FREEPORT-McMoRAN
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Sierrita Operations

December 28, 2007

Via Certified Mail #7006 2150 0004 3614 0791
Return Receipt Requested

Mr. Robert Casey
Arizona Department of Environmental Quality
Water Quality Enforcement Unit
1110 West Washington Street
Phoenix, Arizona 85007-2935

Re: Focused Feasibility Study
Phelps Dodge Sierrita, Inc., Mitigation Order on Consent, Docket No. P-50-06

Dear Mr. Casey:

Phelps Dodge Sierrita, Inc., operating as Freeport McMoRan Copper & Gold, Sierrita Operations ("Sierrita"), submits three copies of the attached Focused Feasibility Study Report. This document was prepared by Hydro Geo Chem, Inc. as described in Sierrita's letter to ADEQ dated May 31, 2007.

Please do not hesitate to contact Mr. Stuart Brown at (503) 675-5252 or myself at (520) 648-8857 if you have any question regarding this submittal.

Very truly yours,

Ned Hall

E. L. (Ned) Hall
Chief Environmental Engineer

ELH:ms
Attachment
20071228-002

xc: John Broderick, Sierrita Operations
Chad Fretz, Sierrita Operations
Ray Lazuk, Freeport McMoRan Copper & Gold Inc.
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FOCUSED FEASIBILITY STUDY FOR THE NORTHERN PORTION OF THE INTERCEPTOR WELLFIELD PHELPS DODGE SIERRITA, INC. MINE TAILING IMPOUNDMENT MITIGATION ORDER ON CONSENT DOCKET NO. P-50-06

Prepared for:

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ADEQ	Arizona Department of Environmental Quality
ADWR	Arizona Department of Water Resources
APP	Aquifer Protection Permit
A.R.S.	Arizona Revised Statutes
ASLD	Arizona State Land Department
CWC	Community Water Company of Green Valley
ft bgs	Feet below Ground Surface
FICO	Farmers Investment Company
FFS	Focused Feasibility Study
gpm	Gallons per Minute
HGC	Hydro Geo Chem Inc.
mg/L	Milligrams per Liter
M&A	Errol L. Montgomery & Associates
MO	Mitigation Order on consent Docket No. P-50-06
NOI	Notice of Intent
NPV	Net Present Value
O&M	operation and maintenance
PAG	Pima Association of Governments
PDSI	Phelps Dodge Sierrita Inc.
PDSTI	Phelps Dodge Sierrita Tailing Impoundment
UIC	Underground Injection Control

1. INTRODUCTION

1.1 Overview of the Focused Feasibility Study

This Focused Feasibility Study (FFS) identifies and evaluates alternatives to improve the effectiveness of the Phelps Dodge Sierrita, Inc. Tailing Impoundment (PDSTI) interceptor wellfield near Green Valley, Arizona (Figures 1 and 2). A preferred mitigation alternative is recommended based on an analysis of the mitigation alternatives.

The interceptor wellfield is a system of wells and pipelines that were installed to intercept tailing seepage along the east edge of the PDSTI (Figure 3). An evaluation of the effectiveness of the interceptor wellfield conducted pursuant to the Mitigation Order on Consent Docket No. P-50-06 (Mitigation Order), under Arizona Revised Statutes (A.R.S.) § 49-286, determined that groundwater pumping effectively captures sulfate-impacted seepage in the southern portion of the interceptor wellfield, but not the northern portion from approximately well IW-6A northward (Figure 3) (Errol L. Montgomery & Associates (M&A), 2007b). This FFS was conducted in response to the findings of the interceptor wellfield evaluation. The objectives of the FFS were to evaluate potential mitigation alternatives for improving the effectiveness of the north portion of the interceptor wellfield and to recommend a preferred mitigation action.

The general approach for the FFS is described in Section 5 of the *Work Plan to Characterize and Mitigate Sulfate with Respect to Drinking Water Supplies in the Vicinity of the Phelps Dodge Sierrita Tailing Impoundment* (Work Plan) Hydro Geo Chem, Inc. (HGC) (HGC, 2006a). The main components of the FFS are: 1) identification and screening of potentially applicable mitigation actions, control technologies, and process options; 2) development and screening of mitigation alternatives; 3) detailed analysis of mitigation alternatives; and 4) recommendation of the preferred mitigation alternative. The FFS is a component of ongoing work by Phelps Dodge Sierrita, Inc. (PDSI) pursuant to the Mitigation Order and the selection of a mitigation action in accordance with A.R.S. § 49-286 as described in the Work Plan. HGC conducted the FFS and prepared this report under contract to PDSI.

The mitigation objective for the FFS is to control, to the extent practicable, sulfate migration from the northern portion of the interceptor wellfield to the regional aquifer. This objective is consistent with the overall objective of the Mitigation Order, which requires mitigation of drinking water supplies exceeding 250 milligrams per liter (mg/L) sulfate if the sulfate originates from the PDSTI. This FFS is specific to increasing the effectiveness of the north portion of the interceptor wellfield and does not address or supersede the broader mitigation objectives that will be evaluated in the Feasibility Study being prepared under the Work Plan.

The development and analysis of mitigation alternatives involves a four-step process. First, potentially applicable mitigation actions, control technologies, and process options capable of controlling seepage from PDSTI were identified and screened qualitatively for effectiveness, implementability, and cost (Section 2). Second, mitigation actions, control technologies, and process options retained by the screening were combined into mitigation alternatives for which conceptual designs were developed (Section 3). Third, the mitigation alternatives were evaluated quantitatively for their benefits and life cycle costs (Section 4). Fourth, a preferred mitigation alternative was selected for recommendation to Arizona Department of Environmental Quality (ADEQ) (Section 5) and further evaluation in the Feasibility Study and Mitigation Plan.

The development of alternatives was based on site-specific data including groundwater chemistry, hydrogeologic conditions in the interceptor wellfield area, existing PDSI infrastructure and land position, and discussions with PDSI personnel and consultants. Cost and engineering-feasibility information was provided by PDSI personnel and consultants, based on vendor quotes and actual costs for similar work. Selection of the recommended alternative was based on A.R.S. § 49-286.B, which states the following: “selection of mitigation measures shall balance the short-term and long-term public benefits of mitigation with the cost of each alternative measure. The director may only require the least costly alternative if more than one alternative may render water usable as a drinking water source.”

1.2 Site Background

The PDSTI is approximately 25 miles south of Tucson and 0.5 to 1.5 miles west of Green Valley in Pima County, Arizona (Figures 1 and 2). The PDSTI covers approximately 3,600 acres east of the Phelps Dodge Sierrita Mine and west of Green Valley.

In the 1970s, groundwater was found to contain elevated concentrations of sulfate in the vicinity of PDSTI and other mines in the Pima mining district (Pima Association of Governments (PAG), 1983a and 1983b). PAG (1983a and 1983b) identified the origin of the sulfate as seepage from various tailing impoundments into the underlying aquifers.

PDSI installed and operates groundwater wells along the eastern and southeastern boundaries of the PDSTI to intercept sulfate-bearing seepage before it can flow eastward and mix with groundwater in the regional flow system. These wells are called the "interceptor wellfield." Water pumped from the interceptor wellfield is used at the mine, thereby reducing the amount of fresh groundwater needed for mine operations. The development and operation of the PDSTI and the interceptor wellfield is described in detail by M&A (2007b).

M&A (2007b) evaluated the effectiveness of the interceptor wellfield based on analysis of groundwater level gradients, sulfate concentration data, and numerical model simulation of groundwater flow in the vicinity of the interceptor wellfield. The evaluation determined that the southern portion of the interceptor wellfield provided an effective hydraulic barrier to seepage from the PDSTI, but the northern portion did not. Seepage capture at the northern portion of the interceptor wellfield, from approximately IW-6A northward (Figure 3), is only partially effective because the small saturated thickness of the basin fill aquifer prevents sufficient pumping to develop effective hydraulic capture. In contrast to the north half of the interceptor wellfield, the greater saturated thickness of the south portion of the wellfield allows the pumping needed to establish effective capture.

1.3 Hydrogeologic Setting

Three generalized hydrogeologic units are identified in the PDSTI area: Recent alluvium, Quaternary and Tertiary basin fill deposits, and the bedrock complex. Recent alluvium is not a significant aquifer because it is typically unsaturated. Basin fill materials are relatively permeable sand and gravel deposits that compose the primary water supply aquifer in the area.

The bedrock consists of indurated sedimentary, igneous, and metamorphic rocks that typically have low permeability and do not constitute a significant aquifer. A comprehensive description of the hydrogeology and water quality in the vicinity of the PDSTI is provided in the Work Plan (HGC, 2006a).

The basin fill is the primary source of water to wells in the PDSTI area. The saturated thickness of the basin fill increases eastward from zero at the western basin margin in the vicinity of the PDSTI to more than 1,000 feet in the central part of the basin near Green Valley. Wells in the central part of the basin are capable of pumping rates greater than 1,000 gallons per minute (gpm) due to the large saturated thickness and relatively high permeability of the basin fill. Figures 4, 5, and 6 are cross sections illustrating the basin fill character and saturated thickness in the vicinity of the north half of the PDSTI. Cross-section locations are show in Figure 3.

