period negotiated with ADEQ.

The applicant must propose and draft a Contingency Plan that will be approved by ADEQ. The plan shall be implemented in the event of an accidental discharge from the facility. The plan will identify the discharge discovery and notification procedure, the general clean up procedures for chemical discharges, leaks, spills, or other releases from the solution management system, and reporting procedures. In the event of an uncontrolled discharge from a Heap Leach Pad, solutions contained within the pad are to be sampled to determine what has been discharged. At a minimum, sampled solutions are to be tested for pH, metals contained within process solutions, and cyanide when present (Total and Weak Acid Dissociable).

FIGURE 2-3 - EXAMPLE OF HEAP LEACH PAD CROSS-SECTION
(PRESCRIPTIVE BADCT DESIGN)



[NOT TO SCALE]

2.4.4 Closure/Post-Closure Criteria

A closure/post-closure strategy must be drafted and submitted to ADEQ for preliminary approval as part of the APP application. The applicant must still comply with the requirements of A.A.C. R18-9-A209(B) prior to formal closure. The closure strategy shall eliminate, to the greatest extent practicable, any reasonable probability of further discharge from the facility and of exceeding Aquifer Water Quality Standards at the applicable point of compliance. Closure will include: characterization and neutralization or rinsing (see Section 3.2.5 for further information) of all spent ore or waste residues; elimination of free liquids; recontouring of heaps as necessary to eliminate ponding; and, if necessary, to prevent the formation of leachate that may adversely impact aquifer water quality after closure, capping with a low permeability layer.

Measures to provide long-term physical stability of the Heap Leach Pad are part of BADCT to the extent that they may affect aquifer loading. Measures in addition to those discussed above may be necessary to stabilize the Heap Leach Pad to be resistant to water and wind erosion. Such erosion can effect the physical stability in the long-term or lead to sediment transport that can discharge pollutants to the aquifer by indirect surface water pathways to groundwater.

Physical stabilization measures that will normally be an integral part of Prescriptive BADCT include:

- Drainage controls upgradient of Heap Leach Pads will normally be left in place at the time of closure to protect the Heap Leach Pad from washout.
- The Heap Leach Pad surface can be stabilized with vegetation or by leaving durable rock on the pile slopes.

TABLE 2-4

HEAP LEACH PADS Prescriptive BADCT		
Category	Element	Prescriptive Criteria
2.4.1 Siting Criteria	2.4.1.1 Site Characterization - Although Prescriptive BADCT does not require full site characterization prior to development of a mining area nor allow for site specific characteristics to be used as components of BADCT, certain siting considerations must be addressed. Obtain data during initial site evaluation, exploration, and/or development, as required to apply and implement the Prescriptive BADCT design.	1) Evaluate site characteristics such as surface water hydrology and general site suitability. 2) Determine if shallow groundwater conditions exist, and document if present. 3) Determine if geologic hazards exist.
	2.4.1.2 Surface Water Control - Identify and define floodplains, and need to protect the integrity of the Heap Leach Pad from surface run-on/run-off.	1) Surface water run-on from upstream watershed areas should be diverted around the facility. Minimum design storm is the 100-year, 24-hour storm event unless a larger design storm is required by another regulatory program or due to potential threat to human life (Appendix E). 2) The facility and related diversion structures must be designed to avoid excessive erosion. 3) If located within the 100-year floodplain, the facility must be protected from damage or flooding from 100-year peak streamflows.
2.4.2 Design, Construction and Operations Criteria	2.4.1.3 Geologic Hazards - Identify geologic hazards at the site. Potential geologic hazards should be considered present if conditions prone to the following occur: • Excessive or differential subsidence. • Collapsing soils. • Landslides. • Strong seismic shaking. • Other potential ground instability.	1) If present, conditions prone to geologic hazards must be documented for consideration in facility design. 2) Potential geologic hazards must be mitigated such that they do not have significant potential to impact the effectiveness of the Prescriptive BADCT design.
	2.4.2.1 Solution and Waste Characterization - Identify expected chemical and physical characteristics of potential contents to ensure compatibility with the design.	1) Chemical characteristics of contained constituents, including organic compounds. 2) Physical characteristics of contained constituents. 3) Temperature of contained constituents. 4) Other parameters as needed for liner design.

HEAP LEACH PADS Prescriptive BADCT		
Category	Element	Prescriptive Criteria
	2.4.2.2 Site Preparation - Prepare site for pad construction	1) Grub and grade the area. 2) Excavate and replace unsuitable material. 3) Subgrade to consist of, at a minimum, six inches of native or natural materials compacted to 95% maximum dry density (standard Proctor; ASTM D-698).
	2.4.2.3 Liner Specifications - Design and install pad components	1) Composite liner consisting of a single geomembrane of at least 30 mil thickness or 60 mil if proposing 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 no greater than 10^{-6} cm/sec. Soil component surface to be smoothed (e.g., rolled) and inspected prior to geomembrane installation. 2) Geomembrane selected based on an evaluation of the liner composition and thickness, height of the heap and foundation characteristics. 3) Geomembrane certified to be UV resistant for areas to be exposed to sunlight. 4) Geomembrane secured by an engineered trench. 5) Activities over geomembrane to be conducted in a manner that minimizes potential for damage. 6) Geomembrane will be covered by a protective/drainage layer of 3/4-inch minus, well draining material with a minimum thickness of 18 inches, and corrugated, perforated HDPE pipe of 3-inch or larger diameter at 20-foot spacing. Materials used in the protective drainage layer shall not deteriorate when in contact with leachate solutions. If an engineering equivalent is used for the protective/drainage layer, it shall provide for removal of solution from the base of the ore pile such that the average and maximum hydraulic head over the liner are less than 2 feet and 5 feet, respectively. 7) Ditches that convey solution to and from the Heap Leach Pad will be designed with a composite liner consisting of a single geomembrane of at least 30 mil thickness or 60 mil if proposing HDPE over a minimum 6 inches of 3/8-inch minus native or natural materials compacted to achieve a saturated hydraulic conductivity no greater than 10^{-5} cm/sec. Soil component surface to be smooth (e.g., rolled) and inspected prior to geomembrane installation.
		8) Quality Assurance/Quality Control program developed and implemented for liner installation, operation and maintenance.

HEAP LEACH PADS Prescriptive BADCT		
Category	Element	Prescriptive Criteria
	2.4.2.4 Perimeter Containment - Design pad perimeter to contain solution and storm run-off.	1) Edges of the Heap Leach Pad that may receive precipitation run-off or solution draindown from the ore pile shall be designed and constructed with a lined perimeter berm sized to safely control and convey run-off from the design storm event. Perimeter berm design should specifically consider required containment capacity for operating flows plus storm flows at the lowest area and other representative locations of the pad perimeter.
	2.4.2.5 Stability Design - Design to provide stability under static and potential seismic loading conditions.	1) Analyze and design to provide stability of the heap under static and potential seismic loading conditions. 2) Shear strengths to be based on site-specific material evaluations. 3) Recommended minimum static factor of safety is 1.3. 4) Seismic stability evaluations should be based on the MPE. 5) When deformation analyses are required (Appendix E), the displacement predicted shall be within the following limits unless engineering evaluations are provided to demonstrate that larger displacements will not jeopardize containment integrity: • Deformations not affecting a geomembrane shall be less than or equal to 1 foot. • Deformations affecting a geomembrane shall be less than or equal to 6 inches.
2.4.3 Facility Inspection Criteria	Inspections to alert permittee of component damage or degeneration, and of potential discharges	1) Inspections to be instituted at the time of pad construction and on a quarterly basis thereafter or after a major storm or surface water event. 2) Inspection to include visual survey to evaluate overall facility integrity and physical inspection of pad design capacity. 3) Develop and implement Contingency Plan approved by ADEQ that specifies permittee courses of action to be taken in the event of an accidental discharge from the facility. 4) Inspection records are to remain on-site or at other approved locations for a period negotiated with ADEQ.

HEAP LEACH PADS Prescriptive BADCT		
Category	Element	Prescriptive Criteria
2.4.4 Closure/Post-Closure Criteria	Prevent, contain or control discharges after closure	1) Closure/Post-Closure Plan to be submitted to ADEQ for approval. Closure Plan to eliminate, to the greatest extent practicable, any reasonable probability of further discharges and of exceeding AWQS at the point of compliance. 2) Neutralization or rinsing of all spent ore or waste residues. 3) Elimination of free liquids. 4) Stabilization of heap materials. 5) Recontouring of the heap as necessary to eliminate ponding.

2.5 TAILING IMPOUNDMENTS

Prescriptive BADCT criteria for a typical Tailing Impoundment design for precious metal operations is discussed herein. However, this design is not representative of base metal operations. On the other hand, if an applicant chooses an impoundment for base metal tailing, that Tailing Impoundment would meet the Prescriptive BADCT criteria. Tailing Impoundments receive and contain finely ground ore residue with residual leach or chemical solutions in the form of a thickened slurry from process facilities.

2.5.1 Siting Criteria

The Prescriptive BADCT criteria are designed to eliminate the need for considering site hydrogeology and vadose zone characteristics, and minimize the need for consideration of other site factors. Therefore, design and operational components of Prescriptive BADCT described in this part are intended to be conservative so that they are protective enough for most sites. Even though the Prescriptive BADCT process does not require full site characterization, certain siting criteria must be addressed as part of the application to confirm that conditions unsuitable for Prescriptive BADCT do not occur at the facility location. Basic siting criteria are identified in the following sections.

The prescriptive design appropriately applied is expected to result in an aquifer loading that will result in conformance with AWQS or will not further degrade the quality of any aquifer that already violates the AWQS at the point of compliance (A.R.S. 49-243.B.3). By law, demonstration of conformance with AWQS at the point of compliance, or demonstration of no further degradation in the quality of any aquifer that already violates an AWQS, is still required to obtain an APP permit, but a simplified approach to this demonstration may be used.

2.5.1.1 Site Characterization

Site characterization information can be gathered from data obtained during the initial site evaluation, exploration or development. Site reconnaissance, test pits and exploration drilling may serve, where possible, a dual role of reserve evaluation and also identification and evaluation of foundation materials and potential areas for borrow materials. Site characterization must: 1) provide surface water drainage information; and 2) delineate areas unsuitable for facility location based on surface and groundwater conditions or potential geologic hazards. Shallow groundwater conditions, if present, must be documented for design consideration and may prohibit the use of Prescriptive BADCT

2.5.1.2 Surface Water Control

The control of surface water is a design factor for the Prescriptive BADCT process. Surface water run-on from upstream watershed areas should be diverted around Tailing Impoundments. Run-off from upstream areas that are not diverted must be considered in the facility's design capacity.

For Prescriptive BADCT Tailing Facilities, the minimum design storm ranges from the 100-year, 24-hour storm event to the Maximum Probable Flood (Appendix E). Considerations discussed in Appendix E, requirements of other regulatory programs, and negotiation between the applicant and ADEQ determine the criteria for each application.
Erosion of diversion structures should be controlled by placing rip-rap at ditch entrances, exits and other erosion sensitive points. Acceptable alternative methods of erosion control include suitable channel geometry, soil cementation, limiting watershed areas (e.g., through the use of additional diversion trenches and dikes), slope down-drain pipes, energy dissipaters (e.g., gabions, rip-rap), retention basins to attenuate peak flows, etc.

If facilities are proposed within the 100-year flood plain, drainage controls must in addition to the above, be designed to protect the facilities from damage or flooding for 100-year peak streamflows.

Lakes, wetlands, springs and other surface waters must be identified in order to safely design the facility (minimize run-on) and minimize any unnecessary discharge to surface waters. Knowing the location of surface waters also will inform the applicant if other agencies must be contacted (see Appendix F).

2.5.1.3 Geologic Hazards

Potential geologic hazards should be considered present if conditions prone to the following occur at the proposed facility location:

- Excessive or differential subsidence;
- Collapsing soils;
- Landslides;
- Strong seismic shaking;
- Other potential ground instability.

If present, conditions prone to these hazards must be documented for consideration in facility design. Geologic hazards will not preclude the use of Prescriptive BADCT provided that such hazards do not have a significant potential to impact the effectiveness of the Prescriptive BADCT design (considering mitigating engineering measures, if any).

2.5.2 Design, Construction and Operations Criteria

2.5.2.1 Solution and Tailing Characterization

The chemical compatibility of liner material and the nature of the liquids/solids to be contained determine in part liner selection. An analysis is to be made of all potential contained constituents of the solid tailing and slurry solution, including organic compounds. Characteristics of importance are outlined in Section 1.2.1.

2.5.2.2 Capacity and Storage Design

Tailing Impoundments must be designed with storage capacity to contain: 1) the design volume of tailing; 2) normal operating solution volume and other inflows such as seepage; 3) the volume of precipitation that may inflow to the impoundment as a result of the design storm (See Section 2.5.1.2) and 4) additional volume adequate to result in a minimum of two (2) feet of freeboard while containing these inflows. Depending on the area of the impoundment and climatic conditions, ADEQ may require additional freeboard. Impoundments should be designed so that there will not be excessive erosion at the low point of the freeboard in the event that the impoundment capacity is ever exceeded.

2.5.2.3 Site Preparation

Site preparation includes clearing the area of vegetation, grubbing and grading as well as embankment and subgrade preparation. Supporting surface slopes and foundation are to be stable and structurally sound. Subsurface materials that affect the integrity and/or stability of the final impoundment design are to be excavated and replaced with appropriately compacted fill. Subgrade is to consist of, at a minimum, six inches native or natural materials compacted to 95% maximum dry density (standard Proctor; ASTM Method D-698) within 3% of the optimum moisture content. The six inches of subgrade is in addition to the low permeability soil components of the liner specified in Section 2.5.2.4, Liner Specifications, if the compacted subgrade material does not satisfy the liner hydraulic conductivity requirements.

2.5.2.4 Liner Specifications

Tailing Impoundments will be designed with a composite liner consisting of 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. This is typically achieved by compacting to over 90% maximum dry density (standard Proctor; ASTM Method D-698) within 3% of the optimum moisture

content. The compacted low permeability soil surface should be finished flat and smooth (e.g., by rolling) and inspected prior to geosynthetic installation to remove protruding particles, if present. In areas exposed to the sun, the geomembrane must be certified UV resistant. Geomembranes are to be selected based on a compatibility analysis using an evaluation of the liner composition and thickness, chemical compatibility, height of the tailing pile and foundation characteristics. The geomembrane is to be secured in an engineered anchor trench. The anchor trench is to be at least two feet deep and two feet wide. The geomembrane must extend across the bottom of the trench and at least one foot up the outside trench wall. The anchor trench backfill must consist of minus 1/2 inch material compacted in 6-inch lifts at 95% of maximum dry density according to the standard Proctor compaction effort (ASTM Method D698).

The geomembrane will be covered by a protective/drainage layer consisting of 3/4 inch minus, well draining material with a minimum thickness of 18 inches, and corrugated perforated HDPE pipe of 3-inch or larger diameter at 20-foot spacing. The drainage layer should be designed to convey flow to a low point where fluids will be removed by gravity-flow (e.g., via a pipe through the base of an embankment) or a dedicated pump. The drainage layer and fluid removal system must be designed to result in minimal hydraulic head over the liner.

If necessary, a geotextile or other material should overlay the drainage layer to prevent deposited tailing from clogging the protective/drainage layer. Materials used in the protective/drainage layer shall not deteriorate when in contact with leachate solutions. The protective/drainage layer should be installed in a single lift with a track-dozer or other low ground pressure procedure, and precautions must be taken to prevent damage to the geomembrane. Geomembrane are not to be used as a structural component of impoundment design.

If Tailing Impoundment containment includes the use of a retention structure (i.e., an embankment), the inner surface of the retention structure will be lined with a geomembrane (same requirements as indicated above) in conjunction with the lining of the Tailing Impoundment area.

To the extent practicable, tailing material should be deposited in the impoundment to form layers that limit the rate of fluid infiltration to the protective/drainage layer and maximize evaporative drying and consolidation of the material.

Standard Number 54 (NSF, 1993), Flexible Membrane Liners, covers geomembranes used in the retention of water and containment of pollutants or chemicals in an environmentally acceptable manner. The successful application of geomembranes covered by this standard depend upon site evaluation, design, material selection, construction, operation and maintenance. The applicant shall refer and adhere to this standard for geomembranes as applicable to the subject facility. Other sources of information on geomembranes include ASTM standards and current technical journals.

Quality Assurance/Quality Control Program must be developed and implemented that meets or exceeds the geomembrane manufacturer's minimum requirements including inspection procedures, field testing (including limits for test failure and a description of the corrective procedures to be used

upon failure), laboratory testing, and repair of seams during installation and final inspection of the completed liner for functional integrity. Liners are to be installed in compliance with manufacturers seaming and seam testing recommendations for installation. Quality Assurance/Quality Control Programs must also address site and subgrade preparation, and installation and testing of the low permeability soil component of liners. Additionally, guidelines for the operation and maintenance of the liner system are to be formulated and implemented for the life of the impoundment facility. Appendix D includes additional guidance on the development of a Quality Assurance/Quality Control Program.

2.5.2.5 Stability Design

The Tailing Impoundment shall be evaluated and designed to provide stability of the impoundment under static and seismic loading conditions. Shear strengths should be based on site-specific material evaluations and not on published values.

Static stability analysis should indicate a static factor of safety of at least 1.5, or 1.3 in the case of prefinal staged construction phases. Seismic stability evaluations should be based on the design earthquake which ranges between the Maximum Probable Earthquake (MPE) and the Maximum Credible Earthquake (MCE). The MPE is the largest earthquake with a 100-year return interval. The MCE is the maximum earthquake that appears capable of occurring under the presently known tectonic framework. Appendix E provides criteria for selecting the design earthquake return interval. The design earthquake should be evaluated considering all known active faults within a distance of 200 kilometers. Seismic stability analyses may include pseudostatic and deformation analyses methods, as further discussed in Appendix E. When deformation analyses are required, the displacement predicted shall be within the following limits unless engineering evaluations are provided to demonstrate that larger displacements will not jeopardize containment integrity:

- Deformations not affecting geomembranes shall be less than or equal to 1 foot.
- Deformations affecting geomembranes shall be less than or equal to 6 inches.

Where upstream phased construction is proposed for a tailings embankment, or for tailings embankments that exceed 100 feet in height, ADEQ may request additional evaluations (e.g., liquefaction potential) to assure that the embankment is stable.

Analytical methodology and design considerations are further discussed in Appendix E, Stability Design Guidance.

Figure 2-4 shows an example cross section of a tailings impoundment under subaerial desposition.

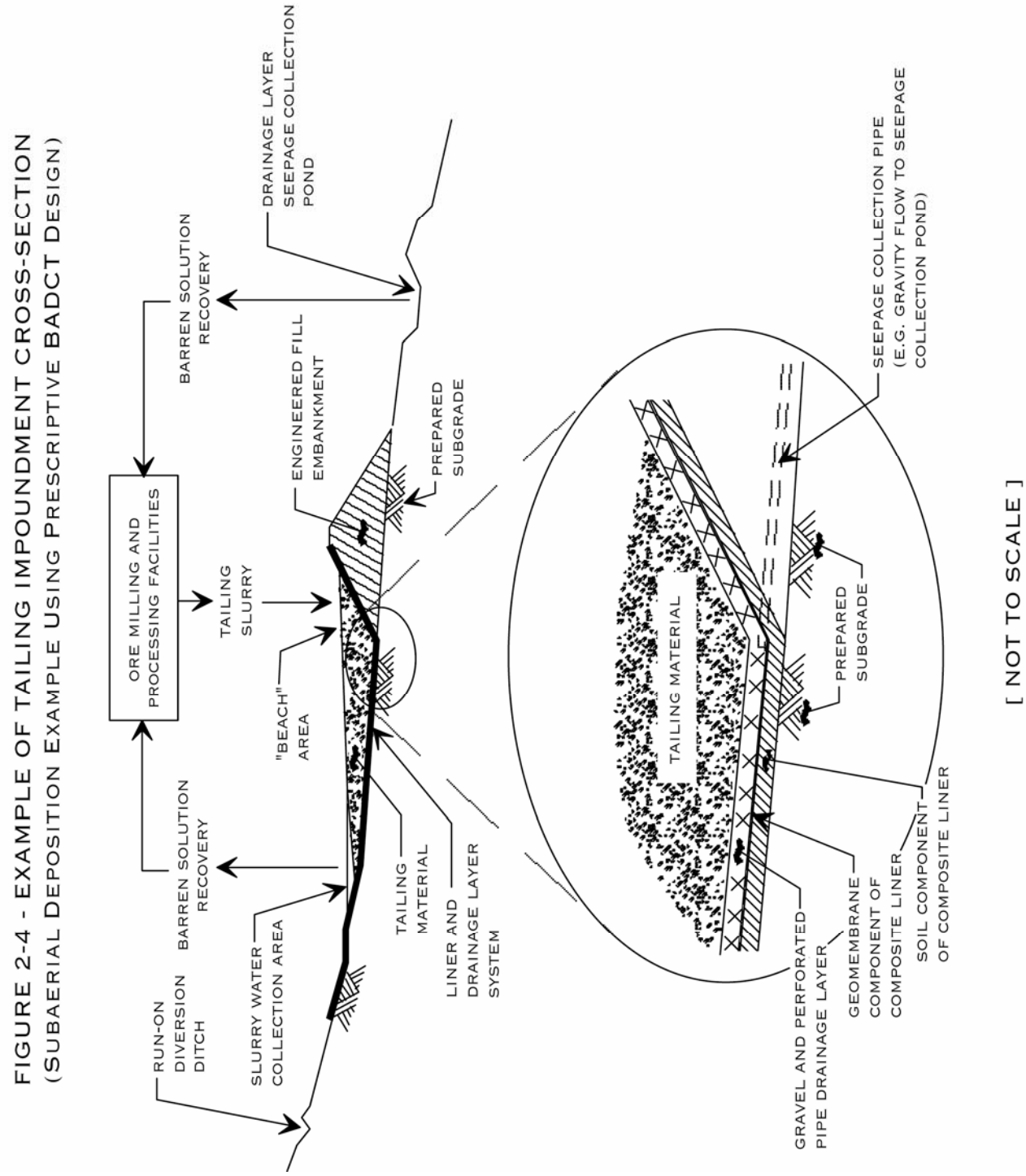


FIGURE 2-4 - EXAMPLE OF TAILING IMPOUNDMENT CROSS-SECTION
(SUBAERIAL DEPOSITION EXAMPLE USING PRESCRIPTIVE BADCT DESIGN)

2.5.3 Facility Inspection Criteria

The objective of facility inspections by the permittee is early detection of component damage or degeneration and of potential discharges from the facility so that steps can be taken to prevent, reduce or stop discharges. Facility inspection is to be instituted at the time of impoundment construction. Thereafter, facility inspection is to be conducted on a quarterly basis and after major storm or surface water events. At a minimum, facility inspection will include: 1) a visual survey of the impoundment to evaluate its overall integrity and 2) physical inspection of the impoundment to ensure design capacity and other engineering criteria (e.g., protective/drainage layer seepage rate) are not exceeded. Additionally, all pipelines that transport fluids from or to the tailing impoundment are to be included in the facility inspection to evaluate the integrity of the structures over time. Further detail regarding inspections that may be required can be obtained through pre-application consultation with ADEQ staff. Records of inspection shall remain on-site or at other approved locations for a period negotiated with ADEQ.

The applicant must propose and draft a Contingency Plan that will be approved by ADEQ. The plan shall be implemented in the event of an accidental discharge from the facility. The plan will identify the discharge discovery and notification procedure, the general clean up procedures for chemical discharges, leaks, spills, or other releases from the solution management system, and reporting procedures. In the event of an uncontrolled discharge from the impoundment, solutions contained within the impoundments are to be sampled to determine what has been discharged. At a minimum, sampled solutions are to be tested for pH, metals contained within process solutions, and cyanide when present (Total and Weak Acid Dissociable).

2.5.4 Closure/Post-Closure Criteria

A closure/post-closure strategy must be drafted and submitted to ADEQ for preliminary approval as part of the APP application. The applicant must still comply with the requirements of A.A.C. R18-9-A209(B) prior to formal closure. The closure strategy shall eliminate, to the greatest extent practicable, any reasonable probability of further discharge from the facility and of exceeding Aquifer Water Quality Standards at the applicable point of compliance. 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.

Contained solutions shall be disposed of by physical removal or containment and evaporation. If physical removal is the chosen option, and if the solution is to be discharged from a point source to "waters of the U.S." (which requires a NPDES Permit) solutions must be treated or neutralized to meet surface water quality standards.

(2-50) PRESCRIPTIVE CRITERIA _____

TABLE 2-5

TAILING IMPOUNDMENTS[1] Prescriptive BADCT		
Category	Element	Prescriptive Criteria
2.5.1 Siting Criteria	2.5.1.1 Site Characterization - Although Prescriptive BADCT does not require full site characterization prior to development of a mining area nor allow for site specific characteristics to be used as components of BADCT, certain siting considerations must be addressed. Obtain data during initial site evaluation, exploration, and/or development, as required to apply and implement the Prescriptive BADCT design.	1) Evaluate site characteristics such as surface water hydrology and general site suitability. 2) Determine if shallow groundwater conditions exist, and document if present. 3) Determine if geologic hazards exist.
	2.5.1.2 Surface Water Control - Identify and define floodplains, and need to protect the integrity of the impoundment from surface run-on/run-off.	1) Surface water run-on from upstream watershed areas should be diverted around the facility. Minimum design storm ranges from the 100-year, 24-hour storm event to the Maximum Probable Flood, based on considerations discussed in Appendix E, requirements of other regulatory programs, and negotiation between the Applicant and ADEQ. 2) The facility and related diversion structures must be designed to avoid excessive erosion. 3) If located within the 100-year floodplain, the facility must be protected from damage or flooding from 100-year peak streamflows.
	2.5.1.3 Geologic Hazards - Identify geologic hazards at the site. Potential geologic hazards should be considered present if conditions prone to the following occur: • Excessive or differential subsidence. • Collapsing soils. • Landslides. • Strong seismic shaking. • Other potential ground instability.	1) If present, conditions prone to geologic hazards must be documented for consideration in facility design. 2) Potential geologic hazards must be mitigated such that they do not have significant potential to impact the effectiveness of the Prescriptive BADCT design.
2.5.2 Design, Construction and Operations Criteria	2.5.2.1 Solution and Tailing Characterization - Identify expected chemical and physical characteristics of potential contents to ensure compatibility with the design.	1) Chemical characteristics of contained constituents, including organic compounds. 2) Physical characteristics of contained constituents. 3) Temperature of contained constituents. 4) Other parameters as needed for liner design.

TAILING IMPOUNDMENTS[1] Prescriptive BADCT		
Category	Element	Prescriptive Criteria
	2.5.2.2 Capacity And Storage Design - Determine the design flood event and estimated inflow seepage.	1) Impoundment must contain adequate volume for: • The design storm volume. • Normal operating solution volume and other inflows. • The design volume of tailing. • Additional two (2) feet freeboard.
	2.5.2.3 Site Preparation - Prepare site for impoundment and embankment construction.	1) Grub and grade the area. 2) Excavate and replace unsuitable material. 3) Subgrade to consist of, at a minimum, six inches of native or natural materials compacted to 95% maximum dry density (standard Proctor; ASTM D-698).
	2.5.2.4 Liner Specifications - Design and install impoundment components	1) Composite liner consisting of a single geomembrane of at least 30 mil thickness or 60 mil if proposing HDPE over, a minimum, twelve inches (placed in two-six 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. Soil component surface to be smooth (e.g., rolled) and inspected prior to geomembrane installation. 2) Geomembrane material selected based on an evaluation of the liner composition and thickness, height of the tailing impoundment and foundation characteristics. 3) Geomembrane certified to be UV resistant for areas exposed to sunlight. 4) Geomembrane secured by an engineered trench. 5) Geomembrane will be covered by a protective/drainage layer of 3/4 inch minus, well draining material with a minimum thickness of 18 inches, and corrugated, perforated HDPE pipe of 3-inch or larger diameter at 20-foot spacing. Drainage layer must be designed to convey flow to a low point where fluids are removed by gravity flow or a dedicated pump in a manner that results in minimal hydraulic head over the liner. Materials used in the protective drainage layer shall not deteriorate when in contact with leachate solutions. 6) If tailing impoundment containment includes the use of a retention structure, the inner surface of the retention structure will be lined with a geomembrane (liner requirements as indicated above) in conjunction with the lining of the tailing impoundment area.

TAILING IMPOUNDMENTS[1] Prescriptive BADCT		
Category	Element	Prescriptive Criteria
		7) Tailing material to be deposited to form a layer that limits infiltration to the protective/ drainage layer. After deposition of a continuous layer of tailing over the protective/ drainage layer, the rate of infiltration into the protective/ drainage layer and the flow capacity thereof must be adequate to limit the average and maximum hydraulic head over the liner to less than two and less than five feet, respectively. Lower heads should be maintained, where practicable. 8) Tailing impoundment to be designed and operated to maintain ponded water reclaimed from the tailing slurry within the limits of the infiltration limiting layer. 9) Quality Assurance/Quality Control program developed and implemented for liner installation, operation and maintenance.
	2.5.2.5 Stability Design - Design to provide stability under static and potential seismic loading conditions	1) Analyze and design to provide stability of the tailing impoundment under static and potential seismic loading conditions. 2) Shear strengths to be based on site specific-specific material evaluations. 3) Static factor of safety at least 1.5, or 1.3 for prefinal staged construction phases. 4) Seismic stability evaluations should be based on the design earthquake (Appendix E). 5) When deformation analyses are required (Appendix E), the displacement predicted shall be within the following limits unless engineering evaluations are provided to demonstrate that larger displacements will not jeopardize containment integrity. • Deformations not affecting a geomembrane shall be less than or equal to 1 foot. • Deformations affecting a geomembrane shall be less than or equal to 6 inches. 6) Additional stability evaluations may be required for embankments higher than 100 feet, or for upstream phased construction.
2.5.3 Facility Inspection Criteria	Inspections to alert permittee of component damage or degeneration, and of potential discharges	1) Inspections to be instituted at the time of impoundment construction and on a quarterly basis thereafter or after a major storm or surface water event. 2) Inspection to include visual survey to evaluate overall facility integrity and physical inspection to ensure impoundment design capacity is not exceeded.

TAILING IMPOUNDMENTS[1] Prescriptive BADCT		
Category	Element	Prescriptive Criteria
		3) Develop and implement Contingency Plan approved by ADEQ that specifies permittee courses of action to be taken in the event of an accidental discharge from the facility. 4) Inspection records are to remain on-site or at other approved locations for a period negotiated with ADEQ.
2.5.4 Closure/Post-Closure Criteria	Prevent, contain or control discharges after closure	1) Closure/Post-Closure Plan submitted to ADEQ for approval. Closure Plan to eliminate, to the greatest extent practicable, any reasonable probability of future discharges and of exceeding AWQS at the point of compliance. 2) 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. 3) Permanent closure for contained solutions can be by either physical removal or containment and evaporation.

(1) Tailing impoundments receive and contain finely ground spent ore with residual leach or chemical solutions in the form of a thickened slurry from process facilities.

PART III

Individual BADCT Guidance

PART 3 INDIVIDUAL BADCT GUIDANCE

3.1 INTRODUCTION

Sections 1.1.3 and 1.1.4 of this guidance manual discuss development of Individual BADCT designs for new and existing facilities, respectively. The approach for developing an Individual BADCT design for a new facility includes, in part, establishing a Reference Design incorporating a combination of demonstrated control technologies which are appropriate for the subject site and then evaluating the aquifer loading potential for the Reference Design and alternative designs. For existing facilities, determination of BADCT involves evaluating technology in use at the existing facility, and then determining if additional demonstrated control technologies should be implemented to reduce aquifer loading potential compared to existing conditions. Part 3 of this manual presents a summary of demonstrated control technologies being applied in the mining industry for the following types of discharging facilities:

- Section 3.2 - Heap Leach Pads
- Section 3.3 - Dump Leaching Facilities
- Section 3.4 - In-Situ Leaching Facilities
- Section 3.5 - Tailing Impoundments
- Section 3.6 - Surface Ponds

Part 3 of this manual is intended for use as a "menu" to assist in selecting demonstrated control technologies (i.e., design features and operating procedures) which may constitute BADCT for facility types listed above. Each facility must be evaluated as a composite of the following general factors: 1) solution, ore and waste characteristics; 2) siting considerations; 3) design, construction, and operation considerations; and 4) closure/post-closure. Demonstrated control technologies and other key considerations related to each of these general factors are summarized in the following sections. Example cross sections of dump leaching and in-situ leaching accompany their respective sections.

The practicable design resulting in the lowest significant pollutant loading to the aquifer will be selected as the BADCT design. If two designs result in similar loadings to the aquifer, and the discharge does not contain pollutants identified in A.R.S. 49-243.I, then the design with the lowest costs (i.e., capital, operations, closure, post-closure and other applicable costs) may be selected as the BADCT design. In such cases, negligible loadings can be considered similar even if relative differences between loadings is significant (e.g., where loadings from alternatives are small compared to the highest loading that could still comply with AWQS, the fact that loadings from one alternative may be up to orders of magnitude smaller may not preclude these loadings from being considered similar). If the facility is a new facility and the discharge contains the pollutants identified in A.R.S. 49-243.I, the facility must limit discharges to the maximum extent practicable regardless of cost.

3.2 HEAP LEACH PADS

3.2.1 Introduction

Heap Leach Pads are generally lined facilities consisting of crushed ore material deposited in a heap on a specially prepared surface (i.e., pad). A leaching solution is applied and allowed to percolate through the ore heap to extract mineral commodities. The Heap Leach Pad liner contains the mineral-bearing solution which is conveyed to processing facilities where the commodities are recovered. Heap Leach Pads are usually located as close to the mine site as possible to reduce haul distance.

Because development of Individual BADCT for a facility is based on aquifer loading, each of the key factors affecting aquifer loading must be considered. Field investigations and evaluations are usually required to provide information necessary for the estimation of aquifer loading as discussed in Section 1.1.3.3. Important considerations for developing individual BADCT for heap leaching are addressed in the following sections:

- Section 3.2.2 - Solution, Ore and Waste Characterization
- Section 3.2.3 - Siting Considerations
- Section 3.2.4 - Design, Construction and Operations Considerations
- Section 3.2.5 - Closure/Post-closure

3.2.2 Solution and Waste Characterization

Evaluation of solution and spent ore characteristics is required to develop the Individual BADCT facility design and estimate aquifer loading that may occur both during operations and in the closure/post-closure period.

Since it may be difficult for new facilities to accurately characterize their process solutions before construction, a process solution from a similar leaching operation may be utilized in developing a characterization. Similarly, as discussed in Section 1.2.1 of this manual, in some cases detailed characterization of spent ore may be deferred until closure of the facility. Proposals for deferring material characterizations should be presented to ADEQ during the pre-application period.

The acid generation potential and the potential for mobilization of metals and other constituents from spent ore should be evaluated. High pH effluent from precious metal ore leaching operations can lead to the release of metals such as arsenic, while low pH effluent from base metal ore leaching operations can lead to the release of various heavy metals.

There is usually a difference between the long-term behavior of oxide and sulfide ores and these must, therefore, be separately characterized. In the case of leaching oxide ores for copper recovery, acid must be added in the leaching process, while in the case of sulfide ores, sufficient

acid generation usually occurs when leaching is underway at steady state conditions. In the long-term, spent oxide copper ore may reduce its acid generation while a spent sulfide copper ore may not. Sulfide gold or silver ores are usually not processed by heap leaching, but can be in some cases. Leaching for gold or silver occurs using a high pH solution. Acid generation does not occur from spent oxide ores leached for gold or silver. Acid generation may be possible from sulfide ores leached for gold or silver if there is enough sulfide in the spent ore to overcome the buffering capacity of the ore and the leach solution.

Section 1.2.1 and B (Solution, Ore and Waste Characterization) discuss analytical testing for solution, and spent ore characterization. It is strongly recommended that characterizations be conducted with input from ADEQ to help assure that adequate information is collected.

3.2.3 Siting Considerations

Detailed site characterization is usually necessary to select an appropriate location for the proposed facility, to provide information for engineering evaluations (e.g., stability analysis and seepage control), and to estimate aquifer loading for the Individual BADCT design. Siting considerations that are key to Individual BADCT development are discussed in the following sections:

- Section 3.2.3.1 - Climate and Surface Hydrology
- Section 3.2.3.2 - Subsurface Conditions
- Section 3.2.3.3 - Geologic Hazards

Additional information and guidance on how site factors (e.g., topography, geology/stability, soil properties, vadose zone, and surface and subsurface hydrology) influence the design of a facility can be found in Section 1.2.4 (Site Factors).

The appropriate level of detail of each aspect of the site characterization is often dependent upon the extent to which the APP applicant plans to utilize various factors in developing the Individual BADCT design. For example, if chemical attenuation (e.g., precipitation, hydrolysis, complexation, etc.) in soils beneath the facility is not expected to play an important role in reducing aquifer loading, then investigation of site soil characteristics affecting chemical attenuation is not necessary. Conversely, where hydrologic isolation provided by the depth to the aquifer beneath the facility and geologic materials in the vadose zone are key in the development of the facility design, detailed investigations of vadose zone thickness, lithology, primary and secondary permeability, etc. are usually required.

It is strongly recommended that the site investigation program be conducted with input from ADEQ so that agreement can be reached on the amount of information to be collected.

3.2.3.1 Climate and Surface Hydrology

In preparing an application for an APP, an applicant must obtain and develop site specific climatic and hydrologic information. Climatic conditions are important to the evaluation of surface water characteristics, process water balances, the potential for leachate formation after closure, the potential for migration through the vadose zone, and other factors discussed in Section 1.2.3. Statistical data on rainfall and evaporation are required to support an APP application.

Surface hydrology information is necessary to develop appropriate surface water controls discussed in Section 3.2.4.2. Hydrologic information must include, at a minimum, the location of perennial or ephemeral surface waters and 100-year floodplains that occur in proximity to the subject facility. If the facility subject to BADCT requirements is located within a 100-year floodplain, an assessment of the 100-year flood surface flow and potential impacts on the facility must be conducted.

Lakes, perennial or ephemeral streams, springs and other surface waters must be identified as necessary to safely design the facility (e.g., minimize run-on) and minimize any unnecessary discharge to surface waters. Knowing the location of surface waters also will assist the applicant in determining if other agencies must be contacted (See Appendix F, Federal, State and Local Environmental Permits). Hydrologic characteristics of wetlands, if present, may also need to be identified.

3.2.3.2 Subsurface Conditions

Subsurface conditions play a key role in the development of Individual BADCT discharge controls discussed in Section 3.2.4.3.

Site specific vadose zone characteristics such as primary and secondary permeability, degree of lithologic stratification, and depth to ground water, are required for the design, construction and operation of a heap leach facility utilizing site characteristics (e.g., geologic containment) as an Individual BADCT element. In some cases, more detailed characteristics of the vadose zone such as in-situ moisture conditions, chemical attenuation capacities, etc., can also be important. Information regarding subsurface characterization can be found in Section 1.2.4 (Site Factors).

3.2.3.3 Geologic Hazards

During the process of site characterization and design development to demonstrate BADCT, engineering geology studies should be performed to identify and evaluate geologic hazards. Geologic hazards as discussed herein are processes capable of producing large ground movements in comparison to those involved in routine analysis of foundation settlements and deformations. Hazards which may disrupt the structural integrity of the discharge control system elements include landslides, subsidence, liquefaction and other earthquake-induced ground failure and collapsing soils. An additional part of design development related to geologic

hazards discussed in Appendix E (Engineering Design Guidance) is the consideration of earthquake forces in slope stability analysis.

The study area relevant to assessment of geologic hazards is determined by site characteristics, but usually requires geologic evaluation of the area up to one-half mile or more outside the perimeter of the discharging facility.

3.2.3.3.1 Landslides

Landslides are sometimes present on hill slopes and may be capable of reactivation by excavation at the toe, adding additional loading to the landslide mass, changes in surface drainage, fluctuations in the water table, or earthquakes. Landslides usually can be identified by interpretation of aerial photography, but may be so large that they will not be apparent if examination is confined to the immediate area of the discharging facility. The Transportation Research Board (1996) provides a comprehensive treatment of this subject.

It is generally preferable to avoid locating facilities in areas prone to landslides. If facilities subject to BADCT are located in areas prone to landsliding, special engineering measures may be needed including buttressing, engineered surface drainage, soil drainage systems, or other measures. Appropriate mechanisms to stabilize landslides will depend upon specific site conditions.

3.2.3.3.2 Subsidence and Settlement

Groundwater declines of as much as 300 feet in the alluvial basins in central and southeastern Arizona are known to have caused subsidence of as much as 20 feet (Jachens and Holzer, 1979, 1982; Holzer and Pampeyan, 1981; Holzer, 1984; Raymond, 1987). Withdrawal of geothermal fluids (Narasimhan and Goyal, 1984), solution extraction of salt (Ege, 1984), coal mining, hard rock mining and other underground excavations (National Coal Board, 1975; Kratzch, 1983; Bieniawski, 1987; Jeremic, 1987; Bell et al., 1988) also can produce large amounts of subsidence. If the cause of the subsidence is regional (e.g., pumping of an areally extensive and uniform aquifer) and the movement occurs at approximately the same rate beneath the entire facility, there may be no impact on the facility. If subsidence is not uniform beneath the facility, different rates or amounts of subsidence can result in horizontal or vertical strains in leachate collection and recovery systems, and other facility components, such as piping systems, prepared subgrades, and structural fills. It can also cause earth fissuring that can provide preferred pathways for seepage migration to the water table. For sites located on the relatively flat alluvial plains, subsidence may alter the grades of internal drains in discharging facilities and modify upstream drainage areas over time.

Settlement can occur under large loads which are placed on the surface, e.g., high leach piles. Settlement due to loading can alter internal drainage in discharging facilities and induce horizontal or vertical strains similar to subsidence.

The subsidence and settlement profiles and corresponding horizontal movement, horizontal strains and the potential for earth fissuring can be evaluated by empirical methods (Helm, 1984), simplified elastic methods (Lee and Shen, 1969; Helm, 1984) and finite element methods (Keaton et al., 1995). Where potential exists for substantial amounts of subsidence or settlement to occur at a facility location, or potential for even moderate amounts of differential subsidence or settlement in a facility subgrade (e.g., due to abrupt changes in the depth to shallow bedrock beneath a facility), these potential deformations must be considered in the design.

3.2.3.3.3 Earthquake-Induced Ground Failure

Stability of heap leach facilities is discussed in Section 3.2.4.4. The following paragraphs discuss the potential for earthquake-induced ground failure caused by liquefaction and faulting.

Liquefaction is usually associated with areas that have all of the following properties:

- Shallow depth to saturation;
- Loose sand, sandy silt, or silty sand lithology;
- High peak ground acceleration under design earthquake conditions.

Liquefaction can produce rapid settlement and/or horizontal spreading of the subgrade, even in relatively flat areas, that can impact the structural integrity of facilities subject to BADCT. Methods for evaluating the liquefaction potential are discussed in Appendix E.

Methods for the evaluation of liquefaction and lateral spreading are provided by Bartlett and Youd (1992). If conditions susceptible to liquefaction occur at the location of a facility subject to BADCT, engineering evaluations should be provided with the APP application that demonstrate the integrity of the facility will not be jeopardized in the event of the Design Earthquake, which ranges between the Maximum Probable Earthquake (MPE) and the Maximum Credible Earthquake (MCE) (Appendix E). The MPE is the largest earthquake with a 100-year return interval. The MCE is the maximum earthquake that appears capable of occurring under the presently known tectonic framework. The Design Earthquake should be evaluated considering all known active faults within a distance of 200 kilometers. Active faults are those which have experienced rupture in the past 35,000 years. Potential earthquake size can be estimated based on correlations with fault length (dePolo and Slemmons, 1990).

As indicated by published fault maps (Nakata et al., 1982; Pearthree et al., 1989; Demsey and Pearthree, 1990; Maulchin and Jones, 1992; Jennings, 1992; Euge et al., 1992), relatively few active faults have been identified in Arizona. Published sources should be used to define regionally-occurring faults. Aerial photographs should also be utilized to confirm the absence of faults in the immediate site vicinity, or to precisely locate nearby faults, if present. Offsets and age of recent movement can be investigated through trenching studies when necessary.

Heap Leach Pads should generally not be located on active faults. Where active faults occur adjacent to a proposed Heap Leach Pad site, caution must be taken to assure that the fault

location is well-defined. Aerial photograph evaluation, and field studies if necessary, should be used to confirm that signs of surface offset (e.g., splay faults) do not occur at the proposed facility location. Where a facility is to be located on an active fault, the applicant may need to evaluate aquifer loadings for an assumed ground rupture to demonstrate that the proposed location is feasible.

3.2.3.3.4 Collapsing Soils

Collapsing alluvial soils which are widely distributed in Arizona (Beckwith and Hansen, 1989) are alluvial fan deposits formed during the past 11,000 years (Holocene era), since the last episode of continental glaciation. The geotechnical properties of these soils which generally are susceptible to self-weight settlement of 2 to 6% of their thickness when wetted are largely a consequence of the dynamics of water-sediment supply in alluvial fan development and associated unsaturated flow processes. Thick deposits of particular concern in engineering analysis occur as coalescing alluvial fans at the base of mountains and along the margins of floodplains of major rivers such as the Gila, San Pedro and Colorado. Deposits as thick as 80 feet occur along the margins of floodplains.

Collapsing soils present the potential for differential subgrade movement and horizontal or vertical strains to liners, piping systems, structural fills, and other facility components similar to those addressed for subsidence in Section 3.2.3.3.2. If conditions susceptible to collapsing soils are present, engineering evaluations should be provided with the APP application that demonstrate the integrity of the facility will not be jeopardized.

3.2.4 Design, Construction and Operations Considerations

The following sections address design, construction, and operations aspects that may constitute part of BADCT for a given facility where they have the potential to affect aquifer loading:

- Section 3.2.4.1 - Site Preparation
- Section 3.2.4.2 - Surface Water Control
- Section 3.2.4.3 - Discharge Control
- Section 3.2.4.4 - Stability Design
- Section 3.2.4.5 - Operational Measures

Section 3.2.4.6 discusses operational monitoring that should be conducted to ensure that the facility is performing and being operated as designed.

3.2.4.1 Site Preparation

Site preparation may consist of a broad range of activities to provide a stable foundation for construction of a facility.

Site preparation for a Heap Leach Pad usually includes stripping of topsoil, vegetation and debris. Soils having low strength or high settlement potential must be excavated and replaced with structural fill or otherwise treated as required to provide a stable foundation. Care must then be taken to provide compaction of structural fill to the extent necessary to adequately limit deformation, and provide the required strengths and permeabilities. Subgrade treatment is usually required for liners, embankments and other structural components.

3.2.4.2 Surface Water Control

The objective of a surface water control system at a heap leach facility is to control run-on and run-off in order to protect the integrity of facilities containing process solutions and prevent uncontrolled releases that can discharge pollutants to the aquifer by indirect surface water pathways to groundwater. BADCT surface water controls at a heap leach facility may include the following:

- Upstream surface water diversion channels or dams that divert run-on away from the Heap Leach Pad area;
- Upstream storm water detention dams or basins that reduce the rate of run-on that must be diverted away from the Heap Leach Pad area;
- Upstream storm water retention dams or basins that store run-off from upgradient areas to reduce the amount of run-on to the Heap Leach Pad area;
- Downstream reclaim/storm water containment ponds, and related channels and diversion dikes or berms that capture run-off from the Heap Leach Pad;
- Provision of freeboard at the Heap Leach Pad perimeter and downstream reclaim/storm water containment ponds to contain run-off from the Heap Leach Pad for the design flood.

BADCT for a proposed facility may use any or all of these components designed to satisfy the following criteria:

- Components that store storm water, rainfall or process fluids (e.g., ponds) must be designed for the design storm volume (See Appendix E);
- Components that divert run-off and run-on (e.g., channels) must be designed to convey the design peak flow.

3.2.4.3 Discharge Control

Discharge control for Heap Leach Pads has been demonstrated through the use of the following components:

- Natural containment and liners;
- Leachate collection/hydrostatic head control;
- Solution control and storage capacity.

These components are further discussed in the following sections. Normally, some form of each of these components will need to be incorporated into the Heap Leach Pad BADCT design.

3.2.4.3.1 Natural Containment and Liners

Geologic features such as low permeability sediments (e.g., clay layers) or bedrock (e.g., low permeability shale or claystones) may be used as BADCT containment elements to the extent that they affect discharge reduction prior to reaching the water table. The applicant must demonstrate that such low permeability is areally extensive that it will function as intended. Additional geologic containment may consist of a demonstration that pollutants would be attenuated in the vadose zone (See Section 1.2.4.5). Thickness, permeability and attenuation capacity of the vadose zone are the factors most commonly relied upon for natural containment beneath a facility. These and any other factors relied upon for natural discharge control must be investigated as part of site evaluations discussed in Section 3.2.3.

Engineered liner systems for Heap Leach Pads are usually comprised of a prepared foundation over which one or more low permeability layers are installed. The low permeability layer or layers may be comprised of compacted natural material (e.g., clay), flexible synthetic material (i.e., geomembrane) or a composite of both.

The subgrade surface immediately below the low permeability layer(s) should be free of debris. For natural liner materials, surface preparation and installation procedures should be incorporated that provide for adequate control over the compacted thickness and permeability. For geomembrane layers, the liner system design and installation procedures should incorporate measures to mitigate the potential for damage by protruding rock particles that could affect containment integrity.

The rate of seepage that may occur through a liner is: (1) inversely proportional to the permeability of the liner; and (2) directly proportional to the amount of hydraulic head over the liner. Because of the dependence of seepage rate on hydrostatic head, the Heap Leach Pad liner design should integrate consideration of leachate collection and hydrostatic head control discussed in Section 3.2.4.3.2.

If a geomembrane is proposed as the uppermost component of a Heap Leach Pad liner, the maximum grain size in the leachate collection layer material and the vertical load of the ore heap must be considered to assure that damage to the geomembrane will not occur. Such damage can be prevented by limiting material in contact with the geomembrane to a relatively small maximum grain size (e.g., minus 3/4-inch), providing a geotextile protection layer over the geomembrane, and other methods. Procedures for constructing the leachate collection layer and the lowermost lift of the heap leach pile should also incorporate precautions, as appropriate, to minimize the potential for damage to the geomembrane (e.g., through the use of low ground pressure equipment).

It is usually preferable to place geosynthetic liner components, when used, in direct contact with fine-grain soil (e.g., a smooth-rolled fine-grained subgrade or a clay layer of a composite liner system). If this configuration is practical, it will limit potential seepage through any minor defects that may occur in the geosynthetic layer. Appendix C (Liner Design Principles and Practices) provides additional discussion of liner design and liner technology which should be considered in the design of containment.

A well designed quality assurance/quality control (QA/QC) program has been found to be an important factor in achieving design performance criteria of engineered liners. Attention to proper construction can make the difference between a facility that performs up to its expected design and one that has problems throughout its operational life. Appendix D (Construction Quality Assurance and Quality Control) provides additional guidance on the development of QA/QC documents.

3.2.4.3.2 Leachate Collection/Hydrostatic Head Control

The BADCT design for a Heap Leach Pad should incorporate measures to control the hydrostatic head of solution over the liner. This limits the driving force for seepage through the liner and also helps to avoid excessive pore pressure that can impact slope stability. Hydrostatic head control can be achieved by providing a permeable leachate collection system immediately above the liner. The drainage capacity of the leachate collection system should exceed the rate at which solution percolates through the ore pile. The potential for subsidence and settlement (See Section 3.2.3.3) to affect liner slope should be considered when calculating leachate collection system drainage capacity.

In general, it is recommended that leachate collection systems include a continuous granular layer immediately above the liner. A wide variety of granular materials have been used in practice. These range from naturally occurring sandy soils, to specially crushed and screened rock to allow for high permeability. Very often, the ore material has a high enough permeability and can therefore be carefully placed to form a collection layer. A geotextile filter fabric overlying the collection layer may be appropriate in some cases to prevent clogging by fine material from the ore heap.

Perforated piping systems can be used to increase the rate of solution removal from the base of the ore heap, thereby reducing the head on the liner. The spacing of these piping systems can be estimated by using the theory of parallel drains (Van Zyl, Hutchison & Kiel, 1988). Appropriate spacing of pipe depends on the characteristics of the granular drainage layer, and on the impingement rate of liquids. If wrapping of drain pipes with filter cloth is proposed, potential for physical, chemical and biological clogging of the filter cloth should be considered. Where intermediate liners are installed on lifts within the pile, drainage layers should also be placed on these liners, if necessary, to prevent saturated conditions that could affect the ability of the pile to satisfy stability criteria.

Corrugated, perforated, polyethylene pipes have been used successfully to collect leachate in Heap Leach Pads. Work by Adams, Muindi, and Selig (1989) indicates that the typical load

transfer is such that the pipe can directly carry about 20-30% of the total vertical load. Under these conditions it may then be possible to have 4-inch diameter collection pipes under loads resulting from heaps as high as 200 to 300 feet.

Collected leachate and storm run-off from Heap Leach Pads should be contained. Information on the design of containment ponds can be found in Section 3.6 (Surface Ponds).

3.2.4.3.3 Solution Control and Storage

Heap Leach Pads that drain to separate ponds should be designed with perimeter containment adequate to control run-off from the design storm. BADCT for providing this capacity usually consists of designing the Heap Leach Pad with lined perimeter berms that control run-off and solution drainage from the pad and convey it to the pad invert where it enters a solution transport ditch or collection ponds. The height of the perimeter berm and the setback of the ore pile from the perimeter berm need to be sized to provide the necessary flow capacity. Leach pad perimeter capacity calculations should include conservative assumptions of potential for drainage constrictions due to talus or washouts at the ore pile toe.

For Heap Leach Pads that may function as impoundments (e.g., for valley leach pads), containment capacity should be provided for the normal storage volume of operating solution and other normal inflows; the design storm volume, which can typically vary from 24 hours to 90 days depending on site conditions; the amount of draindown from the heap that may be expected in the event of a solution circulation system failure or planned shutdown; and an additional two feet of freeboard. Appendix E contains a more detailed discussion of the storage requirements.

Impounding Heap Leach Pads should be designed so that the integrity of the facility is maintained even if the design capacity of the freeboard is exceeded (e.g., the facility must be protected against erosion at the low point of the freeboard).

3.2.4.4 Stability Design

The stability of a heap is a very important consideration as instability could lead to damage to the liner system and potential loss of containment. Stability of a heap is determined by the shear strength of the weakest interface. Often this weakest interface is that between a geomembrane and a clayey foundation or between a geomembrane and some other geosynthetic.

Much has been published about stability analyses. The geotechnical literature contains references not only to analytical solutions but also to computerized evaluations (Blight, 1987; Campbell, 1986).

The Heap Leach Pad should be evaluated and designed to provide stability of the heap under static and potential seismic loading conditions. Where geosynthetics are used, shear strengths should be based on site specific material evaluations and not on published values. Stability

evaluations should be conducted for ultimate pile heights, intermediate construction stages, and maximum anticipated phreatic surfaces that may be critical with regard to stability. The recommended static stability criteria are as follows:

- For static analysis for earthen structures where geosynthetic components are not used and site specific testing has not been conducted, the recommended factor of safety is 1.5;
- For static stability analysis of structures where site specific testing was performed on weak interfaces, including those involving geosynthetic materials, the recommended factor of safety is 1.3.

Seismic evaluations should be based on a design earthquake which ranges between the Maximum Probable Earthquake (MPE) and the Maximum Credible Earthquake (MCE). The MPE is the largest earthquake with a 100-year return interval. The MCE is the maximum earthquake that appears capable of occurring under the presently known tectonic framework. Criteria for selecting the design earthquake return interval are provided in Appendix E. The design earthquake should be evaluated considering all known active faults within a distance of 200 kilometers. Seismic stability analyses may include pseudostatic and deformation analysis methods as further discussed in Appendix E. When deformation analyses are required the displacement predicted shall be small enough so as not to jeopardize containment integrity.

Heap Leach Pad BADCT for seismic stability may include:

- Limiting the ultimate pile height;
- Providing setbacks (benches) between ore lifts to achieve an adequately stable overall slope angle;
- Providing a leach pad design that buttresses the ore pile toe;
- Designing the liner to avoid or withstand potential shear forces;
- Provisions to minimize or eliminate the potential for pore pressure buildup in the ore pile or over the liner.

One or more of these potential BADCT components may be appropriate for a given facility. The BADCT design and stability evaluations in the APP application shall incorporate those measures identified above and/or other measures to the extent necessary such that static and seismic stability criteria are achieved.

Details of slope stability analysis methodologies are discussed in Appendix E.

3.2.4.5 Operational Measures

The following are examples of operating procedures that have been used as parts of a discharge control system to achieve BADCT for heap leaching operations:

- Limit equipment traffic or utilize conveyor stacking to minimize the potential for liner damage;

- Utilize low ground pressure equipment to place leachate collection system drain rock and the initial ore lift if the lift thickness is small;
- Load ore in the uphill direction to allow for maximum passive resistance during operation and reduce slippage along the soil/liner interface;
- Limit the rate of rise of the ore pile to reduce internal shear strains;
- Sequence leaching activities to allow for reaction time, thereby reducing the total amount of time solution is present over the liner;
- Control solution application rates to avoid excessive hydrostatic head buildup over the liner;
- Grade ore pile tops to control runoff and infiltration;
- Provide ore pile grading and locate solution delivery hoses on the top of the ore pile to minimize the potential for pile slope washouts that could effect pad perimeter containment;
- Minimize the volume of normal operating solutions to maximize storm water containment capacity.

Application of operating procedures as a component of BADCT is site specific. Any of the above examples may or may not be appropriate for a given facility, and the design and engineering evaluations should be conducted accordingly. In addition, other operational considerations that help to limit aquifer loading can be proposed as part of BADCT by the applicant.

3.2.4.6 Operational Monitoring

During operation of a heap leaching facility, monitoring should be conducted to ensure that the facility is performing and being operated as designed.

Examples of monitoring to confirm that the facility is performing as designed include:

- Observation of heap deformations to monitor for stability. The type of slope movement that is the primary concern for Heap Leach Pads is translational slope deformation that has the potential to affect containment integrity. The features which are associated with such translational failure consist of crack formation near the crest of the heap, deformation of the sideslopes, and outward translation of the toe. Very often, telltale signs are visible prior to substantial movement. A regular program of observations may be part of ongoing monitoring of the facility. It should be noted that heap leach ore is deposited in a loose state and during leaching some settlement and deformation will usually occur. Such settlement and deformation is not necessarily related to translational type failure that can affect containment integrity;

- Monitoring of any associated leak collection systems to evaluate liner performance;

- Monitoring of any associated vadose zone monitoring systems to evaluate liner performance, attenuation, etc.;

- Monitoring of hydrostatic head over the heap leach pad liner to confirm effectiveness of the leachate collection layer;

- Observing Heap Leach Pad performance and perimeter containment during large storms.

The extent to which ADEQ will require operational monitoring to assure that the facility is performing as designed may depend upon the adequacy of the existing data on which the design is based, and the degree to which the design assumptions are conservative. For example, if an applicant proposes Heap Leach Pad slopes that marginally satisfy static stability requirements discussed in Section 3.2.4.4, ADEQ may recommend monitoring of heap stability as discussed above. Conversely, conservative assumptions of leachate collection system or liner system performance may be proposed by an applicant to justify reduced monitoring needs.

Examples of monitoring to assure that the facility is being operated as designed include:

- For valley leach operations where solutions and/or storm waters are stored on the pad, visual observations should be made on a regular basis to ensure that freeboard requirements are satisfied. If impounded liquids infringe on the design freeboard, it will be necessary to implement a mitigation plan to prevent loss of solution containment;

- Integrity monitoring and visual inspection of the Heap Leach Pad so as to identify any system failures or areas in need of maintenance or repair;

- Periodic analysis of solution, ore and waste chemistry to assure consistency with assumptions and data used for the design basis.

Monitoring requirements to assure that the facility is being operated as designed may apply to most facilities and may be required by APP conditions pursuant to A.A.C. R18-9-A206.

A Contingency Plan is required separate from BADCT pursuant to A.A.C. R18-9-A204. In some cases, an applicant may include some components of the Contingency Plan as part of BADCT (e.g., provisions for backup generators to allow solution circulation during a power outage may affect BADCT containment volume requirements).

3.2.5 Closure/Post-Closure

Closure/post-closure must be considered in the design submitted to ADEQ. The applicant must still comply with the requirements of A.A.C. R18-9-A209(B) prior to formal closure. Arizona

Mined Land Reclamation Statutes (A.R.S. 27-901 through 27-1026) and implementing Rules govern surface reclamation. This BADCT guidance manual is not intended to duplicate or modify requirements of surface reclamation statutes.
The closure strategy shall eliminate, to the greatest extent practicable, any reasonable probability of further discharge from the facility and of exceeding aquifer water quality standards at the applicable point of compliance.

3.2.5.1 Physical Stability

Measures to provide long-term physical stability of the Heap Leach Pad are part of BADCT to the extent that they may affect aquifer loading. The Heap Leach Pad should be stabilized as necessary to be resistant to water and wind erosion. Such erosion can effect the physical stability in the long-term or lead to sediment transport that can discharge pollutants to the aquifer by indirect surface water pathways to groundwater. Any proposed closure configuration must be supported with adequate stability analysis. The applicant or ADEQ may propose stability criteria for closure that is different from operational stability requirements based on long-term conditions that affect aquifer loading potential (e.g., the proposed closure strategy may largely eliminate the potential for aquifer loading, making slope stability less important, or different design earthquake parameters may be appropriate for closure evaluations because the closed facility will be present much longer than it operated).

Examples of physical stabilization measures that may be appropriate to include in BADCT for closure of a Heap Leach Pad include:

- Drainage controls upgradient of Heap Leach Pads will normally be left in place at the time of closure to protect the Heap Leach Pad from washout;

- The Heap Leach Pad surface can be stabilized with vegetation or by leaving durable rock on the pile slopes.

There is considerable debate regarding appropriate slope angles for heap leach pile closure. If vegetation is used to stabilize the surface of the heap, some regrading of angle of repose slopes is needed. Where slopes will be revegetated, the applicant may be required to demonstrate (i.e., through existing natural or engineered examples, or calculations, etc.) the probability of success if slopes steeper than 2.5:1 are proposed.

For heap leach pile slopes that are structurally stable and consist of durable rock, surface stabilization for the purposes of BADCT need not include regrading if slope revegetation is not part of the reclamation plan.

3.2.5.2 Chemical Stability

3.2.5.2.1 General

As part of the overall closure design, it is important to evaluate the potential for leachate generation. Whether or not leachate will occur over the long-term is a water balance issue primarily affected by climate and the ability of the heap to shed water through run-off, evaporation and, where vegetation is present, evapotranspiration. Any proposed closure configuration should be supported by analysis to indicate the rate of leachate generation expected over the long-term. Measures should be taken, to the extent practical, to close the Heap Leach Pad in a manner that will not generate leachate after closure. In cases where leachate is generated, the quality of the leachate which will be released depends on the amount of lixiviant remaining in the heap (e.g., acid, cyanide) as well as the potential of the spent ore to release other contaminants. Other contaminants which can be released include metals such as copper, arsenic, zinc, iron, etc. The release of a specific metal will be dependent on ore mineralogy and pH conditions in the spent ore. The waste characterization studies described under Section 1.2.1 and Appendix B will be the basis for estimating the potential release of contaminants from the spent ore. At the time of closure, such information should be available.

There are basically three types of demonstrated control technologies available for control of leachate release. These are:

- Source control;
- Migration control; and
- Interception and treatment.

The focus of source control is to remove or isolate environmentally available constituents of concern. Examples of source control include rinsing and detoxification to remove cyanide (See Section 3.2.5.2.2), or physical removal of spent ore from the heap for placement in a more controlled environment (e.g., a mined out pit where no groundwater is present). In the case of acid generating spent ore, it could also be beneficial to place the spent ore in a pit under the water table.

Migration control refers to limiting the amount of leachate that may form and migrate through the heap. Typical technologies for migration control include surface grading of the heap to enhance run-off, surface water controls to minimize run-on, establishment of vegetation to promote moisture removal through evapotranspiration or installation of covers that include low permeability caps to limit infiltration. Long-term settlements should be evaluated in the design of covers. Long-term settlement is typically not a concern for spent ore in heaps composed of hard durable rock.

Interception and treatment of leachate is a long-term commitment which must be very carefully evaluated before it is implemented. Leachate can be intercepted by shallow trenches, cutoff walls, and other means, provided that such means intercept the leachate prior to affecting groundwater. The treatment process could consist of lime addition for neutralization or more

sophisticated active treatment processes. Passive treatment, such as construction of wetlands, must be considered a polishing step or only a treatment possibility for low volumes of leachate discharge. Although wetlands may be beneficial, their use must be carefully evaluated with respect to the following:

- The potential that due to seasonal variation of leachate discharge the wetland vegetation cannot be maintained;
- The potential for contaminant concentration in the wetland substrate or biomass; and
- The requirement for ongoing maintenance of the wetland to ensure its long-term capacity.

Other passive treatment methods which will require minimal maintenance are being developed. These include passing the leachate through containers filled with organic materials to precipitate the metals, anoxic limestone drains, etc. It is expected that this area will see considerable development in the next decade and constant updating of technologies will be required.

3.2.5.2.2 Rinsing/Detoxification

In the case of copper leaching, very little research has been done to show the effectiveness of rinsing and detoxification on removing acidity from oxide ores. In the case of sulfide ores, it is not generally feasible to halt the production of acid and available metals in the long-term. However, the arid climate of Arizona and migration control measures discussed in Section 3.2.5.2.1 may be effective in reducing infiltration, thereby minimizing the mobilization of metals and other products of acid generation.

In the case of precious metal mining, where cyanide is used as a lixiviant, heaps are typically rinsed and detoxified. The rinsing or detoxification method employed should reduce the cyanide level in the effluent to such a low value that discharge from the heap will not impact groundwater. Rinsing and detoxification options consist of the following:

- Rinsing with fresh water;
- Rinsing with treated water (e.g., water recycled through the heap to which hydrogen peroxide or calcium hypochlorite has been added); and
- Rinsing with a solution of water and specially adapted bacteria, to biodegrade constituents of concern.

There are many examples in practice where these approaches have been used successfully. When fresh water is used, large volumes can be required, which must then be stored and/or treated/ disposed of in an approved manner. Rest cycles may improve efficiency of rinsing.

Fresh water rinsing may be well-suited at operating mines, where one heap can be rinsed with fresh water while another heap is leached. It may not be suitable at the end of the project when the final heap must be rinsed.

The use of hydrogen peroxide or calcium hypochlorite treatment for the rinse solution has been effective. The use of calcium hypochlorite will result in residual chloride which could impact the environment in the long-term. Much has been written about the use of peroxide treatment (Smith and Mudder, 1992). Other compounds (e.g., copperas) have also been used. Rinsing reagents must be used to assure environmental and human health and safety and effective results. The Arizona State Mining Inspector has prepared a bulletin discussing the safe destruction of cyanide at mining operations.

Bacterial degradation has been successful at heap leach facilities including Yellow Pine in Idaho and Copperstone in Arizona. These bacteria are usually present on-site and are cultured and given special nutrients to increase effectiveness (Thompson, 1990).

The effectiveness of rinsing must be determined through sampling of effluent and/or solids. By sampling the effluent from the heap during and following rinsing a good average water quality may be obtained for the heap effluent. This provides an indication of water quality which could emanate from the heap in the long-term, assuming the heap will not be disturbed. If a heap persistently emits leachate following closure, it should be sampled as part of post-closure monitoring to confirm effective rinsing.

Analytical testing of solid ore residue samples is sometimes also used to assess the effectiveness of rinsing. Tests such as the SPLP or meteoric water mobility discussed in Appendix B can provide data to estimate effluent water quality. Cyanide remaining on the solids can also be quantified. A number of factors must be considered in interpreting the results of solid-phase testing, and they are usually only of qualitative value.

The method or methods to be employed for measuring the effectiveness of rinsing a Heap Leach Pad should be determined using a site specific approach where issues such as heap closure, design and risks associated with effluent discharge are taken into account.

3.3 DUMP LEACHING FACILITIES

3.3.1 Introduction

Dump Leach Facilities are generally unlined leaching facilities consisting of uncrushed, i.e., run of mine (ROM), ore deposited in areas with defined topographic containment (e.g., valleys, canyons, open pits) adjacent to or within the actual mine pit (See Appendix A, Comparison of Copper Leaching Facilities). New Dump Leach Facilities are normally sited in areas that have low permeability soil and bedrock, with sloping terrain to facilitate the collection and recovery of leaching solution. Dump leaching is generally only implemented for processing of copper ores with grades that are too low to heap leach.

Because development of Individual BADCT for a facility is based on aquifer loading, each of the key factors affecting aquifer loading must be considered. Field investigations and evaluations are usually required to provide information necessary for the estimation of aquifer loading as discussed in Section 1.1.3.3. Important considerations for developing Individual BADCT for dump leaching are addressed in the following sections:

- Section 3.3.2 - Solution and Spent Ore Characterization
- Section 3.3.3 - Siting Considerations
- Section 3.3.4 - Design, Construction and Operations Considerations
- Section 3.3.5 - Closure/Post-closure

3.3.2 Solution and Spent Ore Characterization

Evaluation of solution and spent ore characteristics is required to develop the Individual BADCT facility design and estimate aquifer loading that may occur both during operations and in the closure/post-closure period.

Since it may be difficult for new facilities to accurately characterize their process solutions before construction, a process solution from a similar leaching operation may be utilized in developing a characterization. Similarly, as discussed in Section 1.2.1 of this manual, in some cases detailed characterization of spent ore may be deferred until closure of the facility. Proposals for deferring material characterizations should be presented to ADEQ during the pre-application period.

There is usually a difference between the long-term behavior of oxide and sulfide ores in copper dump leaching, and these ore types must, therefore, be separately characterized. In the case of oxide ores, acid must be added in the leaching process, while in the case of sulfide ores, sufficient acid generation usually occurs when the leaching is underway at steady state conditions. In the long-term, spent oxide copper ore may reduce its acid generation while a spent sulfide copper ore may not.

The acid generation potential and the potential for mobilization of heavy metals and other constituents from spent ore should be evaluated.

Section 1.2.1 and Appendix B (Solution, Ore and Waste Characterization) discuss analytical testing for solution and spent ore characterization. It is strongly recommended that characterizations be conducted with input from ADEQ to help assure that adequate information is collected.

3.3.3 Siting Considerations

Detailed site characterization is usually necessary to select an appropriate location for the proposed facility, to provide information for engineering evaluations (e.g., stability analysis

and seepage control), and to estimate aquifer loading for the Individual BADCT design. Siting considerations that are key to Individual BADCT development are discussed in the following sections:

- Section 3.3.3.1 - Climate and Surface Hydrology
- Section 3.3.3.2 - Subsurface Conditions
- Section 3.3.3.3 - Geologic Hazards

Additional information and guidance on how site factors (e.g., topography, geology/stability, soil properties, vadose zone, and surface and subsurface hydrology) influence the design of a facility can be found in Section 1.2.4 (Site Factors).

The appropriate level of detail of each aspect of the site characterization is often dependent upon the extent to which the APP applicant plans to utilize various factors in developing the Individual BADCT design. For example, if chemical attenuation (e.g., precipitation, hydrolysis, complexation, etc.) in soils beneath the facility is not expected to play an important role in reducing aquifer loading, then investigation of site soil characteristics affecting chemical attenuation is not necessary. Conversely, where hydrologic isolation provided by the depth to the aquifer beneath the facility and geologic materials in the vadose zone are key in the development of the facility design, detailed investigations of vadose zone thickness, lithology, primary and secondary permeability, etc. are usually required.

It is strongly recommended that the site investigation program be conducted with input from ADEQ so that agreement can be reached on the amount of information to be collected.

3.3.3.1 Climate and Surface Hydrology

In preparing an application for an APP, an applicant must obtain and develop site specific climatic and hydrologic information. Climatic conditions are important to the evaluation of surface water characteristics, process water balances, the potential for leachate formation after closure, the potential for migration through the vadose zone, and other factors discussed in Section 1.2.3. Statistical data on rainfall and evaporation are required to support an APP application. Surface hydrology information is necessary to develop appropriate surface water controls discussed in Section 3.3.4.2. Hydrologic information must include, at a minimum, the location of perennial or ephemeral surface waters and 100-year floodplains that occur in proximity to the subject facility. If the facility is located within the 100-year floodplain, an assessment of the 100-year flood surface flow and potential impacts on the facility must be conducted.

Lakes, perennial or ephemeral streams, springs and other surface waters must be identified as necessary to safely design the facility (e.g., minimize run-on) and minimize any unnecessary discharge to surface waters. Knowing the location of surface waters also will assist the applicant in determining if other agencies must be contacted (See Appendix F, Federal, State and Local Environmental Permits). Hydrologic characteristics of wetlands, if present, may also need to be identified.

3.3.3.2 Subsurface Conditions

Subsurface conditions play a key role in the development of Individual BADCT discharge controls discussed in Section 3.3.4.3.

Site specific vadose zone characteristics such as primary and secondary permeability, degree of lithologic stratification, and depth to groundwater, are required for the design, construction and operation of a Dump Leach Facility utilizing site characteristics (e.g., geologic containment) as an Individual BADCT element. In some cases, more detailed characteristics of the vadose zone such as in-situ moisture conditions, chemical attenuation capacities, etc., can also be important. Information regarding subsurface characterization can be found in Section 1.2.4 (Site Factors).

3.3.3.3 Geologic Hazards

During the process of site characterization and design development to demonstrate BADCT, engineering geology studies should be performed to identify and evaluate geologic hazards. Geologic hazards as discussed herein are processes capable of producing large ground movements in comparison to those involved in routine analysis of foundation settlements and deformations. Hazards which may disrupt the structural integrity of the discharge control system elements include landslides, subsidence, liquefaction and other earthquake-induced ground failure and collapsing soils. An additional part of design development related to geologic hazards discussed in Appendix E (Engineering Design Guidance) is the consideration of earthquake forces in slope stability analysis.

The study area relevant to assessment of geologic hazards is determined by site characteristics, but usually requires geologic evaluation of the area up to one-half mile or more outside the perimeter of the discharging facility.

3.3.3.3.1 Landslides

Landslides are sometimes present on hill slopes and may be capable of reactivation by excavation at the toe, adding additional loading to the landslide mass, changes in surface drainages, fluctuations in the water table or earthquakes. Landslides usually can be identified by interpretation of aerial photography, but may be so large that they will not be apparent if examination is confined to the immediate area of the discharging facility. The Transportation Research Board (1996) provides a comprehensive treatment of this subject.

It is generally preferable to avoid locating facilities in areas prone to landslides. If facilities subject to BADCT are located in areas prone to landsliding, special engineering measures may be needed including buttressing, engineered surface drainage, soil drainage systems, or other measures. Appropriate mechanisms to stabilize landslides will depend upon specific site conditions.

3.3.3.3.2 Subsidence and Settlement

Groundwater declines of as much as 300 feet in the alluvial basins in central and southeastern Arizona are known to have caused subsidence of as much as 20 feet (Jachens and Holzer, 1979, 1982; Holzer and Pampeyan, 1981; Holzer, 1984; Raymond, 1987). Withdrawal of geothermal fluids (Narasimhan and Goyal, 1984), solution extraction of salt (Ege, 1984), coal mining, hard rock mining and other underground excavations (National Coal Board, 1975; Kratzch, 1983; Bieniawski, 1987; Jeremic, 1987; Bell et al., 1988) also can produce large amounts of subsidence.

If the cause of the subsidence is regional (e.g., pumping of an areally extensive and uniform aquifer) and the movement occurs at approximately the same rate beneath the entire facility, there may be no impact on the facility. If subsidence is not uniform beneath the facility, different rates or amounts of subsidence can result in horizontal or vertical strains in leachate collection and recovery systems, and other facility components, such as piping systems, prepared subgrades, and structural fills. It can also cause earth fissuring that can provide preferred pathways for seepage migration to the water table. For sites located on the relatively flat alluvial plains, subsidence may alter the grades of internal drains in discharging facilities and modify upstream drainage areas over time.

Settlement can occur under large loads which are placed on the surface, e.g., high leach piles. Settlement due to loading can alter internal drainage in discharging facilities and induce horizontal or vertical strains similar to subsidence.

The subsidence and settlement profiles and corresponding horizontal movement, horizontal strains and the potential for earth fissuring can be evaluated by empirical methods (Helm, 1984), simplified elastic methods (Lee and Shen, 1969; Helm, 1984) and finite element methods (Keaton et al., 1995). Where potential exists for substantial amounts of subsidence or settlement to occur at a facility location, or potential for even moderate amounts of differential subsidence or settlement in a facility subgrade (e.g., due to abrupt changes in the depth to shallow bedrock beneath a facility), these potential deformations must be considered in the design.

3.3.3.3.3 Earthquake-Induced Ground Failure

Stability of Dump Leach Facilities is discussed in Section 3.3.4.4. The following paragraphs discuss the potential for earthquake-induced ground failure caused by liquefaction and faulting.

Liquefaction is usually associated with areas that have all of the following properties:

- Shallow depth to saturation;
- Loose sand, sandy silt, or silty sand lithology;
- High peak ground acceleration under design earthquake conditions.

Liquefaction can produce rapid settlement and/or horizontal spreading of the subgrade, even in relatively flat areas, that can impact the structural integrity of facilities subject to BADCT. Methods for evaluating the liquefaction potential are discussed in Appendix E.

If conditions susceptible to liquefaction occur at the location of a facility subject to BADCT, engineering evaluations should be provided with the APP application that demonstrate the integrity of the facility will not be jeopardized in the event of the Design Earthquake, which ranges between the Maximum Probable Earthquake (MPE) and the Maximum Credible Earthquake (MCE) (Appendix E). The MPE is the largest earthquake with a 100-year return interval. The MCE is the maximum earthquake that appears capable of occurring under the presently known tectonic framework. The Design Earthquake should be evaluated considering all known active faults within a distance of 200 kilometers. Active faults are those which have experienced rupture in the past 35,000 years. Potential earthquake size can be estimated based on correlations with fault length (dePolo and Slemmons, 1990).

As indicated by published fault maps (Nakata et al., 1982; Pearthree et al., 1989; Demsey and Pearthree, 1990; Maulchin and Jones, 1992; Jennings, 1992; Euge et al., 1992), relatively few active faults have been identified in Arizona. Published sources should be used to define regionally-occurring faults. Aerial photographs should also be utilized to confirm the absence of faults in the immediate site vicinity, or to precisely locate nearby faults, if present. Offsets and age of recent movement can be investigated through trenching studies when necessary.

Where active faults occur under or adjacent to a proposed dump leach pad site, provision must be made to accommodate movement of the fault in the design. To demonstrate that a proposed location is feasible, the applicant may also need to evaluate aquifer loadings for an assumed ground rupture if the facility is to be located on an active fault.

3.3.3.3.4 Collapsing Soils

Collapsing alluvial soils which are widely distributed in Arizona (Beckwith and Hansen, 1989) are alluvial fan deposits formed during the past 11,000 years (Holocene era), since the last episode of continental glaciation. The geotechnical properties of these soils, which generally are susceptible to self-weight settlement of 2 to 6% of their thickness when wetted, are largely a consequence of the dynamics of water-sediment supply in alluvial fan development and associated unsaturated flow processes. Thick deposits of particular concern in engineering analysis occur as coalescing alluvial fans at the base of mountains and along the margins of floodplains of major rivers such as the Gila, San Pedro and Colorado. Deposits as thick as 80 feet occur along the margins of floodplains.

Collapsing soils present the potential for differential subgrade movement and horizontal or vertical strains to liners, piping systems, structural fills, and other facility components similar to those addressed for subsidence in Section 3.3.3.3.2. If conditions susceptible to collapsing soils are present, engineering evaluations should be provided with the APP application that demonstrates the integrity of the facility will not be jeopardized.

3.3.4 Design Construction and Operations Considerations

The following sections address design, construction, and operations aspects that may constitute part of BADCT for a given facility where they have the potential to affect aquifer loading:

- Section 3.3.4.1 - Site Preparation
- Section 3.3.4.2 - Surface Water Control
- Section 3.3.4.3 - Discharge Control
- Section 3.3.4.4 - Stability Design
- Section 3.3.4.5 - Operational Measures

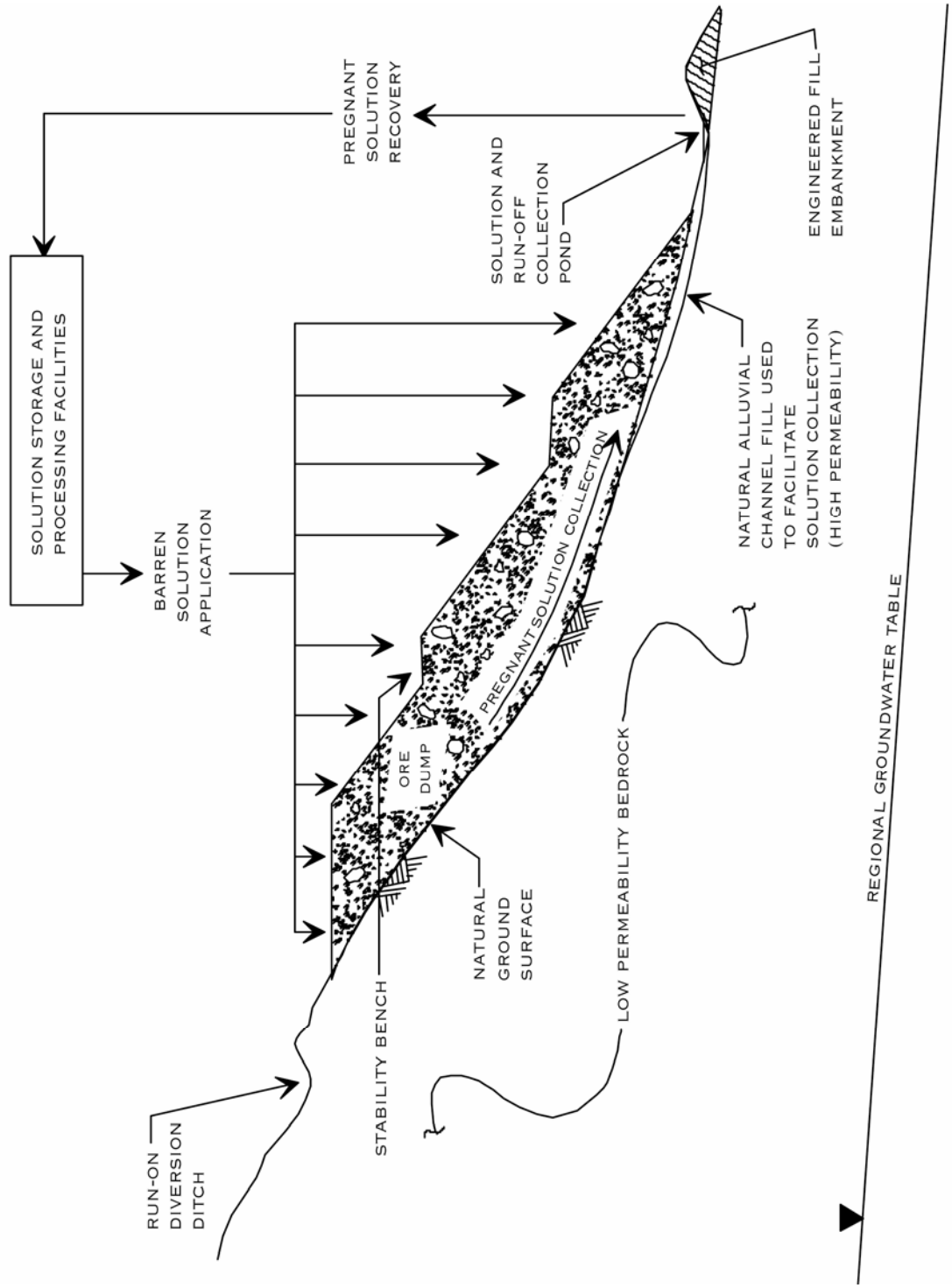
Section 3.3.4.6 discusses operational monitoring that should be conducted to ensure that the facility is performing and being operated as designed.

Figure 3-1 depicts an example cross section of a dump leach facility.

3.3.4.1 Site Preparation

Site preparation may consist of a broad range of activities to provide a stable foundation for construction of a facility, and to minimize the risk of solution "ponding" at the base of the ore pile which increases the driving mechanism (head) for discharge.

FIGURE 3-1 - EXAMPLE OF DUMP LEACH FACILITY CROSS-SECTION



[NOT TO SCALE]

Site preparation for a Dump Leach Facility may involve the selective stripping of topsoil, vegetation and debris where required for stability or solution control. Stripping is not normally required on steep slopes. Soils having low strength or high settlement potential may have to be excavated and replaced with structural fill or otherwise treated as to provide a stable foundation. Care must then be taken to provide compaction of structural fill to the extent necessary to adequately limit deformation and provide the required strengths and permeability. Subgrade treatment is usually required for liners, embankments and other structural components.

3.3.4.2 Surface Water Control

A surface water control system may be necessary at a Dump Leach Facility to control run-on and run-off. This would protect the integrity of facilities containing process solutions and prevent uncontrolled releases that can discharge pollutants to the aquifer by indirect surface water pathways to groundwater. Control of run-on may not be necessary where the facility is designed to accommodate it. BADCT surface water controls at a Dump Leach Facility may include the following:

- Upstream surface water diversion channels or dams that divert run-on away from the dump leach area;
- Upstream storm water detention dams or basins that reduce the rate of run-on that must be diverted away from the dump leach pad area;
- Upstream storm water retention dams or basins that store run-off from upgradient areas to reduce the amount of run-on to the dump leach area;
- Downstream reclaim/storm water containment ponds, and related channels and diversion dikes or berms that capture run-off from the Dump Leach Facility;
- Provision of freeboard at the Dump Leach Facility perimeter to contain run-off from the design flood.

BADCT for a proposed facility may use any or all of these components designed to satisfy the following criteria:

- Components that store storm water, rainfall or process fluids (e.g., ponds) must be designed for the design storm volume (See Appendix E);
- Components that divert run-off and run-on (e.g., channels) must be designed to convey the design peak flow.

3.3.4.3 Discharge Control

Discharge control for Dump Leach Facilities has been demonstrated through the use of natural and engineered containment features and operational practices. The applicant must evaluate the aquifer loading for these site specific features combined with proposed engineering measures.

Potential preferential seepage pathways, if present, must be considered in aquifer loading evaluations.

The following elements have been used as part of discharge control systems to achieve BADCT for Dump Leach Facilities. Because application of the design elements is site specific, all the design elements may not be a part of BADCT for all facilities.

- Interception of storm run-on and groundwater flow in shallow aquifers to control inflows to the facility;
- Natural geologic features functioning as liners such as soil and bedrock having low hydraulic conductivities;
- Shallow bedrock strength conditions, particularly as this may impact the effectiveness of solution control systems or natural containment;
- Attenuation of contaminants in the engineered foundation or natural vadose zone materials;
- Localized engineered containment as required;
- Provision of subdrainage beneath the dump to minimize hydraulic head and promote solution flow and collection. This is usually provided by the segregation of the coarser rock at the base through controlled end-dumping practices;
- Leachate collection systems consisting of granular finger or blanket drains and corrugated perforated HDPE pipes can be used to supplement natural subdrainage (Brawner, 1986). Section 3.2.4.3.2 (Leachate Collection/ Hydrostatic Head Control) includes a discussion on the development of such systems;
- Diversion and retention structures to collect run-off from downstream slopes;
- Engineered hydraulic barriers downstream. These may include soil-bentonite slurry walls with upstream pumpback wells, interceptor well fields and drains with downstream clay or geomembrane barriers. These types of measures can be included as BADCT elements to the extent that they intercept seepage within the vadose zone.
- Steep topography to ensure rapid removal and capture of solution;
- Well defined containment (e.g., within existing pits, canyons and valley fills);
- Hydrologic isolation; and
- Passive containment (See Section 1.2.5).

Collected leachate and storm run-off from the downstream slopes should be contained in ponds with appropriate discharge control elements. Information on the design of such ponds can be found in Section 3.6 (Surface Ponds).

Appendix C (Liner Design Principles and Practices) provides a discussion of liner design and liner technology which should be considered in the design of containment. In the case of geologic containment, site specific hydrogeological evaluations should be conducted.

A well designed QA/QC program has been found to be an important factor in achieving design performance criteria of an engineered facility. Attention to proper construction can make the difference between a facility that performs up to its expected design and one that has problems throughout its operational life. Appendix D (Construction Quality Assurance and Quality Control) provides additional guidance on the development of QA/QC documents.

3.3.4.4 Stability Design

Most Dump Leach Facilities are developed in a confined area and may have only one face that becomes a concern in stability design. Side slope design must be considered in the design of a Dump Leach Facility. This will vary from site to site depending on rock type, rock size, height of dump, earthquake potential, etc. Site specific testing should be performed to evaluate the shear strength of critical interfaces.

Much has been published about stability analyses. The geotechnical literature contains references not only to analytical solutions but also to computerized evaluations (Blight, 1987; Campbell, 1986).

Procedures appropriate for stability analysis of dumps are dictated by the type of ore involved. Where dumps are composed of hard, durable broken rock (meeting definitions of rockfill by Leps, 1988, Sherard and Cooke, 1985, etc.) the dump material itself will be inherently stable under static conditions. In such cases, static stability analysis is only required to evaluate the potential for sliding block failure through potentially weak foundation materials. This failure mode can be analyzed by simplified or limit equilibrium methods.

Dumps composed of hard durable broken rock also possess an inherently high resistance to earthquake forces. They are, however, susceptible to shallow slumping and raveling of the slope face when subject to intense earthquake-induced ground shaking, as well as the potential for sliding block failures along their foundation. For dump leach piles constructed of hard, durable rock, seismic stability evaluations should include: 1) pseudostatic and/or deformation analysis as discussed in Appendix E; and 2) assessment of the potential for raveling material to adversely impact facilities or structures near the pile toe (e.g., solution ditches or ponds).

Dumps composed of softer rock with appreciable silt or clay fines filling the matrix between the larger rock particles may have substantially different stability properties than dumps composed of hard durable rock. Major differences include potentially lower material strength and the potential for significant pore water pressure within the dump material. The same stability analysis procedures which are applicable to water storage and tailing dams (See Appendix E) should be applied to this type of dump. For dump leach piles constructed of this type of material, static and seismic stability analyses should be performed considering potential failure surfaces

within both the pile and foundation materials. Slopes substantially flatter that the angle of repose are sometimes necessary to achieve an adequate margin of safety against slope failure.

The recommended static stability criteria are as follows:

- For static analysis for earthen structures where geosynthetic components are not used and site specific testing has not been conducted, the recommended factor of safety is 1.5;
- For static stability analysis of structures where site specific testing was performed on weak interfaces, including those involving geosynthetic materials, if any, the recommended factor of safety is 1.3.

Seismic evaluations should be based on the Design Earthquake (Appendix E). Seismic stability analyses may include pseudostatic and deformation analysis methods as further discussed in Appendix E. When deformation analyses are required the displacement predicted shall be small enough so as not to jeopardize containment integrity.

Dump Leach Facility BADCT for pile stability may include:

- A specified maximum final design pile height;
- Providing setbacks (benches) between ore lifts to achieve an adequately stable overall slope angle;
- Providing a foundation design that buttresses the ore pile toe;
- Provisions to minimize the potential for pore pressure buildup in the ore pile;
- Providing berms at the edges of benches and/or outside the pile perimeter to protect adjacent facilities from run-out and raveling.

One or more of these potential BADCT components may be appropriate for a given facility. The BADCT design and stability evaluations in the APP application shall incorporate those measures identified above and/or other measures to the extent necessary such that static and seismic stability criteria are achieved.

Stability evaluations conducted should consider ultimate pile heights, intermediate construction stages, and maximum anticipated phreatic surfaces that may be critical with regard to stability. Additional details regarding stability analysis methodology are discussed in Appendix E.