Groundwater elevations in the third quarter of 2007 are shown in Figure 7. Groundwater elevations decrease from west to east in the immediate vicinity of PDSTI, from south to north across the central portion of the study area near Green Valley, and from east to west on the alluvial fan east of the Santa Cruz River. The overall pattern of groundwater flow indicated by groundwater elevations is consistent with expected regional groundwater flow patterns in the southern portion of the Tucson groundwater basin.

Regional groundwater flow is generally from a south-southwest direction to a northeasterly direction in the Green Valley area. As water in the regional aquifer flows northeasterly past the PDSTI, groundwater with background levels of sulfate mixes with sulfate-impacted seepage flowing east from the PDSTI, forming the plume that is being characterized under the Mitigation Order. Figure 8 shows the regional distribution of sulfate in groundwater within the basin fill aquifer as measured by sampling conducted in the third quarter of 2007.

1.4 Hydrogeologic Constraints on Interceptor Wellfield Effectiveness

The objective of the interceptor wellfield is to control the migration of sulfate-impacted seepage to the regional aquifer. The small saturated thickness of the basin fill aquifer in the northern portion of the interceptor wellfield is a primary constraint on the effectiveness of pumping to control seepage because the pumpage attainable at a well or wellfield decreases as the saturated thickness of the aquifer decreases.

The width of a capture zone established by a pumping well or wellfield is directly proportional to its total pumpage (assuming constant hydraulic properties and overlapping capture zones in the case of a wellfield). In the north half of the interceptor wellfield, only low pumping rates can be attained because the saturated thickness of the aquifer is small and drawdown at the wells is a large fraction of the saturated thickness. Consequently, the capture zone of individual wells is small. Pumping in the southern portion of the interceptor wellfield is effective because the larger saturated thickness of the aquifer in the south portion allows pumping at rates sufficient to effectively capture sulfate-impacted seepage. Because of the small saturated aquifer thickness at the north half of the interceptor wellfield, mitigation alternatives for enhancing capture considered increasing the number of wells in the existing wellfield or placing wells east of the PDSTI where the saturated thickness of the basin fill aquifer is greater.

2. IDENTIFICATION AND SCREENING OF POTENTIALLY APPLICABLE MITIGATION ACTIONS, CONTROL TECHNOLOGIES, AND PROCESS OPTIONS

This section discusses the mitigation action objectives and presents a screening analysis of the mitigation actions, control technologies, and process options that may be used to control seepage from the north part of the PDSTI. Mitigation actions are generic categories of responses that can be taken to accomplish the mitigation action objectives (e.g., groundwater control). Mitigation actions can be composed of more than one control technology (e.g., technologies that provide hydraulic or physical containment). Each control technology can consist of one or more process options (e.g., hydraulic containment through vertical wells, horizontal wells, or physical barriers such as slurry walls).

Potentially applicable mitigation actions, control technologies, and process options were identified and screened for effectiveness, implementability, and cost. Effectiveness refers to the ability and reliability of the technology or process option to meet the mitigation objectives over the short- and long-term, consideration of potential impacts to human health and the environment during construction and implementation, and whether the technology or process option is proven and reliable. Implementability is defined for the screening process as the technical and regulatory feasibility of implementing a technology or process option at the site, given the general site conditions and regulatory constraints (e.g. permitting). Effectiveness and implementability were the primary screening criteria. Cost was evaluated qualitatively for the screening and used as a secondary screening criterion to discriminate between control technologies and process options with equivalent effectiveness and implementability.

2.1 Mitigation Action Objectives

Mitigation action objectives are qualitative and quantitative statements of the mitigation goals. The mitigation objective for this FFS is to control sulfate migration from the northern portion of the interceptor wellfield to the regional aquifer. This FFS focuses on evaluation of methods to improve the effectiveness of the northern portion of the interceptor wellfield. The FSS assumes that the southern portion of the interceptor wellfield is effective and will continue operation into the future.

There is no Arizona numeric aquifer water quality standard for sulfate to use as a quantitative mitigation objective. The Mitigation Order adopted a sulfate limit of 250 mg/L for a drinking water supply. Thus, any potential mitigation action that considers groundwater recharge will use the Mitigation Order sulfate limit as a numeric cap for sulfate concentration in water added to the aquifer.

2.2 Mitigation Actions

Mitigation actions included in the screening are: 1) groundwater control, 2) water treatment, and 3) water management (Table 1). Groundwater control includes technologies that establish hydraulic conditions that potentially allow the capture of sulfate-impacted seepage either near the PDSTI or at a downgradient location. Water treatment refers to technologies that can be used to remove sulfate from water either in the aquifer or in water produced for or used by a groundwater control action. Water management actions provide for the use, storage, or release of water-producing mitigation actions. Specific control technologies and process options for these mitigation actions are discussed below and outlined in Table 1.

2.3 Identification and Screening of Control Technologies and Process Options

Control technologies are one or more methods available within a mitigation action. For example, groundwater pumping in combination with a groundwater barrier are two control technologies that can potentially be used for a groundwater control mitigation action. Process options are specific techniques used by a control technology, such as the use of either vertical or horizontal wells for groundwater pumping. Control technologies and process options selected as appropriate for each mitigation action described above are listed in Table 1 along with a summary of effectiveness, implementability, and relative cost. The technologies and process options are described below along with the rationale for eliminating some of them from further consideration.

2.3.1 Groundwater Control Technologies

Groundwater control includes technologies that establish hydraulic conditions allowing the control and removal of sulfate-impacted seepage either near the PDSTI or at a downgradient location. Two categories of groundwater control technologies were considered for the screening: 1) groundwater pumping and 2) groundwater barriers. A screening of these technologies is presented below.

2.3.1.1 Groundwater Pumping

Groundwater pumping involves the use of wells to control the migration of sulfate by the extraction of groundwater. Because sulfate in excess of 250 mg/L appears to be distributed throughout the lateral and vertical extent of the basin fill aquifer in the northern portion of the interceptor wellfield (HGC, 2006a), full containment of groundwater from the north portion of the interceptor wellfield is needed to control sulfate migration. Full containment typically requires a recharge source downgradient or crossgradient of the pumping wells or a groundwater barrier to maintain hydraulic containment and prevent downgradient mass transfer.

The term "groundwater containment" is used in this FFS for a pumping program intended to control sulfate migration, to the maximum extent practicable, by the extraction of groundwater from the north half of the interceptor wellfield. Groundwater containment would require a wellfield with a sufficient number of wells and pumping capacity to depress the water table and establish a capture zone encompassing the north portion of the interceptor wellfield. Groundwater within the capture zone would flow to and be extracted by the wells comprising the wellfield and not beyond it. In an areally extensive aquifer, parameters that must be evaluated in designing a containment wellfield are: 1) extent of containment and minimum pumping requirements, 2) number of wells required to establish containment, and 3) disposition of captured water. The number and configuration of wells required for a containment wellfield, and the need for a groundwater barrier or injection wells to allow efficient capture of groundwater, are a function of aquifer conditions at the points of pumping.

Groundwater pumping actions require water management for pumped water (Section 2.3.3). Four groundwater pumping options were considered for screening:

- Vertical wells proximal to the interceptor wellfield
- Vertical wells distal to the interceptor wellfield
- Horizontal wells proximal to the interceptor wellfield
- Ranney wells

Vertical Wells Proximal to the Interceptor Wellfield

This process option would involve installation of additional pumping wells in the ineffective, northern portion of the interceptor wellfield to establish greater capture than the current wellfield. Wells would be installed to fully penetrate the basin fill. The basin fill along the northern half of the interceptor wellfield ranges from 400 to 600 feet thick (Figures 4a and 4b), however, the observed saturated thickness ranges from about 30 to 200 feet, which limits pumping from the current high capacity wells in the north wellfield. For this reason, the additional wells would be designed as small capacity pumping wells to minimize drawdown at individual wells. A tradeoff arises in that limiting the pumping capacity of individual wells immediately east of the PDSTI requires installation of more wells to pump the total volume needed to establish containment.

The installation and operation of additional wells in the northern portion of the interceptor wellfield could be effective at containment in the short-term (months to years), but the additional pumping would further reduce the saturated thickness of the aquifer resulting in diminished well yields and ineffective capture. More wells could be added over time, but eventually a point of diminishing returns would be reached at which capture of all sulfate-impacted groundwater could not be attained. For this reason, this option is considered to have poor long-term (years to decades) effectiveness. The implementability of this option is good because it can be implemented entirely on PDSI property with minimal delay for permitting or land acquisition. Because of existing infrastructure, engineering time and cost would be minimized. Although potentially ineffective in the long-term, expansion of the northern portion of the interceptor wellfield through the installation of additional vertical wells was retained for further evaluation because of its implementability on PDSI property and use of existing infrastructure.