3.3.4.5 Operational Measures

The following are examples of operating procedures that have been used as part of a discharge control system to achieve BADCT for dump leaching operations.

- End-dumping placement of leach material. End dumping results in coarse material being selectively deposited near the base of the dump, thereby facilitating

solution drainage and limiting hydraulic head at the base of the dump. End dumping also typically results in slope angles several degrees less than the natural angle of repose, thereby providing some inherent slope stability;

- Sequencing of leaching activities to allow for reaction time, thereby reducing the total amount of time solution is applied;
- Varying solution application rates and methods (e.g., flooding, sprinklers or wobblers) to optimize efficiency of solution application;
- Controlling solution application rates to avoid excessive hydrostatic head buildup at the base of the dump;
- Grading of dump surfaces to minimize erosion potential of storm water runoff;
- Providing grading and locating solution delivery hoses on the top of the dump to minimize the potential for slope washouts that could effect dump perimeter containment;
- Minimize the volume of normal operating solutions to maximize storm water containment capacity.

Application of operating procedures as a component of BADCT is site specific. Any of the above examples may or may not be appropriate for a given facility, and the design and engineering evaluations should be conducted accordingly. In addition, other operational considerations that help to limit aquifer loading can be proposed as part of BADCT by the applicant.

3.3.4.6 Operational Monitoring

During operation of a Dump Leaching Facility, monitoring should be conducted to ensure that the facility is performing and being operated as designed. Examples of monitoring to confirm that the facility is performing as designed include:

- Observation of dump deformations to monitor for stability. The type of slope movement that is the primary concern for Dump Leach Facilities is translational slope deformation that has the potential to affect containment integrity. The features which are associated with such translational failure consist of crack formation near the crest of the dump, deformation of the sideslopes, and outward translation of the toe. Very often, telltale signs are visible prior to substantial movement. A regular program of observations should be part of ongoing monitoring of the facility. It should be noted that dump leach ore is deposited in a loose state and during leaching some settlement and deformation will usually occur. Such settlement and deformation is not necessarily related to translational type failure that can affect containment integrity;
- Monitoring of any associated leak collection systems;
- Observing dump performance and perimeter containment during large storms;

- Evaluating solution application and recovery rates and meteorological data to estimate containment effectiveness.

The extent to which ADEQ will require operational monitoring to assure that the facility is performing as designed may depend upon the adequacy of the existing data on which the design is based, and the degree to which the design assumptions are conservative. For example, if an applicant proposes dump slopes that marginally satisfy static stability requirements discussed in Section 3.3.4.4, ADEQ may recommend monitoring of dump stability as discussed above. Conversely, conservative assumptions of leachate collection system performance may be proposed by an applicant to justify reduced monitoring needs.

Examples of monitoring to assure that the facility is being operated as designed include:

- Integrity monitoring and visual inspection so as to identify any system failures or areas in need of maintenance repair;
- Monitoring the volume and chemical composition of solutions applied to the dump to assure consistency with design assumptions.

Monitoring requirements to assure that the facility is being operated as designed may apply to most facilities and may be required by APP conditions pursuant to A.A.C. R18-9-A206.

A Contingency Plan is required separate from BADCT pursuant to A.A.C. R18-9-A204. In some cases an applicant may include some components of the Contingency Plan as part of BADCT (e.g., provisions for backup generators to allow solution circulation during a power outage may affect BADCT containment volume requirements).

3.3.5 Closure/Post-Closure

A closure/post-closure strategy must be drafted and submitted to ADEQ for preliminary approval as part of the APP application. The applicant must still comply with the requirements of A.A.C. R18-9-A209(B) prior to formal closure. Arizona Mined Land Reclamation Statutes (A.R.S. 27-901 through 27-1026) and implementing Rules govern surface reclamation. This BADCT guidance manual is not intended to duplicate or modify requirements of surface reclamation statutes.

The closure strategy shall eliminate, to the greatest extent practicable, any reasonable probability of further discharge from the facility and of exceeding aquifer water quality standards at the applicable point of compliance.

3.3.5.1 Physical Stability

Measures to provide long-term physical stability of Dump Leach Facilities are part of BADCT to the extent that they may affect aquifer loading. The dump should be stabilized as necessary to be resistant to water and wind erosion that can effect the physical stability in the long-term or lead

to sediment transport that can discharge pollutants to the aquifer by indirect surface water pathways to groundwater. Any proposed closure configuration must be supported with adequate stability analysis. The applicant or ADEQ may propose stability criteria for closure that is different from operational stability requirements based on long-term conditions that affect aquifer loading potential (e.g., different design earthquake parameters may be appropriate for closure evaluations because the closed facility will be present much longer than it operated).

Examples of physical stabilization measures that may be appropriate to include in BADCT for closure of a Dump Leach Facility include:

- Upgradient drainage controls will normally be left in place at the time of closure to protect the facility from washout;
- The dump surface can be stabilized with vegetation or by leaving durable rock on the slopes.

There is considerable debate regarding appropriate slope angles for Dump Leach Facility closure. If vegetation is used to stabilize the surface of the dump, some regrading of angle of repose slopes is needed. Where slopes will be revegetated, the applicant may be required to demonstrate (i.e., through existing natural or engineered examples, or calculations, etc.) the probability of success if slopes steeper than 2.5:1 are proposed.

For slopes that are structurally stable and consist of durable rock, surface stabilization for the purposes of BADCT need not include regrading if slope revegetation is not part of the reclamation plan.

3.3.5.2 Chemical Stability

3.3.5.2.1 General

As part of the overall closure strategy, it is important to evaluate the potential for leachate generation. Whether or not leachate will occur over the long-term is a water balance issue primarily affected by climate and the ability of the dump to shed water through run-off, evaporation and, where vegetation is present, evapotranspiration. Any proposed closure configuration should be supported by analysis to indicate the rate of leachate generation expected over the long-term. Measures should be taken, to the extent practical, to close the dump in a manner that will not generate leachate after closure. In cases where leachate is generated, the quality of the leachate which will be released depends on the amount of lixiviant remaining as well as the potential of the spent ore to release other contaminants. Contaminants which can be released include metals such as copper, arsenic, zinc, iron, etc. The release of a specific metal will be dependent on ore mineralogy and pH conditions in the spent ore. The waste characterization studies described under Section 1.2.1 and Appendix B can be the basis for estimating the potential release of contaminants from the spent ore. At the time of closure, such information should be available.

There are basically three types of demonstrated control technologies available for control of leachate release. These are:

- Source control;
- Migration control; and
- Interception and treatment.

The focus of source control is to remove or isolate environmentally available constituents of concern. Examples of source control include rinsing and detoxification (See Section 3.3.5.2.2), or physical removal of spent ore from the dump for placement in a more controlled environment (e.g., a mined out pit where no groundwater is present). In the case of acid generating spent ore, it could also be beneficial to place the spent ore in a pit under the water table.

Migration control refers to limiting the amount of leachate that may form and migrate through the dump. Typical technologies for migration control include surface grading of the dump to enhance run-off, surface water controls to minimize run-on, establishment of vegetation to promote moisture removal through evapotranspiration or installation of covers that include low permeability caps to limit infiltration. Long-term settlements should be evaluated in the design of covers. Long-term settlement is typically not a concern for spent ore in dumps composed of hard durable rock.

Interception and treatment of leachate is a long-term commitment which must be very carefully evaluated before it is implemented. Leachate can be intercepted by shallow trenches, cutoff walls, and other means, provided that such means intercept the leachate prior to it affecting groundwater. The treatment process could consist of lime addition for neutralization or more sophisticated active treatment processes. Passive treatment, such as construction of wetlands, must be considered a polishing step or only a treatment possibility for low volumes of leachate discharge. Although wetlands may be beneficial, their use must be carefully evaluated with respect to the following:

- The potential that due to seasonal variation of leachate discharge the wetland vegetation cannot be maintained;
- The potential for contaminant concentration in the wetland substrate or biomass; and
- The requirement for ongoing maintenance of the wetland to ensure its long-term capacity.

Other passive treatment methods which will require minimal maintenance are being developed. These include passing the leachate through containers filled with organic materials to precipitate the metals, anoxic limestone drains, etc. It is expected that this area will see considerable development in the next decade and constant updating of technologies will be required.

3.3.5.2.2 Rinsing/Detoxification

In the case of copper leaching, very little research is available to show if rinsing and detoxification is effective in removing acidity from oxide ores. With sulfide ores, it is generally not feasible to halt the production of acid and available metals in the long-term. However, the

arid climate of Arizona and migration control measures discussed in Section 3.3.5.2.1 may be effective in reducing infiltration, thereby minimizing the mobilization of metals and other products of acid generation.

The effectiveness of rinsing must be determined through sampling of effluent and/or solids. By sampling the effluent from the dump during and following rinsing a good average water quality may be obtained for the dump effluent. This provides an indication of water quality which could emanate from the dump in the long-term, assuming the dump will not be disturbed.

Analytical procedures discussed in Appendix B should be applied for testing the effectiveness of rinsing using a site specific approach considering known ore characteristics (e.g., sulfide or oxide), closure design, and risks associated with effluent discharge.

3.4 IN-SITU LEACHING

3.4.1 Introduction

In general, in-situ leach operations are those in which mineralized rock is left in place, sometimes fractured or altered to increase porosity and permeability, and subjected to infiltration of solutions in order to dissolve minerals for recovery.

The ore zone targeted for in-situ leaching may be located above the water table, below the water table or both. Leach solutions (barren solutions) may be introduced to the ore using surface distribution systems such as sprinklers or subsurface methods such as wells. Recovery of enriched leaching solutions may involve the use of wells, ponds, or sumps. In some cases, the enriched leach solutions must be discharged to an aquifer prior to recovery. As discussed in Section 1.2.4.5, in-situ leaching facilities can utilize active hydrologic control in an aquifer and aquifer characteristics as part of a BADCT design.

Guidance in this manual for BADCT development at in-situ leach operations is necessarily more general than for other types of facilities due to the higher degree of dependence on site specific factors. BADCT applies to the in-situ leaching process from the application of leaching solutions to the recovery of these solutions. Generally, the objective of BADCT for in-situ facilities is to maintain hydrologic control over leaching solutions throughout the process. Since in-situ leach operations may be subject to 40 CFR 146, Appendix F (Federal, State and Local Environmental Permits) includes a discussion of the Underground Injection Control (UIC) requirements for injection wells.

There are numerous variations of in-situ leaching that may be applied to a given site based on the depth and hydrogeologic characteristics of the ore body and other factors. The discharge control system which constitutes BADCT for an in-situ leaching operation may depend upon the type of in-situ leaching operation and will always be a composite of: site characteristics; design construction and operations considerations; and closure/post-closure measures. Important considerations related to these elements are discussed in the following sections:

- Section 3.4.2 - Types of In-Situ Leaching Operations
- Section 3.4.3 - Solution and Ore Characterization
- Section 3.4.4 - Siting Considerations
- Section 3.4.5 - Design, Construction and Operations Considerations
- Section 3.4.6 - Closure/Post-closure

3.4.2 Types of In-Situ Leaching Operations

Three general types of in-situ leach operations have been identified, as described below.

- In-Situ Leaching With Deep Well Injection;
- In-Situ Leaching Using the Water Table for Capture; and
- In-Situ Leaching With Capture Above the Water Table.

Each of these three general types is illustrated by an example cross section in Figures 3-2, 3-3 and 3-4.

3.4.2.1 In-Situ Leaching With Deep Well Injection

In-situ leaching by deep well injection and extraction involves the recovery of mineral values from the native ore by circulating solvents through the ore in its native geologic state via injection wells. Injection wells and the mine leaching operations are considered to be discharging facilities under A.R.S. 49-241.B. For purposes of this section deep injection wells are defined as wells injecting within an ore body deep below the water table.

Figure 3-2 shows one example of how an in-situ operation with deep well injection might appear in cross section.

3.4.2.2 In-Situ Leaching Using the Water Table for Capture

Leaching using the water table for capture requires a BADCT that mainly utilizes the aquifer (hydrologic sink, pumping, etc.) to manage and control leach solutions. Whether natural or induced, a difference in permeability may exist between the host bedrock and the area to be leached to allow for the managed control and migration of leach solution. In-situ leaching using the water table for capture includes such leaching operations as rubbilization, leaching of subsidence zones, and/or leaching of natural highly fractured zones of rock. Solution application to these operations may include surface application (i.e., ponding, sprays) or injection wells. These operations are further defined below:

- Rubbilization - Rubbilization is the engineered blasting (fracturing) of the ore body in order to create an area of higher permeability than its natural surroundings. The area to be blasted may consist of the perimeter or bottom of existing open pits, areas

between working levels in existing underground mines not presently impacted by subsidence zones, a new ore body, or the perimeter or edge of a quarry, cliff or large sump.

- Subsidence Zones - Subsidence zones are areas of downward settling of the earth's surface. In many such areas the host bedrock is fractured. Examples of subsidence zones exist in breccia pipes and over underground mines.
- Naturally Fractured Zones - Naturally fractured zones of rock may be amenable to in-situ leaching where significantly higher permeability occurs in the mineralized area compared to the surrounding bedrock. This difference in permeability allows for the controlled migration of leach solutions.

An example of an in-situ operation in fractured mineralized bedrock using the water table for capture is illustrated in Figure 3-3.

3.4.2.3 In-Situ Leaching With Capture Above the Water Table

Similar to in-situ leaching using the water table for capture, in-situ leaching with capture above the water table may include rubbilization, leaching of subsidence zones, and/or leaching of natural highly fractured rock zones (See Section 3.4.2.2). Solution application may include surface application (i.e., ponding, sprays) or vadose zone injection wells. The main difference between leaching using the water table for capture and leaching with capture above the water table is that leaching using the water table for capture may include a BADCT that utilizes the aquifer (hydraulic sink, cone of depression, etc.) to manage and control leach solution. Leaching above the aquifer generally utilizes a BADCT that captures solutions before they reach the water table, thereby reducing the amount of discharge. However, in some cases, depending on site specifics, BADCT may utilize capture of leach fluids from an underlying receiving aquifer.

Figure 3-4 suggests how in-situ leaching with capture above the water table might appear in a rubbilization scenario.

FIGURE 3-2 - EXAMPLE OF IN-SITU LEACHING WITH DEEP WELL INJECTION

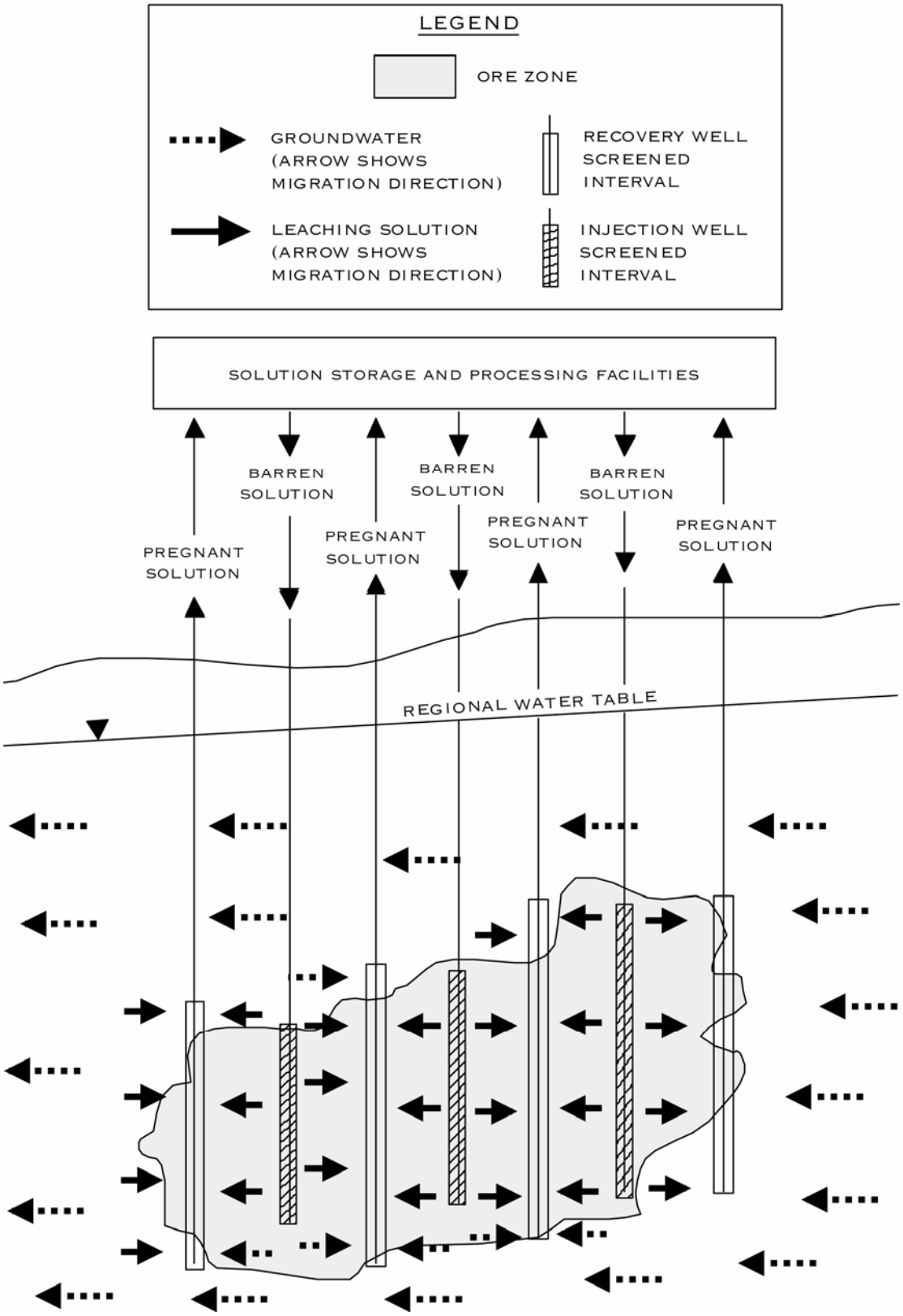


FIGURE 3-3 - EXAMPLE OF IN-SITU LEACHING USING THE WATER TABLE FOR CAPTURE

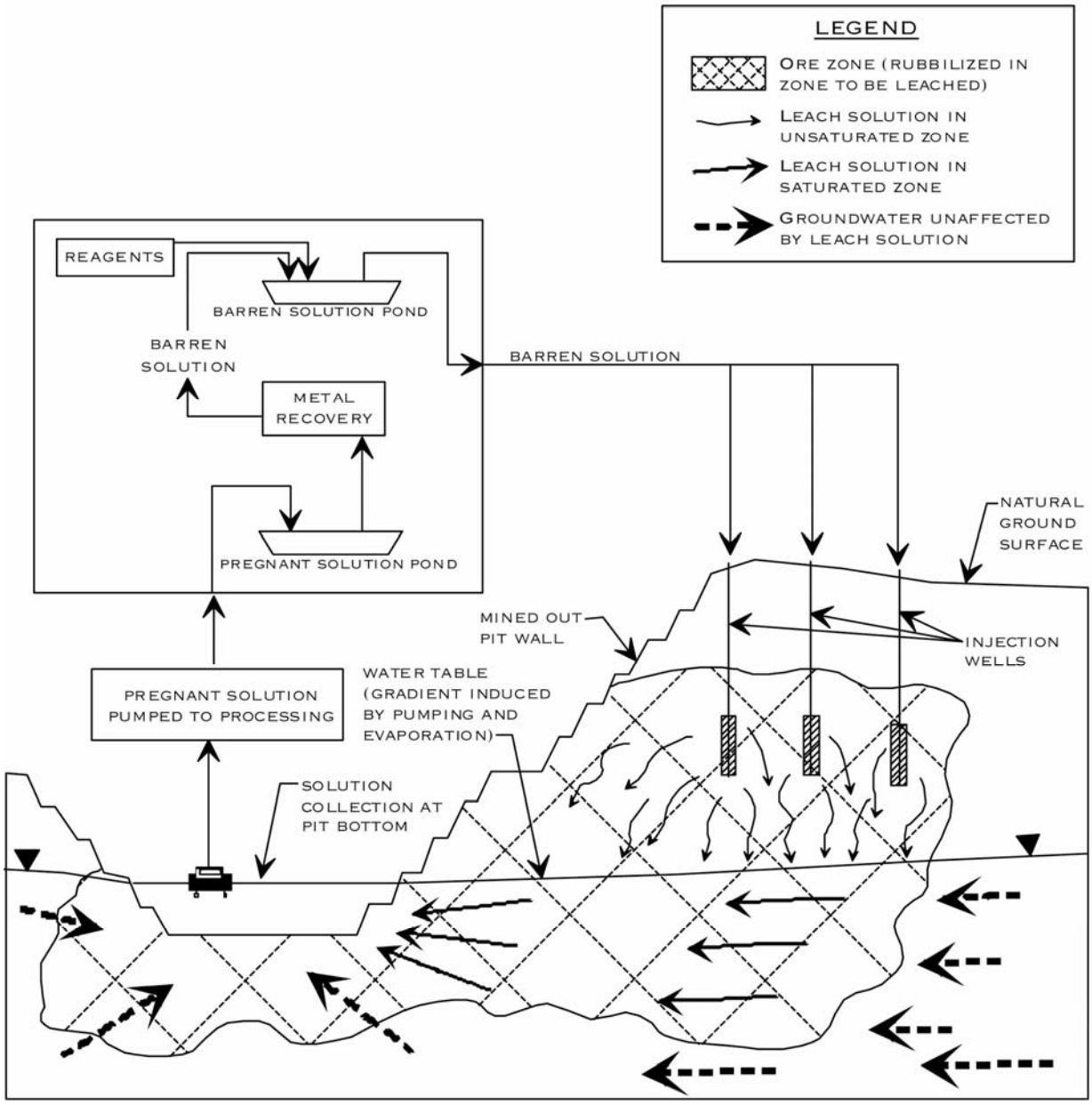


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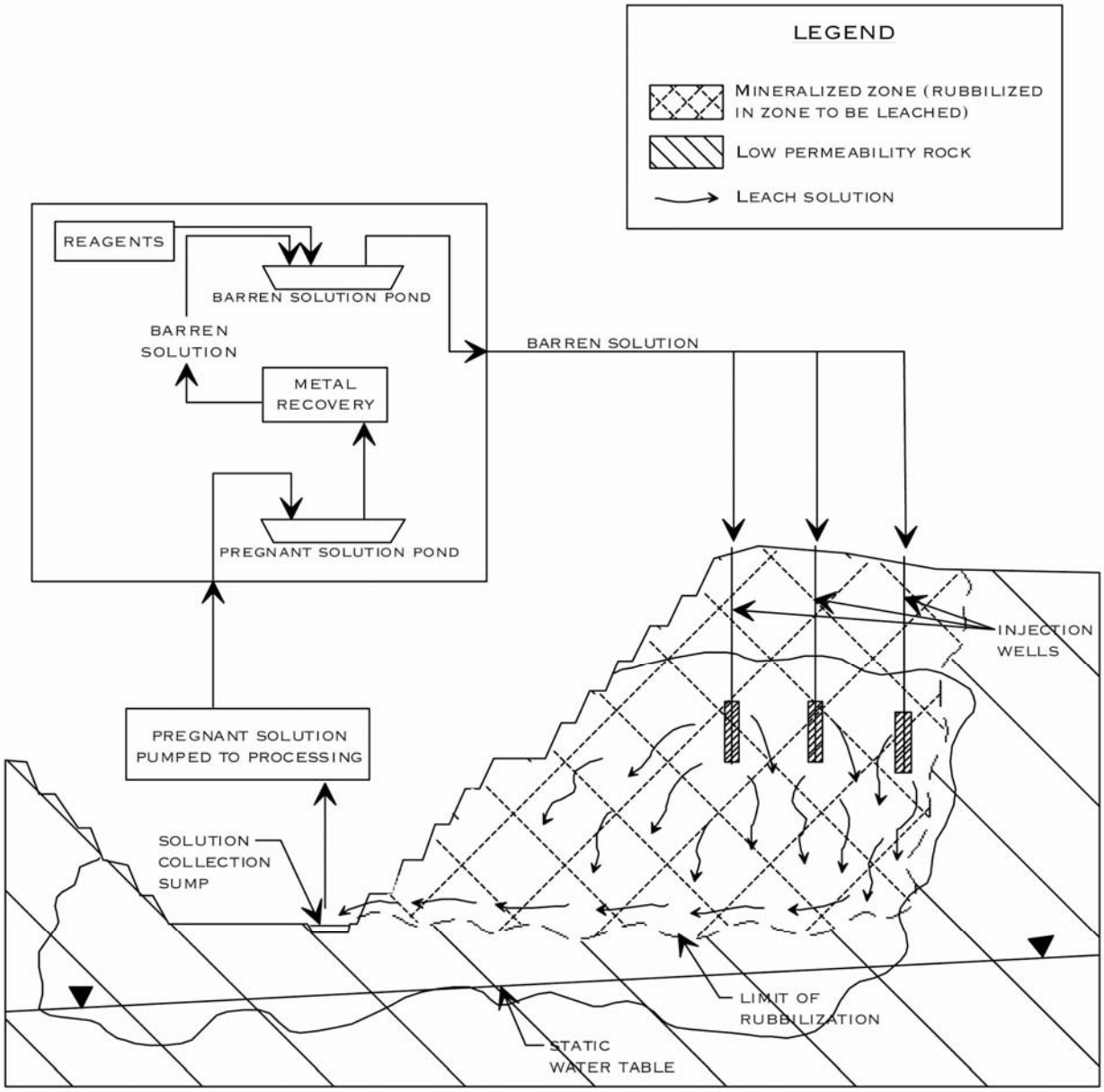
FIGURE 3-4 - EXAMPLE OF IN-SITU LEACHING WITH CAPTURE ABOVE THE WATER TABLE



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3.4.3 Solution Characterization

In the case of in-situ operations, barren and pregnant leach solutions should be characterized to support development of individual BADCT for the facility and to estimate aquifer loading that may occur both during operations and in the closure/post-closure period. Since it may be difficult for new operations to characterize pregnant solutions, such characterizations may be developed using site specific ore geochemistry combined with geochemical equilibrium modeling or data from existing similar operations, or both.

Data from solution characterizations should be evaluated to assure that engineered facilities used for the application and recovery of barren and pregnant solutions (i.e., wells, cutoff walls, etc.) are compatible with the solutions.

A discussion of relevant physical and chemical analyses for material characterization is presented in Section 1.2.1 and Appendix B, Solution, Ore and Waste Characterization..

3.4.4 Siting Considerations

Since the performance of in-situ leach facilities are extremely dependent on site specific geotechnical and hydrogeologic conditions, a detailed site characterization is critical. Hydrogeology and structural geology (e.g., subsidence zones, slope failure, faults, etc.) within the ore body and surrounding area are usually of key importance to solution control at in-situ mining facilities. Characterization of the chemistry of subsurface materials may also be necessary to evaluate the potential for the evolution and fate of pollutants in the aquifer. Additional information and guidance on how site factors, (e.g. topography, soil properties, geology) influence the design of a facility can be found in Section 1.2.4 (Site Factors).

While the degree of subsurface investigations required for in-situ leaching operations may be greater than for other types of mining facilities (due to the high dependence of subsurface conditions for leaching solution control), requisite subsurface data needs can often be satisfied in conjunction with ore body investigations required for project feasibility work that may precede permitting. Therefore, early consultation with ADEQ staff may be particularly valuable to APP applicants for in-situ leaching operations, to provide assurance that data obtained early on can be used to its maximum benefit once the preparation of permitting applications is under way. In any case, it is strongly recommended that the site investigation program for BADCT development be conducted with input from ADEQ so that agreement can be reached on the amount of information to be collected.

Site considerations that are key to BADCT development for in-situ leaching facilities are discussed in the following sections:

- Section 3.4.4.1 - Climate and Surface Hydrology
- Section 3.4.4.2 - Subsurface Conditions
- Section 3.4.4.3 - Geologic Hazards

3.4.4.1 Climate and Surface Hydrology

In preparing an APP application, an applicant should obtain and develop site specific climatic and hydrologic information. Climatic conditions may be important to evaluate surface water charac-teristics, migration potential through the vadose zone, and other factors discussed in Section 1.2.3. Statistical rainfall and evaporation data may be required to support an APP application.

Surface hydrology information is necessary to develop appropriate surface water controls discussed in Section 3.4.5.2. Hydrologic information must include, at a minimum, the location of perennial or ephemeral surface waters and 100-year floodplains that occur in proximity to the subject facility. If wells or other discharge control elements are to be located on a 100-year floodplain, an assessment of the 100-year flood surface flow and potential impacts on the facility must be conducted.

Lakes, perennial or ephemeral streams, springs and other surface waters must be identified as necessary to safely design the facility (e.g., minimize run-on) and minimize any unnecessary discharge to surface waters. Knowing the location of surface waters also will assist the applicant in determining if other agencies must be contacted (See Appendix F). Hydrologic characteristics of wetlands, if present, may also need to be identified.

3.4.4.2 Subsurface Conditions

Hydrogeologic properties such as variations in primary and secondary permeability can be used to control the migration of solution and facilitate pregnant solution recovery. Subsurface geochemical properties may attenuate pollutants and thereby limit aquifer loading. Predictive hydrogeologic and geochemical modeling should be used, as necessary, to evaluate aquifer loading in support of an APP application. Anticipated aquifer water quality at the proposed point of compliance should be assessed.

Information regarding subsurface characterization is further discussed in Section 1.2.4.

Potential for short circuiting of anticipated solution migration pathways due to fractures and solution/rock chemical reactions over time is a potential concern that should be assessed for in-situ mining in most instances.

3.4.4.3 Geologic Hazards

During the process of site characterization and design development to demonstrate BADCT, engineering geology studies should be performed to identify and evaluate geologic hazards. Geologic hazards as discussed herein are processes capable of producing large ground movements in comparison to those involved in routine analysis of foundation settlements and deformations. Hazards which may disrupt the structural integrity of the discharge control system elements (e.g., wells) include landslides, subsidence, liquefaction and other earthquake-induced

ground failure and collapsing soils. An additional part of design development related to geologic hazards discussed in Appendix E (Engineering Design Guidance) is the consideration of earthquake forces in slope stability analysis.
The study area relevant to assessment of geologic hazards is determined by site characteristics, but usually requires evaluation of the area up to one-half mile or more outside the perimeter of the discharging facility.

3.4.4.3.1 Landslides

Landslides are sometimes present on hill slopes and may be capable of reactivation by excavation at the toe, adding additional loading to the landslide mass, changes in surface drainage, fluctuations in the water table, or earthquakes. Landslides usually can be identified by interpretation of aerial photography, but may be so large that they will not be apparent if examination is confined to the immediate area of the discharging facility. The Transportation Research Board (1996) provides a comprehensive treatment of this subject.

It is generally preferable to avoid locating wells or other discharge control system elements in areas prone to landslides. If facilities subject to BADCT are located in areas prone to landsliding, special engineering measures may be needed including buttressing, engineered surface drainage, soil drainage systems, or other measures. Appropriate mechanisms to stabilize landslides will depend upon specific site conditions.

3.4.4.3.2 Subsidence and Settlement

Groundwater declines of as much as 300 feet in the alluvial basins in central and southeastern Arizona are known to have caused subsidence of as much as 20 feet (Jachens and Holzer, 1979, 1982; Holzer and Pampeyan, 1981; Holzer, 1984; Raymond, 1987). Withdrawal of geothermal fluids (Narasimhan and Goyal, 1984), solution extraction of salt (Ege, 1984), coal mining, hard rock mining and other underground excavations (National Coal Board, 1975; Kratzch, 1983; Bieniawski, 1987; Jeremic, 1987; Bell et al., 1988) also can produce large amounts of subsidence. In-situ leaching may result in subsidence through dissolution of underlying rock.

If the cause of the subsidence is regional (e.g., pumping of an areally extensive and uniform aquifer) and the movement occurs at approximately the same rate beneath the entire facility, there may be no impact on the facility. If subsidence is not uniform beneath the facility, different rates or amounts of subsidence can result in horizontal or vertical strains that can impair the integrity or functioning of facility components such as wells, piping systems, and embankments. It can also cause earth fissuring that can provide preferred pathways for seepage migration to the water table. For sites located on the relatively flat alluvial plains, subsidence may alter surface grades and modify upstream drainage areas over time.

Settlement can occur under large loads placed on the surface, e.g., high leach piles. Settlement due to loading can induce horizontal or vertical strains in the subsurface similar to subsidence.

Potential for settlement may be appropriate to consider if wells or other subsurface in-situ leaching elements may be located in an area subject to significant loading.

The subsidence and settlement profiles and corresponding horizontal movement, horizontal strains and the potential for earth fissuring can be evaluated by empirical methods (Helm, 1984), simplified elastic methods (Lee and Shen, 1969; Helm, 1984) and finite element methods (Keaton et al., 1995). Where potential exists for substantial amounts of subsidence or settlement to occur at a facility location, or potential for even moderate amounts of differential subsidence or settlement (e.g., due to abrupt changes in the depth to shallow bedrock beneath a facility), these potential deformations should be considered.

3.4.4.3.3. Earthquake-Induced Ground Failure

The following paragraphs discuss the potential for earthquake-induced ground failure caused by liquefaction and faulting.

Liquefaction is usually associated with areas that have all of the following properties:

- Shallow depth to saturation;
- Loose sand, sandy silt, or silty sand lithology;
- High peak ground acceleration under design earthquake conditions.

Liquefaction can produce rapid settlement and/or horizontal spreading of the subgrade, even in relatively flat areas, that can impact the structural integrity of wells, embankments and other elements that may control discharges at an in-situ leaching facility. Methods for evaluating the liquefaction potential are discussed in Appendix E.

If conditions susceptible to liquefaction occur at the location of discharge control elements for an in-situ leaching facility, engineering evaluations should be provided with the APP application that demonstrate the integrity of the facility will not be jeopardized in the event of the Design Earthquake (Appendix E). The Design Earthquake should be evaluated considering known active faults within a distance of 200 km. Active faults are those which have experienced rupture in the past 35,000 years. Potential earthquake size can be estimated based on correlations with fault length (dePolo and Slemmons, 1990).

As indicated by published fault maps (Nakata et al., 1982; Pearthree et al., 1989; Demsey and Pearthree, 1990; Maulchin and Jones, 1992; Jennings, 1992; Euge et al., 1992), relatively few active faults have been identified in Arizona. Published sources should be used to define regionally-occurring faults. Aerial photographs should also be utilized to confirm the absence of faults in the immediate site vicinity, or to precisely locate nearby faults, if present. Offsets and age of recent movement can be investigated through trenching studies when necessary.

Where active faults occur in the immediate vicinity of a proposed facility, caution must be taken to assure that the fault location is well-defined. Aerial photograph evaluation, and field studies if necessary, should be used to confirm that signs of surface offset (e.g., splay faults) do not occur at the proposed facility location. Where a facility is to be located on an active fault, the applicant must evaluate potential reasonably foreseeable ground rupture scenarios to demonstrate that the proposed location is feasible.

3.4.4.3.4 Collapsing Soils

Collapsing alluvial soils which are widely distributed in Arizona (Beckwith and Hansen, 1989) are alluvial fan deposits formed during the past 11,000 years (Holocene era), since the last episode of continental glaciation. The geotechnical properties of these soils, which generally are susceptible to self-weight settlement of 2 to 6% of their thickness when wetted, are largely a consequence of the dynamics of water-sediment supply in alluvial fan development and associated unsaturated flow processes. Thick deposits of particular concern in engineering analysis occur as coalescing alluvial fans at the base of mountains and along the margins of floodplains of major rivers such as the Gila, San Pedro and Colorado. Deposits as thick as 80 feet occur along the margins of floodplains.

Collapsing soils present the potential for differential subgrade movement and horizontal or vertical strains to wells, foundations, and other facility components similar to those addressed for subsidence in Section 3.4.4.3.2. If conditions susceptible to collapsing soils are present at the location(s) of discharge control elements for an in-situ leaching facility, engineering evaluations should be provided with the APP application that demonstrate the integrity of the element(s) will not be jeopardized.

3.4.5 Design, Construction and Operations Considerations

The following sections address design, construction, and operations aspects that may constitute part of BADCT for a given facility where they have the potential to affect aquifer loading:

- Section 3.4.5.1 - Site Preparation
- Section 3.4.5.2 - Surface Water Control
- Section 3.4.5.3 - Discharge Control
- Section 3.4.5.4 - Stability Design
- Section 3.4.5.5 - Operational Measures

3.4.5.1 Site Preparation

Surface site preparation for in-situ operations is minimal compared to other types of mining. The site may be graded to allow placement of facilities on level surfaces or to protect the site from flooding events. Subsurface site preparation, such as hydrofracture and acid development, may be implemented to increase mineral recovery.

3.4.5.2 Surface Water Control

The objective of a surface water control system at an in-situ leach operation is to control run-on and run-off in order to protect the integrity of facilities containing process solutions and prevent uncontrolled releases that can discharge pollutants to the aquifer by indirect surface water pathways to groundwater. BADCT surface water controls at an in-situ leaching operation may include the following:

- Upstream surface water diversion channels or dams that divert run-on away from the facility areas;
- Upstream storm water detention dams or basins that reduce the rate of run-on that must be diverted away from the facility areas;
- Upstream storm water retention dams or basins that store run-off from upgradient areas to reduce the amount of run-on to the facility areas;
- Downstream reclaim/storm water containment ponds and related channels and diversion dikes or berms that capture run-off from facility areas.

BADCT for a proposed facility may use any or all of these components designed to satisfy the following criteria:

- Components that store storm water, rainfall or process fluids (e.g., ponds) must be designed for the design storm volume (See Appendix E).
- Components that divert run-off and run-on (e.g., channels) must be designed to convey the design peak flow.

Where in-situ leaching utilizes injection wells to discharge leaching solution (as opposed to surface application), undeterred surface water flows on the ground surface above the active leaching operation may not adversely affect discharge controls. In such cases, surface water control systems may be minor. Engineered systems may only be necessary to control surface drainage at locations of key surface features (i.e., well heads, pipeline supports, solution storage/processing facilities, etc.). Conversely, if solution application occurs at the surface, drainage may need to be controlled throughout the application area to minimize mingling of precipitation and process solution.

3.4.5.3 Discharge Control

The objective for discharge controls is to effectively control leach solution. Site specific factors such as surface hydrology, “hydrologic isolation,“ climate, location of the facility, and the known physical and chemical properties of the in-situ leach material are used to determine the amount of engineered containment that is required.

Geologic features such as low permeability zones, steep sloping interface zones (between fractured mineralized zones and host bedrock), and attenuation can be used as effective sub-surface containment. The burden is on the applicant to demonstrate performance of these site specific characteristics.

3.4.5.3.1 Discharge Control - In-Situ Leaching With Deep Well Injection

The following discharge control design elements have been used as part of discharge control systems to achieve BADCT for deep well injection facilities. Under no circumstances, shall any new deep injection wells (defined as Class III wells under EPA UIC regulations) be constructed to allow the migration of fluids into or between underground sources of drinking water. All construction, operational, and monitoring requirements are referenced in Title 40 of the CFR Part 146. It should be noted that application of the design elements is site specific. Thus all the design elements may not be a part of BADCT for all facilities.

- Pumping to create a cone of depression to contain, capture and recycle solutions. Recovery wells should be pumped at a rate greater than the injection rate in order to maintain a cone of depression;
- Boreholes or wells, which may act as conduits for leachate to contaminate aquifers, should be plugged and abandoned in accordance with Arizona Department of Water Resources rule R12-15-816 and required UIC regulations (40 CFR Part 146);
- Proper injection and recovery well design, construction and operation. The UIC regulations (40 CFR Part 146) establish the basis for determining mechanical integrity, construction and operation BADCT for Class III and, where appropriate, Class V injection and recovery wells;
- Passive Containment - In some situations, slurry cut-off walls, hydrologic sinks, or other natural or engineered topographical, geological, or hydrological control measures that can operate without maintenance may satisfy BADCT requirements if employed with additional processes, operating methods, or other alternatives to minimize discharge.

3.4.5.3.1.1 Injection Well Mechanical Integrity - Design

In order to establish BADCT for injection wells the mechanical integrity of the wells must be established. The establishment of mechanical integrity must be based on the application of tests and methods generally accepted by industry. When reporting the results of mechanical integrity tests to ADEQ, a facility shall include a description of the test(s) and the methods used. The following criteria, based on UIC requirements for Class III wells, satisfy the BADCT requirements for injection well integrity:

- There is no significant leak in the casing, tubing or packer;
- There is no significant fluid movement into an aquifer through vertical channels adjacent to the injection well bore;
- Other mechanical integrity tests as approved by ADEQ.

3.4.5.3.1.2 Injection Well Construction

The following criteria, based on UIC requirements for Class III wells, satisfy the BADCT requirements for injection well construction:

- New wells shall be cased and cemented to prevent the migration of fluids into or between aquifers;
- The casing and cement used in the construction of each newly drilled well shall be designed for the life expectancy of the well;
- The following factors may be used to determine and specify casing and cementing requirements;
  - depth to injection zone,
  - injection pressure, external pressure, internal pressure, axial loading, etc.,
  - hole size,
  - size and grade of all casing strings,
  - corrosiveness of injection and formation fluids,
  - lithology of injection and confining zones, and
  - type and grade of cement, including acid resistance and results of cement testing;
- Appropriate logs including cement bond logs and logs of other tests shall be conducted during the drilling and construction of the well and a descriptive report prepared by a knowledgeable log analyst shall be submitted to ADEQ;
- Deviation surveys shall be conducted at sufficiently frequent intervals;
- The following information concerning the injection zone shall be determined;
  - fluid pressure,
  - fracture pressure,
  - physical and chemical characteristics of the formation fluid.

3.4.5.3.1.3 Injection Well Operation

Proper operation of injection wells must include the following:

- Except during well stimulation or formation fracturing, injection pressure in the injection zone, calculated from wellhead pressure, shall not cause new fractures or propagate (i.e. extend) existing fractures in the injection zone or cause the migration of injection and formation fluids into an aquifer;
- Injection between the outermost casing and the well bore is prohibited where the outermost casing is being used to protect underground sources of drinking water;
- Safe operating pressure for the casing shall be determined and maintained; and
- Injection pressure should be monitored for fluctuations as well as any sudden drops in pressure.

3.4.5.3.2 Discharge Control - In-Situ Leaching Using The Water Table For Capture

The following discharge control design elements have been used as part of discharge control systems to achieve BADCT for in-situ leaching facilities using the water table for capture. It should be noted that application of the design elements is site specific. Thus all the design elements may not be a part of BADCT for all facilities.

- Pumping to create and maintain hydrologic control to contain, capture and recycle solutions using the water table. Solution sumps located at the bottom of open pits or within underground workings may not require liners. In some circumstances, due to the natural characteristics of hydrologic sinks, the flow of solutions is towards these sumps. Liners, clay or other media could impede the successful recovery of solutions. Site specific studies should indicate whether or not the sump induces solutions to migrate upward into it;
- Areas where higher hydraulic conductivities are present or induced (blasting, natural or induced subsidence, hydrofracturing, etc.) can be used for effective hydrologic control;
- Induced slopes: Slopes may be engineered into the blast design such that hydraulic gradients are moderately to steeply inclined towards the solution collection sump in the pit bottoms and away from the pit perimeter (towards the drifts, sumps, shafts, etc.). Subsidence zones generally have a naturally occurring slope as defined by structural geology or previous underground mining activities;
- Where applicable, proper injection and recovery well design, construction and operation protocols should be implemented (See 3.4.5.3.1);
- Passive Containment - In some situations, slurry cut-off walls, hydrologic sinks, or other natural or engineered topographical, geological, or hydrological control measures that can operate without maintenance may satisfy BADCT requirements, if employed with additional processes, operating methods or other alternatives to minimize discharge.

3.4.5.3.3 Discharge Control - In-Situ Leaching With Capture Above The Water Table

Several methodologies exist for leaching ore reserves above groundwater level. The objective is to manage the fluid within the vadose zone entirely. Discharge control specific to this process may include the following:

- Application of solution can be used to cause local saturated zones within the vadose zone in the mining area. Capture of leach fluid by recovery wells, sumps or drains in the saturated area can be conducted so that migration of fluid into the underlying aquifer is reduced to the maximum extent practicable;

- Application of leach solution above the mining area and capture of the leach solution above an aquitard or hydrologically isolated region may prevent migration into local aquifers;
- Areas where higher hydraulic conductivities are present or induced (blasting, natural or induced subsidence, hydrofracturing, etc.) can be used for effective hydrologic control;
- Induced slopes: Slopes may be engineered into the blast design such that hydraulic gradients are moderately to steeply inclined towards the solution collection sump in the pit bottoms and away from the pit perimeter (towards the drifts, sumps, shafts, etc.). Subsidence zones generally have a naturally occurring slope as defined by structural geology or previous underground mining activities;
- Where applicable, proper injection and recovery well design, construction and operation protocols should be implemented (See 3.4.5.3.1);
- Passive Containment - In some situations, slurry cut-off walls, hydrologic sinks, or other natural or engineered topographical, geological, or hydrological control measures that can operate without maintenance may satisfy BADCT requirements, if employed with additional processes, operating methods or other alternatives to minimize discharge.

3.4.5.4 Stability Design

The stability of an in-situ operation is directly related to the existence of on-site geologic hazards. Geologic hazards applicable to in-situ facilities are discussed in Section 3.4.4.3.

3.4.5.5 Operational Measures

Solution management criteria will be determined on a site specific basis. The application rate and method of application will vary considerably at each facility and between facilities depending on seasonal adjustments, process needs (e.g., blending requirements, production requirements/ objectives), rock type, mineral grade, etc. The following operating procedures may be used as parts of discharge control systems to achieve BADCT for applicable in-situ facilities:

- Application of leaching solutions in a manner such that operating needs, water conservation, and other environmental factors are optimized. The application rate and method of injection or application may vary considerably at each facility and between facilities depending on seasonal adjustments or on process needs;
- Innovative methods, if appropriate, may be used to maximize the efficiency of leachate recovery wells. Monitoring of well pressures, pumping rates, recovery rates and fluid chemistry can provide data for optimizing injection/recovery well configurations and pumping rates. The optimal configurations for wells and pumping rates will change as ore is recovered;
- Computer control of flow rates to optimize operational efficiencies.