Vertical Wells Distal to the Interceptor Wellfield

This process option considers installation of pumping wells east of the PDSTI to establish containment at a location where the aquifer has sufficient saturated thickness to allow high capacity pumping. Arizona State Land Department (ASLD) controls the undeveloped land east from the PDSI property boundary approximately 4,700 feet (Figure 3). East of the ASLD land is private property and Pima County right-of-way. Basin fill in the area on the east side of the ASLD land is 800 to 900 feet thick as observed at monitoring wells MH-12 and MH-25 (Figures 5 and 6) and has a saturated thickness between 300 and 500 feet. This process option would require permitting and leasing well sites and easements for the infrastructure needed to establish a wellfield (e.g., pipeline corridor, electrical service, access roads).

A new wellfield on ASLD land, private property, or county right-of-way east of the northern interceptor wellfield has the benefit of allowing pumping in a deeper part of the aquifer that can sustain higher pumping rates. A new wellfield east of the interceptor wellfield would require fewer wells to establish groundwater containment compared to the northern portion of the existing interceptor wellfield but would require an increase in the cumulative volume of water pumped. Both the short- and long-term effectiveness of this process option are expected to be good because pumping in the thicker portion of the aquifer can probably contain flow from the north portion of the wellfield and maintain well efficiency. This process option is considered implementable pending successful negotiation of land access and permitting. Access to ASLD land would be required for a pipeline corridor even if wells were on county right-of-way or private property. PDSI currently has right-of-way for an existing pipeline, the Esperanza pipeline, across ASLD property (Figure 9). One aspect of locating new facilities on ASLD property is that permitting and negotiation with ASLD is expected to take at least 14 months to complete. Wellfield construction would probably require another 6 to 12 months for completion. This process option was retained as potentially applicable because of its effectiveness, although it has a potentially long lead time for permitting, land access negotiation, and construction.

Horizontal Wells Proximal to the Interceptor Wellfield

This process option would pump groundwater from one or more horizontal wells placed at the base of the basin fill aquifer in the northern interceptor wellfield. Because a horizontal well would be saturated along a length of approximately 7,000 feet, there would be a greater area for groundwater inflow than is currently available with vertical wells. This should avoid the reduced productivity associated with drawdown at vertical wells.

Horizontal well technology has been incorporated into many environmental remediation applications such as in-situ bioremediation, air sparging, vacuum extraction, and soil flushing and product recovery. This technology is most applicable to sites with relatively shallow soil and or groundwater contamination, and can potentially enhance remediation efforts at sites with low hydraulic conductivities.

The potential advantage of a horizontal well is that the wellfield pumping capacity may be increased relative to vertical wells because long horizontal screens contact a larger area of aquifer and horizontal wells are not as susceptible as vertical wells to reduced efficiency associated with drawdown due to a lowering saturated thickness. Thus, a horizontal well is potentially effective for enhancing capture at the interceptor wellfield. Most horizontal wells are installed to shallow depths for remediation rather than water production (Miller, 1996 and Fournier, 2005).

A contractor specializing in horizontal drilling reported that it would require 2,000 feet of blank casing to reach a depth of 500 feet for screen installation. Although the 500-foot depth of installation was potentially achievable, the contractor indicated that the tracking accuracy decreased with depth and would compromise the ability to install a screen accurately at the base of the basin fill given the irregularities of the basin fill-bedrock contact (Figure 4b). Therefore, the successful installation of a horizontal well in such a way as to provide effective capture along the north portion of the interceptor wellfield is uncertain. For this reason, the implementability of a horizontal well is considered poor and this process option was not considered further.

Ranney Wells

A Ranney well, sometimes referred to by its generic name “horizontal collector well”, consists of one or more horizontal well screen laterals installed into an aquifer from a central vertical caisson. These systems consist of a vertical central shaft, or caisson, typically 16 feet in diameter, excavated to a target depth at which well screens project laterally outward in a radial pattern. The caisson is typically constructed in place from reinforced concrete using the open caisson method with multiple lifts. The caisson serves as a collection point for water that enters the system through the network of well screens. Flow from the aquifer is pumped from the central caisson.

The Ranney well option was considered because the increased wetted screen lengths from the lateral horizontal well screens could potentially allow increased pumpage and minimize drawdown in an area with limited saturated thickness. Ranney wells are typically used for extracting groundwater from shallow aquifers adjacent to streams. The depths of the basin fill in the north portion of the interceptor wellfield range from 400 to 600 feet (Figures 4a and 4b). There are no known uses of Ranney wells at these depths. Further, discussion with the Ranney well vendor indicated that installation of a Ranney well at these depths was impractical. Additionally, the vendor was unaware of an equivalent type of technology that would be applicable at the interceptor wellfield. The Ranney well was eliminated as a process option because of technical impracticability.

2.3.1.2 Groundwater Barriers

Groundwater barriers impede or prevent subsurface flow for the purpose of damming groundwater on the upgradient side of the barrier or channeling flow. Barriers are a common remedial technology effective at isolating portions of impacted aquifers. Barriers are often used to either channel flow around an area to be isolated, to route flow into an area for in-situ treatment, or in combination with upgradient pumping to achieve groundwater containment. Groundwater barriers are used with pumping systems on the upgradient side of the barrier to prevent a buildup of hydraulic head that could lead to flow over or around the barrier.

Groundwater barriers may be either engineered low permeability structures that are physically emplaced in the subsurface or hydraulic barriers that recharge water to create hydraulic pressure fields that alter groundwater flow patterns. The term hydraulic barrier is used in this FFS as a process that recharges groundwater to buildup hydraulic head for the purpose of controlling the direction of groundwater flow and enhancing wellfield capture. This process differs from groundwater pumping which depresses the hydraulic head around a wellfield to create a capture zone, although groundwater pumping can also create a type of hydraulic barrier as discussed in Section 2.3.1.1. A hydraulic barrier may be implementable in cases where installation of a physical barrier is not. Also, hydraulic barriers are not permanent because the hydraulic head field dissipates when recharge is stopped.

The three groundwater barrier options considered for the FFS screening were:

- Physical barriers
- Hydraulic barrier using injection wells
- Hydraulic barrier using infiltration ponds

Physical Barriers

The process option of a physical barrier would place a wall of low permeability or impermeable material in the aquifer downgradient of the interceptor wellfield to allow groundwater levels to build up to a point that allows efficient pumping. Several physical barrier process options are available. Physical barriers, such as slurry walls or funnel and gate systems typically consist of a trench vertically excavated with a backhoe or crane and filled with low permeability material. Barrier materials can be low permeability mixtures of fine-grained soil, clay, or cement. Impermeable material such as polyethylene geomembrane sheeting can also be added to barriers. Sheet piling can be used in some conditions to create a continuous physical barrier of interlocking steel or plastic panels. Soil mixing and permeation, or jet grouting (grout injection) are additional methods of constructing a physical barrier.

Although physical barriers potentially would be effective for enhancing pumping in the north part of the interceptor wellfield, the practically achievable depth of construction of a physical barrier is generally less than 150 feet. Although, chemical reagents could be injected into an aquifer to solidify and create a zone of reduced permeability around the injection point, this is a seldom-used technology with significant uncertainty of effectiveness. For these reasons, a physical barrier is considered to have poor implementability due to technical infeasibility and was not considered further.

Hydraulic Barrier Using Injection Wells

Creation of a hydraulic barrier using injection wells is implementable in that injection wells are a commonly used technology. This process option would install a system of wells to inject water downgradient of the interceptor wellfield. The wellfield could be installed on existing PDSI property in the north half of the interceptor wellfield. Over time, the groundwater mound resulting from injection would increase the local hydraulic head field, increase the saturated thickness, reverse the local hydraulic gradient, and thereby allow effective containment through pumping the existing interceptor wells. Using injection wells to create a hydraulic barrier requires a source of water for injection that is low in sulfate, meets aquifer water quality standards, and would not plug injection wells. Such a water supply could be obtained from existing water supply wells or by treating water pumped at the interceptor wellfield. This option would create a zone of recharge with reduced sulfate concentrations that would migrate downgradient from the interceptor wellfield, although some of the injected water would mix with sulfate-impacted groundwater and be pumped at the interceptor wellfield.

A hydraulic barrier using injection wells could be effective in enhancing seepage capture at the interceptor wellfield. Potential benefits of this option are that injection wells are readily implementable on PDSI property, can utilize existing infrastructure to some degree, and the injected water creates a zone of low sulfate water that migrates away from the interceptor wellfield.

Although injection wells are a commonly used technology, they can be associated with high operation and maintenance (O&M) costs. Factors that would take time for implementation include obtaining a U.S. Environmental Protection Agency Underground Injection Control (UIC) permit and an Arizona Aquifer Protection Permit (APP), engineering design, and construction. Theoretically, this option could be an effective means of controlling groundwater flow from the north portion of the interceptor wellfield, although operation of a full-scale injection wellfield can be demanding due not only to normal challenges of wellfield operation, but also due to clogging that typically occurs in injection wells. Clogging can result from chemical precipitates that form when injected water aerates or mixes with water of a different chemistry, from entrainment of air bubbles that reduce the hydraulic conductivity of the aquifer near the well, or from particulates in the injected water that can clog the well screen, filter pack, and formation. These potential problems can be minimized by careful design and operation, chemical treatment prior to injection to reduce formation of precipitates, and filtration of particulates in injected water (Pyne, 2005). This option was retained for further evaluation because of its potential effectiveness and implementability.

Hydraulic Barrier Using Infiltration Ponds

Like injection wells, infiltration ponds are also a well-developed and commonly used technology. This process option would use surface ponds or an infiltration gallery to create a groundwater mound as a hydraulic barrier downgradient of the interceptor wellfield. The ponded water would infiltrate to the subsurface and migrate to the water table by gravity flow through the vadose zone. A groundwater mound would grow once a continuous zone of recharge is established between the surface and the water table.

Infiltration could be an effective method for recharge, but implementability is dependent on the infiltration capacity at potential recharge sites, the character of subsurface materials, the hydraulic loading required, and land availability. A source of low sulfate water meeting aquifer water quality standards would be required for recharge. Construction and operation of infiltration ponds would require UIC and APP permitting. Access to ASLD land might be required if the size of infiltration basins is larger than feasible on PDSI property.

The vertical permeability of subsurface materials strongly influence the timing and geometry of groundwater recharge by infiltration. As shown by Figure 4b, there are layers of fine-grained sediment between the water table and the surface in the north part of the interceptor wellfield. These layers are expected to have a lower vertical hydraulic conductivity than surrounding materials and can either impede the vertical migration of infiltration or lead to perched water zones in which groundwater may spread laterally. Thus, compared to well injection, the exact placement of recharge water by infiltration is less exact due to site-specific conditions.

Although potentially effective and implementable, infiltration was not considered further because the presence of low permeability fine-grained layers in the vadose zone beneath the interceptor wellfield would slow the development of and potentially interfere with exact placement of the hydraulic barrier. Although infiltration would probably be less expensive than injection wells because it does not require construction and operation of a wellfield, control of the recharge process would not be as exact, verifiable, or able to be adapted if needed as compared to an injection wellfield. For these reasons, infiltration is considered to be less effective than an injection wellfield and was not considered further.

2.3.2 Water Treatment Technologies

Water treatment technologies are processes capable of removing sulfate from water by chemical, physical, or biological means (Lorax Environmental, 2003). Chemical treatment uses reagents to adjust the chemistry of solution to remove sulfate by precipitation or to change sulfate to sulfide by reduction. Physical treatment methods remove sulfate using semi-permeable membranes as ionic filters. Biological treatment uses microbial processes for the biological transformation of sulfate to sulfide or native sulfur. In the context of this FFS, water treatment has two potential applications:

- In-situ treatment would add reagents to the subsurface aquifer to modify the groundwater chemistry in such a way that sulfate in groundwater is either precipitated downgradient of the interceptor wellfield or reduced to sulfide through chemical or biological processes.
- Ex-situ treatment would use conventional water treatment technologies to remove sulfate from water for discharge or use under a water management option (Section 2.3.3) or if a groundwater control option requires water for recharge.

2.3.2.1 In-situ Treatment

In-situ treatment technologies manipulate the groundwater chemistry in the subsurface area to be treated through the injection or infiltration of reagents that can lead to the precipitation, transformation, or destruction of the chemical of concern. In the case of sulfate, in-situ chemical treatment would inject reagents to either precipitate sulfate in the subsurface or reduce sulfate to sulfide. In-situ biological treatment would inject reagents to enhance the activity of endogenous or exotic microbial populations capable of reducing sulfate to sulfide.

In-situ treatment is typically used to treat groundwater containing organic chemicals, although there are also examples of in-situ treatment of metals. The size of typical applications of in-situ treatment in terms of groundwater flow rates and areal extent is small (i.e., hundreds of gpm or less and tens of acres or less) compared to the size of the groundwater flow system from the north part of the interceptor wellfield (i.e., thousands of gpm and hundreds of acres). In-situ treatment requires equipment, infrastructure, and reagent supply to provide a uniform and continuous delivery of chemicals to the zone of treatment to meet the ongoing treatment demand of sulfate loading from the north part of interceptor wellfield. UIC and APP permits would be required for in-situ treatment.

In-situ treatment of sulfate by chemical and biological means is an unproven technology. Although there are some cases of in-situ treatment in which sulfate is reduced by precipitation of metal sulfides in the presence of high metals concentrations, there are few, if any, field demonstrations of in-situ treatment of sulfate only. Chemical precipitation of sulfate as gypsum, barium sulfate, or metal sulfides would not be practical for in-situ treatment because of the low sulfate removal efficiency in the case of gypsum, potential clogging of injection wells and the aquifer by precipitates, the need to inject continuously large amounts of reagents into the aquifer, and the difficulty of uniformly delivering chemicals throughout the saturated thickness of the aquifer so that a continuous zone of treatment is created. The use of reducing agents for in-situ chemical or biological reduction of sulfate would be ineffective because sulfide would remain mobile in groundwater in the absence of metals. Although some sulfide might precipitate as pyrite in the aquifer, most sulfide would either reoxidize to sulfate when mixing with regional groundwater flow or would remain in solution as an undesirable constituent such as hydrogen sulfide.

In summary, in-situ treatment is considered ineffective and not implementable for controlling sulfate loading inflow from the north part of the interceptor wellfield. In-situ treatment was rejected as a potentially applicable process option.

2.3.2.2 Ex-situ Treatment

Ex-situ treatment might be used in the event that sulfate-bearing water needs treatment for water management (e.g., treatment for discharge or use in the event that mine use is no longer available) or groundwater control (e.g., treatment of interceptor wellfield water for reinjection). Process options for ex-situ treatment of sulfate consist of the standard treatment technologies for sulfate removal, such as chemical precipitation, ion exchange, biological treatment, or membrane processes (reverse osmosis, nanofiltration, or electrodialysis reversal) (Lorax Environmental, 2003). Sulfate removal by membrane process is the predominant sulfate treatment methodology used in practice.

As reported in HGC (2006b), Brown and Caldwell reviewed potentially applicable technologies for treating sulfate in drinking water supply wells at concentrations and flow rates similar to the north portion of the interceptor wellfield. The review identified reverse osmosis or nanofiltration as the most feasible treatment technologies for wellhead treatment. Electrodialysis reversal was also identified as a potentially applicable technology that had longer design and construction requirements but that might be applicable in the context of the FFS. Sulfate treatment systems using reverse osmosis, nanofiltration, or electrodialysis reversal are expensive to construct and operate due to power consumption and the production of concentrate reject that needs recycling or disposal. For example, capital costs for a membrane process to treat the interceptor wellfield flow would be on the order of tens of millions of dollars. Reverse osmosis, nanofiltration, or electrodialysis are effective and implementable ex-situ treatment processes that were retained for further evaluation in the event water treatment is needed, although other emerging technologies may be available if treatment is needed (Lorax Environmental, 2003).

2.3.3 Water Management

Groundwater pumped for groundwater control actions would have to be managed by use, storage, or treatment and discharge. Three water management options were screened for potential application.

- Use in mining operations
- Discharge to surface
- Use as drinking water

2.3.3.1 Use in Mining Operations

The current use of water pumped at the interceptor wellfield is as industrial water supply for the Sierrita Mine. The use of water in mining operations provides a beneficial use for sulfate-impacted water and minimizes the demand for fresh water. The use of water in mine processes is dependent on the industrial water demand of the mine and the chemistry of the water. Currently, a steady demand for industrial water in excess of 10,000 gpm is expected for 25 years. The chemistry of water from the interceptor wellfield is suitable for use in mine processes.

Use of water in mining operations is effective and implementable using existing infrastructure. The use of existing infrastructure and the avoidance of the high cost of water treatment make water use at the mine cost-effective compared to surface discharge or use as drinking water which would require costly water treatment. The effectiveness of this process option depends on the magnitude and duration of operational water demands. If groundwater pumping is required following the cessation of mining, other water management process options may need to be implemented. Consideration of post-mine water management is beyond the scope of the FFS, but will be evaluated in the Feasibility Study being prepared under the Mitigation Order Work Plan. Use of water in mining operations was retained as a water management process option.

2.3.3.2 Discharge to Surface

Water generated by groundwater control actions could potentially be discharged to the surface of an ephemeral drainage pursuant to an Arizona Pollutant Discharge Elimination System permit. Water discharged to the surface would infiltrate to the subsurface along the flowing reach created by the discharge. Because this process option would recharge water to the subsurface, treatment of sulfate (Section 2.3.2.2) would likely be needed. Discharge to the surface is effective and implementable, but the cost would be high due to the need for water treatment. This option was eliminated as a potentially applicable process option for water management because of its high cost compared to mine use.

2.3.3.3 Use as Drinking Water

Use as drinking water would require water treatment (Section 2.3.2.2) to meet the sulfate mitigation level and any applicable drinking water standards. Treated water could be conveyed to public water supply lines and sold to a water company to augment the local water supply. The treatment facility and distribution system to implement this option may need to comply with Arizona regulations regarding public water systems (Arizona Administrative Code R18-4-201 through R18-4-290) depending on the exact circumstances.

Use of treated water as a potable supply would be an effective means of water management. As compared to discharge to the surface, use as potable supply would have the potential benefit of reducing water supply pumping by local water providers. This process option is technically implementable, but would require acceptance by a water company and the public. The high cost of treatment required for drinking water supply would make this a high-cost process option compared to mine use. Use as drinking water supply was eliminated as a process option due to its high cost.