3.4.6 Closure/Post-Closure

A closure/post-closure strategy must be drafted and submitted to ADEQ for preliminary approval as part of the APP application. The applicant must still comply with the requirements of A.A.C. R18-9-A209(B) prior to formal closure.

Depending on site specific conditions, fluids impacted by leach solutions may begin, or continue to discharge, from the mine leaching operation after application of leach solution is terminated. In some cases, continued pumping may be conducted to recover economic material or until evaporation ponds reach a safe capacity. If discharge would begin or continue after application of leach solution is terminated, additional closure actions may be required. Such actions for copper operations might include control of natural inflow from land surface to the leaching zone and continued pumping to maintain hydraulic control in the receiving aquifer.

For in-situ uranium facilities in other states, flushing or "sweeping" the aquifer with water (i.e., reverse osmosis) is standard practice.

After it is determined that there is no additional use for the injection and recovery wells, the wells should be plugged and abandoned in accordance with A.A.C. R12-15-816 and all required UIC regulations. Furthermore, the wells shall be plugged and abandoned in a manner that will not allow the movement of fluids either into or between underground sources of drinking water.

3.5 TAILING IMPOUNDMENTS

3.5.1 Introduction

In the permitting of a new Tailing Impoundment, the applicant should review each phase of the proposed development. These include siting, design, construction and operations, closure and post-closure. Important considerations for BADCT analysis and related design for Tailing Impoundments are presented in this chapter. Examples of existing facilities are cited which demonstrate design features and operating procedures which may constitute BADCT.

Tailing Impoundments usually include an engineered fill embankment (sometimes referred to as a "dam") to provide a basin where tailing material is deposited as a hydraulic fill. Because of this configuration, structural components, drainage elements, and operational procedures required to assure slope stability for static and earthquake conditions constitute important parts of the discharge control system.

Tailing disposal in the base metal industry typically involves hydraulic deposition of very large volumes of waste slurries. Based on practical operating experience, theoretical studies and performance monitoring, a philosophy of design has emerged wherein adequate discharge control has been achieved in unlined basins employing control technologies which take advantage of the large net evaporation in the prevailing arid and semi-arid climate in Arizona.

The influence of the arid to semi-arid climate which prevails in Arizona on discharge control is discussed by Hutchison
and Ellison (1992). All major copper and molybdenum Tailing Impoundments in the western United States, British Columbia and northern Mexico are unlined and employ these discharge control technologies to varying degrees and in various combinations. These technologies have included "slime sealing" from the back of the impoundment; special procedures for the sequence and method of spigotting; water management to maintain as small a pond as practical to minimize seepage; and provision of drainage elements at the base tailing to minimize heads that control discharge. A fundamental strategy in applying these technologies to the discharge control system is to minimize effective hydraulic head during operation and promote rapid dewatering after closure so that addition of pollutants to the protected aquifer or aquifers is minimized over the life cycle of the facility (operational, closure and post-closure periods). This strategy often reduces post-closure seepage to small amounts.

The large number of precious metal Tailing Impoundments which have been constructed in the western United States and other arid and semi-arid areas (e.g., Chile, Australia, etc.) during the past 15 years provide demonstration of the discharge control systems elements which may constitute BADCT for precious metal Tailing Impoundments. A few unlined facilities have performed satisfactorily where a low permeability foundation, deep water table and high degree of hydrologic isolation were present. Absent the presence of an adequate "geologic liner," generally accepted practice has been to employ artificial liners for precious metal Tailing Impoundments in conjunction with system elements to minimize heads over the liner and infiltration from the tailing beach and pond.

Regulatory authority over the design, construction and operation of uranium Tailing Impoundments in Arizona is controlled by Environmental Protection Agency (EPA) requirements under the 1978 Uranium Mill Tailings Radiation Control Act (UMTRCA) (PL95-604) and certain standards of the Nuclear Regulatory Commission (NRC) as well as the APP program. These regulations and related regulatory precedents may define BADCT for any new uranium Tailing Impoundments in Arizona.

Because development of Individual BADCT for a facility is based on aquifer loading, each of the key factors affecting aquifer loading must be considered. Field investigations and evaluations are usually required to provide information necessary for the estimation of aquifer loading as discussed in Section 1.1.3.3. Important considerations for developing Individual BADCT for Tailing Impoundments are addressed in the following sections:

- Section 3.5.2 - Solution and Tailing Characterization
- Section 3.5.3 - Siting Considerations
- Section 3.5.4 - Design, Construction and Operations Considerations
- Section 3.5.5 - Closure/Postclosure

3.5.2 Solution and Tailing Characterization

Characterization of the chemical, biologic and physical characteristics of the tailing fluids and solids is necessary to evaluate BADCT design and the potential for discharge of pollutants from the facility. A discussion of relevant material characterization of tailing fluids and solids is presented in Section 1.2.1 and Appendix B (Solution, Ore and Waste Characterization).

Tests on tailing solids to evaluate acid generating characteristics and the potential to mobilize or attenuate the migration of chemical constituents may include Acid-Base Accounting, Humidity Cell Kinetic ABA Analysis, TCLP testing (EPA Method 1311), SPLP testing (EPA Method 1312), soluble ion analysis (swept test), Distribution Coefficient by Short Term Batch Test (ASTM D4319-83) and cation exchange capacity. Additional chemical and geochemical tests and analyses may be required to fully characterize tailing fluids and solids.

Where the controlled deposition of tailing slimes is proposed as part of a BADCT containment system, physical properties of the tailing solids (e.g., grain size), and slurry (e.g., percent solids) may also be important.

3.5.3 Siting Considerations

Detailed site characterization is usually necessary to select an appropriate location for the proposed facility, to provide information for engineering evaluations (e.g., stability analysis, seepage control), and to estimate aquifer loading.

Siting considerations that are key to Individual BADCT development are discussed in the following sections:

- Section 3.5.3.1 - Climate and Surface Hydrology
- Section 3.5.3.2 - Subsurface Conditions
- Section 3.5.3.3 - Geologic Hazards

Additional information and guidance on how site factors (e.g., topography, geology/stability, soil properties, vadose zone, and surface and subsurface hydrology) influence the design of a facility can be found in Section 1.2.4 (Site Factors).

The appropriate level of detail of each aspect of the site characterization is often dependent upon the extent to which the APP applicant plans to utilize various factors in developing the Individual BADCT design. For example, if chemical attenuation (e.g., precipitation, hydrolysis, complexation, etc.) in soils beneath the facility is not expected to play an important role in reducing aquifer loading, then investigation of site soil characteristics affecting chemical attenuation is not necessary. Conversely, where hydrologic isolation provided by the depth to the aquifer beneath the facility and geologic materials in the vadose zone is key in the

development of the facility design, detailed investigations of vadose zone thickness, lithology, primary and secondary permeability, etc. are usually required.

It is strongly recommended that the site investigation program be conducted with input from ADEQ so that agreement can be reached on the amount of information to be collected.

3.5.3.1 Climate and Surface Hydrology

In preparing an application for an APP, an applicant must obtain and develop site specific climatic and hydrologic information. Climatic conditions are important to the evaluation of surface water characteristics, process water balances, the potential for leachate formation after closure, the potential for migration through the vadose zone, and other factors discussed in Section 1.2.3. Statistical data on rainfall and evaporation are required to support an APP application.

Surface hydrology information is necessary to develop appropriate surface water controls discussed in Section 3.5.4.2. Hydrologic information must include, at a minimum, the location of perennial or ephemeral surface waters and 100-year floodplains that occur in proximity to the subject facility. If the facility subject to BADCT requirements is located within a 100-year floodplain, an assessment of the 100-year flood surface flow and potential impacts on the facility must be conducted.

Lakes, perennial or ephemeral streams, springs and other surface waters must be identified to safely design the facility (e.g., minimize run-on) and minimize any unnecessary discharge to surface waters. Knowing the location of surface waters also will assist the applicant in determining if other agencies must be contacted (See Appendix F, Federal, State and Local Environmental Permits). Hydrologic characteristics of wetlands, if present, may also need to be identified.

3.5.3.2 Subsurface Conditions

Subsurface conditions play a key role in the development of Individual BADCT discharge controls discussed in Section 3.5.4.3.

Site specific vadose zone characteristics such as primary and secondary permeability, degree of lithologic stratification, and depth to groundwater are required for the design, construction, and operation of a Tailing Impoundment utilizing site characteristics (e.g., geologic containment) as an Individual BADCT element. In some cases, more detailed characteristics of the vadose zone, such as in-situ moisture conditions, chemical attenuation capacities, etc., can also be important. Information regarding subsurface characterization can be found in Section 1.2.4 (Site Factors).

3.5.3.3 Geologic Hazards

During the process of site characterization and design development to demonstrate BADCT, engineering geology studies should be performed to identify and evaluate geologic hazards. Geologic hazards as discussed herein are processes capable of producing large ground movements in comparison to those involved in routine analysis of foundation settlements and deformations. Hazards which may disrupt the structural integrity of the discharge control system elements include landslides, subsidence, liquefaction, and other earthquake-induced ground failure and collapsing soils. The consideration of earthquake forces in slope stability analysis is an additional part of design development related to geologic hazards discussed in Appendix E (Engineering Design Guidance).

The study area relevant to assessment of geologic hazards is determined by site characteristics, but usually requires geologic evaluation of the area up to one-half mile or more outside the perimeter of the discharging facility.

3.5.3.3.1 Landslides

Landslides are sometimes present on hill slopes and may be capable of reactivation by excavation at the toe, adding additional loading to the landslide mass, changes in surface drainage, fluctuations in the water table, or earthquakes. Landslides usually can be identified by interpretation of aerial photography, but may be so large that they will not be apparent if examination is confined to the immediate area of the discharging facility. The Transportation Research Board (1996) provides a comprehensive treatment of this subject.

It is generally preferable to avoid locating facilities in areas prone to landslides. If facilities subject to BADCT are located in areas prone to landsliding, special engineering measures may be needed including buttressing, engineered surface drainage, soil drainage systems, or other measures. Appropriate mechanisms to stabilize landslides will depend upon specific site conditions.

3.5.3.3.2 Subsidence and Settlement

Groundwater declines of as much as 300 feet in the alluvial basins in central and southeastern Arizona are known to have caused subsidence of as much as 20 feet (Jachens and Holzer, 1979, 1982; Holzer and Pampeyan, 1981; Holzer, 1984; Raymond, 1987). Withdrawal of geothermal fluids (Narasimhan and Goyal, 1984), solution extraction of salt (Ege, 1984), coal mining, hard rock mining and other underground excavations (National Coal Board, 1975; Kratzch, 1983; Bieniawski, 1987; Jeremic, 1987; Bell et al., 1988) also can produce large amounts of subsidence.

If the cause of the subsidence is regional (e.g., pumping of an areally extensive and uniform aquifer) and the movement occurs at approximately the same rate beneath the entire facility, there may be no impact on the facility. If subsidence is not uniform beneath the facility, different rates or amounts of subsidence can result in horizontal or vertical strains in leachate collection and recovery systems, and other facility components, such as piping systems, prepared subgrades, and structural fills. It can also cause earth fissuring that can provide preferred pathways for seepage migration to the water table. For sites located on the relatively flat alluvial plains, subsidence may alter the grades of internal drains in discharging facilities and modify upstream drainage areas over time.

Settlement can occur under large loads which are placed on the surface, e.g., thick tailing deposits. Settlement due to loading can alter internal drainage in discharging facilities and induce horizontal or vertical strains similar to subsidence.

The subsidence and settlement profiles and corresponding horizontal movement, horizontal strains, and the potential for earth fissuring can be evaluated by empirical methods (Helm, 1984), simplified elastic methods (Lee and Shen, 1969; Helm, 1984), and finite element methods (Keaton et al., 1995). Where potential exists for substantial amounts of subsidence or settlement to occur at a facility location, or potential for even moderate amounts of differential subsidence or settlement in a facility subgrade (e.g., due to abrupt changes in the depth to shallow bedrock beneath a facility), these potential deformations must be considered in the design.

3.5.3.3.3 Earthquake-Induced Ground Failure

Stability of tailing facilities is discussed in Section 3.5.4.4. The following paragraphs discuss the potential for earthquake-induced ground failure caused by liquefaction and faulting.

Liquefaction is usually associated with areas that have all of the following properties:

- Shallow depth to saturation;
- Loose sand, sandy silt, or silty sand lithology;
- High peak ground acceleration under design earthquake conditions.

Liquefaction can produce rapid settlement and/or horizontal spreading of the subgrade, even in relatively flat areas, that can impact the structural integrity of facilities subject to BADCT. Because of the hydraulic fill placement method normally associated with Tailing Impoundments, the designer must also consider the potential for liquefaction of the facility itself. Methods for evaluating the liquefaction potential are discussed in Appendix E.

If conditions susceptible to liquefaction occur at the location of a facility subject to BADCT, engineering evaluations should be provided with the APP application that demonstrate the integrity of the facility will not be jeopardized in the event of the Design Earthquake, which ranges between the Maximum Probable Earthquake (MPE) and the Maximum Credible Earthquake (MCE) (Appendix E). The MPE is the largest earthquake with a 100-year return interval. The MCE is the maximum earthquake that appears capable of occurring under the

presently known tectonic framework. The Design Earthquake should be evaluated considering all known active faults within a distance of 200 kilometers. Active faults are those which have experienced rupture in the past 35,000 years. Potential earthquake size can be estimated based on correlations with fault length (dePolo and Slemmons, 1990).

As indicated by published fault maps (Nakata et al., 1982; Pearthree et al., 1989; Demsey and Pearthree, 1990; Maulchin and Jones, 1992; Jennings, 1992; Euge et al., 1992), relatively few active faults have been identified in Arizona. Published sources should be used to define regionally-occurring faults. Aerial photographs should also be utilized to confirm the absence of faults in the immediate site vicinity, or to precisely locate nearby faults, if present. Offsets and age of recent movement can be investigated through trenching studies when necessary.

Tailing facilities should generally not be located on active faults. Where active faults occur adjacent to a proposed tailing facility site, caution must be taken to assure that the fault location is well-defined. Aerial photograph evaluation, and field studies if necessary, should be used to confirm that signs of surface offset (e.g., splay faults) do not occur at the proposed facility location. Where a facility is to be located on an active fault, the applicant must evaluate aquifer loadings for an assumed ground rupture to demonstrate that the proposed location is feasible.

3.5.3.3.4 Collapsing Soils

Collapsing alluvial soils which are widely distributed in Arizona (Beckwith and Hansen, 1989) are alluvial fan deposits formed during the past 11,000 years (Holocene era), since the last episode of continental glaciation. The geotechnical properties of these soils, which generally are susceptible to self-weight settlement of 2 to 6% of their thickness when wetted, are largely a consequence of the dynamics of water-sediment supply in alluvial fan development and associated unsaturated flow processes. Thick deposits of particular concern in engineering analysis occur as coalescing alluvial fans at the base of mountains and along the margins of floodplains of major rivers such as the Gila, San Pedro and Colorado. Deposits as thick as 80 feet occur along the margins of floodplains.

Collapsing soils present the potential for differential subgrade movement and horizontal or vertical strains to liners, piping systems, structural fills, and other facility components similar to those addressed for subsidence in Section 3.5.3.3.2. If conditions susceptible to collapsing soils are
present, engineering evaluations should be provided with the APP application that demonstrate the integrity of the facility will not be jeopardized.

3.5.4 Design, Construction and Operations Considerations

The following sections address design, construction, and operations aspects that may constitute part of BADCT for a given facility where they have the potential to affect aquifer loading:

- Section 3.5.4.1 - Site Preparation

- Section 3.5.4.2 - Surface Water Control
- Section 3.5.4.3 - Discharge Control
- Section 3.5.4.4 - Stability Design
- Section 3.5.4.5 - Operational Measures

Section 3.5.4.6 discusses operational monitoring that should be conducted to ensure that the facility is performing and being operated as designed.

3.5.4.1 Site Preparation

Site preparation may consist of a broad range of activities to provide a stable foundation for construction of a facility.

Site preparation for a Tailing Impoundment usually includes stripping and stockpiling of topsoil, vegetation and debris where required for liner installation or starter dam construction. Soils having low strength or high settlement potential may have to be excavated and replaced with structural fill or otherwise treated as required to provide a stable foundation. This is particularly important for the embankment foundation. Care must be taken to provide adequate compaction of structural fill to the extent necessary to adequately limit deformations and provide the required strengths and permeabilities. Subgrade treatment is usually required for liners, embankments, and other structural components.

3.5.4.2 Surface Water Control

The objective of a surface water control system at a Tailing Impoundment is to control run-on and run-off in order to: 1) minimize run-on into the Tailing Impoundment; (2) prevent overtopping of the embankment; and 3) protect the overall facility integrity to prevent uncontrolled releases that can discharge pollutants to the aquifer by indirect surface water to groundwater pathways. BADCT surface water controls at a Tailing Impoundment may include the following:

- Upstream surface water diversion channels or dams that divert run-on away from the Tailing Impoundment;
- Upstream storm water detention dams or basins that reduce the rate of run-on that must be diverted away from the Tailing Impoundment;
- Upstream storm water retention dams or basins that store run-off from upgradient areas to reduce the amount of run-on to the Tailing Impoundment;
- Downstream reclaim/storm water containment ponds and related channels and diversion dikes or berms that capture run-off or seepage from the Tailing Impoundment;
- Provisions of freeboard for the impoundment to contain the design flood;

- Drainage control channels to control run-off from embankment slopes.

BADCT for a proposed facility may use any or all of these components designed to satisfy the following criteria:

- Components that store storm water, rainfall or process fluids (e.g., ponds) must be designed for the design storm volume (See Appendix E);
- Components that divert run-off and run-on (e.g., channels) must be designed to convey the design peak flow.

3.5.4.3 Discharge Control

Containment of tailing has been demonstrated through the use of geologic features, hydrostatic head control, and liner systems. Geologic features such as low permeability sediments (e.g., clay layers) or bedrock (e.g., low permeability shale or claystones) may be used as BADCT containment elements to the extent that they affect discharge reduction prior to reaching the water table. The applicant must demonstrate that such low permeability is areally extensive such that it will function as intended. Additional geologic containment may consist of a demonstration that pollutants would be attenuated in the vadose zone (See Section 1.2.4.5). Thickness, permeability and attenuation capacity of the vadose zone are the factors most commonly relied upon for natural containment beneath a facility. These and any other factors relied upon for natural discharge control must be investigated as part of site evaluations discussed in Section 3.5.3.

A well designed quality assurance/quality control (QA/QC) program has been found to be an important factor in achieving design performance criteria of a facility. Attention to proper construction can make the difference between a facility that performs up to its expected design and one that has problems throughout its operational life. Appendix D (Construction Quality Assurance and Quality Control) provides additional guidance on the development of QA/QC documents.

3.5.4.3.1 Base Metal Tailing Impoundments

The following design elements have been used as part of discharge control systems to achieve BADCT for base metal Tailing Impoundments. Because application of the design elements is site specific, all the design elements may not be a part of BADCT for all facilities.

- Interception of storm run-off and groundwater flow in shallow aquifers to minimize water inflow;
- Natural geologic features functioning as liners;
- Localized lining with geosynthetic materials and/or clay;

- Slime sealing beneath the tailing pond (Vick, 1983). If properly done, this can produce an effective vertical hydraulic conductivity of $1x10^{-7}$ centimeters per second or less;
- Provision of subdrainage beneath the impoundment to minimize hydraulic head and promote dewatering after closure;
- Leachate collection systems consisting of granular finger or blanket drains and corrugated perforated HDPE pipes can be used to supplement natural subdrainage (Brawner, 1986);
- Lining beneath the main underdrains is sometimes done to further minimize seepage;
- Centerline embankment construction to obtain a non-liquifiable stability zone;
- Drains and reclaim water pump back systems to lower or eliminate the phreatic surface in the embankment;
- High-strength, free draining rockfill zones in the embankment;
- Channels and dikes or berms to collect run-off from downstream slopes;
- Engineered hydraulic barriers downstream of the embankment and above the natural regional ground water table. These may include soil-bentonite slurry walls with upstream pumpback wells, reclaim wells and trench drains with downstream clay or geomembrane barriers.

Seepage of tailing fluid should be contained in detention and reclaim ponds with appropriate discharge control elements as discussed in Section 3.6. Storm run-off from the downstream slopes of embankments may also need to be contained (e.g., if tailing material is used for embankment construction).

3.5.4.3.2 Precious Metals Tailing Impoundments

Except for Tailing Impoundments with low permeability foundations and good isolation from protected aquifers, discharge control systems for modern precious metals Tailing Impoundments have included liners. Geomembrane, clay, soil, and composite clay- or soil- geomembrane liners have been employed (Giroud and Bonaparte, 1989a, 1989b; Daniel, 1987, 1993; Giroud and Peggs, 1990; National Sanitary Foundation, 1992; U.S. Environmental Protection Agency, 1987, 1992a, 1992b; Haile, 1985; Haile and Brown, 1988; Knight and Haile, 1984; Hutchison and Ellison, 1992; Giroud and others, 1992). In some cases, varying liner configurations and liner materials may be appropriate over different areas of a Tailing Impoundment due to differences in the amount and persistence of hydraulic head. Most recent designs have involved lining at least portions of the facility with composite systems composed of at least 2.0 feet of soil having a low hydraulic conductivity (i.e., $1x10^{-6}$ centimeters per second or less) overlain by a geomembrane. Textured geomembranes have been employed to obtain high geomembrane-soil interface strength. Appendix C (Liner Design Principles and Practice) provides a discussion of liner design and liner technology which should be considered in the design of containment. In the

case of geologic containment detailed site specific hydrogeologic evaluations should be conducted.

Typically, a granular overliner, finger drains or a full blanket drain with a system of corrugated perforated HDPE pipes is placed to minimize hydraulic head over the liner (Haile and East, 1986; Van Zyl and Robertson, 1980) and to promote the collection of tailing fluids. A fabric filter cover or geotextile may be needed to keep fine grained tailing from entering the drainage system. Typically, the drains are directed to a toe drain along the upstream face of the impoundment embankment. This directs liquids to a pipe that penetrates the embankment and carries the collected liquids to a lined pond from which it can be reclaimed. Additional discharge control system elements that can be applied to precious metal Tailing Impoundments are discussed above in Section 3.5.3.3.1.

3.5.4.3.3 Uranium Tailing Impoundments

Although ADEQ is required to conduct an independent review, BADCT for uranium Tailing Impoundments is usually dictated by regulatory authority of the Federal government. Under the Uranium Mill Tailing Radiation Control Act (UMTRCA) of 1978 (PL 95-604), Congress directed the Environmental Protection Agency (EPA) to set standards to provide protection from hazards associated with uranium mill tailing. Title I of the Act addresses tailing of inactive mill sites, while Title II addresses active mill tailing and covers new facilities. Specific regulations developed by the EPA under the UMTRCA directive are presented in 40 CFR 192 and 40 CFR 61 Subparts A through C for Title I and Title II sites, respectively. Nuclear Regulatory Commission (NRC) licensing requirements presented in 10 CFR 40 Appendix A have been modified to conform to 40 CFR 192 requirements. Groundwater protection standards are presented in 40 CFR 191 Subpart C. The State of Arizona is not an NRC Agreement State with respect to uranium mill tailing; therefore, the NRC serves as the lead agency for both old tailing closure and new facility licensing. The NRC does, however, work cooperatively with the State and recognizes the State's various specific regulatory and permitting requirements in such areas as water discharge.

Basic criteria relative to the design of a new uranium Tailing Impoundment are as follows:

- Control of tailing shall be effective for up to 1,000 years to the extent reasonably achievable and in any case, for at least 200 years;
- Provide reasonable assurance that releases of radon-222 from residual radioactive material to the atmosphere will not exceed an average release rate of 20 picocurries per square meter per second;
- Requirements for liner systems to be installed for groundwater protection;
- Protect surface water quality;
- Limit area of active tailing disposal to a maximum of 40 acres;
- Limit area of tailing subject to erosion to a maximum of 10 acres.

While the UMTRCA regulations are distinctly separate from the provision of the Resource Conservation and Recovery Act (RCRA), there is, particularly in the groundwater regulations, a provision to be consistent with RCRA to the maximum extent practicable.

Current uranium tailing disposal concepts were developed during the processes of the Generic Environmental Impact Statement on Uranium Milling in the late 1970s (U.S. Nuclear Regulatory Commission, 1979). The "prime optimum" established in this process was below grade disposal in mines or excavated pits. "Dry" disposal and double liners with seepage collection systems have emerged as the preferred discharge control technologies.

3.5.4.4 Stability Design

In designing a Tailing Impoundment, an adequate margin of safety must be provided against slope failure, which could result in a surface discharge with the potential to affect groundwater quality. Appendix E provides additional guidance on stability design. The tailing facility should be evaluated and designed to be adequately stable under static and potential seismic loading conditions. Stability evaluations should be conducted for ultimate embankment heights, intermediate construction stages, and maximum anticipated phreatic surfaces that may be critical with regard to stability. Stability of tailing embankments may be highly dependent on: 1) tailing properties and deposition techniques; and 2) embankment design and construction techniques. The applicant should provide adequ ate data, including data obtained from site specific material testing, as required to support the stability analysis. The recommended static factor of safety is 1.5, or 1.3 in the case of prefinal staged construction phases.

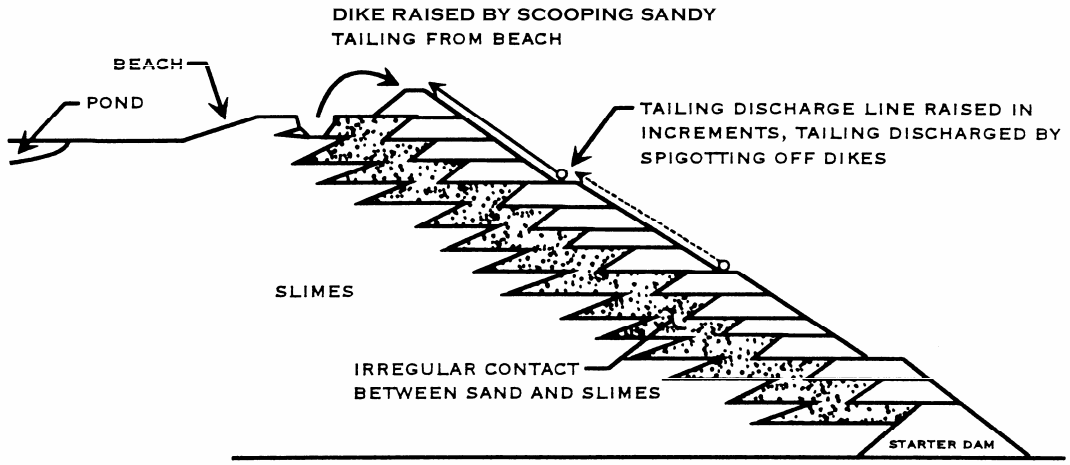
Seismic evaluations should be based on the Design Earthquake (Section 3.5.3.3.3 and Appendix E). Seismic stability analyses may include pseudostatic and deformation analysis methods as further discussed in Appendix E. When deformation analyses are required the displacement predicted shall be small enough so as not to jeopardize containment integrity.

The BADCT design in the APP application shall incorporate measures such that the static and seismic stability criteria are achieved.

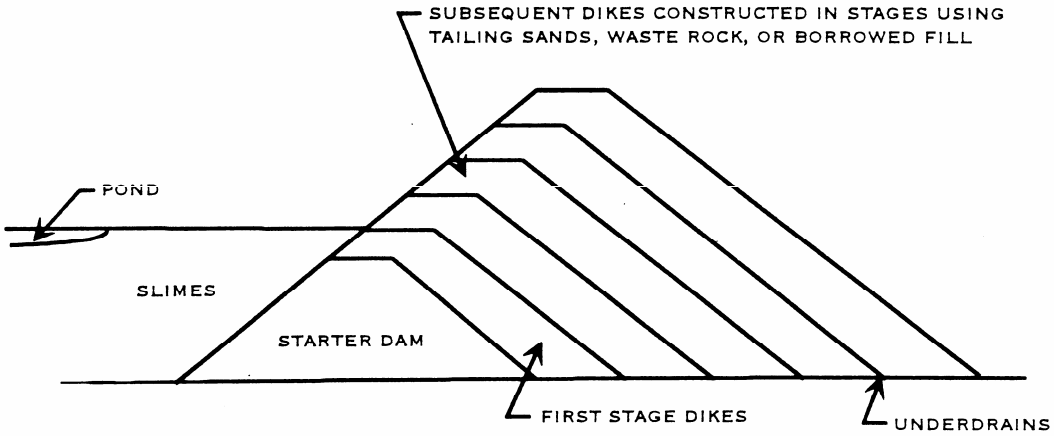
Figure 3-5 illustrates three commonly used geometries for stability design. In the upstream tailing dam method, a "starter dam" is initially built and the tailing deposited by peripheral spigotting. The dam is ordinarily raised in an upstream geometry by building dikes of sandy materials from the tailing beach excavated by backhoes, draglines or bulldozers. This method has been successfully used at many sites (W.A. Wahler and Associates, 1974, Klohn and Maartmann, 1972). Where the rate of building is sufficiently low (generally less than 10 to 15 feet per year) and earthquake forces do not control design, there is little risk of undrained strength behavior and upstream construction can be safely employed. In the prevailing arid and semi-arid climate, the peripheral spigotting procedures result in very low rates of infiltration through the beach, a low phreatic surface, and unsaturated tailing in most of the slope. This affords the conditions for safe application of upstream construction, if rates of rise of the tailing are sufficiently low to minimize excess pore pressures. Finite strain consolidation analysis procedures (Barrett, 1987; McPhail and Dorman, 1987; Ferguson and others, 1985; Murphy and

Williams, 1990; Schiffman and Carrier, 1990) are useful in evaluating the magnitude of excess pore pressures, the potential for undrained strength behavior of the saturated tailing, and the feasibility of upstream construction.

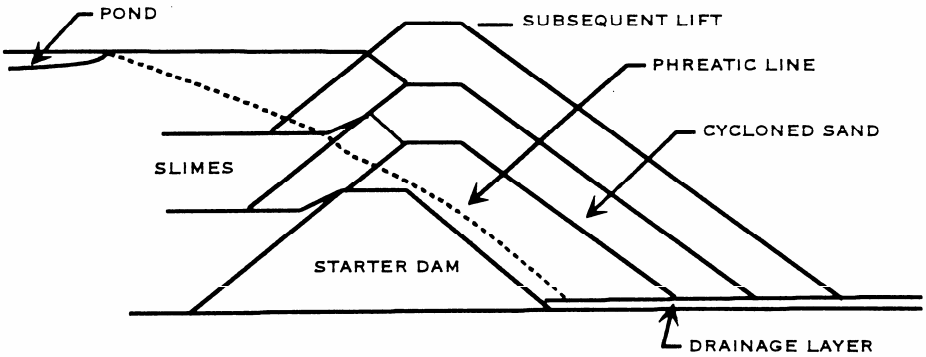
FIGURE 3-5 - TAILING DAM CONSTRUCTION METHODS



A. UPSTREAM METHOD OF TAILING DAM CONSTRUCTION



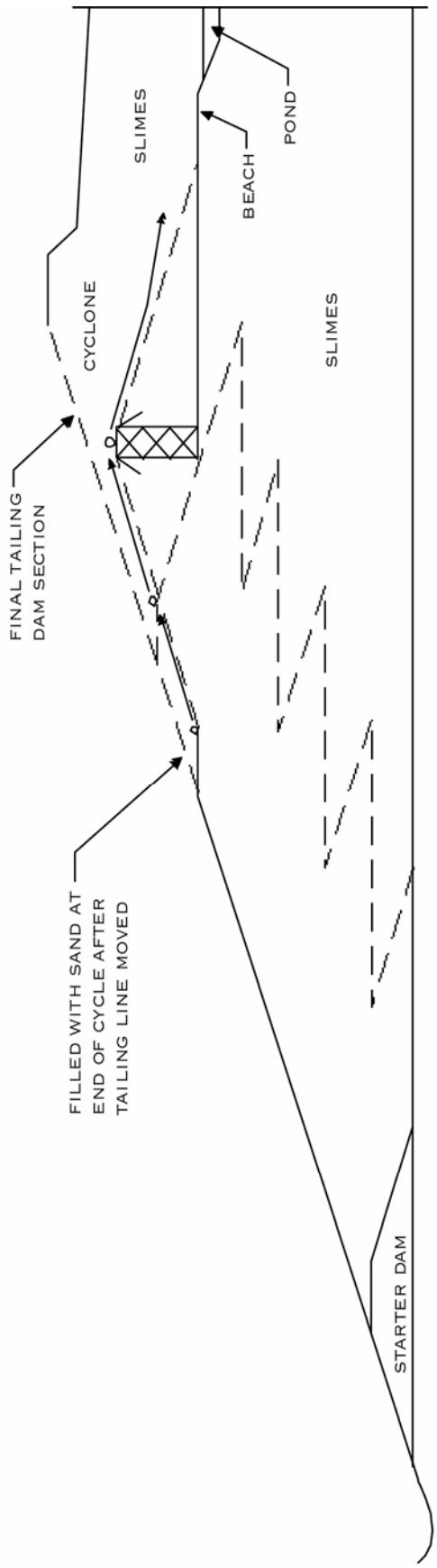
B. DOWNSTREAM METHOD OF TAILING DAM CONSTRUCTION



C. CENTERLINE METHOD OF TAILING DAM CONSTRUCTION

[NOT TO SCALE]

FIGURE 3-6 - UPSTREAM TAILING DAM CONSTRUCTION USING CYCLONES



[NOT TO SCALE]

In the execution of an upstream construction design, the starter dam is usually either constructed of permeable material to act as a drain or finger drains are provided through the starter dam.
A variation of the upstream construction method which has been successfully used in Arizona (Dopson and McGregor, 1973; Keener, 1973; W.A. Wahler and Associates, 1974) is to provide a relatively thick zone of cycloned sand beneath the slopes (Figure 3-6). This has the advantage of providing a free draining zone and facilitating construction of dikes for raises.

Where design is controlled by undrained shear strength, behavior due to high rates of building, high intensity earthquake forces, etc., it is necessary to provide a free draining stability zone in the downstream portion of the dam. These zones have been constructed of tailing sands (underflow) produced with hydrocyclones, mine waste rock, other borrow materials or some combination of these materials in the centerline or downstream configurations illustrated in Figure 3-5. Analysis for recent dams has demonstrated that a centerline configuration produces adequate stability even when very high seismic forces are involved (Castro and Troncoso, 1989).

A variety of construction procedures have been employed for cycloned sand zones (Klohn and Maartmann, 1972; Klohn, 1984; Watermeyer and Williamson, 1978; Lyell and Prakke, 1988; Caldwell and others, 1983). Sometimes cyclone sands are excavated and compacted. Another deposition method is cellular construction in which the sands are produced by single or double cycloning at a central cyclone station which may be located off the dam. The sands are repulped into a slurry, sluiced into cells, and compacted with bulldozers. Finer materials are decanted from the cells with small spillways. This method has been used widely for the construction of tar sand tailing dams in Alberta (Mittal and Hardy, 1977; Yano and Fair, 1988). Similar applications of the cellular method were used for Casapalca tailing dam in Peru (Brawner, 1978) and the Highland Valley L-L dam in British Columbia (Scott and Lo, 1988; Scott and others, 1988).

Conformance of the centerline design approach to BADCT is demonstrated by the successful performance of several high copper and molybdenum tailing dams of centerline construction (Caldwell and others, 1983; Klohn and Maartmann, 1972, Klohn, 1979). Dams built by centerline construction with cycloned sands include the Mulholland and Mammoth Dams at Bagdad, Arizona (Caldwell and others, 1983) and Brenda Dam (Klohn, 1984), Gibraltar Dam (Klohn, 1979), Highland Valley Copper Co., L-L and J-J Dams (Scott and others, 1988) in British Columbia. The Cyprus Thompson Creek facility in Idaho (Dorey and Byrne, 1982; Stine and others, 1986) was also constructed by the centerline method with cycloned sands. Extensive drains were constructed in these dams to maintain a low phreatic surface. The cycloned sands to some height above the phreatic surface are compacted to high densities to assure drained shear strength behavior.

The ASARCO Elder Gulch Dam near Superior, Arizona, the Yankee Doodle tailing dam in Butte, Montana (Poindexter and Holmes, 1982), and Highland Valley H-H dam (Scott and others, 1988) are centerline dams built with mine waste rock dumped in thick lifts and/or granular borrow zones. The Seferif Mines du Rif tailing dam in Morocco (Brawner, 1978) is another example of a structure built largely with the rockfill centerline method. These dams employ technology developed for rockfill water storage dams (Sherard, 1985; Leps, 1988; International Commission on Large Dams, 1989; Taylor, 1977).

3.5.4.5 Operational Measures

It should be noted that application of the operating procedures is site specific and may not be a part of BADCT for all facilities. The following operating procedures have been used as parts of discharge control systems to achieve BADCT for Tailing Impoundments.

- Maintenance of small tailing ponds consistent with sedimentation requirements (Coates and Yu, 1977);
- Short discharge cycles, of spigotting or single-point discharge, with ample time between cycles. By frequently changing discharge points for the tailing slurry, desiccation of the beach occurs so that infiltration through the beach takes place primarily as unsaturated flow (Van Zyl, 1987; Vick, 1983). This limits infiltration through the beach to very small values. A variation of this approach is the use of subaerial (thin layer) deposition techniques wherein special spray bars or multiple lines on spigots more evenly spread the slurry over the beach. Very short deposition cycles can also be employed (Haile and East, 1986; Robertson and others, 1978; Haile and Brown, 1988; Knight and Haile, 1983; 1984);
- Limiting the rate rise to prevent triggering of undrained behavior of tailing by internal shear strains;
- Reclaiming process solutions with barge mounted pumps or decant towers.

3.5.4.6 Operational Monitoring

During operation of a Tailing Impoundment, monitoring should be conducted to ensure that the facility is performing and being operated as designed. Examples of monitoring to confirm that the facility is performing as designed include:

- Measurement of pore pressures and deformations to assure an adequate factor of safety against slope failure. A regular program of observations should be part of the ongoing monitoring of the facility;
- Seepage or drain system monitoring to evaluate the volume of fluids being discharged from the facility;
- Monitoring of associated leachate collection systems to evaluate liner performance;
- Monitoring of any associated vadose zone monitoring systems to evaluate liner performance, attenuation, etc.

The above examples may not apply to all tailing facilities. The extent to which ADEQ will require operational monitoring to assure that the facility is performing as designed may depend upon the adequacy of the existing data on which the design is based and the degree to which the

design assumptions are conservative. For example, if slopes marginally satisfy static stability requirements discussed in Section 3.5.4.4, ADEQ may recommend frequent monitoring of parameters related to stability. Conversely, conservative assumptions may be proposed by an applicant to justify reduced monitoring needs.

Examples of monitoring to assure that the facility is being operated as designed include:

- Integrity monitoring to identify any system failures or areas in need of maintenance repair;
- Tailing discharge monitoring to confirm that the volume of tailing deposited does not exceed the design capacity;
- Freeboard monitoring to ensure the availability of design freeboard. Visual observations should be made on a regular basis to ensure that freeboard requirements are satisfied. In the case where freeboard is not sufficient, it will be necessary to develop a mitigation plan to prevent loss of solution containment.

Monitoring requirements to assure that the facility is being operated as designed may apply to most facilities and may be required by APP conditions pursuant to A.A.C. R18-9-A206.

A Contingency Plan is required separate from BADCT pursuant to A.A.C. R18-9-A204. In some cases an applicant may include some components of the Contingency Plan as part of BADCT (e.g., provisions for backup generators to allow solution circulation during a power outage may affect BADCT containment volume requirements).

3.5.5 Closure/Post-Closure

Closure/post-closure must be considered in the design submitted to ADEQ. The applicant must still comply with the requirements of A.A.C. R18-9-A209(B) prior to formal closure. Arizona Mined Land Reclamation Statutes (A.R.S. 27-901 through 27-1026) and implementing Rules govern surface reclamation. This BADCT guidance manual is not intended to duplicate or modify requirements of surface reclamation statutes.

The closure strategy shall eliminate, to the greatest extent practicable, any reasonable probability of further discharge from the facility and of exceeding aquifer water quality standards at the applicable point of compliance.

In closing a Tailing Impoundment, the objective is to restrict liquid migration to and from the facility. Several techniques can be used depending on site specific conditions. Provisions employed for closure of Tailing Impoundments may include:

- Diversion or detention of surface water run-on;
- Recontouring of the surface to reduce ponding and promote evaporation of direct precipitation;

- Surface compaction and/or construction of engineered covers on the top of the impoundment to minimize infiltration from precipitation and surface water run on and prevent erosion;
- Provision of slope protection for erosion control;
- Containment of storm run-off from slopes with detention ponds sized for appropriate design floods;
- Revegetation for transpiration and erosion control; and
- Continued operation and maintenance of seepage collection and treatment systems.

3.6 SURFACE PONDS

3.6.1 Introduction

As addressed in this manual, Surface Ponds are impoundments, other than Tailing Impoundments, that are: 1) used to collect or store fluids at mining operations; and 2) subject to regulation under A.R.S. 49-243.B. Examples include process solution ponds, overflow ponds, and seepage collection ponds. Surface Ponds do not include: 1) impoundments used solely to store run-off that are regulated under the Federal Clean Water Act (A.R.S. § 49-245.01); or 2) other ponds exempted from the APP program pursuant to A.R.S. § 49-250.

Because development of Individual BADCT for a facility is based on aquifer loading, each of the key factors affecting aquifer loading must be considered. Field investigations and evaluations are usually required to provide information necessary for the estimation of aquifer loading as discussed in Section 1.1.3.3. Important considerations for developing Individual BADCT for Surface Ponds are addressed in the following sections:

- Section 3.6.2 - Solution Characterization
- Section 3.6.3 - Siting Considerations
- Section 3.6.4 - Design, Construction and Operations Considerations
- Section 3.6.5 - Closure/Postclosure

3.6.2 Solution Characterization

The characteristics of the material discharged to a Surface Pond will have considerable impact on the BADCT design. A discussion of relevant material characterization is presented in Section 1.2.1 (Waste Type and Process Solution Characteristics) and Appendix B (Solution, Ore and Waste Characterization Tests). It is strongly recommended that characterizations be conducted with input from ADEQ to help assure that adequate information is collected. It is important that selected design elements are compatible with the expected characteristics of the contained material.

3.6.3 Siting Considerations

Detailed site characterization is usually necessary to select an appropriate location for the proposed facility; to provide information for engineering evaluations (e.g., stability analysis and seepage control); and to estimate aquifer loading for the Individual BADCT design. Siting considerations that are key to Individual BADCT development are discussed in the following sections:

- Section 3.6.3.1 - Climate and Surface Hydrology
- Section 3.6.3.2 - Subsurface Conditions
- Section 3.6.3.3 - Geologic Hazards

Additional information and guidance on how site factors (e.g., topography, geology/stability, soil properties, vadose zone, and surface and subsurface hydrology) influence the design of a facility can be found in Section 1.2.4 (Site Factors).

The appropriate level of detail of each aspect of the site characterization is often dependent upon the extent to which the APP applicant plans to utilize various factors in developing the Individual BADCT design. For example, if chemical attenuation (e.g., precipitation, hydrolysis, complexation, etc.) in soils beneath the facility is not expected to play an important role in reducing aquifer loading, then investigation of site soil characteristics affecting chemical attenuation is not necessary. Conversely, where hydrologic isolation provided by the depth to the aquifer beneath the facility and geologic materials in the vadose zone are key in the development of the facility design, detailed investigations of vadose zone thickness, lithology, primary and secondary permeability, etc. are usually required.

It is strongly recommended that the site investigation program be conducted with input from ADEQ so that agreement can be reached on the amount of information to be collected.

3.6.3.1 Climate and Surface Hydrology

In preparing an application for an APP, an applicant must obtain and develop site specific climatic and hydrologic information. Climatic conditions are important to the evaluation of surface water characteristics, process water balances, the potential for migration through the vadose zone, and other factors discussed in Section 1.2.3. Statistical data on rainfall and evaporation are required to support an APP application.

Surface hydrology information is necessary to develop appropriate surface water controls discussed in Section 3.6.4.2. Hydrologic information must include, at a minimum, the location of perennial or ephemeral surface waters and 100-year floodplains that occur in proximity to the subject facility. If the facility subject to BADCT requirements is located within a 100-year floodplain, an assessment of the 100-year flood surface flow and potential impacts on the facility must be conducted.

Lakes, perennial or ephemeral streams, springs and other surface waters must be identified to safely design the facility (e.g., minimize run-on) and minimize any unnecessary discharge to surface waters. Knowing the location of surface waters also will assist the applicant in determining if other agencies must be contacted (See Appendix F, Federal, State, and Local Environmental Permits). Hydrologic characteristics of wetlands, if present, may also need to be identified.

3.6.3.2 Subsurface Conditions

Subsurface conditions play a key role in the development of Individual BADCT discharge controls discussed in Section 3.6.4.3.

Site specific vadose zone characteristics such as primary and secondary permeability, degree of lithologic stratification, and depth to groundwater are required for the design, construction, and operation of a Surface Pond utilizing site characteristics (e.g., geologic containment) as an Individual BADCT element. In some cases, more detailed characteristics of the vadose zone, such as in-situ moisture conditions, chemical attenuation capacities, etc., can also be important. Information regarding subsurface characterization can be found in Section 1.2.4 (Site Factors).

3.6.3.3 Geologic Hazards

During the process of site characterization and design development to demonstrate BADCT, engineering geology studies should be performed to identify and evaluate geologic hazards. Geologic hazards as discussed herein are processes capable of producing large ground movements in comparison to those involved in routine analysis of foundation settlements and deformations. Hazards which may disrupt the structural integrity of the discharge control system elements include landslides, subsidence, liquefaction, and other earthquake-induced ground failure and collapsing soils. The consideration of earthquake forces in slope stability analysis is an additional part of design development related to geologic hazards discussed in Appendix E (Engineering Design Guidance).

The study area relevant to assessment of geologic hazards is determined by site characteristics, but usually requires geologic evaluation of the area up to one-half mile or more outside the perimeter of the discharging facility.

3.6.3.3.1 Landslides

Landslides are sometimes present on hillslopes and may be capable of reactivation by excavation at the toe, adding additional loading to the landslide mass, changes in surface drainage, fluctuations in the water table, or earthquakes. Landslides usually can be identified by interpretation of aerial photography, but may be so large that they will not be apparent if

examination is confined to the immediate area of the discharging facility. The Transportation Research Board (1996) provides a comprehensive treatment of this subject.

It is generally preferable to avoid locating facilities in areas prone to landslides. If facilities subject to BADCT are located in areas prone to landsliding, special engineering measures may be needed including buttressing, engineered surface drainage, soil drainage systems, or other measures. Appropriate mechanisms to stabilize landslides will depend upon specific site conditions.

3.6.3.3.2 Subsidence and Settlement

Groundwater declines of as much as 300 feet in the alluvial basins in central and southeastern Arizona are known to have caused subsidence of as much as 20 feet (Jachens and Holzer, 1979, 1982; Holzer and Pampeyan, 1981; Holzer, 1984; Raymond, 1987). Withdrawal of geothermal fluids (Narasimhan and Goyal, 1984), solution extraction of salt (Ege, 1984), coal mining, hard rock mining and other underground excavations (National Coal Board, 1975; Kratzch, 1983; Bieniawski, 1987; Jeremic, 1987; Bell et al., 1988) also can produce large amounts of subsidence.

If the cause of the subsidence is regional (e.g., pumping of an areally extensive and uniform aquifer) and the movement occurs at approximately the same rate beneath the entire facility, there may be no impact on the facility. If subsidence is not uniform beneath the facility, different rates or amounts of subsidence can result in horizontal or vertical strains in leachate collection and recovery systems, and other facility components, such as piping systems, prepared subgrades, and structural fills. It can also cause earth fissuring that can provide preferred pathways for seepage migration to the water table. For sites located on the relatively flat alluvial plains, subsidence may alter the grades of internal drains in discharging facilities and modify upstream drainage areas over time.

Settlement can occur under large loads which are placed on the surface. Settlement due to loading can alter internal drainage in discharging facilities and induce horizontal or vertical strains similar to subsidence.

The subsidence and settlement profiles and corresponding horizontal movement, horizontal strains and the potential for earth fissuring can be evaluated by empirical methods (Helm, 1984), simplified elastic methods (Lee and Shen, 1969; Helm, 1984) and finite element methods (Keaton et al., 1995). Where potential exists for substantial amounts of subsidence or settlement to occur at a facility location, or potential for even moderate amounts of differential subsidence or settlement in a facility subgrade (e.g., due to abrupt changes in the depth to shallow bedrock beneath a facility), these potential deformations must be considered in the design.

3.6.3.3.3 Earthquake-Induced Ground Failure

Stability of Surface Pond facilities is discussed in Section 3.6.4.4. The following paragraphs discuss the potential for earthquake-induced ground failure caused by liquefaction and faulting.

Liquefaction is usually associated with areas that have all of the following properties:

- Shallow depth to saturation;
- Loose sand, sandy silt, or silty sand lithology;
- High peak ground acceleration under design earthquake conditions.

Liquefaction can produce rapid settlement and/or horizontal spreading of the subgrade, even in relatively flat areas, that can impact the structural integrity of facilities subject to BADCT. Methods for evaluating the liquefaction potential are discussed in Appendix E.

If conditions susceptible to liquefaction occur at the location of a facility subject to BADCT, engineering evaluations should be provided with the APP application that demonstrate the integrity of the facility will not be jeopardized in the event of the Design Earthquake, which ranges between the Maximum Probable Earthquake (MPE) and the Maximum Credible Earthquake (MCE) (Appendix E). The MPE is the largest earthquake with a 100-year return interval. The MCE is the maximum earthquake that appears capable of occurring under the presently known tectonic framework. The Design Earthquake should be evaluated considering all known active faults within a distance of 200 kilometers. Active faults are those which have experienced rupture in the past 35,000 years. Potential earthquake size can be estimated based on correlations with fault length (dePolo and Slemmons, 1990).

As indicated by published fault maps (Nakata et al., 1982; Pearthree et al., 1989; Demsey and Pearthree, 1990; Maulchin and Jones, 1992; Jennings, 1992; Euge et al., 1992), relatively few active faults have been identified in Arizona. Published sources should be used to define regionally-occurring faults. Aerial photographs should also be utilized to confirm the absence of faults in the immediate site vicinity, or to precisely locate nearby faults, if present. Offsets and age of recent movement can be investigated through trenching studies when necessary.

Surface Ponds should generally not be located on active faults. Where active faults occur adjacent to a proposed facility, caution must be taken to assure that the fault location is well-defined. Aerial photograph evaluation, and field studies if necessary, should be used to confirm that signs of surface offset (e.g., splay faults) do not occur at the proposed facility location. Where a facility is to be located on an active fault, the applicant must evaluate aquifer loadings for an assumed ground rupture to demonstrate that the proposed location is feasible.

3.6.3.3.4 Collapsing Soils

Collapsing alluvial soils which are widely distributed in Arizona (Beckwith and Hansen, 1989) are alluvial fan deposits formed during the past 11,000 years (Holocene era), since the last episode of continental glaciation. The geotechnical properties of these soils, which generally are

susceptible to self-weight settlement of 2 to 6% of their thickness when wetted, are largely a consequence of the
dynamics of water-sediment supply in alluvial fan development and associated unsaturated flow processes. Thick deposits of particular concern in engineering analysis occur as coalescing alluvial fans at the base of mountains and along the margins of floodplains of major rivers such as the Gila, San Pedro and Colorado. Deposits as thick as 80 feet occur along the margins of floodplains.

Collapsing soils present the potential for differential subgrade movement and horizontal or vertical strains to liners, piping systems, structural fills, and other facility components similar to those addressed for subsidence in Section 3.6.3.3.2. If conditions susceptible to collapsing soils are present, engineering evaluations should be provided with the APP application that demonstrate the integrity of the facility will not be jeopardized.

3.6.4 Design, Construction and Operations Considerations

The following sections address design, construction, and operations aspects that may constitute part of BADCT for a given facility where they have the potential to affect aquifer loading:

- Section 3.6.4.1 - Site Preparation
- Section 3.6.4.2 - Surface Water Control
- Section 3.6.4.3 - Discharge Control
- Section 3.6.4.4 - Stability Design
- Section 3.6.4.5 - Operational Measures

Section 3.6.4.6 discusses operational monitoring that should be conducted to ensure that the facility is performing and being operated as designed.

3.6.4.1 Site Preparation

Site preparation may consist of a broad range of activities to provide a stable foundation for construction of a facility.

Site preparation for a Surface Pond usually includes stripping of topsoil, vegetation and debris. Soils having low strength or high settlement potential must be excavated and replaced with structural fill or otherwise treated as required to provide a stable foundation. Care must then be taken to provide compaction of structural fill to the extent necessary to adequately limit deformation, and provide the required strength and permeability. Subgrade treatment is usually required for liners, dams, embankments and other structural components.

3.6.4.2 Surface Water Control

The objective of a surface water control system at a Surface Pond facility is to control run-on and run-off in order to protect the integrity of facilities containing process solutions and prevent uncontrolled releases that can discharge pollutants to the aquifer by indirect surface water pathways to groundwater. BADCT surface water controls at a Surface Pond facility may include the following:

- Upstream surface water diversion channels or dams that divert run-on away from the pond area;
- Upstream storm water detention dams or basins that reduce the rate of run-on that must be diverted away from the pond area;
- Upstream storm water retention dams or basins that store run-off from upgradient areas to reduce the amount of run-on to the pond area;
- Downstream reclaim/storm water containment ponds and related channels and diversion dikes or berms that capture run-off from the pond area;
- Provision of freeboard to contain run-off that may flow into the pond from the design flood.

BADCT for a proposed facility may use any or all of these components designed to satisfy the following criteria:

- Components that store storm water, rainfall or process fluids (e.g., ponds) must be designed for the design storm volume;
- Components that divert run-off and run-on (e.g., channels) must be designed to convey the design peak flow.

3.6.4.3 Discharge Control

3.6.4.3.1 Liners

A liner system is normally an integral part of demonstrated control technology for discharge control at Surface Ponds with contents that have significant concentrations of potential pollutants. A variety of lining systems have been used in practice that include natural materials (e.g., compacted low permeability soil or clay) and synthetic materials (e.g., geomembranes), and composites of both. The characteristics of the pond contents and the nature of operations (e.g., duration of liquid presence) at the pond are key in determining an appropriate liner system. The degree of natural hydrologic isolation (e.g., geologic containment) may also affect liner design.

Processing solutions usually contain liquids with substantial concentrations of potential pollutants, and process solution ponds characteristically have a substantial and persistent hydraulic head over the liner. For these conditions a double-liner with a leak collection and removal system (LCRS) between the upper and lower liners is often employed. The upper liner

is normally a geomembrane, and the lower liner may be a geomembrane or geomembrane/soil composite. The LCRS allows leakage through the upper liner to be monitored and removed, so that hydraulic head over the lower liner can be maintained very low. With a low hydraulic head over the lower liner, seepage through the liner system will normally be very small even if some defects in the lower liner are present. The LCRS system is further discussed in Section 3.6.4.3.2.

Where pond contents contain lower concentrations of potential pollutants and/or if the pond will only contain fluids for short periods of time, an LCRS may not be warranted. Single lined ponds are often used under such conditions. Overflow ponds are an example where solution may be present for only short intermittent periods. Where overflow ponds capture excess solutions following rainstorms, process reagent concentrations may be relatively dilute. Single liners may incorporate a geomembrane, compacted low permeability soil, or a composite of both. Some sites may provide a source of native soils that can be compacted to achieve low permeabilities, in combination with amendments (e.g., commercially obtained bentonite), if necessary.

When practicable, it is usually desirable to incorporate a composite liner consisting of a geomembrane in direct contact with low permeability soil, either for single liner or the lower layer of a double liner system. The combination of these two materials in direct and intimate contact significantly reduces seepage potential in the event of defects in the geomembrane (Hutchison and Ellison, 1992)

When geomembrane components are used, liner design and installation procedures should incorporate appropriate measures to prevent damage to the geomembrane during and after installation. Geomembranes should normally be installed over smooth (e.g., rolled) surface following careful inspection and removal of debris or protruding rock particles, if any. Pond liners exposed to sunlight must be resistant to ultraviolet radiation.

A well designed quality assurance/quality control (QA/QC) program has been found to be an important factor in achieving design performance criteria of a facility. Attention to proper construction can make the difference between a facility that performs up to expected design and one that has problems throughout its operational life. Appendix D (Construction Quality Assurance & Quality Control) provides additional guidance on the development of QA/QC plans.

3.6.4.3.2 Leak Collection and Removal System (LCRS)

LCRS is included among the more effective liner-system configurations because it provides an indication of defects in the upper liner. Defects that result in excessive seepage through the upper liner can be identified and repaired. LCRS also allows removal of leakage that may occur through the upper liner; thus reducing the potential to leak through a lower liner.

The following is a partial list of factors that can affect liquid transmission in the drain layer of an LCRS:

- Impingement rate of liquid on the collection drain layer

- Drain layer slope;
- Configuration of the drainage pipe and;
- Hydraulic conductivity of the drainage layer media (i.e. sand, gravel, or geosynthetic).

When considering nongranular LCRS, the following design elements should be evaluated:

- Performance verification
- Hydraulic transmissivity;
- Compressibility;
- Compatibility with liners and leachate;
- Ability to collect and store leachate, and
- Useful life of the system.

3.6.4.4 Stability Design

The stability of a pond may have to be evaluated when the design includes a large embankment.

The pond facility should be evaluated and designed to provide stability under static and potential seismic loading conditions. Where geosynthetics are used, shear strengths should be based on site specific material evaluations and not on published values. The recommended static stability criteria are as follows:

- For static analysis for earthen structures where geosynthetic components are not used and site specific testing has not been conducted, the recommended factor of safety is 1.5.;
- For static stability analysis of structures where site specific testing was performed on weak interfaces, including those involving geosynthetic materials, the recommended factor of safety is 1.3.

Seismic evaluations should be based on the Design Earthquake (Section 3.6.3.3.3 and Appendix E). Seismic stability analyses may include pseudostatic and deformation analysis methods as further discussed in Appendix E. When deformation analyses are required the displacement predicted shall be small enough so as not to jeopardize containment integrity.

The BADCT pond design shall incorporate necessary measures such that static and seismic stability criteria are achieved.

Appendix E provides additional guidance on stability design.

3.6.4.5 Operational Measures

It should be noted that application of operating procedures is site specific and may not be a part of BADCT for all facilities. The following operating procedures have been used as part of a discharge control system to achieve BADCT for pond facilities.

- Contain only those materials for which the facility has been designed to contain;
- Minimize containment times where consistent with the pond function;
- Minimize operating level;
- Avoid reagent concentrations that are higher than required for desired results;
- Incorporate protective berms to prohibit run-out of materials from dumps and heaps if such facilities are located nearby.

3.6.4.6 Operational Monitoring

During operation of a Surface Pond, monitoring should be conducted to ensure that the facility is performing and being operated as designed. The following are recommended as operational monitoring requirements, but may not apply to all Surface Ponds.

- Physical inspection of the pond berms and liners so as to identify any system failures or areas in need of maintenance repair;
- Regular inspection of liner system for liner integrity and performance;
- Regular monitoring of the leak collection system flow rates and maintenance of leak collection sump capacity;
- Freeboard monitoring to ensure the availability of design freeboard. Visual observations should be made on a regular basis to ensure that freeboard requirements are satisfied. In the case where freeboard is not sufficient, it will be necessary to develop a mitigation plan to prevent loss of solution containment;
- Regular monitoring of solids build-up in the pond and procedures for solids removal;
- Regular maintenance and monitoring of pump performance;
- Maintenance of surface water diversion systems.

A Contingency Plan is required separate from BADCT pursuant to A.A.C. R18-9-A204. In some cases, an applicant may include some components of the Contingency Plan as part of BADCT (e.g., provisions for backup generators to allow solution circulation during a power outage may affect BADCT containment volume requirements).

3.6.5 Closure/Post-closure

Closure/post-closure must be considered in the design submitted to ADEQ. The applicant must still comply with the requirements of A.A.C. R18-9-A209(B) prior to formal closure. Arizona

Mined Land Reclamation Statutes (A.R.S. 27-901 through 27-1026) and implementing Rules govern surface reclamation. This BADCT guidance manual is not intended to duplicate or modify requirements of surface reclamation statutes.

The closure strategy shall eliminate, to the greatest extent practicable, any reasonable probability of further discharge from the facility and of exceeding aquifer water quality standards at the applicable point of compliance.

Post-closure discharge control for a Surface Pond is accomplished by either removal of the pond and associated residue or by closure in-place. In addition, a plan to address groundwater impacts must be included for any facility that has impacted groundwater.

Post-closure care and monitoring may be required if the closure does not remove or decontaminate all waste, waste constituents, and contaminated components contained within the Surface Pond or pollutants identified in the subsurface soils from discharging activities.

3.6.5.1 Closure by Removal

To accomplish closure by removal, all liquid and solid waste must be removed from the facility and disposed of properly. Any underlying soil that has been contaminated by the facility may also need to be removed or decontaminated. Appropriate sampling and analysis may need to be performed to verify that any contaminants remaining in the subsurface are below any applicable regulatory standards and will not adversely affect water quality. Applicable regulatory clean-up standards are not limited to the Aquifer Protection Program. Other regulatory standards or programs may apply. Geomembranes should be removed and disposed of properly. The facility should be backfilled with clean soil compacted sufficiently to preclude future settlement. Surface grading should occur to avoid ponding unless such grading is not practicable.

3.6.5.2 Closure In-Place

Closure in-place may involve varying degrees of removal or reconfiguring Surface Ponds. In most cases, free liquids should be removed through evaporation or other means. Solid residue may be removed from the pond liner, or left in-place if the final pond configuration will mitigate potential impacts to aquifer water quality. Synthetic liners may be folded into the pond bottom or otherwise treated to achieve the specific closure design goals. Pond areas should be graded to avoid surface ponding, unless this configuration is not practicable due to site topography.

When closure in-place is used, a low permeability cover may be necessary to limit infiltration. The cover design and surface configuration should consider site specific needs and factors related to limiting infiltration, protecting low permeability components from damage or erosion, minimizing potential maintenance needs, and cover longevity.

APPENDIX A

COMPARISON OF COPPER LEACHING FACILITIES

A.1 INTRODUCTION

The recovery of metals by leaching techniques has been practiced throughout the world for centuries. In the United States, the recovery of copper from dilute mine waters has been ongoing for more than 100 years, while the recovery of gold, uranium and other metals has been practiced for decades. In recent years, however, certain technical innovations have heightened the importance of solution copper mining including advances in solvent extraction - electrowinning (SX-EW) technology and reagents, improvements in heap and dump construction, advances in in-situ leaching technology, and development in acid and acid-ferric cure processes for oxide and mixed oxide-sulfide ores. In addition, solution mining is beginning to be appreciated for certain intrinsic advantages over conventional mining and milling. These advantages include generally lower capital and operating costs, faster startup times, and the ability to mine and treat low-grade sources that otherwise were uneconomical to mine (Hiskey, 1986; Bartlett, 1992).

However, with the increase of mineral production via hydrometallurgical techniques, comes the added responsibility of protecting the groundwater and surface waters from metal-laden solutions. This section outlines three of the four principal types of leaching methods being practiced in the United States: Dump Leaching, Heap Leaching, and In-situ Leaching. The fourth type, confined leaching in vats & tanks, is not discussed here.

A.2 DUMP LEACHING

Dump leaching is generally only implemented at copper operations and is the principle method by which copper is leached from run-of-mine low-grade ores. Leach dumps typically cover hundreds of acres, rise to heights of 500 feet or more, and contain several million tons of uncrushed, low grade ore. Leach dumps are usually located adjacent to the mine site to minimize haulage costs and to increase the economic efficiency of the operation. They are located on low permeability soil or bedrock with sloping terrain to facilitate the collection and recovery of the pregnant leach solution (PLS). The leach cycle for this type of operation is extremely long, usually measured in decades (Hearn and Hoye, 1988). Table A-1 provides further details on this type of copper leaching operation.

Dump leaching operations can impact the environment in a number of ways. Storm water run-off from dump leaching facilities can contribute to violations of surface water standards. Subsurface seepage from raffinate or pregnant leach solution ponds associated with dump leaching can contribute to violations of aquifer water quality standards. Because leaching dumps generally do not contain liners, subsurface seepage of leach solution to an underlying aquifer can

occur. However, a properly managed dump leaching operation will minimize subsurface seepage from the dump into the underlying aquifer.

A.3 HEAP LEACHING

Heap leaching is primarily used in the gold industry but has had success in the copper industry as well. Heap leaching involves placement of leach-grade ore (either crushed or run-of-mine) on a specially prepared surface (i.e., a pad). Heap leach facilities are typically smaller than dump leach facilities both in the copper and gold industries. In the gold industry, a cyanide solution is used as a leaching solution. Sulfuric acid is predominantly used in the copper heap leaching. Copper heap leaching is generally practiced with oxide ores because oxides leach more rapidly than sulfides, which allows quicker cost recoveries; and because the oxide leachate has a higher copper concentration than sulfide leachate.

The construction of heap leaches is generally conducted in smaller lifts (8' to 20' depending on rock type, size, grade, etc.) than for leach dumps and are operated to minimize truck traffic and dozer work on the surface of the ore to minimize compaction. Copper heap leaching has been used in place of dump leaching in areas where the underlying geologic formations are of high permeability or poses low neutralization characteristics, the terrain is too flat to ensure solution recovery, or due to economics, (e.g., it is more cost-effective to construct a heap leach close to the mine site than haul ore over longer distances to a more suitable dump leach site (Hearn and Hoye, 1988; Derkics, 1985; Hiskey, 1986). Table A-1 further outlines this type of copper leaching operation.

Environmental impacts from heap leaching operations are similar to those for dump leaching. Violations of surface water quality standards due to storm water run-off from heap leaching facilities and subsurface seepage from ponds can still occur. However, a properly managed heap leaching operation will minimize subsurface seepage from the heap into the underlying aquifer. The construction and integrity of the liners used in heap leaching operations will determine whether or not seepage from heap leach pads or ponds will be a problem.

A.4 IN-SITU LEACHING

In-situ leaching is performed on a material deposit that is in its natural or original position. There are generally three types of in-situ copper leaching situations: (1) deep deposits below the water table (2) near surface deposits below the water table and (3) near surface deposits above the water table (Murr, 1980).

The economics of current mining and recovery methods often prevents the mining of ore that either contains insufficient metal values or entails high site preparation or operating expenses. For these reasons, the use of the in-situ method is increasing as a means of recovering additional copper from old mine workings (open pits, block caved areas, backfilled slopes) from which the primary sulfide deposit has been removed, or from new operations which have deep ore deposits that cannot be mined using conventional mining methods. As with dump and heap leaching

facilities, in-situ leaching is dependent on site specifics, including the location of the deposit, type and grade of ore (deep sulfide deposits may require injection of oxygen), geology (permeability and porosity of the ore-body and surrounding host rock), and hydrologic factors (unsaturated flow conditions for facilities above the water table, and saturated flow conditions for facilities below the water table). In addition, the following seven characteristics are generally determined to be required for a successful in-situ leach operation (Hiskey, 1986; Hearn and Hoye, 1988):

- Non-acid consuming host rock;
- Host rock that will not decrepitate;
- Host rock sufficiently fractured to permit access of solutions;
- Concentration of mineral primarily along fracture surfaces;
- Mineral that dissolves within the required time frame;
- Ability to recirculate solutions through the ore;
- Availability of adequate water supplies.

In-situ leaching minimizes the possibility of storm water contamination by eliminating open excavations, and the storage of ore, waste rock and overburden. However, because in-situ leaching operations are conducted subsurface, the possibility of directly contaminating aquifers is increased. The leaching and recovery of solution may contribute to violations of aquifer water quality standards if solution recovery is inadequate.

A.5 CONCLUSIONS

In determining which type of leaching facility should be designed and constructed at any given location, the applicant must consider several factors including site specifics (topography, geology, hydrogeology, climatic factors, the land use and population density surrounding the operation, etc.), size of the operation, type and grade of ore leached, duration of leach cycles (recovery time), economics (capital costs, haulage and operating costs, competitiveness of the operation in the world market, etc.), and the available demonstrated technology for each type of facility on an industry wide basis. Once the applicant determines which type of facility is applicable to the site specifics, a BADCT design must be developed. Sections 3.2, 3.3, and 3.4 outline demonstrated control technologies used in developing a BADCT design for heap, dump, and in-situ leaching operation, respectively.

TABLE A- 1

Comparison of Copper Leaching Technologies[1]			
Category	Dump Leach	Heap Leach	In-Situ
Material	Usually treats low grade ore.	Usually treats moderately high grade Cu ores.	Low to high grade ore, dependent upon site conditions and mine layout.
Material Size	Usually run of mine size.	Usually ore is crushed to optimize recovery.	Determined by in-situ degree of fracturing; In some cases where interstitial porosity is low, the ore may be prepared by blasting or hydraulic fracturing.
Base	Usually deposited on surface of low permeability rock and soil.	Usually built on specially prepared lined pads.	Existing geologic formations having low hydraulic conductivity.
Mineralogy	Contains predominantly sulfide mineralization (pyrites). Copper/sulfide ratio generates sulfuric acid, which provides heat, and supports bacterial activity.	Mostly oxides or silicates, at times mixed with oxide/sulfide ores.	Oxides, silicates and some sulfides; best suited for deep-lying oxide deposits.
Lixiviant	Acid/ferric-sulfate solutions, effective air circulation and good bacterial activity are required to provide sufficient recovery.	Simple sulfuric acid solution can effectively treat oxide minerals.	Depending on the ore type: Sulfuric acid, Acid cure, Acid-ferric cure or Acid ferric sulfate.
Leach Cycle	Measured in years, usually in decades; Requires intermittent application of solution (resting).	Shorter periods ranging from days to months with continuous application of solution.	Usually measured in years (typically 1-25 years).
Area	Cover hundreds of acres; rise 500 feet or more; contain tens of millions of tons of materials.	Generally magnitudes of order smaller; on the average contain 100,000 to 500,000 tons of material.	Can cover hundreds of acres; contains millions of tons of materials.
Location	Adjacent to mine site to minimize haulage costs.	Varies depending on economics (grade, haulage costs) and site factors (low sloped terrain, high permeability or high neutralizing characteristics of host rock).	Siting is determined by location of ore body.
Degree of Copper Recovery	20 to 60%.	50 to 70% or more.	Variable.

(1) While heap leaching is a term used in the precious metal industry, the terms heap leaching, dump\leaching, and in-situ leaching are used to describe specific types of operations in the copper industry.

APPENDIX B

SOLUTION, ORE AND WASTE CHARACTERIZATION

B.1 INTRODUCTION

In order to meet the criteria of defining current and past facility discharges and provide information necessary for a proper evaluation of facility design criteria, the applicant must present characterization of all applicable wastes at the facility in sufficient detail to allow the ADEQ to evaluate the proposed design, construction, operation, closure and post-closure plans.

Since the materials will vary between facilities depending on site specifics, the degree of characterization that must be conducted will also vary from site to site. Below is a list of tests often applied to characterize materials that are commonly used or discharged at mining facilities. Part A outlines a tiered approach to characterize solid materials such as tailing, waste rock and ore. When using the tiered approach, it is recommended that the applicant first conduct the applicable tests listed in Tier #1. If additional characterization is necessary for a facility, the applicant must then conduct test(s) listed in Tier #2, as applicable. Part B outlines tests to be considered to characterize organic wastes or wastes containing organics. Part C outlines parameters that may be tested for in various solutions (e.g., process solution) based on site specifics.

The Arizona Administrative Code (A.A.C.) R18-9-AZ02(A)(4) requires that a summary of the known past facility discharge activities and the proposed facility discharge activities be conducted to indicate all of the following:

- The chemical, biological, and physical characteristics of the discharge;
- The rates, volumes and frequency of the discharge for each facility;
- The location of the discharge.

In addition, A. R. S. 49-243.A.7. states:

A. "The director shall consider, and the applicant for an individual permit may be required to furnish with the application, the following information:

1. *The design of the discharge facility.*
2. *A description of how the facility will be operated.*
3. *Existing and proposed pollutant control measures.*
4. *A hydrogeologic study defining and characterizing the discharge impact area, including the vadose zone.*
5. *The use of water from aquifers in the discharge impact area.*
6. *The existing quality of the water in the aquifers in the discharge impact area.*
7. *The characteristics of the pollutants discharged by the facility.*

8. Any other relevant federal or state permits issued to the applicant.
9. Any other relevant information the director may require.

B. The director shall issue a permit to a person for a facility other than a recharge project or an underground storage and recovery project if the person demonstrates that either paragraphs 1 and 2 or paragraphs 1 and 3 of this subsection will be met:

1. That the facility will be so designed, constructed and operated as to ensure the greatest degree of discharge reduction achievable through application of the best available demonstrated control technology, processes, operating methods or other alternatives, including, where practicable, a technology permitting no discharge of pollutants. In determining best available demonstrated control technology, processes, operating methods or other alternatives the director shall take into account site specific hydrologic and geologic characteristics and other environmental factors, the opportunity for water conservation or augmentation and economic impacts of the use of alternative technologies, processes or operating methods on an industry-wide basis. However, a discharge reduction to an aquifer achievable solely by means of site specific characteristics does not, in itself, constitute compliance with this paragraph. In addition, the director shall consider the following factors for existing facilities:

(a) Toxicity, concentrations and quantities of discharge likely to reach an aquifer from various types of control technologies.
(b) The total costs of the application of the technology in relation to the discharge reduction to be achieved from such application.
(c) The age of equipment and facilities involved.
(d) The industrial and control process employed.
(e) The engineering aspects of the application of various types of control techniques.
(f) Process changes.
(g) Non-water quality environmental impacts.
(h) The extent to which water available for beneficial uses will be conserved by a particular type of control technology.

2. That pollutants discharged will in no event cause or contribute to a violation of aquifer water quality standards at the applicable point of compliance for the facility.

3. That no pollutants discharged will further degrade, at the applicable point of compliance, the quality of any aquifer that already violates the aquifer quality standard for that pollutant."

The applicant and the ADEQ will determine the exact type and degree of waste characterization needed at each facility on a site specific basis. Testing of ore may be required to aid in characterization of potential discharge, particularly where the wastes have not been generated. The list of tests and parameters described below is not an exhaustive list; the applicant may

propose and ADEQ may require other tests. By the same token, just because certain tests and parameters for each type of test are listed in this appendix, does not mean the applicant is required to conduct all or, depending on site specifics, any of these tests. It is strongly recommended that the applicant propose a waste characterization plan and present it to ADEQ for review and comment early in the permitting process, preferably during the pre-application phase. During the pre-application process, the applicant should be prepared to present its waste characterization plan (e.g., discharge determination, proposed waste characterization tests, sampling plan including number of samples, etc.) for discussion. It is in the best interest of the applicant to receive ADEQ concurrence for the waste characterization plan in order to avoid future delays (e.g., implementation and review of future studies due to deficiencies) and/or costs (e.g., minimization of unnecessary studies which the applicant may conduct but ADEQ does not require).

The following information is meant to offer guidance as to what should be considered when preparing a waste characterization plan for various types of facilities. The goal of waste characterization with respect to BADCT is to 1) define the characteristics of the discharge, and 2) ensure the design of the facility is compatible with the waste. All analytical testing work should be conducted at a state-certified laboratory. While a state-certified laboratory and current standard analytical methods should be used for testing that is planned to support an APP application, an applicant may proposed to use historic data obtained for other purposes (e.g., exploration or feasibility work) or from previous testing to replace or augment pertinent material characterizations. In such cases, the burden is on the applicant to demonstrate the validity of the historic data.

B.1.1 Tailing, Heap Leach and Dump Leach

Typically, physical and chemical characteristics of the tailing, heap and dump leach material are required. However, because copper leaching operations often use or produce acid and leach metals, some testing may be deferred until closure. Proposals for deferring material characterizations should be presented to ADEQ during the pre-application period. Similarly, in cases where process solution and/or tailing solution chemistry data are available, leach testing of the solid material phase may not be necessary.

Physical and chemical characteristics of tailing, heap and dump leach material can usually be obtained by conducting the appropriate Part A, Tier 1 tests outlined below. Physical characterization includes grain size, density, and shear strength analyses for use in stability assessments and to aid in characterizing water conditions within the deposited material.

Chemical characterization includes a description of the mineral content of the material to establish whether it has the potential for acid generation and whether leachate from it could pose a threat to groundwater quality, leach testing to assess the quality of leachate that may form, and acid base accounting testing to assess the acid generation potential.

Where necessary, more refined physical and chemical characterization may be required. Procedures are contained under Part A, Tier 2. Physical testing includes determination of

hydraulic conductivities and moisture retention capacities to further define water conditions in the wastes, and to aid in evaluating the amount of leachate that may be formed. Chemical testing includes more accurate procedures for predicting the quality of leachate formed by acid generation, total metals analyses where long-term leachate quality predictions are needed, radionuclide testing where radioactivity is a potential concern, and miscellaneous chemical leachate testing to refine aquifer loading calculations for constituents such as TDS, BOD, COD, etc.

Where organic constituents are potentially present, or where the material may not be exempt from the Resource Conservation and Recovery Act (RCRA), Part B testing should be conducted to characterize the organic constituents and to classify the material for regulatory purposes.

As mentioned above, solutions associated with tailing facilities and leaching facilities (i.e., pregnant and barren solutions, raffinate, etc.) should be characterized according to procedures such as those outlined in Part C below.

B.1.2 Waste Rock Dumps

Waste rock dumps may discharge depending on site specifics. The burden of proof lies with the applicant to demonstrate that the waste rock dump does or does not discharge.

The applicant may want to use site specific attributes (e.g., attenuation and dispersion, percent fines and percent moisture of material in the dump) or demonstrate that the material in the waste dump is significantly inert, has a high neutralization potential or does not generate acid. In these cases, additional characterization as described in Part A, Tiers #1 and #2 may be necessary.

In still other cases, the applicant may choose to recognize up-front that a new or existing waste rock dump will be acid generating (sulfide dump). In these cases, the applicant may agree to focus on controls such as operating practices and closure plans in the APP application, rather than instituting rigorous engineering controls, to meet the criteria for discharge minimization as referenced in A.R.S. 49-243.B.1. Sufficient waste characterization must be performed to support the proposed operational practices and closure plans.

B.1.3 Characterization of discharge to surface impoundments including holding, storage settling, treatment or disposal pits, ponds and lagoons; injection wells; mine tailing piles and ponds; and mine leaching operations.

The applicant should characterize the solution in surface impoundments that discharges from injection wells, in detention ponds from mine tailing piles or ponds, solutions from SX/EW circuits (raffinate and PLS impoundments), vehicle maintenance and wash areas, from mine leaching operations, and other solutions in accordance with Part C of this Appendix. The number and types of parameters to be analyzed will be determined on a site specific basis.

PART A. CHARACTERIZATION OF TAILING, SPENT ORE AND WASTE ROCK:

TIER #1 Primary Analytical Procedures for Waste Characterization

1. Description of Mineralogy and Lithology

The applicant should provide a description of the mineralogy and lithology of the mineral deposit and waste rock. The level of detail which is appropriate will be dependent on site and project specific details. Lithologic description may include color, rock type, texture, sorting, angularity/roundness, induration, grain-size distribution, and other relevant properties as applicable. Definition of mineral types and proportions of the various lithologies is important, as well as relative percentages of the different lithologies, in order to determine whether acid rock drainage and metals leachability are potential issues. In some cases, the sulfide percentages should be evaluated.

2. Leach Testing

A. General

Leach testing should be conducted on a sufficient number of representative samples of waste rock, tailing, or other applicable wastes to determine the potential types and levels of pollutants that may be leached from waste materials under the effects of rainfall or run-on percolating through the material. (In cases where process solutions and/or tailing solutions are available, these solutions may be analyzed and leach testing may not be necessary.) The results of leach testing may be used in conjunction with the acid-base accounting data to aid in the engineering, designing and material selection of the facility. Sufficient samples should be collected for leach testing to adequately characterize the waste material.

While leach testing may be conducted by one or more of the following procedures, the Synthetic Precipitation Leaching Procedure (SPLP) is the preferred approach.

B. Synthetic Precipitation Leaching Procedure (SPLP)

The Synthetic Precipitation Leaching Procedure (EPA Method 1312), also known as the SPLP, is an EPA test method developed for various solid wastes to determine if the material will leach pollutants under the effects of meteoric water percolating through the material. The method is adopted here as a meteoric water leach test to determine the types and levels of pollutants that may leach from various mine materials. Because of this application, it is necessary that the applicant collect a sufficient number of samples to adequately characterize the material. The leachate can be analyzed for the following parameters: 1) inorganic (e.g., primary metals, major cations and anions, radionuclides, etc.), and 2) organic compounds e.g., cyanide species, volatile

compounds, and semi-volatile compounds) and 3) indicator/physical parameters (pH, EC, temperature).

C. Meteoric Water Mobility Procedure

The Meteoric Water Mobility Procedure is a method developed by the State of Nevada and is similar to the SPLP, except that the Nevada test uses a nitric acid lixiviant with a pH between 5.5 and 6.0 while the SPLP uses a sulfuric and nitric acid lixiviant with a pH of 4.2 (east of the Mississippi River) or 5.0 (west of the Mississippi).

D. Leachable Sulfates and Soluble Solids

The leachable sulfate and soluble solids tests use an extraction fluid (lixiviant) of deionized water to leach any readily soluble sulfate or other constituents such as chloride, nitrate, cadmium, sodium, etc., which are then tested in the filtered solution using standard analytical methods. The test was developed by the Arizona Department of Health Services, Division of State Laboratory Services (Arizona State Lab) and is summarized below. The method is useful for making determinations of the levels of dissolved solids and other pollutants that may be leached from various mine wastes (and soils) under the effects of meteoric water percolation.

Test Method

The extraction is done using a 1:10 ratio of soil (solid):deionized water, followed by shaking and filtering in accordance with 62-1.3.2.2 in Black, et al (1965). Although the reference calls for a 1:5 ratio, typically a 1:10 ratio is used so that sufficient volume of water is obtained for the various analyses conducted. Following filtration, the leachate is analyzed for pH, sulfate and total dissolved solids (at a minimum). Additional tests for chloride, fluoride, calcium, sodium, magnesium, potassium, may also be conducted. Analytical methods used are as described in EPA 600/4-79-020, Methods for Chemical Analysis of Water and Wastes and as listed below:

Constituent/parameter	**Test Method**
Sulfate	EPA 9036 or 375
Total dissolved solids	EPA 160.1
pH	EPA 150.1
Chloride	EPA 325
Fluoride	EPA 340
Calcium	EPA 215
Magnesium	EPA 242.1
Potassium	EPA 258.1
Sodium	EPA 273.1

The extraction for nitrate is somewhat different, as it uses a 1:3 ratio of soil (solid):water, and the water is a calcium sulfate water ($CaSO_4$), followed by shaking and filtering in accordance with 84-5.3.3.1 in Black, et al, (1965), followed by analysis using EPA Method 353.

E. Bottle Roll Test

Conventional Bottle Roll Tests (i.e., 48 or 72 hour tests) may be conducted to determine the types and levels of pollutants that may leach from various mine waste materials. A description of the test should be provided. Samples shall be analyzed for the following parameters: 1) inorganic (e.g., primary metals, major cations and anions, radionuclides, etc.), and 2) organic compounds e.g., cyanide species, volatile compounds, and semi-volatile compounds) and 3) indicator/physical parameters (pH, EC, temperature).

3. Acid-Base Accounting (ABA) Analysis

A. General

Acid-base accounting analysis is the procedure used to predict whether or not a given waste material has the potential to generate acid mine drainage (AMD), or acid rock drainage (ARD) as it is sometimes referred. If the material of a discharging facility may be considered to be acid generating due to the geology and mineralogy, then the applicant may be requested to conduct the following procedure. The procedure consists of collecting a representative number of samples for determination of the acid generation potential (AGP) and the acid neutralization potential (ANP). A comparison between the AGP and ANP is then made to determine if the sample analyzed has a net acid generating potential. Two types of predictive testing are generally conducted: static and kinetic. Static testing is usually conducted first, and depending on the results, kinetic testing may be required. Static tests consist of a determination of the sulfur content of the waste material which is equated to the maximum potential acidity or the AGP, and the acid neutralization potential of waste, which is generally based on a neutralization titration conducted on the sample. A determination of the carbonate content may also be used to determine the ANP. A total sulfur analysis may overestimate the AGP because it also includes non-acid generating species such as sulfate, so it is advisable to determine only those species that may potentially generate acid upon oxidation; i.e., sulfide sulfur and elemental sulfur. Kinetic tests need to be conducted on samples where the results of static tests are uncertain and where a more representative qualitative characterization of leachate is required for material that has an acid generation potential.

An applicant for an individual APP should adequately characterize any tailing or other waste materials that are subject to the APP program requirements (e.g., materials that discharge). In the case of waste rock, the applicant should conduct an ABA analysis if that waste rock facility will discharge, and if it has the potential to be acid generating (e.g., if the rock contains significant sulfide minerals and/or minimal carbonates). Sufficient documentation of the non-acid generation potential must be submitted to ADEQ.

B. Sample Collection

The primary objective of a sampling program is to obtain representative samples from a range of geochemical groups within each lithologic unit in order to characterize materials that may generate an acid rock drainage and have a reasonable probability of causing pollutant to reach an aquifer The sampling program should be designed so that the collected samples are representative of the different lithologic units with respect to acid generation and should be collected in such a manner that the samples are representative of different areas in the mine development and can be used to estimate the extent of acid generation, and the suitability of non-acid generating material for mitigating ARD. For existing operations, where necessary to document adequate characterization, sampling should be conducted in such a manner as to document the horizontal and vertical variation of the properties that are used to determine if a given sample or pile will yield ARD. Samples to be collected from new and existing mines may be from drill core, pit walls, excavated rock, adit walls, and from surface and subsurface (from borings) samples from ore, waste and tailing piles.

Implementation of a sampling plan may require several iterations in order to adequately characterize the materials. Analysis of samples from a lithologic unit may indicate significant variance in the ABA results. This variance may require that more or different lithologic groups be defined, samples collected and analyzed to confirm homogeneity with the defined lithologic units.

The following factors should be considered in creating a representative sampling plan:

Lithological and mineralogical variation;
Degree and extent of primary and secondary sulfide, and oxide mineralization;
Form in which mineralization occurs (e.g., disseminated or in veins);
Mass and volume of different lithologies;
Degree and extent of fracturing;
Degree of oxidation.

For new facilities, samples collected during the exploration phase or during definition of the ore body may be used as initial samples for characterization purposes. Three dimensional (3-D) geological models of waste rock material may also be an acceptable procedure in conjunction with sampling. In specific instances, it may be necessary to implement a leachability and/or ABA sampling and testing program during active mining if the initial sampling did not adequately characterize the materials present or if design decisions are based only on initial samples. The intent of an on going sampling and testing program would be to provide adequate waste characterization and may not need to be continued over the life of the project.

C. Predictive Testing - Static Tests

Static tests are designed to determine the balance between potentially acid-generating minerals and acid-neutralizing minerals in a given sample. In general, acid-generating minerals include sulfide minerals and elemental sulfur, and acid-neutralizing minerals include carbonate minerals (and to a lesser degree hydroxide and alumino-silicate minerals). In theory, a sample will

generate a net acidity at some point in time if the amount and distribution of material with acid neutralization potential is insufficient to neutralize any acid that is formed or if the acid-neutralizing minerals react slower than the acid generating materials. Static tests are used to determine if a given sample will generate acid at some time, but cannot predict when acid-generation will occur nor the quality of drainage emanating from waste materials.

Static tests consist of the determination of the maximum potential acidity (or acid generation potential, AGP) which is based on either the total sulfur content or on the sulfide sulfur content of a sample, and the determination of the gross neutralization potential (or acid-neutralization potential). The total sulfate sulfur content of a sample may need to be determined for some samples, if sulfate sulfur is significant, since sulfate sulfur is not an acid-generating form and should be excluded from the acid-generation calculation. The acid-neutralization potential is based on either an acid-neutralization titration or on the total carbonate content. The net neutralization potential (NNP) is the difference between the acid neutralization potential and the acid generation potential, expressed as tons of calcium carbonate equivalent per kiloton of sample:

$$NNP = ANP - AGP, \text{ as tons of } CaCO_3\text{/kton of sample}$$

If NNP is less than -20 tons of $CaCO_3$/kton, it can be considered acid generating. Between -20 and +20, the potential exists for the waste to form acid. The more positive, the lower the risk. When the NNP is above +20 the material can generally be considered non-acid generating. Prediction of the acid generating potential when the NNP is between +20 to -20 tons of $CaCO_3$/kton of sample is more difficult due to uncertainty in analysis and conversion factors. Samples that fall into this range of uncertainty may be tested further using kinetic test methods if it is determined that this additional data will assist in the design of the facility.

Ratios of ANP/AGP can also be used to assess the acid generation potential (e.g. ANP/AGP ratio of 1:0 is equivalent to an NNP of zero) if the ratio of a sample's neutralization potential and acid production potential is greater than 3:1, then there is a low risk for acid drainage to develop and the material can generally be considered non-acid generating. For ratios between 3:1 and 1:1, uncertainty arises and additional testing is usually necessary using kinetic test methods as described under the Tier #2 protocols. Those samples with a ratio of 1:1 or less are more likely to generate acid (Smith and Barton-Bridges, 1991).

D. Examples of test methods for determining the AGP/ANP are summarized as follows:

Acid Generation Potential:

Parameter	Test Method
Total Sulfide Sulfur	Determine acid-leachable (Sulfur Species); sulfate and then total sulfur; or as in Standard Methods of Chemical Analyses; or EPA Method 9030A[(1)] ; or EPA Method 9030A[(2)]
Total Sulfate Sulfur	EPA Method 9035, 9036, or 9038
Total Sulfur	Leco Furnace/Analyzer
Acid Neutralization Potential:	
(Gross Neutralization Potential Titration	as in Sobek, et al, 1978[(3)]
Total Carbonate	Leco Furnace/Analyzer

Other ABA test methods may be used (e.g. Modified Acid-Base Accounting - EPA Method 670, Net Acid Productive Test, Nevada Procedures, etc.) as long as equivalent or better detection limits are achieved, equivalent or better quality assurance/quality control is achieved and the alternative tests are appropriate to the materials being tested.

4. Physical Characteristic Tests

A. General

In order to properly design a facility, the total mass or volume of material (total gallons, total tons) must be estimated and included in the APP application. In some cases, the design of the facility requires additional physical properties such as bulk density, grain size distribution, moisture content (e.g., tailing facilities) and strength characteristics. These properties may need to be calculated and included in the application only if they have an effect on the design.

In some instances, it may be necessary to describe other physical properties such as the Atterberg limits, permeability, moisture-density relationships and the compaction test, if the waste materials are proposed to be used in the construction of liners, berms, etc.

B. Grain size, density and shear strength

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(1) Acid soluble and non-acid soluble sulfides.

(2) Extractable sulfides.

(3) Sobek, A.A., Schuller, W.A., Freeman, J.R., and Smith, R.M., Field and Laboratory Methods Applicable to Overburdens and Minesoils, EPA-600/2-78-054, March, 1978.