2.4 Summary of Screening of Technologies and Process Options

The screening of technologies and process options considered a range of potentially applicable actions for incorporation into mitigation alternatives. The screening process qualitatively narrowed the range of options on the basis of effectiveness and implementability (Table 1).

Process options retained by the screening are listed below:

- Groundwater Control Actions:
  - Vertical Wells Proximal to the Interceptor Wellfield
  - Vertical Wells Distal to the Interceptor Wellfield
  - Hydraulic Barrier Using Injection Wells
- Water Treatment Actions:
  - Ex-Situ Treatment by Membrane Processes
- Water Management Actions:
  - Use in mining operations

3. DEVELOPMENT AND SCREENING OF MITIGATION ALTERNATIVES

Mitigation alternatives are combinations of technologies and process options that will meet the mitigation objective of controlling sulfate migration from the northern portion of the interceptor wellfield to the regional aquifer. This section formulates and describes mitigation alternatives consisting of process options retained by the previous screening evaluation (Section 2.4). Section 3.1 discusses the basic process options constituting the mitigation alternatives. Section 3.2 describes each alternative. Section 4, the detailed analysis of alternatives, evaluates the performance and cost of the mitigation alternatives.

3.1 Development of Mitigation Alternatives

The mitigation alternatives consist of technologies and process options retained by the previous screening evaluation (Table 1). At a minimum, the alternatives utilize groundwater control and water management actions. Water treatment actions are available but are not needed to implement groundwater control or water management actions.

Groundwater control actions retained by the screening include the following:

- Expand the pumping capacity in the north half of the interceptor wellfield by the installation of a large number of low capacity wells on PDSI property,
- Develop a new wellfield consisting of a small number of high capacity wells on land east of the PDSTI and interceptor wellfield, and
- Develop an injection wellfield along the northern portion of the interceptor wellfield on PDSI property to create a hydraulic barrier and increase capture by the existing wellfield.

Groundwater control actions will need to use a containment operating strategy because sulfate concentrations in groundwater exceed the Mitigation Order action level over most of the saturated thickness of the basin fill aquifer at potential wellfield locations. Thus, for conceptual design, groundwater flowing to the prospective wellfield locations was considered to be pumped to establish a capture zone enveloping the northern interceptor wellfield. A containment operating strategy would control sulfate migration from the northern portion of the interceptor wellfield and reduce sulfate mass loading to the regional aquifer. Groundwater pumping may be conducted under PDSI's existing grandfathered Type 2 water right, its existing mineral extraction groundwater withdrawal permit, a permit to withdraw poor quality groundwater within an active management area, or other instruments yet to be identified.

Groundwater control and water management actions form the basis of the three mitigation alternatives evaluated by the FFS. These approaches are:

- Alternative 1 – Expanded Pumping at Interceptor Wellfield
- Alternative 2 – New Wellfield east of the PDSTI
- Alternative 3 – Enhanced Capture at the Interceptor Wellfield Using Injection Wells

Each of these approaches would use the water in mining operations.

3.2 Description of Mitigation Alternatives

This section contains conceptual descriptions of the three mitigation alternatives, one of which has two implementation options resulting in a total of four individual mitigation alternatives. The alternatives were developed under the direction of PDSI and are conceptual in scope. Any alternative implemented by PDSI would be subject to engineering evaluation and may be modified to ensure effective performance based on site-specific factors. The level of detail presented in this FFS is intended to provide sufficient information and a common basis for comparison purposes and selection of a remedy that meets the mitigation objective. The alternative descriptions in the FFS are not intended to serve as the final design.

3.2.1 Alternative 1 – Expanded Pumping at Interceptor Wellfield

Expansion of the existing northern portion of the interceptor wellfield (Figure 9) was considered by M&A (2007c) due to their familiarity with the infrastructure and operation. M&A (2007c) evaluated the potential to install additional interceptor wells to improve capture at the PDSTI, including additional wells in the north and middle part of the interceptor wellfield. M&A (2007c) recommended an expanded wellfield design based on preliminary numerical modeling of capture. M&A (2007c) is included as Appendix A.

Alternative 1 consists of the following:

- Increased pumping at the northern and middle interceptor wellfield by installing a large number of low capacity wells
- Water use in mining operations

Alternative 1 would be implemented by the installation of 25 additional extraction wells along the PDSI property boundary in the northern portion of the interceptor wellfield. In addition, two extraction wells would be installed at the middle of the interceptor wellfield. The proposed wells along the PDSI boundary would replace the existing north wellfield. An option to include an additional five extraction wells in future years is also proposed by M&A (2007c). The total pumpage from all 32 wells would be between approximately 1,250 and 1,850 gpm.

Alternative 1 would require the following activities:

- Design, permit, survey, install, and develop extraction wells
- Purchase and install pumps and associated controls
- Design and construct header piping from the new wells to the existing interceptor wellfield pipeline

Water produced from the new extraction wells would be transported through the existing interceptor wellfield pipeline to the mine for reuse (Figure 9). The existing interceptor wellfield pipeline has a capacity of approximately 11,000 gpm, which is sufficient capacity to convey the increased flow from the northern interceptor wells. The pumping of 1,250 and 1,850 gpm from the expanded interceptor wellfield would be offset by an equivalent reduction in pumping at the Canoa Ranch wellfield.

3.2.2 Alternative 2 – New Wellfield East of the PDSTI

Alternative 2 consists of the following:

- Groundwater containment at a wellfield east of the PDSTI
- Water use in mining operations

Alternative 2 would develop a groundwater containment wellfield east of the PDSTI where the saturated thickness of basin fill is thicker than at the interceptor wellfield and allows for higher pumping rates and greater capture. Two implementation options were considered for Alternative 2. Alternative 2A would consist of a wellfield entirely on ASLD land approximately 2,500 feet east of the PDSTI. The wells were not placed closer to the PDSTI due to concern about adequate aquifer thickness. Alternative 2B would consist of a wellfield 4,700 feet east of the PDSTI along the boundary between ASLD and private property. The saturated thickness of the basin fill is expected to be greater for Alternative 2B than for Alternative 2A. Numerical modeling of groundwater capture was used to develop preliminary designs for the two wellfield options (Sections 4.1 and 4.3.2).

Alternatives 2A and 2B would consist of six or seven wells pumping between approximately 3,350 and 6,800 gpm which would be used in mine operations. A review of existing PDSI infrastructure indicates that water from an offsite wellfield would best be conveyed to the mine via the existing interceptor wellfield pipeline. Water produced from the new wellfield would be piped back to the interceptor wellfield pipeline through a new pipeline that would be installed along the right-of-way of the existing Esperanza pipeline. It is assumed that wells pumping less than 40 gpm in the existing northern interceptor wellfield would be retired once containment is established at the new wellfield. The seven northern interceptor wells that pump greater than 40 gpm would continue to be operated.

A major consideration for Alternatives 2A and 2B is permitting and land status. Alternative 2A is proposed for implementation on ASLD property entirely. Permitting and leasing land from ASLD is expected to take at least 14 months. The ASLD property is relatively undeveloped and would be used for installation of basic infrastructure for the alternative such as access roads, wells, pipelines, and electrical service. ASLD would require biological and cultural resource evaluations for the well sites and pipeline alignments. A fee for water pumpage would also be required by ASLD. Alternative 2B is proposed to use either Pima County right-of-way or private property, although ASLD land would also be a possibility if needed. Installation of wells and pipelines on county right-of-way or private land would require time to negotiate use of private property or to permit right-of-way access, but is expected to take less time than permitting on ASLD land. Also, there would be no ASLD water pumpage fee, assuming it is not necessary to site any wells on ASLD land.

Alternatives 2A and 2B would require the following activities:

- Land use permitting and lease negotiation with ASLD
- Acquisition or leasing of private land or permitting county right-of-way access (Alternative 2B only)
- Develop roads to well sites and along pipeline corridor
- Install electrical service
- Design, permit, install, and develop extraction wells
- Purchase and install pumps and associated controls
- Design and construct pipelines from the new wells to the interceptor wellfield pipeline

3.2.3 Alternative 3 – Enhanced Capture at the Interceptor Wellfield Using Injection Wells

Alternative 3 consists of the following:

- Seepage containment at the interceptor wellfield using injection wells downgradient of the northern portion of the interceptor wellfield
- Water use in mining operations

Alternative 3 would implement a hydraulic barrier consisting of a line of injection wells on PDSI property downgradient of the northern portion of the interceptor wellfield. A preliminary design for the injection well concept was developed and tested using a numerical flow and transport model to evaluate its feasibility and effectiveness (Section 4.1). For conceptual design it was assumed that Alternative 3 would install a system of 12 to 24 wells to inject water downgradient of the interceptor wellfield. The number of injection wells is uncertain because injection well efficiency is not yet known. The groundwater mound resulting from injection would develop a hydraulic head field to increase the saturated thickness, reverse the local hydraulic gradient, and allow effective operation of the existing interceptor wells. The injection wellfield could be installed on PDSI property in the north half of the interceptor wellfield.

Preliminary simulations indicate that injecting between approximately 2,400 and 3,200 gpm of water containing no more than 200 mg/L sulfate and pumping from the 11 existing interceptor wells for a total flow between 2,200 and 3,000 gpm, would prevent offsite migration of water containing more that 250 mg/L sulfate. The production needed from the existing interceptor wells is considered achievable because the water injection will increase the saturated thickness at the interceptor wells. Water pumped from the interceptor wells would be transported to the mine for use through the existing interceptor wellfield pipeline.

Three potential sources of potable water for injection were evaluated: Canoa Ranch water supply, Community Water Company of Green Valley (CWC), and treated interceptor wellfield water. PDSI's Canoa Ranch wells supply fresh water to the mine from a pipeline that passes along the south side of the PDSTI (Figure 9). The Canoa Ranch water system possesses sufficient capacity and low sulfate content to supply the injection wells. Using Canoa Ranch water for injection supply would require constructing a 3-mile pipeline from the Canoa Ranch pipeline to the injection wellfield including a flow control system with back flow prevention. Use of CWC water would require buying water from CWC and routing it to the injection well pipeline from CWC's Reservoir No. 2 at the north end of the interceptor wellfield. CWC as a water source was evaluated conceptually because it is uncertain whether CWC would be willing or able to provide a water source for recharge. Use of treated interceptor wellfield water for injection would require construction and operation of a water treatment and storage facility at which water from the interceptor wellfield could be treated and reinjected.

Preliminary cost estimates were developed for the three water supply options to identify order of magnitude costs (Appendix B). Capital and 25-year net present value, assuming a 7.8 percent discount rate minus a 2.25 percent escalation rate (NPV(25)), cost estimates are listed below:

- Canoa Ranch Water Supply: Capital = \$2,070,000, NPV(25) = \$7,400,000
- CWC Water Supply: Capital = \$806,000, NPV(25) = \$46,900,000
- Treated Interceptor Wellfield Water Supply: Capital = \$12,300,000, NPV(25) = \$24,400,000

Based on cost, the Canoa Ranch water supply is selected as the most cost-effective source of water for injection.

As discussed in Section 2.3.1.2, injection wellfields can be subject to significant O&M concerns related to well clogging. To collect the data needed to develop an operationally effective wellfield that can meet and maintain injection rates, geochemical modeling to evaluate the potential for precipitates and a pilot test would need to be conducted.

The goals of the pilot test would be to identify the following:

- initially achievable water injection rates and productivity loss over time,
- site-specific causes of productivity losses,
- effective methods to reduce productivity losses,
- effective well rehabilitation techniques, and
- actual number of injection wells needed.

Alternative 3 would require the following activities:

- Obtain UIC and APP permits
- Conduct pilot test and other studies needed for wellfield design
- Design, permit, install, and develop injection wells

- Purchase and installation of flow control and associated equipment
- Design and construct a pipeline and flow control system from the Canoa Ranch pipeline

4. DETAILED ANALYSIS OF MITIGATION ALTERNATIVES

The detailed analysis of mitigation alternatives evaluates the effectiveness, implementability, and cost of the proposed mitigation alternatives. The mitigation alternatives are individually evaluated to determine their effectiveness at meeting the mitigation action objective (Section 2.1), and evaluated in comparison to one another to identify relative benefits and costs between alternatives. Uncertainties in the assumptions used to evaluate the alternatives are also discussed.

The mitigation alternatives identified in Section 3.2 were analyzed in a three-step process. First, specific rates for groundwater control actions were determined for each alternative using numerical simulations of groundwater flow. The pumping/injection rates for groundwater control actions were selected to meet the mitigation action objective of controlling sulfate migration in groundwater from the northern portion of the interceptor wellfield to the regional aquifer. Second, preliminary conceptual designs were developed for each alternative considering possible pumping/injection locations, water routing distances, and infrastructure requirements to identify a practicable and cost-effective implementation approach. Third, a cost analysis was conducted for each alternative based on the conceptual design.

4.1 Numerical Modeling of Mitigation Alternatives

Numerical modeling was used to estimate pumping/injection rates for groundwater control actions and to predict the effectiveness of the alternatives at controlling sulfate-impacted groundwater from the north half of the interceptor wellfield. As described in Appendix A, Alternative 1 was evaluated using a numerical model for the PDSTI and the downgradient region that was constructed and described by M&A (2007a). HGC also used the M&A (2007a) model to develop and evaluate Alternatives 2A and 2B.

The M&A (2007a) model was created using MODFLOW, a finite-difference groundwater flow model (Harbaugh and McDonald, 1996). The results of the numerical modeling simulations were evaluated for effectiveness of hydraulic capture by tracing hydraulic streamlines (i.e., particle tracking). Particle traces were processed using MODPATH, a particle-tracking post-processing package developed for MODFLOW (Pollack, 1994).

No additional calibration or model improvements to the M&A (2007a) model were attempted as part of HGC's evaluation. Therefore, the reliability of the model predictions is contingent on how well the original model represents the tailings and regional aquifer near the PDSTI. A recent reevaluation of aquifer data indicates that saturated hydraulic conductivity in the vicinity of the PDSTI may be higher than modeled. If this is the case, the required pumping rates are expected to increase. Consequently, use of the results of the modeling simulations should be limited to the purposes of the FFS and should not be used for final design. Because of the uncertainty in the saturated hydraulic conductivity and how it affects model predictions, pumping rates estimated for Alternatives 2A and 2B were doubled to conservatively develop wellfield designs based on the high range of potential flow.

To evaluate injection wells for Alternative 3, HGC constructed a numerical flow and solute transport model using TRACRN (Travis and Birdsell, 1998). TRACRN is a 3-dimensional finite difference computer code developed by Los Alamos National Laboratories. TRACRN is capable of simulating the flow of both gas and liquid and solute transport under conditions of variable liquid saturation. The model for Alternative 3 was used primarily to test the injection well concept and to develop a preliminary estimate of extraction/injection rates and the well spacings needed.

4.2 Cost Analysis Methodology

A detailed cost analysis was made for each mitigation alternative based on expected permitting and design tasks, equipment procurement, construction, and O&M activities for systems capable of the hydraulic loads from extraction or injection wells. Capital and O&M costs for each alternative were calculated over a 25-year operational period to determine the NPV(25). A discount rate of 7.8 percent minus an escalation rate of 2.25 percent was used to calculate the NPVs. The cost analysis was conservative in that designs and O&M requirements were based on high range estimates of potential pumping/injection requirements.

Capital costs were based as much as possible on vendor quotes developed specifically for this FFS. Wellfield O&M costs were based on PDSI's interceptor wellfield expenditures in 2006 including labor, operating expenses, repair/replacement of equipment, material and instruments, electricity for pumps, well and pump repair/replacement, hydrological consulting, and fabrication. Water distribution costs were calculated from capital estimates of infrastructure needed for the alternatives and the O&M for the pumping and water routing assumptions of the alternatives. The costs associated with each mitigation alternative are discussed in Section 4.3. The costs indentified in Section 4.3 are the incremental cost of the respective alternatives and do not account for the cost of operating the southern interceptor wellfield.

4.2.1 Water Fees

Water fees are paid to Farmers Investment Company (FICO) and ADWR for the amount of groundwater pumped. These fees are a cost that PDSI would incur for mine water from whatever source, regardless of any actions proposed in this FFS. For the purpose of calculating water fees for the FFS, it was assumed that there would be no additional cost to PDSI for FICO or ADWR water pumpage fees long as PDSI's 2005 groundwater pumpage is not exceeded and the FFS pumping is offset by reducing pumping elsewhere.

By agreement, PDSI pays FICO for groundwater that PDSI pumps or uses on certain properties. PDSI makes an annual payment to FICO if it pumps an amount of groundwater up to a fixed annual allocation. In the event that annual PDSI chargeable groundwater pumping exceeds the fixed annual allocation, overage charges apply according to a graduated schedule. The schedule of overage payments prescribes the charge based on the quantity of water pumped in excess of the fixed annual allocation. Because pumpage for Alternatives 1, 2A, and 2B would not exceed PDSI's 2005 pumpage and would offset pumping at the mitigation wells with equivalent reductions in pumping at the Canoa Ranch wellfield, there is no net increase in the FICO payment. Alternative 3 would increase the net pumping in excess of PDSI's

2005 groundwater pumpage because it pumps an additional 3,200 gpm (annualized to 5,160 acre-feet) for injection that does not result in equivalent pumping elsewhere. Consequently, an increase in the FICO payment is applied to Alternative 3, but not Alternatives 1, 2A, and 2B.

The annual ADWR fee for water pumped pursuant to a grandfathered Type 2 water right is $3.10 per acre-foot. Only Alternative 3 pumps groundwater in excess of PDSI's 2005 groundwater pumpage. The annual pumpage in excess of PDSI's 2005 pumpage is approximately 5,166 acre-feet for Alternative 3. Therefore, the ADWR fee is applied to the excess pumpage in Alternative 3, but not Alternatives 1, 2A, and 2B.

Groundwater extracted on ASLD property is subject to an annual fee. The annual fee is assessed by an appraisal and bidding process conducted by ASLD. Based on discussion with ASLD, a groundwater extraction fee of $85 per acre-foot has been applied in the Tucson Active Management Area. Alternative 2A is the only alternative that would pump from ASLD property and be subject to groundwater extraction fee. For the purpose of costing Alternative 2A, the ASLD groundwater extraction fee was assumed to be $85 per acre-foot.