A grain-size distribution analysis (particle size distribution analysis) may be conducted on waste materials such as tailing, if applicable. The grain-size distribution should be determined using ASTM D2217, or D421 for particles greater than 75 mm (particles retained on the No. 200 sieve) and ASTM D422 for particles smaller than 75 mm (particles passing the No. 200 sieve). The following tests may also be conducted where applicable:

Parameter	**Test Method**
Moisture content	ASTM D2216
Atterberg limits	ASTM D4318
Permeability	ASTM D2434
Moisture-density relationships	ASTM D698, ASTM D1557, & ASTM D4609
In-place density	ASTM D2937
Unconfined compressive strength	ASTM D2166
Triaxial compression	ASTM D2850

TIER #2 Miscellaneous Analytical Procedures for Additional Waste

1. Predictive Testing - Kinetic Tests

Kinetic tests may be conducted to confirm the results of static tests, to determine the rates of acid-generation, acid-neutralization, sulfide oxidation, and to test control or treatment methods. Kinetic tests may be necessary if the NNP, as determined by static testing fails, (i.e., are less than 20 tons of $CaCO_3$/kton of sample or which have an ANP/AGP ratio of less than 3) or if it is determined that this additional data will assist in the design of the facility (e.g., the rate of acid generation over time is negligible, then long term control may not be necessary). Applicants may propose control technologies (or other alternatives) in lieu of additional kinetic testing for samples that exhibit a net acid generation potential.

In short, kinetic tests involve the chemical weathering of samples under controlled laboratory or on-site conditions in order to determine the various rates of neutralization, oxidation, etc. Several kinetic test methods exist, but the most reliable and informative methods are humidity cell tests, modified soxhelet extraction tests, shake flask tests, column/lysimeter tests and test plots/piles. Humidity cell tests and modified soxhelet extraction tests are becoming the most common method used, due to the time and cost factors involved with other methods. Humidity cell tests typically require 10 weeks or longer, plus additional time for the analyses and reporting.

2. Metals

In some cases, the applicant may choose to conduct a metals analysis (dissolved or total metals depending on site specifics) on solid waste materials (waste rock, tailing, etc.) to determine the levels of metals contained in the waste and to give an indication of the potential level of pollutants that may be released from the waste upon oxidation and/or under the effects of chemical weathering. See EPA SW-846 for detailed descriptions of various solid waste analytical methods pertinent to the characterization of mine wastes and process solutions.

3. Radionuclides

On a case by case basis, discharging facilities may be required to include radiological characterization of tailing and waste rock. The following parameters/constituents may be tested:

Constituents/Parameter	Test Method
Gross Alpha Particle Activity	EPA 9310
Gross Beta Particle Activity	EPA 9310
Radium 226	EPA 9320
Radium 228	EPA 9320
Uranium Total*	EPA 908
Radon 222	EERF manual 78-1

***Uranium (total) is the sum of the particle activities from U-234, U-235, and U-238.**

Uranium mining and processing facilities (and other facilities on a case-by-case basis) should include the following constituents:

Constituents/Parameter	Test Method
Thorium-228	EPA 907
Thorium-230	EPA 907
Thorium-232	EPA 907
Thorium-234	EPA 907

Uranium mining and milling facilities (and other facilities on a case-by-case basis) should include characterization of tailing, waste rock, leach ore, and other wastes, where applicable. The following constituents should be tested:

Constituents/Parameter	Test Method
Gross Alpha Particle Activity	EPA 9310
Gross Beta Particle Activity	EPA 9310
Radium 228	EPA 9320
Alpha emitting radium isotopes	

4. Other Leach Tests (TCLP, WET)

Several leach tests have been developed for making hazardous waste determinations of solid wastes under the Federal Resource Conservation and Recovery Act (RCRA). The Toxicity Characteristic Leaching Procedure (TCLP) is used to make hazardous waste determinations using a method comparable to the SPLP and Nevada tests except that the TCLP test uses an organic acid (acetic acid) as the lixiviant instead of inorganic acids. The TCLP test, however, is not used to regulate mining wastes which are excluded from regulation under RCRA Subtitle C by the Bevill Exclusion (CFR 261.4(b) and Federal Register Volume 56, No. 114, 1991).

The State of California has developed a leaching procedure known as the Waste Extraction Test (WET). This test is used to make hazardous waste determinations in California and is similar to the TCLP in that an organic acid lixiviant is used. Mining waste characterizations sometimes utilize a modified WET method in which the same procedure is used, but deionized water is substituted for the organic acid lixiviant to more closely simulate expected mining site conditions.

If the applicant has data available from these or other types of leach tests, the Department may accept the information as supporting documentation in the application.

PART B. CHARACTERIZATION OF ORGANIC WASTES OR WASTES CONTAINING ORGANICS

1. Organic Analyses

A. Total Petroleum Hydrocarbons

Petroleum hydrocarbons are found in many mine wastes and solutions including solvent extraction reagents, flotation reagents, vehicle, floor, and equipment wash waters, and from spills. The total petroleum hydrocarbon analysis detects petroleum compounds in the C_6 to C_{40+} range, but does not distinguish between the different types of hydrocarbons present. If that information is needed, it will be requested on a case-by-case basis. The following methods should be used when TPH analyses are required:

Solid matrix analysis:	BLS-181 (Arizona State Laboratory method)
Liquid matrix analysis:	EPA 418.1

B. Polynuclear Aromatic Hydrocarbons

Polynuclear aromatic hydrocarbons (PAHs) are a group of hydrocarbons found in crude oil and sometimes in refined oil products including kerosene, diesel fuel, fuel oils, lubricating oils and asphalt. Many PAHs are included in the list of organic substances referenced in A.R.S. 49-243.I. When an analysis for PAHs is needed, the following compounds should be tested:

PAH*	**Referenced in A.R.S. 49-243.I**
Benzo(a)pyrene	Yes
Benzo(b)fluoranthene	Yes
Dibenzo(a,h)anthracene	Yes
Dibenzo(a,i)pyrene	Yes
Indeno(1,2,3-cd)pyrene	Yes

*Additional PAHs may be analyzed on a case by case basis.

Samples analyzed for PAHs should be tested using the following methods:

Solid matrix analysis:	EPA Method 8310
Liquid matrix analysis:	EPA Method 610

C. Phenol Analyses

Phenols (or phenolics) are a class of semi-volatile compounds that may be found in mine wastes and process solutions as the result of the use of flotation reagents containing phenolics, cresols or cresylic acid. Process solutions (and seepage) and tailing from mills using reagents that contain phenolics, cresols, or cresylic acid should be analyzed for the following compounds:

Phenolic	**Referenced in A.R.S. 49-243.I**
2,4-dinitrophenol	Yes
Phenolics (total)	No

Samples analyzed for phenolics should be tested using the following methods:

Solid matrix analysis:	EPA Method 8040
Liquid matrix analysis:	EPA Method 604

D. Volatile Organic Compounds (VOCs) and Carbon Disulfide

Many organic compounds may be present in mine wastes depending on the process employed by the facility. For example, carbon disulfide is a breakdown product of xanthate and dithiocarbamate process reagents. Volatile organic and other compounds may be present if used

in beneficiation. Facilities using VOCs (as referenced in A.R.S. 49-243.I.) and carbon disulfide in their process should analyze for these compounds. The following tests may be conducted where applicable:

Parameter	**VOC Method**	**CS2 Method**
Liquid Waste	EPA 601/602	EPA 601/602
Solid Waste	EPA 8010/8020	EPA 8015

The State of Arizona is currently developing a sample collection method for VOCs that utilizes a methanol field immersion procedure to preserve VOC constituents for improved analytical results from solid samples.

2. Hazardous Waste Determination

If the applicant proposes to dispose of wastes on discharging sites that are not specifically exempted by RCRA Subtitle C, or if the waste has not been treated (e.g., bioremediation), a hazardous waste determination may need to be made by the applicant. This may be needed for wastes such as sludges derived from washing vehicles, process piping and equipment, or laboratory wastes. Authorization to dispose of hazardous waste should be obtained from ADEQ - Hazardous Waste Compliance Unit prior to disposal. Facilities that treat the material prior to deposition, (e.g., a facility that treats a volume of petroleum contaminated soil to concentrations below regulatory limits, or a facility that uses "clean" sewage sludges for reclamation nutrients) need not perform characterization tests prior to deposition with prior authorization from the ADEQ - Solid Waste or Hazardous Waste Compliance groups. Hazardous waste determinations should be conducted in accordance with 40 CFR 262.11.

PART C. CHARACTERIZATION OF PROCESS SOLUTIONS, WASTEWATERS, AND MINE WATERS

Process solutions, wastewaters, mine waters and other solutions or liquids generated at the mine or mill site should be chemically characterized for a variety of parameters and constituents listed below as applicable:

1. **Metals - A metals analysis should include the following metals:**

Antimony (Sb)	Arsenic (As)	Barium (Ba)
Beryllium (Be)	Cadmium (Cd)	Chromium (Cr)
Lead (Pb)	Mercury (Hg)	Selenium (Se)
Thallium (Tl)	Nickel (Ni)	

In some instances total metals may be appropriate and in others dissolved metals may be appropriate. This may be a matter negotiated with ADEQ. Other metals may be of concern and may be requested on a site specific basis. These may include Aluminum (Al), Boron (B), Copper (Cu), Cobalt (Co), Iron (Fe), Manganese (Mn), Silver (Ag), and Zinc (Zn).

Typical test methods used for the analysis of metals following a complete wet chemical digestion includes the inductively coupled plasma (ICP)-emission spectroscopy (EPA Method 200.7 or 6010) which is a simultaneous multi-element method, and atomic absorption spectroscopy which is a single-element method (EPA 200 series methods or 7000 series methods). Mercury should be analyzed using EPA Method 245.1 or EPA Method 7470.

2. Major Cations and Anions

Major Cations consist of the following constituents:

Constituent	Test Method
Calcium (Ca)	EPA 215 or 200.7
Magnesium (Mg)	EPA 242.1 or 200.7
Potassium (K)	EPA 258.1 or 200.7
Sodium (Na)	EPA 273.1 or 200.7
Iron (Fe)	EPA 236.1
Hardness [4]	EPA 130 or Calc.

Facilities utilizing an ammoniacal leach, leaching at high pH, or that use ammonia as a neutralizing agent or process reagent may be required to include ammonia in the analyses, using EPA Method 350.

[4] Hardness may also be determined as the sum of the Ca and Mg concentrations expressed as $CaCO_3$

Major Anions consist of the following constituents:

Constituent	**Test Method**
Total Alkalinity	EPA 310.1
Phenolphthalein Alkalinity	EPA 310.1
Bicarbonate	Calculation
Carbonate	Calculation
Hydroxide	Calculation
Sulfate (SO_4)	EPA 375.2
Chloride (Cl)	EPA 325.2
Fluoride (F)	EPA 340.2
Nitrate - Nitrite as N	EPA 353.2

In some instances, the following constituents may need to be determined:

Constituent	**Test Method**
Phosphorus (Total) as P	EPA 365
Bromide (Br)	EPA 320
Iodide (I)	EPA 345
Silica	EPA 370.1

Bromide should be determined for facilities utilizing a bromide leach process. Phosphorus may be needed in some instances, such as in facilities that contain sanitary wastewater, discharge to surface water bodies or where needed to make an accurate cation-anion balance. Iodide, (and bromide) should be tested in situations where it is needed to make a cation-anion balance or where brines are used in processing or are being processed. Silica should be tested in situations where it is needed to make a cation-anion balance.

3. Physical/Indicator Parameters

Specific conductance (EC), pH and temperature should be measured in the field any time a sample is collected. EC and pH should also be measured in the laboratory as a verification of the field measurements. Any process solution, seepage, leachate, wastewater or other applicable liquids should include a determination of the total dissolved solids (TDS) concentration. In some instances, other physical and chemical parameters will be requested, on a case-by-case basis. Collection and documentation of information should be in accordance with applicable guidance manuals and ADEQ's *Quality Assurance Project Plan*.

The following parameters should be measured in the field at the time of collection

Constituent	**Test Method**
Specific conductance (EC)	EPA 120.1
pH	EPA 150.1
Temperature	EPA 170.1

In site specific instances, the following parameters may be required:

Constituent	**Test Method**
Total Dissolved Solids (TDS)	EPA 160.1
Biochemical Oxygen Demand (BOD)	EPA 405.1
Chemical Oxygen Demand (COD)	EPA 410
Total Organic Carbon (TOC)	EPA 415.1
Dissolved Organic Carbon (DOC)	
Total Suspended Solids (TSS)	EPA 160.2
Turbidity	EPA 180.1
redox potential (Eh)	ASTM D1498
Dissolved Oxygen	EPA 360.1

4. Reagents and Organics

Since many mining facilities utilize process reagents that are organic in nature or have organic constituents, it is necessary to identify the category or types of reagents, and where applicable, the organic products that are added in tailing, leach ore or in waste streams generated at mining and milling facilities. A brief description of their use may also prove helpful (e.g., frother, collector, lixiviant, pH control, etc.). In addition, mining and milling facilities utilizing organic process reagents that contain organics specified in A.R.S. 243.I should provide a characterization of those parameters in the process solutions, waste waters, mine waters, seepage, leachate and other solutions, as applicable. The applicant should submit the Material Safety Data Sheet (MSDS) of these reagents that are not on file at ADEQ. Based on MSDSs and other available information, a proposed analytical suite should submitted to ADEQ for review and comment prior to initiating characterization.

It should be noted that the brands and compositions of reagents will most likely change over the life of the facility due to technological advances, economics, etc. This is why it is important for the applicant to identify the category or types of reagents rather than the specific brand. A change in a reagent brand or composition does not, in itself, constitute a major modification, unless the change includes organic materials that are referenced in A.R.S. 49-243.I. or are not similar to the permitted

category or types of reagents. A change in a reagent brand or composition should be reported to ADEQ during the following self-reporting period. New MSDSs, if not already on file at ADEQ, should also be submitted at this time.

5. Radiochemicals

The particle activities of naturally occurring radionuclides are sometimes found in process solutions, seepage, leachate, waste waters or other liquids and should be determined for discharging facilities.

Constituent	Test Method
Gross Alpha Particle Activity	EPA 900.0
Gross Beta Particle Activity	EPA 900.0
Radium 226	EPA 903.1 or 901.1
Radium 228	EPA 904.0 or 901.1
(Uranium (total)([5])	EPA 908
Radon 222	EERF manual 78-1

Uranium mining and processing facilities that discharge should also include the following constituents:

Constituent	Test Method
Thorium 228	EPA 907.0
Thorium 230	EPA 907.0
Thorium 232	EPA 907.0
Thorium 234	EPA 907.0

6. Cyanide Species

Mining and milling facilities that utilize cyanide in processing and which may discharge should analyze the discharging material for total, free and weak acid dissociable (WAD) cyanide using the following methods:

Solid Matrix analysis:	Total CN	EPA 9010
	WAD CN	ASTM D2036
	Total CN	EPA 335
Liquid Matrix Analysis:	Free CN	ASTM D4282
		EPA 335
	WAD CN	ASTM D2036

7. Nutrients and Bacteria

Mining and milling operations that discharge and which commingle sanitary wastes and/or sewage sludge from waste treatment plants with mine materials may be required to provide an analyses for bacteria and nutrients. Information regarding necessary characterization and monitoring can be obtained from the ADEQ's Wastewater APP Unit.

Where applicable, these operations may have to submit similar information in order to obtain a Solid Waste Approval, an Effluent Re-Use Permit, a Storm Water Permit, and/or an APP. Efforts to coordinate the necessary information should be made by the applicant and the ADEQ to avoid duplication of data and analysis.

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(5) Uranium (total) is the sum of the particle activities from U-234, U-235, and U-238.

8. Miscellaneous

1. List of organic substances referenced in A.R.S. 49-243.I.

APPENDIX C
LINER DESIGN PRINCIPLES AND PRACTICE

C.1 INTRODUCTION

The major objectives of a liner system are to protect human health, the environment, and to maximize solution and waste containment. Liner systems are provided to contain solutions that can contaminate the environment when released (as in the case of cyanided tailing), or have economic values which are important to the economics of the project (as in heap leach facility), or both.

The purpose of this appendix is to provide a discussion and guidance on the principles and practices of liner design and liner technology which should be considered in the design of a containment system.

C.2 DEFINITION OF LINER SYSTEM

It is common to refer to a "heap leach pad liner" or "pregnant solution pond liner." While the main purpose of these "liners" is to contain solutions, their composition and construction may differ considerably. It is incorrect to consider the low permeability member as representing the "liner" because it has to interact closely with other elements to form a complete liner system.

A liner system typically consists of:
- prepared foundation;
- combination of low permeability elements and possibly granular drainage layers; and
- a cover or protection layer in most cases.

Each of these elements plays an important role in determining the reliability of the liner system. A prepared foundation is required to provide a base for the placement of a low permeability element. If the foundation conditions could result in large settlements due to loading, then specific precautions may have to be taken. These precautions could consist of replacing the compressible materials in the foundation with structural fill, or providing extra fill so that settlement can be tolerated without changing the drainage on top of the liner system or the containment abilities of the liner system.

The low permeability elements are provided for containment. These elements can consist of natural clay materials, bentonite-amended materials and geosynthetic materials, such as geomembranes. These elements can be installed separately or in combinations that can be constructed in the field or installed in premanufactured sheets (e.g., Geosynthetic-Clay Liners, or GCLs). A liner system sometimes includes drainage layers for hydraulic head control and leakage collection and removal. These layers can consist of natural drainage materials such as sands and gravels as well as synthetic materials such as geonets and perforated pipes. The

combination of low permeability elements and drainage layers is what finally determines the reliability of the containment system.

A cover layer can be provided as the top layer of the liner system for a number of reasons. In the case of clay, a cover layer is typically provided to protect the clay from evaporation and subsequent desiccation (contraction and cracking due to a removal of moisture from the clay). In the case of geomembranes a cover is typically provided to prevent wind damage, and to protect against ultraviolet light, and dynamic loading that occurs during heap construction.

In designing a liner system, each of the components must be carefully evaluated to provide a reliable product which will provide containment under site specific conditions. Because of their value, certain materials, such as a geotextile layer, are included in a proposed liner system since they provide puncture resistance. It is, however, important that the performance of the total integrated system incorporating all the components be for both containment and stability. Inclusion of components after completion of the system design, without a design re-evaluation, could result in serious consequences, such as instability of the overall structure, as the frictional resistance between the new and existing components could be low.

C.3 DEVELOPMENT OF A RELIABLE LINER SYSTEM

There are two parameters which determine the amount of leakage through a liner system.
These are:

- the hydraulic head on the liner; and,
- the permeability of the liner.

By minimizing the head on the liner and minimizing the permeability, a liner system can be developed which will provide maximum containment. It is useful to consider liner performance on a qualitative or intuitive basis prior to presenting quantitative evaluations.

The permeability, or hydraulic conductivity, of a clay liner is determined by the flow of liquid through the available pores in the constructed liner. The "permeability" of geomembranes is dependent on the inherent hydraulic conductivity of the material (which is very low as will be discussed in future sections) as well as the size and shape of holes or other imperfections in the liner.

Consider the case of a geomembrane, with a hole of say $10mm^2$, being suspended in the air and containing water. Water will freely flow through the hole in the membrane, restricted only by the hydraulic resistance posed by the dimensions of the hole. If the same membrane is now placed on a gravel layer of high permeability, then flow through the hole may not be restricted very much as the gravel will behave as an open porous medium similar to the free air. Next consider placing the membrane containing the hole, on a steel plate and providing perfect contact between the membrane and the plate. No flow will take place through the hole because of the low "permeability" of the steel plate. Finally, consider placing the geomembrane with the hole on top of a compacted clay having a low permeability. Furthermore, perfect contact is

maintained between the geomembrane and the clay. The potential flow through the hole in the membrane is then very low as it is controlled by the head on the liner, the size of the hole and the permeability of the clay.

This qualitative analysis shows that a "low permeability" liner system for containment can be developed by placing a geomembrane in direct contact with a low permeability soil layer to form a "composite liner." The term "composite liner" refers to a geomembrane liner in intimate contact with a low permeability soil. Note that "low permeability" is not given a specific value as it depends on the availability and characteristics of site specific materials.

By maintaining a low head on top of a liner, it is possible to reduce potential leakage through the liner. It is relatively easy to maintain a low head (in the order of 0.3 m to 1.5 m) on top of a liner for a heap leach pad. In order to maintain a low head on a liner in the case of a tailing impoundment or process water pond, additional drainage and/or liner components located above the liner must be included. In the case of a tailing impoundment, a high permeability granular drain can be placed on top of the liner to allow for drainage of the low permeability deposited tailing; therefore, effectively providing a reduction of the head on the liner system. In the case of a process water pond, it is typical to place a drainage layer and another geomembrane on top of the bottom liner system. The top geomembrane liner serves as the first line of defense. Any leakage occurring through the top liner will be collected in the drainage layer and pumped out so that a low head is maintained on the bottom liner system. The drainage layer therefore performs as a leakage collection layer and functions to maintain a low head on the bottom liner. Approaches to liner system designs are contained in the literature including Mine Waste Management (Hutchison and Ellison, 1992).

C.4 TYPICAL LINER SYSTEMS

C.4.1 Pond Liners

Depending on the nature of the impounded fluids, pond liners may consist of a composite geomembrane clay liner or two geomembrane liners on top of a prepared foundation.

Most often two synthetic liners are used for containment of process liquids. A leak collection system is installed between the two geomembrane liners so that any leakage through the top liner can be evacuated, thereby reducing the head on the lower liner. It is important to recognize that the amount of leakage through the top liner is never representative of the amount of leakage reporting to the environment. Figure C-1 is a schematic of a typical pond liner system.

Depending upon the fluid chemistry, a single or composite liner system may be adequate.

C.4.2 Pad Liner Systems

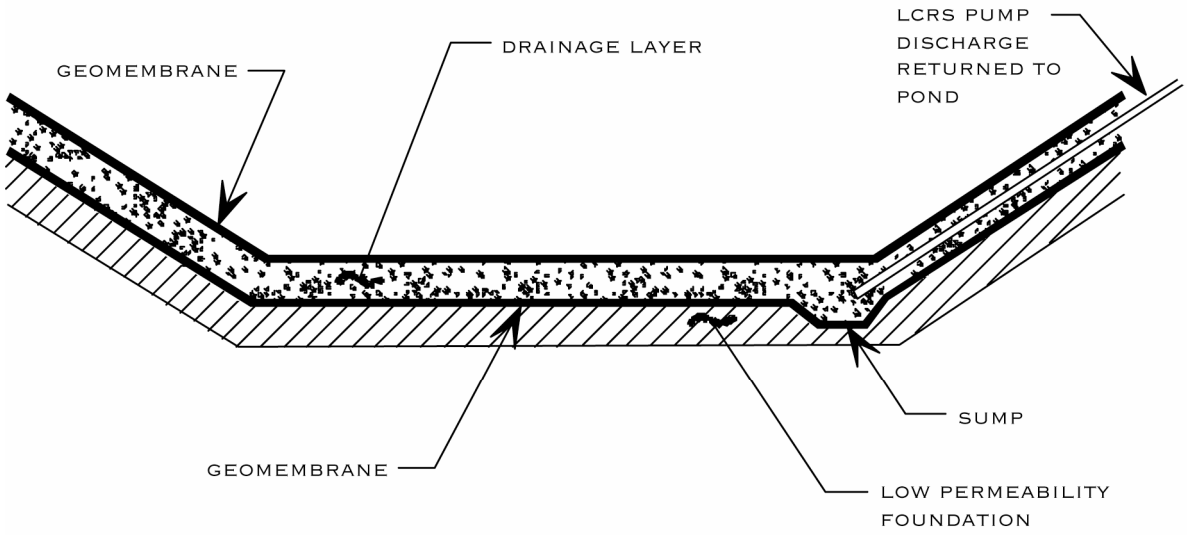
Many designs have been used for pad liner systems. Harper, Leach and Tape (1987) provide a summary of some liner system configurations. The major consideration is site conditions, including the location of groundwater with respect to the pad liner system and the materials available on site for pad construction. Other considerations are regulatory requirements and operator performance. A composite liner is appropriate for most pads. Heap leach pads are seldom subjected to hydraulic heads in excess of 1 to 2 feet. A second liner and a leak collection system may not reduce the head on the bottom liner sufficiently under these low hydraulic heads to justify their expense. Figure C-2 presents a schematic of a typical composite pad liner system.

C.4.3 Tailing Impoundment Liner Systems

Historically, tailing from flotation circuits have been deposited in unlined impoundments relying on the relatively benign nature of the tailing solids and liquids and the relatively low permeability of the consolidated slimes to minimize potential groundwater impacts. However, lined impoundments are relatively common for tailing subjected to chemical leaching such as uranium, gold and silver. Liner systems ranging from geologic containment only, through single soil or synthetic liners, to multilayer systems have been used. Emphasis must be placed on the site specific tailing impoundment design needs and consideration of how much additional seepage reduction the liner provides compared to that provided by the relatively low permeability of the consolidated tailing.

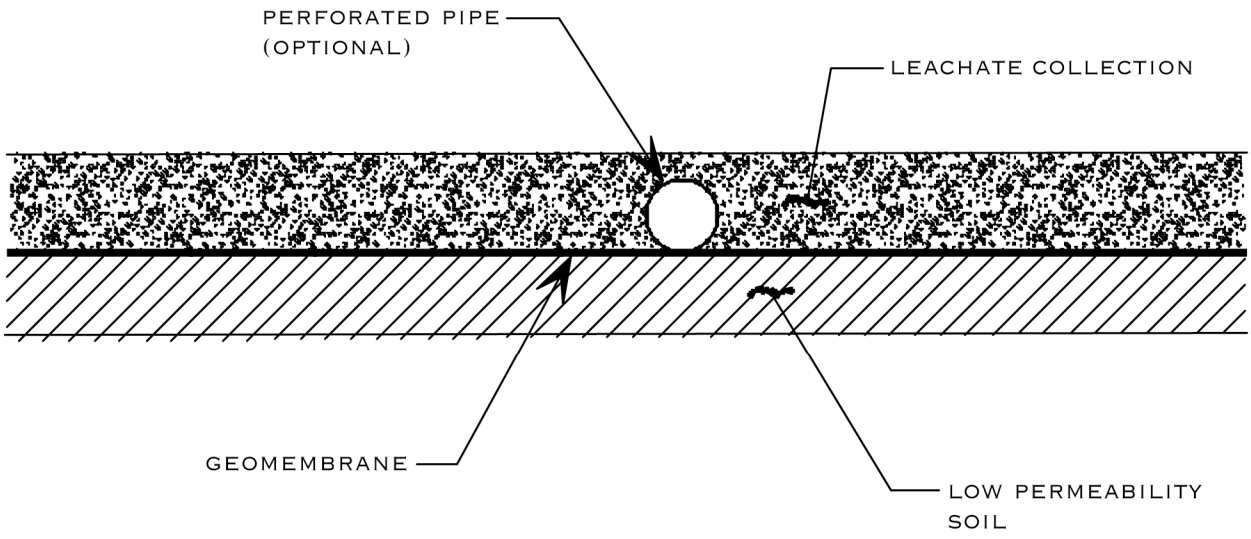
Many tailing liner systems consist of a single soil or geomembrane liner constructed on a prepared foundation and covered by a protective layer which may also function as a drain. For precious metal and uranium tailing, the containment system may consist of a composite liner of compacted soil covered with a geomembrane liner such as HDPE. Figure C-2 presents a schematic of this liner system. By intercepting and directing seepage into a collection system, the protective cover/drain layer reduces the potential hydraulic head on the composite liner, thereby minimizing the potential for seepage losses.

FIGURE C-1 - POND LINER SCHEMATIC



[NOT TO SCALE]

FIGURE C-2 - COMPOSITE PAD LINER SCHEMATIC



[NOT TO SCALE]

C.5 SELECTION AND DESCRIPTION OF LINER MATERIALS

C.5.1 Liner Selection

The selection of a particular type of liner material depends upon the conditions under which the liner must function, as well as the solution that is being contained.

In a heap leach operation, the leach pad liner system and the liner system in the solution storage impoundments contain the same solution. However, the type of liner system selected for the leach pad may be significantly different from the type of liner system selected for the solution storage pond. The leach pad liner system is subject to the overall stresses imposed by the heap, as well as local stresses imposed by equipment used in constructing the heap. The pond liner system is subject to the lower and more uniform stresses imposed by storage of solutions. These differences may require selection of different liner materials on a strength basis.

For an expanding leach pad, the ore is placed on the liner and left there, such that the liner is exposed to the elements only during heap construction. At the edge of the heap, in collection ditches and in solution storage impoundments, the liner is exposed to the elements on a continuous basis. This difference in exposure to the elements may dictate that a different material be used in ditches and impoundments than beneath the heap.

In comparing a leach solution storage pond with a typical wastewater storage pond, the selection of a liner may differ due to the nature of the impounded liquid, even though the conditions for loading, hydraulic driving heads and exposure are the same. A leach solution storage pond for precious metal leaching contains a high pH cyanide solution, whereas a wastewater impoundment may contain solutions of low pH or with organic solvents, or solutions with chemistry that changes over time. The liner for a leach solution storage pond must function under a much narrower range of conditions than a wastewater impoundment, and therefore, the designer may have a different range of liner materials to select form.

C.5.2 Clay Liners and Amended Soil Layers

Soil liners (also referred to as clay liners) consist of selected materials placed in lifts and compacted to prescribed moisture content and density, producing a liner with a hydraulic conductivity below a predetermined value. This maximum predetermined value is based on reducing leakage to meet site specific requirements.

The performance of the liner is highly dependent upon the composition or characteristics of the material, the method of construction and the method of liner protection.

Figure C-3 illustrates grain size distributions of two soils: one a silty clay, the other a silty, clayey sand. In general, the higher percentage of fine-grained particles in a material (especially

clay-sized particles) the lower the material permeability. Therefore, the silty clay maybe a more desirable material than the silty, clayey sand.

Figure C-4 illustrates the plasticity characteristics of two soils: one a low plasticity clay, the other a high plasticity clay (determined from the plasticity chart). In general, the higher the liquid limit and plasticity index of a material, the lower the permeability. Based upon the plasticity chart alone, the high plasticity clay may be more desirable than the low plasticity clay. Other factors, such as construction and protection from weathering, may have an impact on material selection. The high plasticity clay will be more difficult to compact during construction than the low plasticity clay because it may stick to equipment and form clods. Also, the high plasticity clay may have a higher potential of shrinkage (upon drying) than the low plasticity clay, and may require more careful protection from drying. A silty clay of low to medium plasticity is more suitable for a clay liner than a high plasticity clay.

The compaction behavior of soils is well described in a number of basic geotechnical engineering texts (such as Holtz and Kovacs, 1981). Laboratory compaction tests are used to investigate the compaction behavior of a specific soil. The most commonly used test is the standard Proctor test. Soil is compacted in a 4-inch (100m) diameter by 4 1/4-inch (108mm) high mold using a drop hammer. The soil is compacted in three lifts of even thickness, using 25 blows per lift from a 5.5-lb hammer (2.49 kg) which is dropped freely through 12 inches (305 mm) (ASTM Test Method D-698). The results are plotted as water content (weight of water to weight of dry soil, expressed as a percentage) versus dry unit weight. From the typical compaction curve shown in Figure C-5, it can be seen that the dry unit weight first increases with an increase in moisture content. A maximum dry unit weight is reached at a moisture content designated as the optimum moisture content, after which the dry unit weight decreases. This behavior is typical of all soils except clean sands.

The values of maximum dry unit weight and optimum moisture content are mostly dependent on the soil type and the compaction energy (e.g. weight of roller used). Other factors, such as type of compaction (e.g. sheepsfoot versus smooth steel drum) also play minor roles. The primary factors affecting compaction are summarized below:

- Soil type - An increase in clay content increase the optimum moisture content and decreases the maximum dry unit weight. A silty clay has a much more peaked compaction curve than a high plasticity clay; therefore, a small change in moisture content affects the dry unit weight significantly for silty clay; and,
- Compaction energy - An increase in compaction energy decreases the optimum moisture content and increases the maximum dry unit weight.

There is a significant change in soil hydraulic conductivity with change in compaction water content, and therefore dry unit weight. Figure C-6 shows a typical set of results obtained from laboratory testing. Other test results are documented in Holtz and Kovacs (1981), Day and Daniel (1984), and Mudell and Bailey (1984). The hydraulic conductivity reduces about two orders of magnitude with a relatively small increase in water content. The lowest hydraulic conductivity is reached when the compaction water content is slightly higher than the optimum

water content. It is important that careful control of compaction water content and dry unit weight be exercised to ensure that a clay liner has a low hydraulic conductivity.

The clay mineralogy is obviously important in determining the permeability of a compacted clay liner. However, this cannot be changed in the field unless a clay amended soil liner is constructed. In general, montmorillonite clays have a lower hydraulic conductivity than kaolinite clays. Furthermore, a sodium montmorillonite is less permeable than a calcium montmorillonite.

Failure of a clay liner occurs when the hydraulic conductivity increases considerably above the design value, either locally or over a larger area. Reasons for a clay liner failure include:

- Differential settlement of the foundation causing localized cracking of the clay liner;
- Drying out of the clay liner (desiccation) leading to the development of microcracks; and,
- Alternation of the liner permeability due to geochemical reactions between liner and leach solution.

The first type of failure (differential settlement) can be eliminated by careful site preparation. Attention must be paid to proper compaction of the subsoil prior to pad placement. Clay is quite flexible and can resist some differential movement without cracking, especially when it is compacted wet of optimum. However, large movements or strains up to 0.2 percent may cause cracking (Caldwell et al., 1984).

Desiccation cracking of a clay liner can be minimized by keeping liner moisture content as close to the compacted moisture content as possible. If the time between liner construction and placement is short, the liner surface can be regularly sprayed with water to prevent drying. The best approach is to cover the clay liner with a layer of fine sand or tailing (if available) immediately after construction. This layer should be at least six inches thick, but may have to be thicker if drying is to be prevented over a long period.

Failure of a liner due to geochemical reactions is prevented by careful evaluation of the liner during design. Although this is of more concern for solution storage ponds the potential for geochemical reactions between the contained solution and liner (such as cation exchange) should be tested. This is generally done by attenuation tests or long-term permeability tests.

Many soils do not satisfy the low permeability requirements for a liner but are sometimes close. Addition of a suitable clay may reduce the hydraulic conductivity to an acceptable level. A suitable clay may be found in a borrow source close to the site or may have to be imported over long distances (e.g. pure bentonite in powder form). Addition of clay helps to reduce the void space and permeability. However, the physicochemical interaction of the clay with the compaction water plays a more important role. Some expansion of the clay lattice occurs, thereby filling the voids more completely.

FIGURE C-3 - GRAIN SIZE DISTRIBUTION SILTY CLAY AND CLAYEY SAND

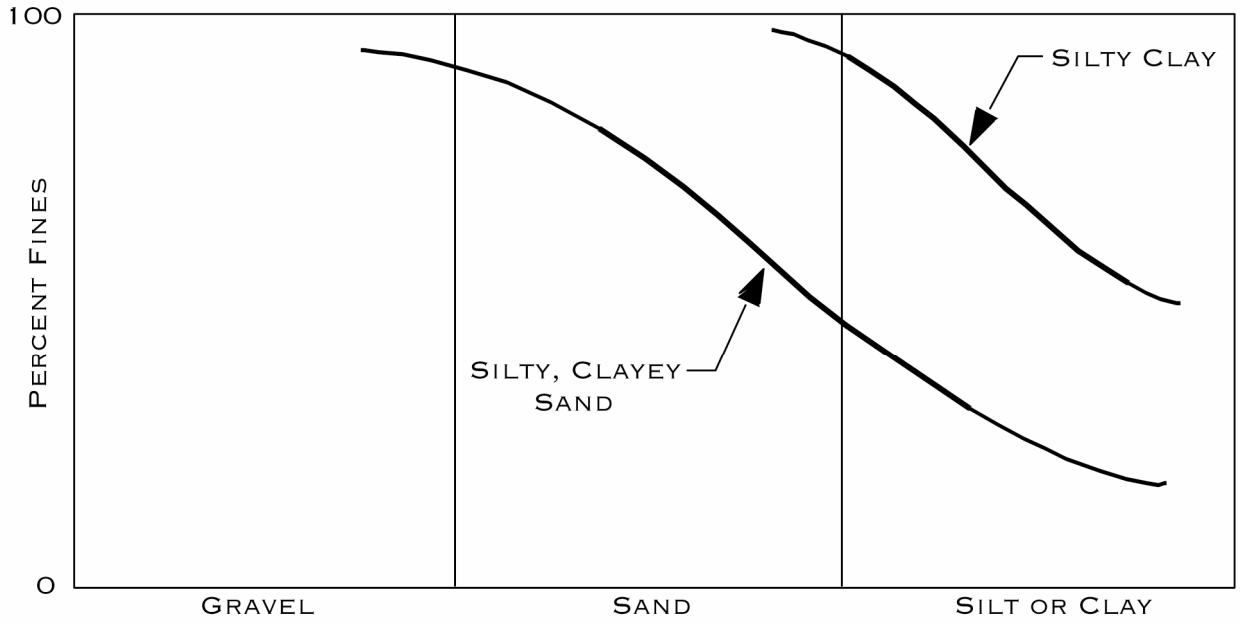


FIGURE C-4 - PLASTICITY CHARACTERISTICS LOW AND HIGH

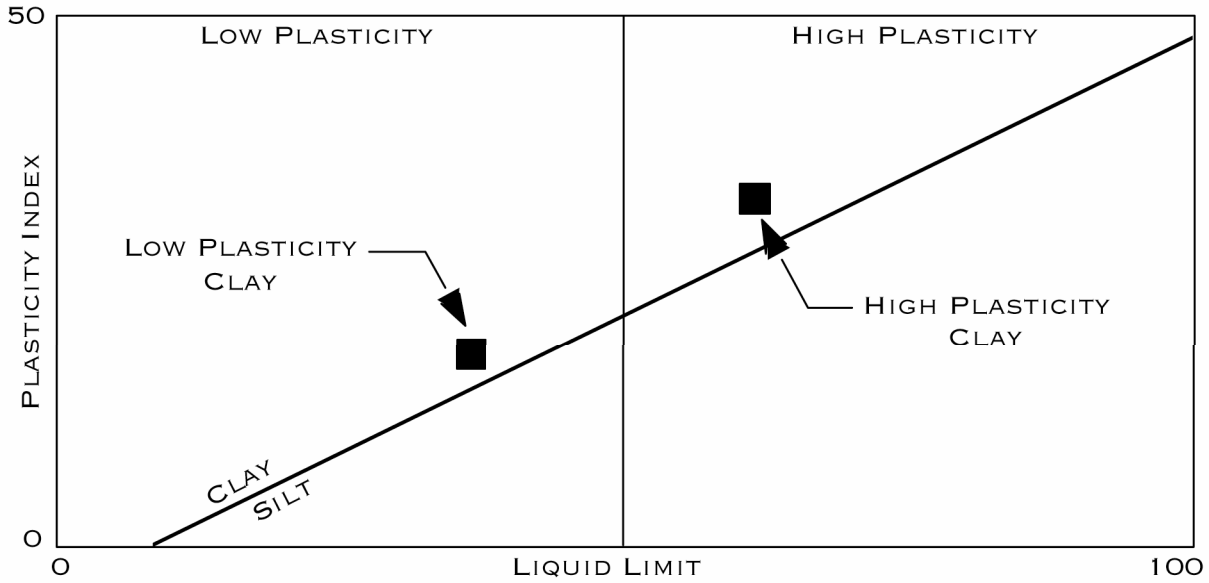


FIGURE C-5 - COMPACTION CURVE

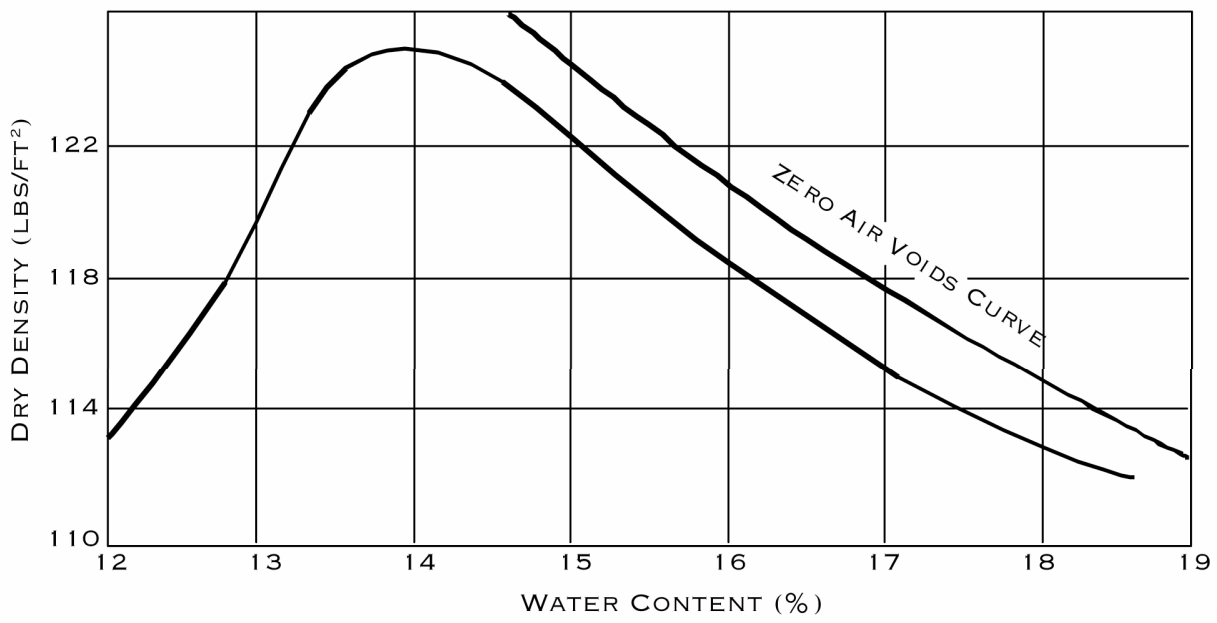
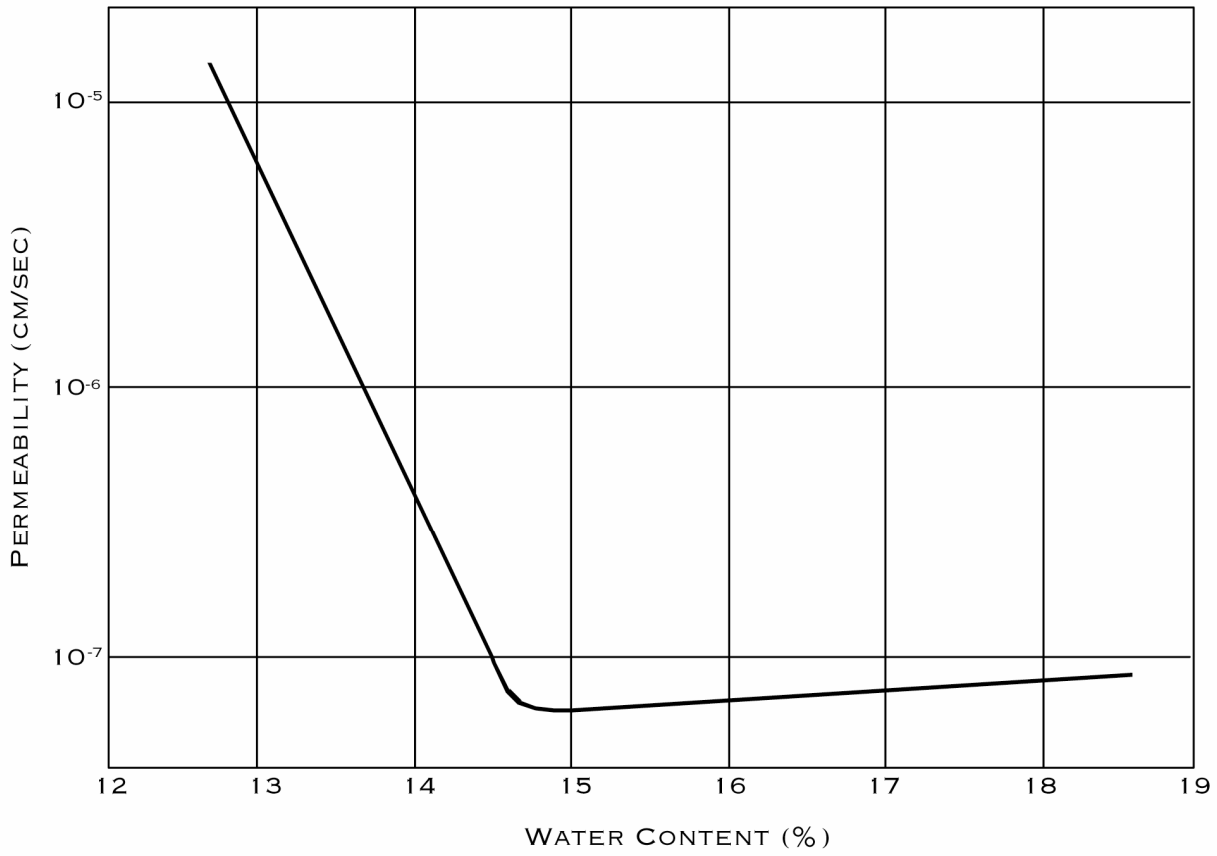


FIGURE C-6 - TYPICAL LABORATORY TEST RESULTS



C.5.3 Geomembrane Liners

Thin synthetic films have been used as liner materials since the 1940's (Kays, 1977). Since that time numerous advances have been made in both the raw materials as well as the manufacturing of the synthetic liner materials. Because of the explosion in the number of synthetic materials used in earth construction, new terminologies were proposed in the 1980s, and these synthetic liners are now referred to as geomembranes because they are capable of containing solutions. Much has been published on the use of geomembranes and the design of liner systems (e.g. Koerner, 1990, 1993). The interested reader is referred to these and the other literature on this topic for a more detailed description.

The mining industry in the U.S. has used a variety of geomembrane liner systems for heap leach facilities and tailing impoundments. In the 1970s, a number of heap leach facilities were constructed using polyvinyl chloride (PVC), while the use of high density polyethylene (HDPE) became common in the 1980s for both heap leach facilities and tailing impoundments. In the late 1980s very low density polyethylene (VLDPE) was introduced and used extensively for heap leach pads and tailing impoundments. Manufacturing of the resin to produce this material was halted in late 1994. Throughout this whole period PVC has continued to be used at a number of facilities. Other materials such as Hypalon– and XR-5 (chlorosulfinated polyethylene) have also found application in the mining industry, however, in smaller quantities.