4.3 Analysis of Individual Mitigation Alternatives

Hydrologic analysis and numerical modeling were used to evaluate the different groundwater pumping scenarios for the Alternatives 1, 2A, and 2B and the hydraulic barrier injection system of Alternative 3. Pumping and injection rate assumptions for the alternatives are based on simulation conditions that provided capture or control of sulfate-bearing water from the northern interceptor wellfield to the extent practicable.

4.3.1 Alternative 1 – Expanded Pumping at Interceptor Wellfield

Alternative 1 assumes installation of 32 extraction wells (the nominal case of 27 wells plus 5 additional wells) along PDSI's eastern and northeastern property boundary to a depth of between 550 and 700 ft bgs. Figure 10 shows the location of wells, pipelines, and other infrastructure for the nominal case included in Alternative 1. The two southern most wells were assumed to pump at 50 and 600 gpm, whereas all other wells were estimated between 20 and 40 gpm. The aggregate pumping rate for Alternative 1 was estimated at between 1,250 and 1,850 gpm. The preliminary design used for costing was based on the estimated high flows for Alternative 1.

The preliminary piping design utilized the existing northern IW manifold piping. The existing manifold piping would be extended north of IW-21 in diameters from 6 inches to 2 inches to include the eight additional extraction wells north and northwest of IW-21. The furthest south replacement well would be connected to the main manifold using an 8-inch HDPE distribution piping while the remaining replacement wells would be connected using 2-inch distribution piping (Figure 10).

Implementability

The implementability of Alternative 1 is good. The installation of additional wells can be conducted entirely on PDSI property with minimal permitting time. Alternative 1 should not have significant leadtime for engineering and construction because the use of existing infrastructure would require only limited modifications for implementation. Additionally, water produced from the new wellfield can be delivered to the mine immediately using the existing interceptor wellfield pipeline. There will be some necessary incremental downtime for the extraction system while converting the existing electrical service for use at the new wells. Alternative 1 is expected to take 12 to 16 months to design and construct.

Effectiveness

The wellfield installed for Alternative 1 is estimated to be 80 percent effective in capturing groundwater flow from the northern portions of the interceptor wellfield due to the limited saturated thickness of the aquifer in the area (Appendix A). Additionally, the effectiveness of the wellfield is expected to decline over time due to continued dewatering, resulting in diminished well yields and incomplete capture. Although the wellfield would be moved to the eastern limit of the PDSI property, the saturated thickness of the aquifer may only be marginally greater than at the current interceptor wellfield. For this reason, the same pumping inefficiencies that limit the existing wellfield are expected to limit a new wellfield. Although Alternative 1 may potentially be effective at increasing capture in the short-term, replacement wells proximal to the existing interceptor wellfield is not an effective long-term option. Therefore, the effectiveness of Alternative 1 is judged to be poor.

Cost

The estimated project cost for Alternative 1 included pre-construction costs, capital costs, O&M costs, and replacement/repair costs. A detailed summary of estimated costs for Alternative 1 is presented in Appendix D.

The estimated pre-construction costs included a minor amount of surveying and permitting associated with construction of well drilling pads, access roads, and piping runs. No archeological or endangered species surveys are anticipated to be required. Also included are costs associated with engineering design and construction drawing/specifications for: electrical installations; wellhead instrumentation; control and telemetry; piping and valving; and groundwater extraction wells.

Capital costs include: well drilling and construction; pump assembly and installation; electrical equipment, materials, and installation; discharge piping and installation; and construction/project management.

Annual O&M costs include electrical power for the new wellfield, additional electrical power required by the interceptor wellfield pump station, supplies, labor, and hydrogeologic consulting. The Canoa Ranch wellfield O&M costs were estimated to be offset proportionally by the amount of additional water pumped from the new wellfield. These savings in Canoa

Ranch water costs were estimated at $210,000 per year. Cost savings from the reduction in electrical use and O&M associated with the proposed retirement of the existing northern interceptor wellfield were estimated at $257,000 annually.

Supplies and labor costs were estimated using interceptor wellfield costs incurred during 2006. Interceptor wellfield costs for operating year 2006 are summarized in Appendix C. These supply and labor costs are assumed to be proportional to the number of associated process wells. The 1.52 cost factors provided in Appendix D are, therefore, the proportion of additional process wells to existing wells multiplied by the sum of 2006 operating supplies costs ($34,821) and labor costs ($114,052), totaling $149,000 (Appendix C).

Annual costs associated with the repair and/or replacement of materials and equipment included labor, piping, pumps, and motors. Repair and replacement costs are also estimated from interceptor wellfield costs during 2006. These repair and replacement costs are assumed to be proportional to the total flow rate. The 0.31 cost factors provided in Appendix D are, therefore, the proportion of additional flow to existing flow from wells multiplied by the 2006 sum of equipment/materials repair and/or replacement costs ($97,357), well/pump repair and/or replacement costs ($325,447), additional fabrication costs ($75,039), and maintenance and repair labor costs ($209,822), totaling $708,000 (Appendix C).

Cost Summary

Pre-construction and capital costs for Alternative 1 were estimated to be $7.9 million. Annual O&M costs were estimated at $340,000. The 25-year NPV was estimated to be $11.7 million. Costs reflected in these estimates assumed an upper estimate of extraction at 1,850 gpm.

A comparative summary of estimated costs for Alternative 1 (as detailed in Appendix D) is presented in Table 2. These costs are preliminary estimates and subject to variation of +/-35 percent.

4.3.2 Alternative 2A – New Wellfield 2,500 Feet East of the PDSTI

Alternative 2A consists of pumping wells located 2,500 feet east of PDSI property on ASLD property. Alternative 2A was designed assuming the Esperanza pipeline right-of-way could be used for installation of new pipelines.

Alternative 2A assumed installation of 7 wells at depths ranging from approximately 630 to 730 ft bgs. The wells would be aligned on a north-south line in the middle of ASLD property (Figure 11). The predicted capture zone associated with Alternative 2A is shown on Figure 12. Simulated pumping rates for the wells range from 250 to 550 gpm, with a total pumping rate of 3,350 gpm. The preliminary design used for costing was based on a doubling of pumping rates to 6,700 gpm due to uncertainty in the hydraulic conductivity. Estimated drawdowns at the wells after 30 years of pumping are estimated to range from 75 to 135 feet.

Water extracted for Alternative 2A would be piped to the interceptor wellfield for use at the mine. Figure 11 delineates the location of the Alternative 2A wellfield and piping runs. Due to the quantity of flow, the preliminary piping design was unable to utilize the existing IW manifold piping until the pipeline transitions to 28-inch diameter in the vicinity of extraction well IW-2. An additional pipeline parallel to the IW manifold piping was therefore required to handle the additional flow. This pipeline would consist of 8- to 26-inch HDPE within the wellfield manifolding and 28-inch from the wellfield junction to the 28-inch transition in the existing IW piping.

Implementability

The implementability of Alternative 2A is considered good, although a long leadtime is required for permitting. Alternative 2A requires permitting and negotiation with ASLD, which is expected to take at least 14 months to complete. Wellfield design and construction are expected to take another 12 to 16 months once access is attained. The total time expected to implement Alternative 2A is 26 to 30 months. The ASLD property is relatively undeveloped and would require the installation of the basic infrastructure needed to establish the wellfield including roads, drilling pads, pipeline corridors, and electric service.

Effectiveness

The effectiveness of Alternative 2A is good. Figure 12 shows that the simulated capture zone for Alternative 2A encompasses the northern interceptor wellfield and the northeastern corner of the PDSTI. Developing a groundwater containment wellfield east of the interceptor wellfield allows pumping in a deeper part of the aquifer that can sustain the pumping rates needed for capture. The wellfield for Alternative 2A is expected to contain flow from the north portion of the interceptor wellfield without dewatering the aquifer to the degree that pumping rates decline significantly. Therefore, the long-term effectiveness of Alternative 2A is good.

Cost

The estimated project costs for Alternative 2A included pre-construction costs, capital costs, O&M costs, and replacement/repair costs. A detailed summary of estimated costs for Alternative 2A is presented in Appendix D.

The estimated pre-construction costs included Clean Water Act Section 404 surveying and permitting associated with construction of well drilling pads, electrical lines, access roads and piping runs, archeological survey, and endangered species survey. Also included are costs associated with engineering design and construction drawing/specifications for: electrical installations; well head instrumentation; control and telemetry; piping and valving; and groundwater extraction wells.

Capital costs include: well drilling and construction; pump assembly and installation; overhead power lines; electrical equipment, materials and installation; discharge piping and installation; and construction/project management.

Annual operation and maintenance costs include electrical power for the new wellfield, additional electrical power required by the interceptor wellfield pump station, supplies, labor, State Land lease, State Land water pumping fee, and hydrogeologic consulting. The Canoa Ranch wellfield O&M costs were reduced proportionally by the amount of additional water pumped from the new wellfield. The saving in Canoa Ranch wellfield O&M costs were estimated at $1.1 million per year. Cost savings from the reduction in electrical use and O&M associated with the proposed retirement of northern interceptor wells that pump less than 40 gpm were estimated at $34,900 annually.