In the case of reusable leach pads the low permeability member of the liner system is typically a low porosity asphalt sometimes combined with a layer of rubberized asphalt. The latter is a mixture of ground-up tires and asphalt and is applied by spraying it in a thin film.

The characteristics of the various geomembrane liners must be considered in selecting the appropriate material for the site. Extensive information is available from manufacturers as well as from the literature on geomembrane characteristics. Furthermore, new materials are developed on a regular basis and changes are made to the formulations of existing materials; therefore, the designer must stay up-to-date to ensure that such information is included in the design of new facilities.

C.5.4 Leakage Through Liner Systems

Seepage losses through clay liners are controlled by slow mass liquid flow through the pores of the clay layer. The lower the hydraulic conductivity of the clay layer the lower this mass flow until it is finally mostly controlled by physiochemical considerations, and flow takes place by diffusion. In general the seepage through a clay liner can be calculated using Darcy's equation:

$$Q = kiA \qquad [1]$$

where:

- Q =seepage quantity;
- k =hydraulic conductivity;
- i =seepage gradient; and
- A =surface area through which seepage takes place.

Water vapor transmission can occur through intact geomembrane liners (Koerner, 1990). An equivalent hydraulic conductivity can be estimated for geomembrane liners. The equivalent hydraulic conductivity of estimating vapor transmission through geomembrane liners using Darcy's equation is in the order of $1x10^{-11}$ cm/sec.

The calculation of leakage rates through geomembrane liners is more difficult because its magnitude depends on the size and shape of the opening in the liner, as well as the material underlying and overlying the liner. Empirical equations have been proposed for calculating leakage rates through holes in geomembrane liners (Bonaparte et al., 1989; Giroud, J.P., and Bonaparte, R., 1989a and b; Giroud, J.P., et al., 1992).

(a) rate of leakage due to defects in geomembranes overlain and underlain by high permeability materials (e.g. impoundment primary liners with geonet, or other high-permeability leak collection system):

$$Q = C_b a(2gh)^{0.5} \quad [2]$$

(b) Rate of leakage though a geomembrane resting on high permeability material and overlain by a medium permeability drainage material (e.g. heap leach pad liner overlain by ore and underlain by a leak collection system):

$$Q = 3a^{0.75}h^{0.75}k_d^{0.5} \quad [3]$$

(c) Rate of leakage through a composite liner with a hole in the geomembrane, good contact between geomembrane and clay (e.g., synthetic liner on clay):

$$Q = 0.21\ a^{0.1}h^{0.9}k_s^{0.74} \quad [4]$$

In equations 2 to 4, the symbols are defined as follows:

Q = steady state rate of leakage through one hole in geomembrane layer (m^3/s)
C_B =dimensionless coefficient, $C_B = 0.6$
g =acceleration of gravity, $g = 9.81\ m/s^2$
a =area of the hole in the geomembrane (m^2)
h =head of liquid on top of the geomembrane (m)
k_s=hydraulic conductivity of the low permeability soil underlying the geomembrane (m/s)
k_d=hydraulic conductivity of the drainage material overlying the geomembrane (m/s)

Typical seepage values for specific liner systems are provided by Hutchison and Ellison (1992). As was intuitively derived above, quantitative evaluations of equations 1 to 4 show that if the synthetic liner is underlain by a low permeability layer, the leakage rate through a hole in the synthetic liner will be much lower than that through a hole in a freely drained single synthetic liner (Eq. 2) or a single clay layer. In a composite liner, the hole restricts the flow into the clay liner to a small area. Flow into the clay, therefore, initially takes place under unsaturated flow conditions. The behavior of the synthetic and clay liner composite is, therefore, more beneficial than that of any layer by itself.

APPENDIX D

CONSTRUCTION QUALITY ASSURANCE & QUALITY CONTROL

D.1 INTRODUCTION

It is important to incorporate appropriate provisions for construction quality control/quality assurance into the project documents to assure that the discharge control systems elements are built in accordance with the design. Managing construction quality involves both quality control (QC) and quality assurance (QA). QC refers to testing and activities conducted by the manufacturer, contractor and/or installer in the case of geomembranes, to ensure that materials being produced (e.g., liner material, drain rock, concrete) were as specified. QA involves testing during construction to assure the constructed elements meet the design intent and criteria. It is often appropriate to conduct "third party" QA inspection, using an organization or persons, not affiliated with the owner/operator or manufacturer/installer. QC and QA overlap in many instance; therefore, they are discussed together within this appendix. Actual construction quality control/quality assurance (QA/QC) programs must be designed to incorporate those methods and procedures appropriate for specific construction activities and site conditions.

The purpose of this appendix is to provide guidance on the development of QA/QC documents. A well designed QA/QC plan has been found to be an important factor in achieving design performance criteria of a lined facility. Attention to proper construction can make the difference between a facility that performs up to its expected design, and one that has problems throughout its operational life. Construction QA/QC is addressed in detail in Daniel and Koerner (1995).

The goal of a good QA/QC plan should be to minimize the number of defects during installation by insuring that proper construction techniques and procedures are used and that the project is completed in accordance with approved plans and specifications. QA/QC activities usually include inspections, audits and evaluation of materials and workmanship, and material testing to document the quality of the constructed facility.

The QA/QC documents should be a written document(s) that include a detailed description of the QA/QC activities. The documents should focus on those elements of the design and installation that are critical to the function of the facility. The QA/QC documents are usually written by the design engineer, and at a minimum, should include:

- Delineation of responsibility and authority;
- Statement of qualifications of QA/QC personnel;
- Design specifications;
- Inspections and inspection testing;

- Sampling requirements associated with the inspection activities;
- Acceptance/rejection criteria and corrective measures;
- Quality assurance of the post-installation phase;
- Documentation requirements.

D.2 DELINEATION OF RESPONSIBILITY AND AUTHORITY

The design and construction of a lined facility involves a large number of organizations, including the permitting agency, the facility owner/operator, the design engineer, the QA/QC personnel, and the construction and installation contractors. The responsibility and the lines of authority of organizations and personnel involved in permitting, designing and constructing the facility should be described in the QA/QC documents. Good communication among all involved parties is a key element for proper construction. Periodic meetings will benefit all parties by ensuring familiarity with the design, construction procedures, the QA/QC documents and any design changes.

A pre-construction meeting to resolve any uncertainties about the design, the QA/QC documents, etc. should be held following the completion of the facility design and award of the construction contract. During construction, daily meetings should be held to review progress, and as necessary, problem or work deficiency meetings can be held to resolve construction issues. All meetings should be documented.

D.3 STATEMENT OF QUALIFICATIONS OF QA/QC PERSONNEL

The QA/QC documents should identify the training and experience of the QA/QC personnel, including the geomembrane installer and field supervisor. This information should document their ability to fulfill their assigned responsibilities.

D.4 DESIGN SPECIFICATIONS

The QA/QC documents should list the design specifications for the facility. One of the main purposes of QA/QC is to verify and ensure that the facility is built according to these specifications. The rest of the documents are built around this goal.

D.5 INSPECTIONS AND INSPECTION TESTING

The QA/QC documents should describe the inspection activities to be implemented. The inspection activities should include observations and tests that will be used to ensure that materials, construction and installation of the components of the lining system meet or exceed all design criteria, plans and specifications. QA/QC inspections should include inspection of earthwork, liner materials and installation, and the leachate collection and removal systems.

Appropriate tests should be selected for inspecting the quality of the construction materials and the workmanship. Exact procedures should be well defined and, when appropriate, should reference established standards such as those recommended by ASTM or other acceptable agencies. In all cases, the most up-to-date standards should be used. Inspection methods and procedures applicable to various elements of liner construction are listed on Table D-1 (adopted from EPA guidance document EPA/530-SW-86-031.

It is recommended that the QA/QC inspections meet the following criteria:

- A QA/QC inspection test should be a good indicator of a design quality;
- A QA/QC inspection test or observation should be accurate and precise. The test results or observations should be documentable; i.e. the results or observations should be numbers or well-defined terms or phrases.
- The results of a QA/QC inspection should be available within a short period of time so that acceptance decisions can be made without causing interference with contractor performance;
- A QA/QC inspection test should be easy to run using simple, rugged equipment;
- Preferably, a QA/QC inspection test should be nondestructive (i.e., not damage the integrity of any component of the installed lining system). Destructive testing, though, may be the only option (i.e., liner seam shear and peal testing).

QA/QC data will fall into two categories: attribute-type data or measurement data. Attribute data can be based on classifications such as pass/fail, acceptable/defective, etc. Measurement type data are test values that can be used to compute summary statistics that can be compared to numerical standards.

D.6 SAMPLING REQUIREMENTS

Because it is not possible nor economically feasible to perform a 100% sampling of all processes and materials, the QA/QC sampling documents should provide for visual inspection and sampling strategies for acquiring representative samples of the total process. Visual inspection may encompass up to 100% coverage. The QA/QC documents should describe the sampling strategy, including units or material to be sampled, the size of the sample, the sampling procedure, and the number of specimens to be tested per sample.

Two basic sampling strategies can be used:

- Judgmental sampling;
- Statistical sampling.

Judgmental sampling refers to a sampling procedure where decisions are based on the educated judgment of the inspector. This would include sampling based on areas of

suspected weakness. Success of judgmental sampling is dependent on knowledge, capability and experience of the inspector.

Statistical sampling methods are based on principals of probability theory. These methods are used to estimate characteristics of the overall material and construction process. This method is more rational, and easier to document than judgmental methods.

In practice, good QA/QC documents will use a combination of visual inspection and both sampling methods described above.

D.7 ACCEPTANCE / REJECTION CRITERIA AND CORRECTIVE MEASURES

The acceptance or rejection criteria for inspection activities should be stated in the QA/QC documents. In addition, the documents should state the criteria for accepting or rejecting any measurements that appear to be atypical or in error (outliers). These outliers may be related to random variability inherent in the data resulting from the testing of a material or process; or, it may be related to deviation in the test procedure or an error in calculating or recording a value.

Whenever material or work is rejected because of QA/QC inspection activities, it should be indicated that it does not meet the design specifications and what corrective measures must be implemented.

D.8 DOCUMENTATION

Thorough documentation is an important part of the implementation and success of a QA/QC plan and should be described in detail. The documentation should include daily summary sheets, inspection sheets, problem identification and corrective action reports, block evaluation reports, acceptance reports and the final documentation to be submitted to the permitting agency. Provisions for final storage of the QA/QC records should also be included.

TABLE D-1
Construction Inspection Methods[1]

Facility Component	Factors to be Inspected	Inspection Methods	Test Method Reference[2]
Foundation	Removal of unsuitable materials	Observation	NA
	Proof rolling of subgrade	Observation	NA
	Filling of voids	Observation	NA
	In-place density	(See low permeability soil liner component)	
	Surface finishing	Observation	NA
	Sterilization	Supplier's certification & observation	NA
	Slope	Surveying	NA
	Depth of excavation	Surveying	NA
	Seepage	Observation	NA
	Index properties	Visual-manual procedure	ASTM D2488
		Particle size analysis	ASTM D422
		Atterberg limits	ASTM D4318
		Soil classification	ASTM D2487
	Cohesive soil consistency (field)	Penetration tests	ASTM D3441
		Field vane shear test	ASTM D2573
		Hand penetrometer	Hosley, 1943
		Handheld torvane	Lanz, 1968
		Field expedient unconfined compression	TM 5-530 (U.S. Dept. of Army, 1971)
	Strength (laboratory)	Unconfined compressive strength	ASTM D2166
		Triaxial compression	ASTM D2850
		Unconfined compression strength for soil-cement	ASTM D1633
	Volume change	(See low permeability soil liner component)	
Embankments	Dike slopes	Surveying	NA
	Dike dimensions	Surveying; observations	NA
	Compacted soil	(See low permeability soil liner component)	
	Drainage system	(See leachate collection system component)	
	Erosion control	(See cover system component)	
Low Permeability Soil Liner	Coverage	Observation	NA
	Thickness	Surveying; measurement	NA
	Clod size	Observation	NA
	Tying lifts together	Observation	NA
	Slope	Surveying	
	Installation of protective cover	Observation	NA

TABLE D-1 *continued*

Facility Component	Factors to be Inspected	Inspection Methods	Test Method Reference(2)
Low Permeability Soil Liner *Continued*	Soil type (index properties)	Visual manual procedure	ASTM D2488
		Particle size analysis	ASTM D422
		Atterberg limits	ASTM D4318
		Soil classification	ASTM D2487
	Moisture content	Oven dry method	ASTM D2216
		Nuclear method	ASTM D3017
		Calcium carbide (speedy)	ASTM D4944
		Direct heating	ASTM D4952
		Microwave	ASTM D4643
	In-place density	Nuclear methods	ASTM D2922
		Sand cone	ASTM D1556
		Rubber balloon	ASTM D2167
		Drive cylinder	ASTM D2937
	Moisture-density relationship	Standard Proctor	ASTM D698
		Modified Proctor	ASTM D1557
		Soil-cement M-D test	ASTM D558
	Strength (laboratory)	Unconfined compressive strength	ASTM D2166
		Triaxial compression	ASTM D2850
		Unconfined compressive strength for soil-cement	ASTM D1633
	Cohesive soil consistency (field)	Penetration tests	ASTM D3441
		Field vane shear test	ASTM D2573
		Hand penetrometer	Horsley, 1943
		Handheld torvane	Lanz, 1968
		Field expedient unconfined compression	TM 5-530 (U.S. Dept. of Army, 1971)
	Permeability (laboratory)	Fixed wall	SW-870
		Flexible wall	ASTM D5084 SW-846 Method 9100
	Permeability (field)	Double ring infiltrometer	ASTM D5093 ASTM D3385
	Susceptibility to frost damage	Soil-cement wet-dry test	ASTM D559
		Soil-cement freeze-thaw test	ASTM D560
	Volume change	Collapse potential	ASTM D5333
		Swell or settlement potential (on-dimensional)	ASTM D4546
Geomembrane Liners	Thickness	Nonridged vinyl chloride plastic sheeting (paragraph 9.1.3, deadweight method)	ASTM D1593
		Polyethylene & ethylene copolymer plastic sheeting (paragraph 10.2)	ASTM D3020

TABLE D-1 *continued*			
Facility Component	Factors to be Inspected	Inspection Methods	Test Method Reference(2)
Geomembrane Liners *Continued*	Thickness *Continued*	Flexible Poly (vinyl chloride plastic sheeting, paragraph 9.2)	ASTM D3083
		Reinforced plastic sheeting (testing coated fabrics)	ASTM D751
		Nominal thickness	ASTM D5199
	Tensile properties	Rigid thick plastic sheeting (standard method test for tensile properties of plastics)	ASTM D638
		Reinforced plastic sheeting (Grab method A - testing coated fabrics)	ASTM D751
		Thin plastic sheeting	ASTM D882
	Tear strength	Reinforced sheeting (modified tongue tear method B - testing coating fabrics & sheeting)	ASTM D751
		Plastic sheeting (Die C-test method for initial tear resistance of plastic film & sheeting)	ASTM D1004
	Puncture resistance	Index puncture	ASTM D4833
		Pyramid puncture	ASTM D5494
	Compatibility	Waste to membrane liners	EPA 9090
		Chemical resistance of geosynthetics to liquids	ASTM D5322
		Resistance to soil-burial	ASTM D3083
	Bonding materials	Manufacturer's certification	NA
	Bonding equipment	Manufacturer's certification	NA
	Handling & storage	Observation	NA
	Sampling	Geosynthetics for testing	ASTM D4354
	Seaming	Field seams used in joining flexible polymeric sheet membranes	ASTM D4437
		Factory seams used in joining manufactured flexible sheet membranes	ASTM D4545
		Peel testing	ASTM D413, Method A
		Shear testing	ASTM D816, Method C ASTM D816, Method B
	Sealing around penetrations	Observation	NA
	Anchoring	Observation	NA
	Coverage	Observation	NA
	Installation of upper bedding Layer	Observation	NA
	Physical requirements	Nonridged vinyl chloride plastic sheeting	ASTM D1593
		Polyethylene & ethylene copolymer plastic sheeting	ASTM D3020

TABLE D-1 *continued*

Facility Component	Factors to be Inspected	Inspection Methods	Test Method Reference(2)
Geomembrane Liners *Continued*	Physical requirements *Continued*	Flexible poly (vinyl chloride) plastic sheeting	ASTM D3083
Leachate Collection and Removal Systems:			
Granular Drainage & Filter Layers	Thickness	Surveying; measurement	NA
	Coverage	Observation	NA
	Soil type	Visual-manual procedure	ASTM D2488
		Particle size analysis	ASTM D422
		Soil classification	ASTM D2487
	Density	Nuclear methods	ASTM D2922
		Sand cone	ASTM D1556
		Rubber balloon	ASTM D2167
	Permeability (laboratory)	Constant head	ASTM D2434
Synthetic Drainage & Filter Layers	Material type	Manufacturer's certification	ASTM D4759
	Handling & storage	Observation	ASTM D4873
	Coverage	Observation	NA
	Overlap	Observation	NA
	Sewn geotextiles	Seam strength	ASTM D4884
	Temporary anchoring	Observation	NA
	Folds & wrinkles	Observation	NA
	Geotextile properties	Nominal thickness	ASTM D5199
		Tensile strength	ASTM D4595
		Puncture resistance	ASTM D4833
		Tear resistance	ASTM D4533
		Breaking load & elongation	ASTM D4632
		Density	ASTM D5261
		Temperature effects	ASTM D4594
		Deterioration due to UV light & water	ASTM D4355
		Abrasion resistance	ASTM D4886
		Fabric permittivity	ASTM D4491
		Fabric permittivity (under load)	ASTM D5493
		Transmitivity (in-place flow)	ASTM D4716
		Apparent opening size	ASTM D4751
		Clogging potential	ASTM D5101
Pipes	Material type	Manufacturer's certification	NA
	Handling & storage	Observation	NA
	Location	Surveying	NA
	Layout	Surveying	NA
	Orientation of perforations	Observation	NA

TABLE D-1 *continued*			
Facility Component	Factors to be Inspected	Inspection Methods	Test Method Reference[2]
Pipes *Continued*	Jointing		
	Solid pressure pipe	Hydrostatic pressure test	Section 4, AWWA C600
	Perforated pipe	Observation	NA
Cast-In-Place Concrete Structures	Sampling	Sampling fresh concrete	ASTM C172
	Consistency	Slump of Portland cement concrete	ASTM C143
	Compressive strength	Making, curing and testing concrete specimens	ASTM C31
	Air content	Pressure method	ASTM C231
	Unit weight, yield and air content	Gravimetric method	ASTM C138
	Form work inspection	Observation	NA
Electrical & Mechanical Equipment	Equipment type	Manufacturer's certification	NA
	Material type	Manufacturer's certification	NA
	Operation	As per manufacturer's instructions	NA
	Electrical connections	As per manufacturer's instructions	NA
	Insulation	As per manufacturer's instructions	NA
	Grounding	As per manufacturer's instructions	NA
Cover Systems:			
Cover Foundation	Waste placement records/ waste placement process	Observation	NA
	Soil backfill	(See foundation component)	
Low-Permeability Soil Barrier	(See low-permeability soil liner component)		
Flexible Membrane Barrier	(See flexible membrane liner component)		
Bedding Layer	(See flexible membrane liner component)		
Drainage & Gas Venting Layers	(See leachate collection system component)		
Topsoil & Vegetation (Erosion Control Measure)	Thickness	Surveying	NA
	Slope	Surveying	NA
	Coverage	Observations	NA
	Nutrient content	Ash, moisture, organic matter content	ASTM D2974 ASTM D5268
	Soil pH	Soil pH; lime requirements	ASTM D4974 ASTM D2976
	Type	Classification	ASTM D2607 (field) ASTM D4427 (lab)
	Vegetation type	Supplier's certification; observations	NA
	Seeding time	Supplier's certification; observations	NA

1. Adopted from EPA Guidance Document EPA/530-SW-86-031.
2. For all test methods, the most up-to-date standard should be used.

APPENDIX E

ENGINEERING DESIGN GUIDANCE

E.1 INTRODUCTION

This appendix provides a more detailed discussion of the design approaches that can be utilized in support of a BADCT application. These design guidelines will be updated from time to time and as the state of the art evolves.
The following topics are dealt with in the sections that follow:

- Stability Design Guidance is provided in Section E.2 and
- Hydrologic Design Guidance is provided in Section E.3.

E.2 STABILITY DESIGN GUIDANCE

E.2.1 Introduction

This section presents methodologies for completing both static and dynamic stability analyses for the various types of embankments and material piles at mine facilities. These analyses are required for both the prescriptive and individual design approaches for process solution and surface ponds, heap leach pads, tailing impoundments and dump leaching. ADEQ may also require stability analyses for waste rock piles where it is established that discharge (as defined in ARS, Title 49, Chapter 2) could occur. Special considerations for evaluating embankments constructed on or with saturated tailing materials are discussed.

A mass of granular material which is bounded by a sloping surface is subject to internal shearing stresses because of the gravitational force which tends to pull the upper portions of the mass downward toward a more nearly level surface. During earthquakes these stresses are temporarily increased due to ground shaking which causes the mass of material to move from side to side and up and down. If the shear strength of the material is at all times greater than the maximum induced shear stress, the slope will remain stable. On the other hand, if the strength at any time should be less than the stress, the material will slump or slide down the slope until a position is reached such that the shear stress is reduced to a value less than the shear strength.

The presence of saturated conditions reduces the strength due to pore water pressure buildup (Spangler and Handy, 1982) which reduces the effective stresses between soil grains and hence the frictional resistance. Drainage measures to minimize seepage and control discharge can also improve embankment stability by reducing the extent of the saturation zone, and the design of these drainage systems should therefore be coordinated with stability design. The purpose of this section is to outline stability design considerations that apply, to varying degrees, to all types of facilities, but are most critical for high embankments constructed with tailing, particularly those with a rapid rate of construction and where pore pressures have a limited opportunity to dissipate.

E.2.2 Documentation Requirements

Design to achieve an adequate margin of safety against slope failure is a critical performance objective for public safety, protection of life and property, and containment of wastes for aquifer and surface water protection. The applicant must provide documentation of stability analyses, seepage analyses (as appropriate) and seismic deformation analyses (where applicable) along with appropriate laboratory and in situ tests for characterization of the engineering properties of the embankment materials (i.e., shear strength, permeability and consolidation properties), and results of foundation investigations including boring logs, engineering geology mapping and in situ and laboratory test data. This must include documentation of earthquake design parameters, construction staging analyses of material placement to define rate of construction, water balance analyses, a description of the rationale for selection of the stability analysis methodology, and results of the stability analyses including related analyses of consolidation, pore pressure generation and seepage, as well as design analyses for the associated drains and filters.

E.2.3 Special Embankment & Foundation Shear Strength Considerations

The following discusses drained and undrained loading conditions and appropriate methods of stability analysis for mine facilities.

Embankment stability is controlled by the shear strength of the foundation, embankment structure and tailing or other deposited materials. Where embankments are underlain by rock or stiff alluvium, foundation settlements and shear strength do not usually exert a significant influence on design. However, where softer foundation materials are present, the response of these materials may control geotechnical design, dictating the need for detailed characterization and analysis of foundation performance.

Most hydraulically deposited mine tailing (e.g. tailing deposited in slurry form by spigotting or single-point discharge without compaction) are of relatively low density and will increase in density (i.e., consolidate) when subjected to consolidation and/or shear strains. Where these shear strains occur at a sufficiently rapid rate and are of a sufficiently large magnitude and there is insufficient time to dissipate pore water pressure, excess pore pressures (i.e., those higher than hydrostatic) are generated and undrained shear strength behavior is “triggered.” Under these conditions stability is controlled by the residual undrained shear strength or “steady state” shear strength (Poulos, 1981; Castro and others, 1982; Poulos and others, 1985; Poulos, 1988a, 1988b; McRoberts and Sladen, 1992).

Where upstream construction is involved, where the rate of construction is relatively fast or where a significant zone of loose saturated tailing exists, undrained shear strength of the tailing will usually control design. Large shear strains can potentially be created by differential settlements within the dam slopes and foundation, rapid rise or lowering of the water table within the slopes, earthquakes or a combination of two or more of these factors. A number of both earthquake-induced and “static” liquefaction slope failures have occurred in tailing dams and similar hydraulic fill structures, several of which have had disastrous consequences (Conlin, 1985; Castro and Troncoso, 1989; Troncoso, 1990a, 1990b; Ladd, 1991). Thus, the potential susceptibility of the tailing to undrained strength behavior and “liquefaction” slides are the

paramount stability design considerations and dictate the appropriate geotechnical investigations and design and construction procedures.

A large amount of published data on the shear strength of tailing material (Mittal and Morgenstern, 1975; Nelson and others, 1977; Volpe, 1979; Vick, 1983; Chen, 1984; Chen and Van Zyl, 1988) show that the drained shear strength falls within a relatively narrow range. Thus, in slope stability analysis for zones of tailing where drained shear strength is applicable, the shear strength can often be estimated satisfactorily from published data.

Placement of tailing by hydraulic fill methods usually results in low densities so contraction (decrease in volume resulting in increase in density) occurs in response to shear strains. The mechanics of the triggering of undrained shear strength of tailing and its measurement and interpretation is more complex however. Detailed site specific investigations are usually necessary to establish whether undrained behavior is a dominant factor in stability analysis, and to estimate what the undrained shear strength is. Various in-situ and laboratory tests can be used to evaluate undrained shear strength, and a large amount of data related to the performance of undrained tailing and similar hydraulic fills is available (Castro and Troncoso, 1989; Marcuson and others, 1990; Poulos, 1981; Poulos and others, 1985; Troncoso, 1990a, 1990b; Castro and others, 1982; Stark and Mesri, 1992; McRoberts and Sladen, 1992). Test methods used should take into consideration the type of material (i.e., cohesionless or cohesive), and type of construction (e.g., homogeneous embankment or zoned fill).

Permeability or hydraulic conductivity measurements are sometimes required to determine the phreatic surface and the pore pressure distribution in placed material in order to conduct stability analyses. In cases where the material is used as a barrier against infiltration, permeability, as well as the moisture retention capacity of the material may be required. Wherever possible, the ADEQ prefers field tests to those conducted in the laboratory. Appropriate testing protocols include, but are not limited to, the following:

TEST	PROTOCOL
Field Hydraulic Conductivity	• Sealed Double Ring Infiltration Test: - ASTM D5093-90
Laboratory Hydraulic Conductivity	• Flexible Wall Permeater. - ASTM D5084-90
Field Soil Moisture Determinations	• Water Retention: - Method of Soil Analysis (A. Klute, 1986), Section 27
Laboratory Soil Moisture Determinations	• Porosity: - ASTM D4404 • Water Retention: - Method of Soil Analysis (A. Klute, 1986), Section 26 • Field Capacity: - Method of Soil Analysis (A. Klute, 1986), Section 36

For existing tailing deposits, the undrained shear strength can be estimated from corrected standard penetration tests (SPTs) (Seed and Harder, 1990), cone penetration tests (CPTs) (Mitchell and Tseng, 1990), shear wave velocities measured by seismic cones (Campenella and others, 1986) or other methods. Isotropically consolidated undrained triaxial tests with pore pressure measurements on remolded samples in conjunction with careful measurements of in-place density (Poulos, 1981, 1988a, 1988b) can also be used.

Where compacted cycloned sands are placed in the embankment, that portion below the phreatic surface should be compacted to densities at which dilatant behavior will occur in response to shear strains (i.e., volume increases rather than the decreases discussed above). Under these conditions, negative pore water pressures develop and drained strength behavior is assured. The density required to assure dilatant behavior increases with increasing effective vertical stress (Poulos, 1981, 1988a, 1988b; McRoberts and Sladen, 1992) and therefore increases with depth below the surface. For low dams, the density required to assure drained shear strength behavior can usually be determined from published data. For higher dams, a comprehensive program of isotropically consolidated undrained triaxial tests is usually necessary.

E.2.4 Stability Analysis Methodology

E.2.4.1 General

Key steps in stability analysis involve:

- Describe the facility;
- Establish static and seismic performance criteria;
- Establish facility model for analysis including material properties;
- Perform static analyses;
- Perform dynamic analyses, as appropriate (i.e., either pseudostatic or deformation analysis, or both);
- Modify design applying BADCT, if necessary;
- Iterate the analysis (as appropriate).

Details of the analysis methodology are provided below and are presented in flow chart format in Figure E-1. The analysis and design process are iterative; i.e., if analysis results are not acceptable (do not meet the design criteria), the facility design and/or construction procedure are changed and the analysis repeated until acceptable results are achieved. The methodology outlined here is generally used to design earth dams in the United States and include additional special considerations for the unique characteristics of mine waste (e.g., saturated tailing) and mining construction practices. The process is designed to start with the more straightforward analyses and to proceed to the more detailed analyses as necessary.

E.2.4.2 Describe the Facility

Describing the facility includes establishing: (1) the size of the facility including the major dimensions such as heights, slopes and lengths; (2) the types of materials in the embankment/structure and foundation, i.e., natural soil or rock fill, hydraulically deposited tailing, cycloned or excavated tailing etc. …); (3) operational considerations, including material placement schedules and intermediate construction stages; (4) the pattern of circulation of water through the facility; and (5) the likely distribution of pore water pressure within ponds, impoundments, and the materials at various time periods based on seepage analysis. For construction involving tailing material, it is essential to evaluate or establish whether or not the material is to be placed hydraulically or is otherwise potentially liquefiable or subject to rapid drawdown.

E.2.4.3 Establish Design Criteria

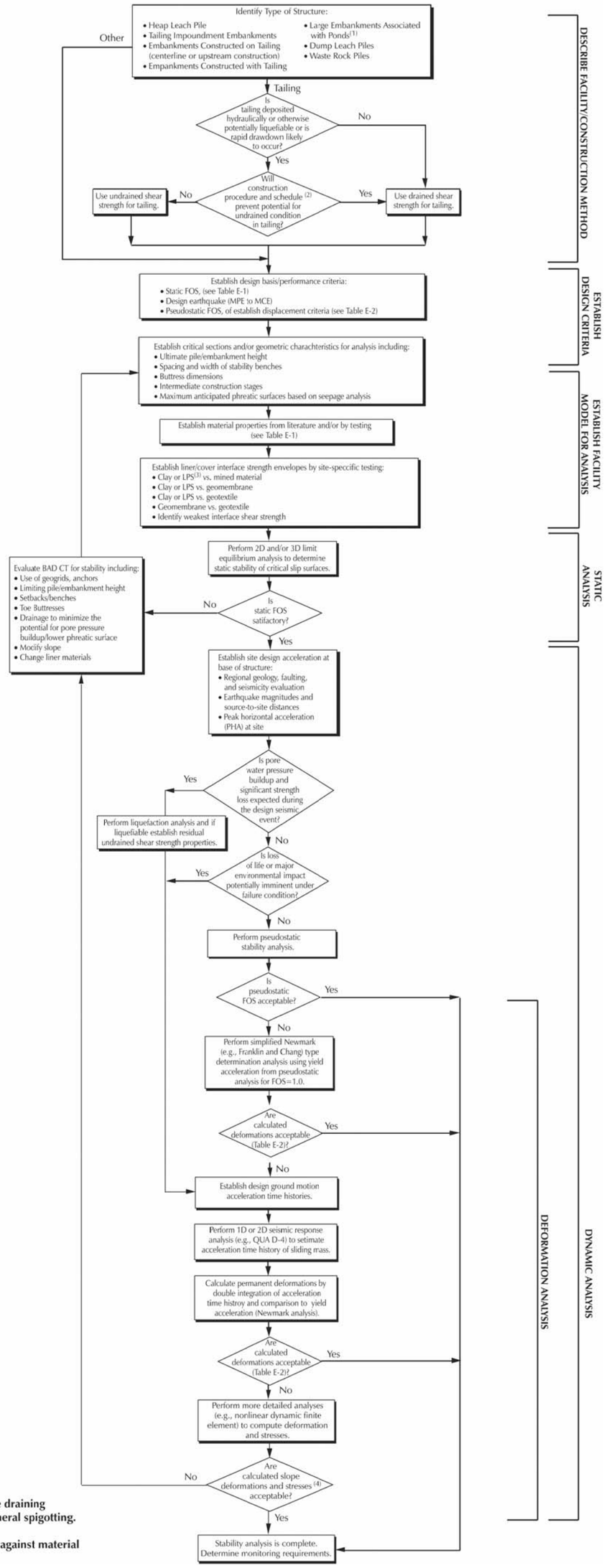
The required design criteria for various types of facilities for both static and dynamic loading conditions are outlined in Tables E-1 and E-2, respectively. For special conditions (such as a mine site located near an especially sensitive environmental feature), the ADEQ may require different and possibly more conservative criteria.

Generally, the computed factor of safety (FOS) against failure determined by the static analysis should be greater than 1.5 using conservative estimates for material strengths without site specific testing. When such testing is performed on actual samples of materials to be used in construction, and at conditions (e.g., overburden pressure, moisture content, density, etc.) representative of planned construction, and quality control testing (e.g., moisture content, density, grain size) is implemented during actual construction of the earth structure, the degree of conservatism is reduced and a FOS of 1.3 can be used (U.S. Army Corps of Engineers, 1983; U.S. Mine Safety and Health Administration, 1983; and U.S. Bureau of Reclamation, 1991).

The minimum design earthquake is the maximum probable earthquake (MPE). The MPE is defined as the maximum earthquake that is likely to occur during a 100-year interval (80% probability of not being exceeded in 100 years) and shall not be less than the maximum historical event. This design earthquake may apply to structures with a relatively short design life (e.g., 10 years) and minimum potential threat to human life or the environment.

Where human life is potentially threatened, the maximum credible earthquake (MCE) should be used. MCE is the maximum earthquake that appears capable of occurring under the presently known tectonic framework.

FIGURE E-1
SLOPE STABILITY ANALYSIS APPROACH



E-5

(1) **Embankments higher than 20 feet.**
(2) **Such as use of cycloned sands or other free draining materials, very slow rate of building, peripheral spigotting.**
(3) **LPS=Low permeability soil.**
(4) **Stresses in liners (if present) are evaluated against material yield peoperties.**

TABLE E-1

Static Stability Design Criteria (For Both Prescriptive and Individual Approaches)	
Facility	Minimum Required Factor of Safety (FOS)
Heap Leach Pile	1.5 Without testing 1.3 With testing(1)
Tailing Impoundment Embankments	1.5 Without testing 1.3 With testing(1)
Embankments Constructed on Tailing or Constructed With Tailing	Final Construction Stage; 1.5 Without testing 1.3 With testing(1) Intermediate Construction Stage; 1.3 Without testing
Large(2) Embankments Associated with Ponds	1.5 Without testing 1.3 With testing(1)
Dump Leach Piles	1.5 Without testing 1.3 With testing(1)
Waste Rock Piles	The applicant is required to establish whether or not discharge can occur. If potential for discharge exists stability analyses should be performed and FOS should meet the same criteria as for Dump Leach Piles.

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(1) Refers to site specific testing of material shear strengths and/or liner interface strengths and quality control testing (e.g., moisture, density, grain size) during construction. The testing program should establish drained shear strength parameters for long-term (static) stability analyses and, where appropriate, undrained shear strength parameters for rapid loading conditions (e.g., earthquake or rapid drawdown).

(2) Embankments higher than 20 feet.

TABLE E-2

Dynamic Stability Design Criteria[1]		
Facility	Prescriptive BADCT	Individual BADCT
• Heap Leach Piles • Tailing Impoundment Embankments • Embankments Constructed on Tailing or Constructed With Tailing • Large[3] Embankments Associated with Ponds	• For final construction stages: - Computed pseudostatic FOS 1.1[2] without testing. - Computed pseudostatic FOS 1.0[2] with testing. • For intermediate construction stages: - Computed pseudostatic FOS 1.0[2] with or without testing.	• For final construction stages: - Computed pseudostatic FOS 1.1[2] without testing. - Computed pseudostatic FOS 1.0[2] with testing. • For intermediate construction stages: - Computed pseudostatic FOS 1.0[2] with or without testing.
	and/or[4]	and/or[4]
	• Liners and covers: - Deformations 1 foot, without geomembranes.[5] - Deformations 6 inches, with geomembranes.[5] • Covers that are maintained: - Deformations 1 foot.[5]	• Predicted deformations shall not jeopardize containment integrity.
• Dump Leach Piles	Not Applicable	• For final construction stages: - Computed pseudostatic FOS 1.1[2] without testing. - Computed pseudostatic FOS 1.0[2] with testing.[1] • For intermediate construction stages: - Computed pseudostatic FOS 1.0[2] with or without testing.
		and/or[4]
		• Predicted deformations shall not jeopardize containment integrity.
• Waste Rock Piles	The applicant is required to establish whether or not discharge can occur. If potential for discharge exists stability analysis should be performed with FOS and deformation criteria the same as for dump leach piles under Individual BADCT.	

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(1) Refer to Section E.2.4.3 for discussion of design earthquake selection.

(2) Applicable only when material types involved (e.g., clayey soils or large, coarse rock fragments) do not exhibit high potential for pore water pressure buildup and associated significant strength loss under loading.

(3) Embankments higher than 20 feet.

(4) For conditions with high potential for pore water pressure buildup and associated significant strength loss deformation analyses must be completed. Also, if loss of life or major environmental impacts are potentially imminent under failure conditions deformation analyses should be performed.

(5) Larger deformations may be acceptable if engineering evaluations are provided to demonstrate that they will not jeopardize containment integrity.

Judgment should be used to establish the actual design earthquake, which may range between the MPE and the MCE, taking into account the following factors:

- Potential threat to human life or the environment;
- Facility life;
- Potential future property development downstream of the embankment or earth structure;
- Seismic history in the area.

Recommended design criteria for dynamic stability are summarized in Table E-2 and include FOS for pseudostatic analyses and allowable deformations for the deformation analyses. When pseudostatic analyses are performed, the computed FOS should be equal to or greater than 1.1 using conservatively assumed material strengths. Where site specific testing is performed for material properties, a FOS of 1.0 can be used. A detailed deformation analysis should be performed if these FOS criteria are not met. Deformation analysis should also be performed in cases where: (1) there is a high potential for pore water pressure buildup and associated significant strength loss; or (2) failure could result in loss of life or major environmental impact. Design deformations for prescriptive BADCT are generally limited to 1 foot, or to 6 inches when geomembrane stretching can occur. For the Individual BADCT approach deformations should be limited on a case-by-case basis so as not to jeopardize containment integrity.

E.2.4.4 Establish Facility Model for Analysis

The designer must establish the scenarios that are to be analyzed (e.g., intermediate, or staged construction slopes, final slopes) and develop representative critical analysis cross sections and/or geometric characteristics for each scenario. The objective is to select locations and cross sections representing the most critical conditions. In establishing these cross sections, consideration must be given to such items as:

- Ultimate waste pile/embankment height;
- Spacing and width of stability benches;
- Buttress dimensions;
- Intermediate construction stages;
- Maximum anticipated phreatic surface in the embankment and foundation;
- Geomembrane interfaces;
- Anchor points for geomembranes (if appropriate).

Generally material properties can be selected for use in the analysis either from literature values representative of the site conditions or by site specific testing. For long-term (static) stability analysis, drained shear strength parameters are needed. Undrained shear strength properties are required for rapid loading (e.g. earthquake) conditions where drainage is not fast enough to alleviate pore pressure buildup and associated strength loss. Where geosynthetic or clay cover/liners are involved, however, the interface shear strengths will generally control or have a major influence on slope stability. It is important to establish these strength characteristics by performing site specific testing using actual planned materials and representative conditions (e.g., overburden, moisture content, density, etc.).

E.2.4.5 Static Analysis

Static stability of slopes is performed for the facility model and selected cross sections using limit equilibrium analysis methods by searching for circular and noncircular failure surfaces having the lowest computed factor of safety. These analyses can be executed very efficiently with computer codes. Generally accepted effective stress analysis (ESA) and total stress analysis (TSA) procedures are presented by the U.S. Army Corps of Engineers (1983) and U.S. Bureau of Reclamation (1991). ESA method is used for evaluating long-term static stability of embankments. TSA method is used for cases of rapid loading (e.g., earthquake or rapid drawdown).

Where undrained conditions are possible for a large part of the slope static or dynamic liquefaction failures must be considered as discussed in E.2.4.6.2, and it is also advisable to perform undrained strength analysis (Poulos, 1988a, 1988b; Ladd, 1991). The concept upon which undrained strength analysis is based is that for a liquefaction failure to occur, a progressive deformation process takes place until the shear strength of all parts of the failure surface is reduced to the high strain residual, undrained shear strength or steady-state shear strength. If the factor of safety is greater than 1.0 for steady-state shear strength conditions, large-slope deformations are not expected provided appropriate strength parameters and analysis procedures were used.

A portion of a structure may rest on the geomembrane liner. This is usually the case for precious metals tailing dams. For this case, the shear strength of the liner interfaces, which is usually weaker than the dam embankment and foundation materials, must be considered in stability analysis (Mitchell and others, 1990).

If the computed FOS is less than acceptable values, the designer can evaluate the use of various BADCT to improve the stability. Such approaches as limiting embankment height, use of setbacks or benches, toe buttresses, drainage, flatter slopes and changing liner material to give greater interface strengths can be considered. The analysis is then repeated after appropriate design modifications are made until the results are acceptable.

When the computed static FOS is acceptable, dynamic analyses can be performed on the cross sections found to be critical as outlined in the following sections.

E.2.4.6 Dynamic or Earthquake Analysis

In parts of southwestern Arizona near the San Andreas fault zone, northern Arizona in the projection of the Intermountain Seismic Belt, and extreme southeastern Arizona, seismic activity is relatively high compared to the remainder of the state. Depending on earthquake recurrence intervals, earthquake forces in these areas may control design. Detailed seismic evaluations are necessary in these areas to properly evaluate seismic risk and establish earthquake design parameters. In the remaining portions of Arizona, the seismicity may be low enough not to be of concern. However, preliminary evaluations are required to substantiate that seismicity is not of concern.

E.2.4.6.1 Seismic Design Parameters

Site specific evaluation of seismic hazard and earthquake design parameters is necessary to establish the dynamic stability methods appropriate for design. Typical design parameters that need to be determined (Figure E-1) include:

- Earthquake magnitudes and source to site distances;
- Peak horizontal acceleration and design ground motion acceleration time histories for use in the deformation analyses.

Deterministic methods based on estimated ground motions from identified active faults and probabilistic methods based on earthquake history are commonly used in the establishment of earthquake design parameters (Krinitzsky, 1993). Except for the portions of Arizona influenced by the San Andreas Fault Zone in southern California (a tectonic plate boundary of intense seismic activity), seismic activity is generally low, and deterministic methods are generally considered to be preferable (Krinitzsky, 1993). Earthquake design parameters are usually selected based on professional judgment considering both probabilistic and deterministic analysis. Information on active and potentially active faults useful in deterministic analysis is given by Nakata and others (1982), Pearthree and others (1983), Menges and Pearthree (1989), Scarborough and others (1983), U.S. Bureau of Reclamation (1986), Menges and Pearthree (1989), Dempsey and Pearthree, (1990), Maulchin and Jones (1992), Jennings (1992) and Euge and others (1992). An active fault is defined as a fault that has ruptured in the last 35,000 years.

Procedures used in deterministic analysis involve the estimation of earthquake magnitude based on correlation with length of fault rupture (dePolo and Slemmons, 1990) and estimation of on-site accelerations with attenuation relationships (Campbell, 1991). Probabilistic analysis of ground motions in Arizona are presented by Algermissen and others (1990) and Euge and others (1992).

The above referenced evaluations include literature surveys to determine the location and extent of regional faulting, local geologic and fault mapping, review of historic seismic records, air photo interpretation and field seismic and trenching activities where necessary. Based on the results of these evaluations the seismic source model and parameters are established; i.e., type of faults, magnitude of earthquake, distance of fault from site. A deterministic or probabilistic analysis approach is followed to develop peak horizontal accelerations and site response spectra. Depending upon material types, models can be used to evaluate attenuation or amplification of the ground motions up through the embankment mass if appropriate.

E.2.4.6.2 Liquefaction Analyses

As referenced above, liquefaction occurs when pore water pressure equals or exceeds the overburden pressure. During an earthquake, this can occur in low-density granular material where the pore water cannot drain rapidly enough during the shear displacements caused by the seismic loading. To evaluate the potential of the material to liquefy, methods by Seed and others (1983), Davis and others (1988), Seed, (1988), Robertson, (1983) and Seed and others (1985) can be utilized. These methods typically use in-situ densities estimated either from laboratory

consolidation or simulated tailing depositional testing for new facilities, and by sampling, SPT, cone-penetrometer, or pressure meter tests for existing facilities. Susceptibility to liquefaction should be calculated for various depths within the material using the empirical charts provided in the above references. Residual undrained shear strength parameters need to be developed (from literature, correlations or testing programs) for use in post-liquefaction deformation analyses.

The extent to which liquefaction is estimated to occur should be taken into account when considering seismic stability analyses. Where extensive liquefaction is estimated to occur, the design, construction procedures and/or operations may have to be modified to improve drainage and/or increase strength or avoid the liquefiable area.

E.2.4.6.3 Pseudostatic Stability Analysis

If pore pressure buildup is not expected and deformations are not expected to be large (Seed, 1979), and provided that potential threat to human life or potential major environmental impacts are not imminent under failure conditions (such as a dump leach pile constructed of large, coarse, free draining material on good foundation materials and not located adjacent to occupied buildings or sensitive environmental features), it generally will suffice to perform a limited pseudostatic type analysis. Most of Arizona is tectonically stable and design peak horizontal ground accelerations (PHAs) and earthquake durations are often low enough not to trigger liquefaction of loose saturated tailing or otherwise control design. Pseudostatic analysis (Seed, 1979; Hynes-Griffin and Franklin, 1984; Leps and Jansen, 1984) may be sufficient in these areas to confirm an earthquake resistant design. For these cases, limit equilibrium analyses using a seismic coefficient applied to the weight of the potential sliding mass, to reflect effects of dynamic loading, is performed. Seismic coefficients recommended for use depend upon earthquake magnitude, geometry, and other factors as discussed in Seed, 1979; Seed and Martin, 1966; and Bray and others, 1995. If the computed FOS is not acceptable, a deformation analysis is recommended (Figure E-1).

E.2.4.6.4 Deformation Analyses

Either simplified permanent seismic deformation analyses or more detailed dynamic analyses may be applicable depending upon the case being evaluated. For cases where pore water pressure buildup and associated strength loss are not expected, deformations can be estimated based on PHA and the yield acceleration determined from pseudostatic analysis with FOS = 1.0 using hand calculation methods (e.g., Franklin and Chang, 1977). Otherwise, or if loss of life or major environmental impacts are potentially imminent under failure conditions, more detailed dynamic deformations analyses should be completed. In more detailed analyses, pre-earthquake shear stresses and vertical effective stresses in the slope are first estimated by finite-element or other numerical methods using drained strength parameters. The earthquake induced cyclic shear stresses in the slope are then estimated by one-dimensional (Idriss and Sun, 1992) or two-dimensional dynamic response analysis and compared with the cyclic shear stress ratios required to trigger liquefaction estimated from in situ tests (Seed and Harder, 1990; Mitchell and Tseng, 1990). In this way, the potentially liquefiable zone within the slope (and possibly the foundation) is estimated, and limit equilibrium analysis is performed for appropriate failure surfaces including post-earthquake cases which consider redistribution or migration of excess

pore pressures to compute yield acceleration using undrained strength parameters for the liquefiable zone. Computer codes (e.g., QUAD-4) are available to perform these analyses. Permanent deformations of selected failure surfaces are then estimated by the Newmark sliding-block approach with procedures such as those of Makdisi and Seed (1978; 1979) and Houston and others (1987). More rigorous dynamic analysis procedures (e.g., nonlinear dynamic finite element methods) may be applicable where very large seismic forces and/or geomembrane liners are involved (Lo and others, 1988). Dynamic stability analysis for waste fill which rest on geomembrane liners is addressed by Seed and Bonaparte (1994).

A key aspect in the above analyses is the application of the appropriate material strength parameters. For unsaturated material, the drained shear strength should be used. For saturated material that is susceptible to liquefaction and including the case of rapid water level drawdown adjacent to a fill or cut slope, the residual undrained shear strength should be utilized while the drained shear strength can be utilized for material that is not susceptible to liquefaction. In the case of a lined embankment for a pond the analysis should include an assessment of the potential for a liner leak to cause portions of the embankment to become saturated requiring the use of reduced strength parameters for the saturated material.

In summary, more detailed dynamic response/deformation analysis of slopes can include the following:

- QUAD-4 (2-D equivalent linear finite element analysis) to develop detailed dynamic response (i.e., time history of horizontal accelerations of sliding block), and
- Newmark displacement double integration analysis using results of detailed dynamic response analysis.

or

- A nonlinear dynamic analysis of waste/liner system using a finite element computer code such as LINOS (Bardet, 1986) to obtain deformations and stresses in the embankments, liner and cover systems.

If calculated displacements are acceptable (Table E-2) the design can proceed. Otherwise, the designer should consider performing a more rigorous deformation analysis, modifying the design (e.g., geometry and/or construction materials) and/or using structural components (e.g., geogrids, anchors) to take the loading.

E.3 HYDROLOGIC DESIGN GUIDANCE

E.3.1 Introduction

The two design storm parameters of importance include the: (1) design peak flows that are used to size diversion structures such as ditches and spillways; and (2) design storm volumes that are needed to size runoff containment ponds or other facilities such as tailing impoundments that collect storm precipitation and runoff. Each of these parameters needs to be established for a specified return period (or frequency); e.g., 100-year event, which reflects the level of risk that is incorporated into the design.

This section outlines how storm return periods should be established, how the design flood peak and volumes are estimated, and how pond or impoundment storage capacities can be determined. More specifically:

- Section E.3.2 discusses how design storm return periods are selected;
- Section E.3.3 describes how design flood peaks are determined;
- Section E.3.4 outlines how design storm volumes are established;
- Section E.3.5 describes the basis for determining pond or impoundment capacities.

E.3.2 Design Storm Return Periods

For the prescriptive BADCT, the appropriate design storm return period is 100 years unless another regulatory program requires a larger design storm program or there is a threat to human life as discussed below. For the individual BADCT approach, a return period needs to be established. It typically ranges from a 25-year event to a 500-year event. If exceedance of the design peak flow or volume could result in failure that would pose an imminent risk to human life, then the Probable Maximum Flood (PMF) event should be utilized for both prescriptive and individual BADCT.

In establishing the appropriate design flood return period for individual BADCT, the following factors should be considered:

- Potential threat to human life;
- Potential threat to infrastructure such as bridges, roads, powerlines, buildings and railroads;
- Potential threat to the environment;
- Facility life;
- Potential future downgradient property development;
- Requirements of any other agencies that may be relevant.

Table E-3 provides guidance in selecting design return periods. It lists the probabilities of occurrence of a specific design flood event during the life of the facility designed for that specific flood event.

E.3.3 Design Peak Flows

The design peak flows are typically calculated for the most intense period of the design storm event and can be determined by the rational method for small catchments; i.e., less than 5 square miles (Chow, 1964; Linsley and others, 1982) and the unit hydrograph method for larger catchments (U.S. Bureau of Reclamation Design of Small Dams, 1987, and U.S. Soil Conservation Service, National Engineering Handbook, Section 4, 1972). There are also publications available that contain empirical formulas or curves that can be used to establish design flood peaks.

For sizing ditches, all that is typically needed is the design flood peak flow. However, for sizing spillways on ponds or impoundments that have capacity to store or attenuate a significant portion of the runoff volume, the entire flood hydrograph (i.e., flood flow versus time curve) can be used to route the flood through the storage and calculate the resultant reduced peak flow over the spillway. Flood routing techniques are discussed in several of the above references.

TABLE E-3

Encounter Probabilities					
Facility Life (Years)	Design Event Return Period - Years (Frequency)				PMF (Assuming 10,000)
	25	50	100	500	
10	.34	.18	.10	.02	.001
20	.56	.33	.18	.04	.002
50	.87	.64	.39	.10	.005

The values in the table above are the probability of the design event being exceeded at least once during the indicated facility life. They therefore represent the facility lifetime risk of damage or failure.

The values are based on the following formula:

Probability: $P = 1 - (1 - 1/Tr)^m$

where

Tr = return period of design event - years
m = facility life - years

E.3.4 Design Storm Volume

The design storm volume is the total storm runoff volume that occurs during the design storm of the selected return period which is determined as outlined above, and is used to calculate the amount of storage needed to contain the storm water. As distinct from the design peak flows which occur during relatively short intense storm periods, the design storm volume increases with the storm's duration, until the critical design storm duration is reached, which corresponds to that time period in which the maximum amount of water would accumulate in the pond or impoundment. For longer durations, evaporation losses start exceeding the incremental storm volumes.

For prescriptive BADCT, a critical design storm duration of 24 hours is required. For individual BADCT, the facility-specific critical design storm duration is established by considering several durations and determining which results in the maximum required storage capacity to contain the design flood volume. Section E.3.5 below outlines how the design storm volume is used to size ponds. These same procedures are also used to establish the critical design storm duration.

E.3.5 Pond Capacity

E.3.5.1 General

While the discussions in this section pertain to ponds, pond systems, consisting of several interconnected ponds, and impoundments that store liquids, the text has been simplified by referring only to ponds. Typically ponds or impoundments are utilized to collect process solutions, runoff water, rainfall and wastewaters. Where feasible, process water and storm water should be kept separate so that storm water can be discharged rather than stored or mixed with process water.

Where the quality of the collected water is poor and cannot be discharged to the environment, the pond, impoundment, or pond system, must have sufficient capacity to store the water it collects without overtopping. While process solutions and wastewater flows and storage requirements can usually be reliably estimated, the amount of rainfall and runoff that collects is dependent on weather conditions and can vary significantly depending on the size, duration and number of rainstorms that occur. For design purposes, therefore, the volume of the design storm that corresponds to a specified frequency (return period) and a critical duration is utilized. Where the critical storm duration is not known, the calculations outlined below and in E.3.5.2 are performed for various storm durations and the duration resulting in the largest required pond capacity is the critical duration.

A pond must typically be sized to accommodate the following inflows and outflows, depending on the type of mining facility involved. Storage is required to provide for minimum operating water levels that facilitate the operation of pumps, for example, as well as the water that accumulates during the critical storm duration:

- Typical pond inflows include:
  - Runoff or snowmelt from the upgradient mining facility;
  - Rainfall or snow directly onto the pond;
  - Leach solution or raffinate;
  - Transfers from other ponds;
  - Reagent addition;
  - Gravity draindown from heaps when the solution application system is shut down.(Water that is stored in the heap during leaching will typically draindown over a period of days or weeks).
- Typical pond outflows include:
  - Transfers to other facilities or ponds;
  - Evaporation;
  - Discharge.

E.3.5.2 Data Sources

More details on pond water balance computations, specifically for heap leach operations, is contained in Van Zyl, Hutchison and Kiel (1988).

Storm rainfall data for different durations can be obtained from the local weather station and adjusted for the site. The NOAA (National Oceanic and Atmospheric Administration of the U.S. Department of Commerce, 1973) has undertaken extensive statistical analyses of precipitation on a regional basis. They have published a series of atlases that provide maps of all the western states depicting contours of the 6- to 24-hour events for the 2, 5, 10, 25, 50 and 100 years return periods. (Note: These atlases currently only include data up to 1973 and the data should be supplemented from other sources for subsequent years. Revised and updated atlases should be available from NOAA.) Statistical rainfall data for longer durations can be obtained from reference documents such as the Design of Small Dams (United States Bureau of Reclamation, 1987) and from analyses conducted at specific weather stations. Methods for converting storm rainfall into runoff peaks and volumes include the rationale formula and the determination of unit by hydrographs, which are discussed in the references contained in Section E.3.2.1.

For analyses with PMF, both the local-storm PMF and general-storm PMF (6- through 72-hour duration) should be evaluated. For Arizona, Hydrometeorological Report (HMR) No. 49 distributed by NOAA can be utilized in estimating the PMF.

For larger catchments, it may be appropriate to use available long-term streamflow data, from the catchment of interest or another similar catchment in similar climatic conditions. Statistical evaluations of streamflow data (R.K. Linsley, M.A. Kohler and J.L.H. Paulhus, 1982) can be used to determine both design flood peaks and hydrographs.

In all cases, the applicant should obtain and use the latest available information. Furthermore, when determining storm volumes of critical duration the historic precipitation data base used should extend over a long enough period to accommodate at least one or more wetter than average periods. Historic variations from average rainfall are addressed by Creighton (1990).

E.3.5.3 Water Balance Computations

The typical water storage fluctuations during a year in a heap leach solution collection pond is shown in Figure E-2. Each of the storage zones depicted in that figure provide the following functions:

- Minimum operating volume: This reflects the minimum volume of stored water to facilitate operation of PLS pumps at a heap leach pad, or the water recycle pumps in a tailing impoundment;
- Average seasonal volume: This reflects how the actual volume of water contained in the pond would vary during an average year in response to the wet and dry seasons. As indicated, the pond is operated so that the volume never falls below the minimum operating requirement;

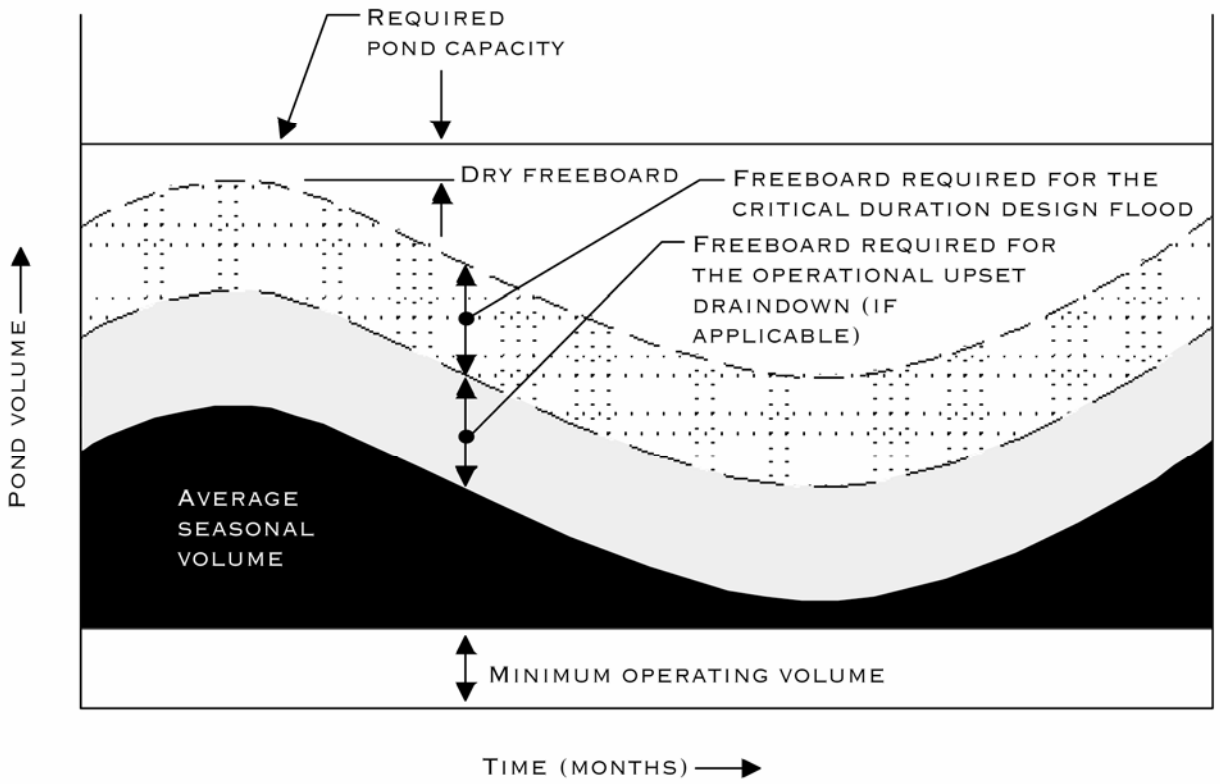
- Freeboard required for operational upset, e.g., heap leach draindown as a result of pump failure. This is an additional storage provision to accommodate draindown of the heaps for a specified period of time;
- Freeboard required for the critical storm event: This is a further storage provision to accommodate the critical duration design storm should it occur. An assumption is this storm adds to the water volumes occurring during average climatic conditions. If a water storage pond is located downstream of a catchment area that is prone to erosion, a sediment transport study is required to determine pond capacity due to the deposition of sediment..
- Dry freeboard: This is the amount of "dry" freeboard between the maximum design water level and the lower of either the pond crest elevation or the spillway crest elevation.

As shown in Figure E-2, the required pond capacity is established as the following:

storage capacity = minimum operating volume
+ maximum average seasonal volume
+ volume required for freeboard to allow for operational upset
+ volume for freeboard required for critical duration storm event including sediment
+ volume required for "dry" freeboard

The simplest way to determine the critical storm duration and appropriate pond capacities is to complete monthly or quarterly water balance analyses for a year using the most critical facility layout, design storms of different durations and different operation scenarios. As discussed below, use the storm duration that results in the maximum pond volume as the critical (or design) condition. Consider types of operating scenarios:

FIGURE E-2 - CONCEPTUAL ILLUSTRATION OF POND CAPACITY DETERMINATION



- Normal Operating Scenario:
  - Assume worst time of year, i.e., when average seasonal volume in the pond is a maximum;
  - For heap leaches assume that recycle pumps would be off for a specified period of time and that a corresponding amount of draindown from the heap would occur and increase the required pond capacity;
  - Calculate the required pond capacity using the above average drainage seasonal volume, the draindown volume as appropriate, the flood rainfall and runoff during the critical storm duration and the "dry" freeboard.
- Shut-Down Scenario:
  - As above except that, for heap leaches, rinsing and complete draindown over a specified period of time need to be incorporated;
  - As above, calculate the required pond capacity.

The required pond capacity would be the maximum developed for any of the above scenarios. In order to reduce the required pond volumes, use can be made of the following BADCT elements:

- Overflow ponds to store excess flood waters;
- Emergency standby power generators to continue operation of recycle pumps, for example, during power outages.

APPENDIX F

FEDERAL, STATE AND LOCAL ENVIRONMENTAL PERMITS

F.1 INTRODUCTION

The purpose of this Appendix is to identify for the potential applicant other possible environmental permits including Federal, State and local regulatory requirements. The information presented herein is intended only as an overview of other regulatory requirements and should not be interpreted as a complete list of every possible circumstance requiring a permit. The applicant is urged to contact the appropriate regulatory agency for applicability to a specific site.

The discussions in Section F.2 are broadly centered around regulatory requirements for environmental protection affecting the various media of water, air and waste programs. Each, in turn identifies the types of permitting and certification required at the federal and state level.

Section F.3 provides guidance for the applicant on other requirements that may impact the operation of a mine.

F.2 COMMON TYPES OF PERMITS AND APPROVALS APPLICABLE TO MINES

Compliance with environmental laws may require an operator and/or owner to apply for several different types of permits and approvals. Much additional information about permits, approvals, certifications, notifications and their associated time frames and fees is presented on the permitting page of ADEQ's web site at the following address:

- http://www.azdeq.gov/function/permits/index.html

The following discussion deals with the most common types of permits and approvals applicable to mining operations.

F.2.1 National Environmental Policy Act (NEPA)

EIS or EA	All Federal Agencies and ADEQ

The NEPA process evaluates the environmental effects of federal undertakings. If a facility is developed on federal land, then the appropriate agency, such as the U.S. Bureau of Land Management (BLM) or U.S. Forest Service, will initiate the NEPA action. If an undertaking is determined to meet the preliminary criteria for a significant impact to the environment (significant impact) the agency will conduct an environmental assessment (EA). The result of the EA is either a decision record incorporating no significant impact or recommending the

preparation of an environmental impact statement (EIS). However, an agency may choose to conduct an EIS without the preliminary EA. An EIS is subject to public input and review by the U.S. Environmental Protection Agency (EPA). If the EIS is determined to be unsatisfactory, appeal procedures are in place. ADEQ has a cross-media team that reviews draft EISs, develops comments on the drafts, when appropriate, and submits them to lead agencies.

F.2.2 Surface Water - Clean Water Act

AZPDES Permit — Issued by ADEQ, includes Storm Water

If a facility discharges wastewater or stormwater to a defined "water of the U.S." which includes lakes, streams, dry streambeds and washes, an AZPDES permit is required. AZPDES permits contain narrative and numerical limitations to ensure that state water quality standards (WQS) are met in the receiving water. All facilities which discharge stormwater are required to apply for a stormwater permit under the AZPDES program. If only storm water is discharged, then the facility may be permitted under a general storm water permit such as a Multi-Sector General Permit.

401 Water Quality Certification — ADEQ Certification of Federal Permits

Under Section 401 of the Clean Water Act, ADEQ may review all federal actions within the State to ensure compliance with WQS and for consistency with approved water quality planning and management programs (401 Certification). ADEQ will issue a Letter of Certification if the applicant meets the certification criteria. A state water quality certification is necessary before EPA issues a 402 permit. Although ADEQ is authorized to issue 402 permits under the AZPDES program, there may be instances when EPA issues a 402 permit in Arizona, which requires a 401 certification.

404 Permit — Issued by USACE

A Section 404 permit is required if construction or operations at a facility will result in a land clearing excavation and the deposition of fill materials into a "water of the U.S." Either individual or general permits can authorize such discharges. The U.S. Army Corps of Engineers (USACE) has the primary responsibility for the issuance of Section 404 permits. The EPA provides oversight and shares enforcement authority with USACE. The U.S. Fish and Wildlife Service reviews Section 404 permits for compliance with the Endangered Species Act.

Nationwide 404 permits are general permits issued by USACE which apply across the U.S. Prior to issuance, these permits are given to ADEQ for 401 Certification. ADEQ reviews and may certify Nationwide permits without constraints, or may choose to impose additional conditions that permittees must follow as part of Nationwide permit coverage. Also, ADEQ may not generically certify some Nationwide permits and instead require individual certifications to be obtained for such projects in Arizona. In these cases, the applicant must apply for and obtain a 401 certification from ADEQ even if no notification to USACE is required under a Nationwide 404 permit.

F.2.3 Air Quality - Clean Air Act

Class I and II Permits	ADEQ and Delegated Counties

Under Title V of the Clean Air Act, EPA has approved ADEQ's air quality program to draft and issue air quality operating permits (A.R.S. 49-421, et seq.,). Mining facilities may be required to submit an application for an air quality permit to either ADEQ, Maricopa County, Pima County or Pinal County, depending upon the location of the proposed mining operation. The appropriate permitting authority then reviews the application and makes a determination as to whether an air quality permit is necessary.

Air quality permits issued by ADEQ are classified into two different categories: Class I and Class II permits. Class I permits are issued to facilities that have the potential to emit more than 100 tons per year of a single pollutant (e.g. major sources). Class II permits are issued to facilities that do not have the potential to emit more than 100 tons per year of a single pollutant (e.g. true minor sources), or to facilities that have accepted limitations in order to avoid being classified as a major source of air pollution (e.g. synthetic minor sources). Both classifications of permits are subject to a minimum of 30 days of public comment prior to any final decision to approve the issuance of such a permit. In addition to the public comment period, Class I permits are also subjected to a 45 day EPA review period prior to any final decision to approve the issuance of a proposed permit. During this time EPA has the opportunity to provide ADEQ with comments on the permit, as well as exercise its authority to either approve or object to the proposed issuance of the permit.

F.2.4 Waste Disposal - Resource Conservation and Recovery Act (RCRA)

Hazardous Waste Management Act	ADEQ
Hazardous Waste Generator I.D.	EPA
Hazardous Waste Disposal	ADEQ and County

Some activities at mining facilities generate hazardous waste (A.R.S. Title 49, Chapter 5, Article 2). It is the responsibility of the owner/operator to determine if an activity generates hazardous waste as defined in subtitle C of RCRA. Certain solid waste from the extraction, beneficiation and processing of ores and minerals may fall under the Bevill exemption (i.e., solid wastes which are not hazardous wastes) contained in 40 CFR 261.4(b)(7). Generators of hazardous waste may notify ADEQ so that a hazardous waste generator ID number may be assigned. An owner/operator must also be aware of county ordinances and rules regarding hazardous waste generation.

Facilities that treat, store for more than 90 days, or dispose of hazardous waste (TSD facilities) must notify and take part in the permitting process. ADEQ is authorized by EPA to issue all TSD facility permits except for facilities on tribal lands. Compliance with county ordinances and rules may require more stringent measures than compliance with RCRA or HWMA.

Solid Waste Facilities	ADEQ, County and City
Special Waste Facilities	ADEQ, County and City

A.R.S. Title 49, Chapter 4, authorizes ADEQ to regulate solid wastes and special wastes (such as asbestos, auto shredder fluff and petroleum contaminated soils). According to A.R.S. 49-701.01(B)(16), only mining industry off road waste tires that are larger than 3 feet in diameter, rock leach material, tailing and slag produced and maintained at the site of the mining or metallurgical operation are exempted from State solid waste regulations. In addition, pursuant to A.R.S. 49-701.01(B)(15) and 49-701.01(B)(17), material produced in connection with a mining or mineral processing operation are exempt from the solid waste 100-year floodplain location restriction.

F.2.5 Underground Storage Tanks (USTs)

UST	ADEQ, City or State Fire Marshall

Underground Storage Tank (UST) statutes and rules address administrative and operational compliance for the life of the UST system, as well as corrective actions if a release occurs (A.R.S. Title 49 Chapter 6; A.A.C. Title 18, Chapter 12). Additionally, a permit for installation or removal of a UST system must be obtained from the State Fire Marshal or the local fire department with jurisdiction. If a release occurs or is suspected, it must be reported to ADEQ within 24 hours of discovery. ADEQ oversees all remedial activities (corrective actions) associated with releases of regulated substances from UST systems.

F.2.6 Other State Permitting Programs

Direct Re-Use of Reclaimed Water Permit	ADEQ
Drywells	ADEQ
Biosolids	ADEQ

In addition to the requirement to obtain an aquifer protection permit (APP) for discharging facilities, a facility proposing to re-use treated effluent for irrigation must obtain a reclaimed water permit from ADEQ's Water Permits Section (A.R.S. 49-104.B.13 and 18 A.A.C. 9, Article 7). A reclaimed water permit cannot be issued until the wastewater treatment plant is classified for reclaimed water under an individual APP. The wastewater treatment plant's APP will govern the quality of the effluent to be reused.

A drywell is designed and constructed specifically for the disposal of storm water. Disposal of other wastewaters in a drywell, either solely or in conjunction with storm water, must conform to the exempt activities listed in ARS §49-250(B) (23) or must comply with an APP.

Biosolids are nutrient-rich organic by-products resulting from wastewater treatment that can be beneficially recycled. Only biosolids of a high quality (as determined through sampling) can be land applied. ADEQ's Biosolids/Sewage Sludge Management Program (18 A.A.C. 9, Article 10) implements 40 CFR 503, Subpart C of the Clean Water Act and requires that any person

applying, generating or transporting biosolids/sewage sludge in Arizona must register that activity with the department. If ADEQ determines that the site restrictions and management practices will not protect public health or the environment, ADEQ may require an AZPDES permit. In addition, the owner or operator of a biosolids surface disposal site must apply for an APP.

F.2.7 Comprehensive Emergency Response, Compensation and Liability Act (CERCLA)

EPA's Superfund program is applied on a facility specific basis. Sites targeted for assessment by the Superfund program are listed first on the CERCLIS database. After a preliminary assessment and site investigation, the site is ranked. If a site ranks onto the national priority list, (NPL) EPA will require a full assessment and clean-up of the site under the CERCLA authority. CERCLA requires full cost recovery of EPA's staff and legal expenses from the responsible party or parties.

F.2.8 Water Quality Assurance Revolving Fund (WQARF)

Through the WQARF Program, ADEQ identifies, assesses, and cleans up soil and groundwater that is contaminated with hazardous substances. The program conducts these efforts state-wide with support from state funds and also oversees privately-funded cleanup efforts. Responsible parties are identified and notified, then legal and technical evidence is gathered for recovery of ADEQ's costs and enforcement of cleanup requirements. Funding is dependent upon the direct transfer of funds from legislative appropriations, corporate income tax, cost recovery, and special fees. Responsible parties are required to pay the costs associated with WQARF investigations.

Beginning in April 1998, a Registry was created as required by A.R.S. § 49-287.01. Sites are added as they complete the Registry listing process which includes scoring, notifying owners and operators within the site, and providing a 30-day public comment period.

The WQARF Program also provides fiscal support to the Voluntary Remediation Program, which typically manages cleanup activities at more than 50 sites in any given year. This program provides an opportunity for property owners to remediate contamination and receive review and closure from ADEQ before a site is listed on the WQARF Registry.

F.2.9 UIC Requirements For Injection Wells

The statutory definition for injection wells under 40 CFR 144.3 is "a 'well' into which fluids are "injected." A "well" under 40 CFR 144.3 is defined as "a bored, drilled or driven shaft or a dug hole, whose depth is greater than the largest surface dimension." In-situ leach operation injection and recovery wells are either Class III or Class V injection wells as defined in 40 CFR 144.6.

Class III injection wells are defined in the Underground Injection Control Program (UIC) in 40 CFR Part 146.5 as wells which inject solutions for extraction of minerals including:

- Mining of sulfur by the Frasch process;
- In-Situ production of uranium or other metals. This category includes only in-situ production from bodies which have not been conventionally mined. Solution mining from conventional mines such as stope leaching is included in Class V;
- Solution mining of salts and potash.

All Class III wells in Arizona must obtain a federal UIC permit as required under 40 CFR 144.25. Prior to obtaining a federal UIC permit the facility may need to apply to EPA for an aquifer exemption. An aquifer exemption is needed if the discharge from the Class III well could result in the violation of primary drinking water standards in an underground source of drinking water. The federal definition for an underground drinking water source is given under 40 CFR 144.3.

Class V wells are defined as injection wells that do not fall into the classification for Class I, II, III or IV wells. In-situ leach operations below an aquifer at facilities that have been conventionally mined, such as underground workings, fall into the Class V well category. The Class V classification applies to the solution mining of conventional mines and injection wells used in experimental technologies (40 CFR 146.5(e)). Under the regulations at 40 CFR 144.12, a facility may be required to obtain a federal UIC permit for a Class V well if there is evidence that the discharge will cause a violation of primary drinking water standards within the an underground source of drinking water.

Construction, operation and monitoring requirements for injection wells are described in 40 CFR Part 146. Requirements under the federal regulations are given for the following: well mechanical integrity (40 CFR 146.8), plugging and abandoning of Class I, II and III wells (40 CFR 146.10), construction for Class III wells (40 CFR 146.32) and operation of Class III wells (40 CFR 146.33). The federal UIC requirements provide part of the basis for establishing BADCT for injection wells.

F.2.10 State Board of Registration

Except as exempted by A.R.S. 32-144.A.7 (employees of mining companies), professional documents, such as reports, plans and specifications, are to be signed by an Arizona registered engineer or geologist (A.A.C. R 4-30-304).

F.3 OTHER REGULATIONS AND PERMITS APPLICABLE TO MINES

The following is a list of additional environmental requirements that may impact the operation of a mine. Some of these requirements, such as the Endangered Species Act and Archaeological Resources Protection Act will influence the requirements of permits written under the programs

listed above. Other authorities, such as the Native Arizona Plants Act, will require the facility to acquire a special permit or license for a particular operation (i.e. native plant removal permit). This is not a definitive list; additional permits or approvals may be necessary.

Federal Land Policy and Management Act	U.S. Bureau of Land Management U.S. Forest Service
Toxic Substances Control Act	U.S. EPA
Endangered Species Act	U.S. Fish and Wildlife Arizona Game and Fish
Archaeological Resources Protection Act	Arizona State Parks
Native Arizona Plants Act Arizona Protected Native Plants and Removal Permit	Arizona Department of Agriculture
Mining Land Reclamation	State Mine Inspector
Miscellaneous Permits/Approvals	
Emergency Planning/Community Right to Know Act	State, County
Migratory Bird Treaty Act	U.S. Fish and Wildlife Arizona Game and Fish
Hazardous Materials Transportation Act	Arizona Department of Transportation
Pollution Prevention Plan and Toxic Data Report Requirements	ADEQ Waste Programs Division EPA
Dam Safety Regulations, Water Rights and Drilling Permits	Arizona Department of Water Resources
UMTRCA	NRC
Zoning	City and County

PART 5

GLOSSARY OF TECHNICAL TERMS

Acid-Base Accounting - A general term referring to the quantification of acid generating potential and acid neutralization potential by static testing.

Acid Generation Potential (AGP) - The amount of acid that can be generated by weathering of minerals in a rock without considering *Acid Neutralization Potential*. The AGP is measured by static acid-base accounting procedures and is usually expressed in calcium carbonate equivalence (e.g., tons $CaCO_3$ per kiloton of material). AGP must be considered in conjunction with *Acid Neutralization Potential* to determine the net potential for production of acid.

Acid Mine Drainage (AMD) - A condition of surface runoff or infiltration of water with low pH and elevated concentrations of dissolved natural constituents (e.g., metal salts) resulting from weathering of certain rock-forming minerals. Both a source of acid generation and a supply of water adequate for transport of the acid must be present for this phenomena to occur. AMD may be most frequently attributed to mining sites (thus the term Acid "Mine" Drainage), but can occur from any area where there is adequate water in contact with unoxidized (i.e., sulfide) rock that has been excavated and moved to a location where oxidation is rapid compared to its natural state. A term sometimes used as a synonym is *acid rock drainage*.

Acid Neutralization Potential (ANP) - The amount of acid that can be consumed by minerals in a rock or soil. The ANP is measured by static acid-base accounting procedures and is usually expressed in calcium carbonate equivalence.

Active Fault - For purposes of BADCT, an *Active Fault* is a fault that has experienced rupture in the past 35,000 years.

Adsorption - A chemical process where a molecule attaches to the surface of another phase, without becoming incorporated into that phase.

Alluvium - A general term for unconsolidated geologic materials deposited by running waters (e.g., streams and rivers).

Anoxic Limestone Drain - A seepage treatment system comprised of a crushed limestone filled french drain designed to result in throughflow under oxygen deficient (reducing) conditions to remove metals and acidity.

Anticline - A geologic structure consisting of a fold in which rock strata decrease in age away from the core of the fold. (i.e., an arch-shaped fold unless the structure has been overturned).

Aquifer - A geologic unit that contains sufficient saturated permeable material to yield usable quantities of water to a well or spring (A.R.S. 49-201.2).

Aquifer Loading - The quantity of a potential pollutant or pollutants able to migrate downward to the uppermost aquifer underlying a facility or site, usually expressed in mass per unit area per unit time.

Aquitard - A natural zone of low permeability that inhibits the migration of groundwater.

Arizona Administrative Code (A.A.C.) - A multi-volume set containing the final, summary, exempt and emergency rules adopted by the State of Arizona.

Arizona Revised Statues (A.R.S.) - The revision and codification of the laws of Arizona of a general or public nature adopted and enacted into law.

Attenuation (Natural) - The process by which a compound is reduced in concentration over time, through adsorption, degradation, dilution, and/or transformation.

Atterberg Limits - Water content boundaries between the states of consistency of a soil (e.g., plastic limit).

Barren Solution - Solution applied to ore to dissolve mineral commodities. Leaching operations in arid climates such as Arizona are usually a closed-loop recirculating system, where the barren solution is reconstituted from pregnant solution after processing, with make-up water added as necessary.

Batch Test - A test involving reacting or leaching a quantity of representative material (e.g., soil ore, tailing) to obtain empirical data.

Beach - The sloping surface of hydraulically deposited tailing material.

Bedrock - A general term for consolidated and lithified geologic materials.

Borrow - Earth materials used for construction.

Bulk Density - The density of a material measured in mass per unit volume.

Buttress - An engineered structure and/or compacted earth support system for stabilizing over steepened slopes at their toe.

Column Test - A test designed to simulate the leaching or reaction of a liquid percolated through a granular material (e.g., soil, ore, tailing). The granular material is normally contained in a vertical pipe or column, with liquid added at the top and effluent collected at the bottom.

Complexation - Formation of a complex compound from simpler chemical elements.

Composite Liner - A liner comprised of two or more low permeability components in direct contact with each other (e.g., a layer of clay and a geomembrane).

Cone of Depression - The depression produced in a water table or piezometric surface by pumping.

Design Earthquake - An earthquake utilized as the basis for developing appropriate ground motion characteristics for seismic design of a facility.

Design Peak Flow - The maximum flow rate calculated for the design storm at a given point in an engineered drainage system. Design peak flow is used in sizing components that convey flow (e.g., ditches and channels)

Design Storm - The storm size (usually identified by recurrence interval and duration) utilized in the design and sizing of engineered drainage systems.

Design Storm Volume - The total runoff volume that discharges to an engineered pond or impoundment during the design storm.

Detoxification - The treating of spent ore or other mine waste to reduce or eliminate its toxicity. Detoxification procedures can include rinsing and physical, chemical or biological treatment.

Discharge - The addition of a pollutant from a facility either directly to an aquifer or to the land surface or the vadose zone in such a manner that there is reasonable probability that the pollutant will reach an aquifer (A.R.S. 49-201.12).

Dry Unit Weight - The weight of mineral matter divided by the volume of the entire element. Also referred to as dry density.

Dump Leaching Facility - Generally a leaching facility consisting of uncrushed ore deposited in an unlined area with defined topographic containment. In Arizona, dump leaching is generally only used for copper ore with grades that are too low to heap leach.

End Dumping - The process of dumping material from the back of a dump truck. Dump leach piles, heap leach piles and overburden rock piles are commonly constructed by end-dumping the material over the top edge of the pile slope.

Engineering Equivalent - A discharge control system or element that is different than that specified for Prescriptive BADCT criteria, but which will control discharge as effectively or more effectively than the Prescriptive BADCT component it is intended to replace.

Evapotranspiration - The process by which water is volatilized to the air through either direct evaporation or transpiration by vegetation, with no distinction made between the two components (i.e., evaporation + transpiration).

Evaporative Depth - The depth below the ground surface to which water can be removed through evapotranspiration.

Factor of Safety - The ratio of forces contributing to slope stability (e.g., due to intergranular friction and cohesion) versus forces working against slope stability (e.g., gravity, seismic acceleration) estimated in seismic stability analyses.

Fixation - A process by which chemical constituents are immobilized or chemically bound in a matrix.

Freeboard - Height of containment above the surface of a contained liquid.

Gabion - A cylinder or cage, usually constructed of metal mesh, filled with rocks and used for erosion protection in stormwater control channels, at dam foundations, etc.

Geocomposite - A general term for a premanufactured composite material (e.g., geosynthetic clay liner) designed for use in engineered structures.

Geomembrane - A low permeability plastic liner.

Geonet - A coarse plastic net designed for use as a drainage layer in engineered systems.

Geosynthetic - A general term for synthetic materials (e.g., geomembranes or geotextiles) used in engineered earth structures.

Geosynthetic-Clay Liner (GCL) - A factory-manufactured hydraulic barrier typically consisting of bentonite clay or other very low permeability material supported by geotextiles or geomembranes which are held together by needling, stitching or chemical adhesives.

Geotextile - A fabric designed for various uses in engineered earth structures. Common uses include wrapping or covering of materials to be buried to prevent their physical damage, incorporation into fills to spread load distribution, and use as a filter medium to capture fine particles.

Head or Hydraulic Head - The height of a fluid above a reference point (e.g., a plastic liner). Head is the driving force that exerts pressure causing water to migrate.

Heap Leach Pad - A lined relatively flat constructed area and solution containment features, on which ore is loaded and then leached with a solution to dissolve and recover minerals.

Holocene - Epoch of geologic time encompassing the period from 10,000 years ago through present time.

Hydraulic Conductivity - A measurement of the relative ease with which a porous medium can transmit water under a potential gradient. It is dependent on physical properties of the porous medium (i.e., the size, shape and degree of connection between openings through which liquid can flow).

Hydraulic Head - See *Head*.

Hydrograph - A water level or rate of flow record as a function of time.

Hydrolysis - Decomposition or alteration of a chemical substance by water.

Infiltration - Downward movement of water through the soil surface into the ground. Some or all of the water that infiltrates may still be removed through evapotranspiration.

Injection Well - A well which receives discharge through pressure injection or gravity flow (A.A.C. R18-9-101(14)). Injection wells are commonly used to deliver leaching solution to an ore body for in-situ leaching operations.

In-Situ Leaching - The application of leaching solution to an ore body that is in-place, for the purpose of extracting a mineral commodity.

Interface Strength - The shear strength at the interface of two materials (e.g., the contact between a plastic liner and a clay layer).

Invert - The low point of a drainage collection or conveyance system.

Kinetic Acid-Base Analysis - Laboratory tests designed to initiate what happens in nature and run over a period of time to determine the potential for rock to be acid-generating. Kinetic testing methods include humidity cell tests, column tests, etc.

Leachate Collection and Recovery System (LCRS) - An engineered assembly of components installed between the upper and lower liner of a double liner system and designed to drain fluid from above the lower liner. The LCRS relieves the hydraulic head above the lower liner to minimize downward seepage.

Leaching - The process of dissolving mineral commodities from ore. For copper ores, leaching is usually accomplished by treating the ore with and acidic solution. For precious metals ores, leaching is usually accomplished using a basic solution with additional reagents to dissolve the mineral commodity (e.g., sodium cyanide).

Lithology - The physical and mineralogical makeup of geologic materials.

Liquifaction - The sudden large decrease of shearing resistance of a cohesionless soil caused by a collapse of the structure by shock or strain (such as an earthquake) and associated with an increase of porewater pressure.

Lixiviant - A fluid used for leaching or extracting mineral or other components from a solid material.

Lysimeter - A device used to measure the quantity or rate of movement of water through soil, or to collect such water.

Maximum Credible Earthquake (MCE) - The maximum earthquake that appears capable of occurring based on the presently known tectonic framework.

Maximum Probable Earthquake (MPE) - The maximum earthquake likely to occur during a 100-year interval (80 percent probability of not being exceeded in 100 years).

Mine Pit - An area from which ore and overburden are excavated.

Neutralization Potential - See *Acid Neutralization Potential*.

Non-Storm Water Pond - A pond that contains seepage or inflow from a tailing impoundment, waste dump, process area, etc., where potential pollutant constituents in the seepage or inflow have concentrations that are relatively low (e.g., compared to process solutions) but exceed Arizona surface water quality standards. Non-storm water ponds also include secondary containment structures and overflow ponds that contain process solution for short periods of time due to process upsets or rainfall events.

Optimum Moisture Content - The moisture content at which the greatest degree of compaction is obtained.

Ore - Rock that can be mined for extraction of a mineral commodity under conditions that allow a profit to be made.

Outcrop - A bedrock exposure at the ground surface.

Overburden - Non-Ore rock and soil overlying an ore body. Non-ore rock that is interspersed with ore is also often referred to as overburden. For surface mining operations, overburden must usually be excavated to access ore material for removal. Mining operations characteristically minimize the amount of overburden excavated to control mining costs. Overburden is also referred to as *waste rock*.

Oxidation - Any process which increases the proportion of oxygen or acid-forming or radical in a compound.

Oxide Ore - Ore material that has been oxidized through natural geologic processes and no longer contains significant quantities of sulfide minerals.

Packer - A tool used to seal a well or boring at a specific location to isolate a given vertical zone (e.g., for testing or production).

Passive Containment - Natural or engineered topographical, geological or hydrological control measures that can operate without continuous maintenance (A.R.S. 49-243.G.1).

Peak Flow - The maximum flow rate for a given storm at a given point in an engineered drainage system.

Perched Water Table - The top surface of a local zone of saturation located above the regional water table. Perched water tables usually occur immediately above a low permeability stratum within the vadose zone that intercepts downward-percolating water and causes some of it to accumulate above the stratum.

Percolation - Downward movement of water in the vadose zone. Percolation occurs when the moisture content exceeds the specific retention.

Permeability - A measurement of the relative ease with which a porous medium can transmit liquid under a potential gradient. It is dependent on physical properties of the liquid (i.e., viscosity and density) and the porous medium (i.e., the size, shape and degree of connection between openings through which liquid can flow).

Phreatic Surface - The water table or top surface of a zone saturated with water within an engineered earthen structure (e.g., an embankment).

Pore Pressure - Pressure present within the pore fluid of a soil.

Porosity - The percentage of the total volume of rock or soil that is occupied by void space.

Pseudostatic Analysis - Static analysis of slope stability that incorporates a simulated horizontal force equal to the horizontal acceleration of the design earthquake times the mass of the potentially sliding material.

Pregnant Solution or **Pregnant Leach Solution** (PLS) - Mineral-laden solution recovered from a leaching operation. Leaching operations in arid climates such as Arizona are usually a closed-loop recirculating system, where the mineral commodity of interest is recovered from the pregnant solution and residual liquid is refortified with leaching reagent to make barren solution.

Process Solution Pond - A pond that contains pregnant, barren or recycling process solutions. An overflow pond that continually contains process solution as a normal function of facility operations is also considered a process solution pond.

Quality Assurance - A planned system of activities that provide assurance that a facility was constructed as specified in the design.

Quality Control - A planned system of inspections that are used to directly monitor and control the quality of a construction project.

Raveling - Rolling of loose surficial rocks down a slope due to gravity.

Recovery Well - A well utilized to recover mineral-laden solution as part of an in-situ leaching process.

Riprap - Rock placed in channels, on embankments, etc. to prevent erosion.

Rubbilization - The engineered blasting of in-place rock to increase its permeability for the purposes of facilitating in-situ leaching.

Run of Mine - Uncrushed rock, broken only by blasting and excavation.

Run-On - Surface flow onto or into a given area caused by precipitation.

Run Off - Surface flow from a given area caused by precipitation that does not infiltrate or evaporate.

Run-Out - Transport of soil or rock beyond the toe of a slope due to momentum from dumping from the top of the slope.

Seismicity - Movement of the ground caused by an earthquake.

Settlement - The gradual downward movement of a structure due to loading and compression of the soil below the foundation.

Sliding Block Failure - A form of landslide movement in which an entire large block of material, typically rock, moves as a unit for some distance out of a slope.

Slime Sealing - The hydraulic placement of finely ground tailing in a manner designed to create a hydraulic barrier/layer (e.g., against the upgradient side of a tailing impoundment embankment).

Specific Retention - Ratio of the volume of water a soil or rock can retain against gravity drainage to the total volume of the soil or rock.

Static Water Elevation - The equilibrium elevation of standing water in a well or piezometer not affected by pumping.

Static Stability - The relative stability of a slope or structure under static (nonseismic) conditions.

Subaerial Deposition - The hydraulic deposition of tailing in thin layers for defined periods of time over a beach in a manner that promotes rapid dewatering and evaporative drying of the deposited tailing.

Subsidence - Mass movement involving gradual downward sinking of the ground surface.

Sulfide Ore - Ore material that contains significant quantities of sulfide minerals.

Surface Pond - An impoundment other than a tailing impoundment that is: (1) used to collect or store fluids at a mining operation; and (2) subject to regulation under A.R.S. 49-243.B.

Syncline - A geologic structure consisting of a fold in which rock strata increase in age away from the core of the fold. (i.e., a trough-shaped fold unless the structure has been overturned).

Tailing - Finely ground ore residue remaining after milling and mineral extraction.

Tailing Impoundment - An impoundment designed to receive and contain finely ground ore residue particles and residual leach or chemical solutions remaining after milling and mineral extraction.

Talus - Unconsolidated rock or soil fragments deposited at the base of slopes due to gravity.

Vadose Zone - A zone below the ground surface containing water under pressure that is less than atmospheric pressure. Also referred to as the *unsaturated zone*.

Valence State - The electric charge of an atom. The valence state is dependent upon the number of electrons in the outermost shell of the atom and largely controls the chemical properties of the atom.

Valley Leach - A heap leach or dump leach operation in which the ore being leached is located in a valley such that the valley slopes and bottom provide for both containment and collection of the solution at the outlet to the valley.

Waste Rock - See *Overburden*.

Water Balance - The net sum of liquid inflows and outflows for a given system.

Watershed - The area that contributes surface runoff to a given system.

PART 6
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