Supplies and labor costs were estimated using interceptor wellfield costs in 2006 (Appendix C). These supply and labor costs are assumed to be proportional to the number of associated process wells. The 0.34 cost factor provided in Appendix D is, therefore, the proportion of additional process wells to existing wells multiplied by the 2006 sum of operating supplies costs ($34,821) and labor costs ($114,052) totaling $149,000 (Appendix C).

Annual costs associated with the repair and/or replacement of materials and equipment included labor, piping, pumps, and motors. Repair and replacement costs are also estimated using interceptor wellfield costs during 2006. These repair and replacement costs are assumed to be proportional to the total flow rate. The 1.11 cost factor provided in Appendix D is therefore the proportion of additional flow to existing flow from wells, multiplied by the 2006 sum of equipment/materials repair and/or replacement costs ($97,357), well/pump repair and/or replacement costs ($325,447), additional fabrication costs ($75,039), and maintenance and repair labor costs ($209,822), totaling $708,000 (Appendix C).

Cost Summary

Pre-construction and capital costs for Alternative 2A were estimated to be $8.0 million. Annual operation and maintenance costs estimates were approximately $1.9 million. The 25 year NPV was estimated at $30.8 million. The NPV for 25 years was strongly impacted by the assumed State Land water use fees. An upper estimate of the required groundwater extraction flow rate of 6,700 gpm was used to conservatively estimate costs for Alternative 2A.

A comparative summary of estimated costs for Alternative 2A (as detailed in Appendix D) is presented in Table 2. These costs are preliminary estimates and subject to variation of +/-35 percent.

4.3.3 Alternative 2B – New Wellfield 4,700 Feet East of the PDSTI

Alternative 2B assumes installation of six wells to depths ranging between approximately 760 to 1,000 ft bgs. The wells are aligned in a north-south array along the east boundary of ASLD property, east and northeast of the PDSI interceptor wellfield (Figure 13). The alignment of the wells in a north-south array at the eastern boundary of the ASLD takes advantage of the eastward increase in the saturated thickness of the basin fill (Figure 6). The predicted capture zone associated with Alternative 2B is shown on Figure 14. Simulated pumping rates for the wells range from 550 to 600 gpm, with a total pumping rate of 3,400 gpm. As with Alternative 2A, the preliminary design used for costing was based on a doubling of pumping rates to 6,800 gpm due to uncertainty in the hydraulic conductivity. Estimated drawdowns at the wells after 30 years of pumping range from 70 to 90 feet.

Water extracted for Alternative 2B would be piped to the interceptor wellfield pipeline for use at the mine. Figure 13 delineates the location of the Alternative 2B wellfield and piping runs. Due to the higher flow rates, the preliminary piping design was unable to utilize the existing IW manifold until the pipeline transitions to 28-inch diameter in the vicinity of extraction well IW-2. An additional pipeline parallel to the IW manifold piping would therefore be required to handle the anticipated flow rates. This pipeline would consist of 8- to 22-inch HDPE within the wellfield manifolding and 28-inch from the wellfield junction to the 28-inch transition in the IW existing piping.

Implementability

The implementability of Alternative 2B is considered good. Preliminary analysis of land status indicates there is a good possibility that extraction wells and header pipeline can be installed on county right-of-way or private land. Although Alternative 2B would still use ASLD land for the pipeline corridor from the six new wells to the interceptor wellfield pipeline, the new pipeline would be installed along the existing right-of-way for the Esperanza pipeline.

Minimizing the use of ASLD land potentially has the advantage of requiring less time for permitting compared to Alternative 2A. Alternative 2B would require permitting and negotiation with ASLD regarding the Esperanza pipeline right-of way. However, permitting is expected to require less effort because of the pre-existing pipeline. Use of county right-of-way or private land for installation of basic infrastructure (wellfield including roads, drilling pads, pipeline corridors, and electric service) would require necessary permitting and approvals, but would likely be more expedient than developing the wellfield on ASLD land. Obtaining land access is expected to take 6 months. Wellfield and pipeline design and construction are expected to take 12 to 16 months once access is secured. The total time expected to implement Alternative 2B is 18 to 22 months.

Effectiveness

The effectiveness of Alternative 2B is good. Figure 14 shows that the simulated capture zone for Alternative 2B encompasses the northern interceptor wellfield and the northeastern corner of the PDSTI. Alternative 2B would place the wellfield further east and in an area where the basin fill is expected to have greater saturated thickness than other mitigation alternatives. For this reason, Alternative 2B requires fewer wells than Alternative 2A and is expected to be able to sustain the pumping rates needed to capture groundwater flow from the northern interceptor wellfield area. Alternative 2B is considered to have good long-term effectiveness.

Cost

The estimated project costs for Alternative 2B include pre-construction costs, capital costs, O&M costs, and replacement/repair costs. A detailed summary of estimated costs for Alternative 2B is presented in Appendix D.

The estimated pre-construction costs include: Clean Water Act Section 404 surveying and permitting associated with construction of well drilling pads; electrical lines; access roads and piping runs; archeological survey; and endangered species survey. Also included are costs associated with engineering design and construction drawing/specifications for: electrical installations; wellhead instrumentation; control and telemetry; piping and valves; and groundwater extraction wells.

Capital costs include: well drilling and construction; pump assembly and installation; overhead power lines; electrical equipment, materials, and installation; discharge piping and installation; and construction/project management.

Annual O&M costs include electrical power for the new wellfield, additional electrical power required by the interceptor wellfield pump station, supplies, labor, and hydrogeologic consulting. The Canoa Ranch wellfield O&M costs were estimated to be offset proportionally by the amount of additional water pumped from the new wellfield. These saving in Canoa Ranch water costs were estimated at $1.2 million per year. Savings in costs by the reduction in electrical use and O&M associated with the proposed retirement of northern interceptor wells that pump less than 40 gpm were estimated at $34,900 annually.

Supplies and labor costs are estimated from interceptor wellfield costs incurred during 2006 (Appendix C). These supply and labor costs are assumed to be proportional to the number of associated process wells. The 0.29 cost factor in Appendix D is, therefore, the proportion of additional process wells to existing wells multiplied by the sum of 2006 operating supplies costs ($34,821) and labor costs ($114,052), totaling $149,000 (Appendix C).

Annual costs associated with the repair and/or replacement of materials and equipment include labor, piping, pumps, and motors. Repair and replacement costs are also estimated using interceptor wellfield costs in 2006. These repair and replacement costs are assumed to be proportional to the total flow rate. The 1.13 cost factor provided in Appendix D is, therefore, the proportion of additional flow to existing flow from wells, multiplied by the sum of 2006 equipment/materials repair and/or replacement costs ($97,357), well/pump repair and/or replacement costs ($325,447), additional fabrication costs ($75,039), and maintenance and repair labor costs ($209,822), totaling $708,000 (Appendix C).

Cost Summary

Pre-construction and capital costs were estimated to be $8.2 million. Annual O&M costs estimates are approximately $875,000. The NPV(25) was estimated to be $18.6 million. An upper estimate of required groundwater extraction flow rates of 6800 gpm was used to conservatively estimate costs for Alternative 2B.

A comparative summary of estimated costs for Alternatives 2B (as detailed in Appendix D) is presented in Table 2. These costs are preliminary estimates and subject to variation of +/-35 percent.

4.3.4 Alternative 3 – Enhanced Interceptor Wellfield Using Injection Wells

Alternative 3 assumes installation of a system of injection wells to an average depth of approximately 550 ft bgs to inject water downgradient of the interceptor wellfield. A line of 12 to 24 injection wells would extend from about 200 feet south of IW-6A to about 300 feet north of IW-21, located along the property line, approximately 300 feet downgradient (east) of the existing interceptor wells. The injection well locations would be 'staggered' with respect to the interceptor well locations (Figure 15). Recharge water would be obtained from the Canoa Ranch pipeline and conveyed to the injection wells via a new pipeline.

Alternative 3 would involve injection of between 2,400 and 3,200 gpm of potable water through 12 to 24 injection wells into the aquifer, and pumping from the 11 existing northern interceptor wells of between 2,200 to 3,000 gpm. The groundwater mound resulting from injection would increase the hydraulic head allowing effective containment at the existing interceptor wells. The wellfield could be installed on PDSI property in the north half of the interceptor wellfield. The preliminary design used for costing was based on the estimated high flow for Alternative 3 and assumed the high number of injection wells as discussed in Section 3.2.3.

Figure 15 delineates the location of the Alternative 3 injection wellfield and piping runs. The preliminary piping design entails installation of a 22-inch HDPE pipeline originating from the water tanks location on the Canoa Ranch pipeline and extending to the injection wells. Sufficient water capacity and pressure exists at this location to satisfy injection requirements of the proposed injection wellfield. No modifications to the interceptor wellfield pipeline are anticipated to handle groundwater extraction.

Implementability

The technical implementability of Alternative 3 is moderate to good. The installation of a system of injection wells in the northern portion of the interceptor wellfield can be conducted entirely on PDSI property and some existing infrastructure could be utilized. Water produced from extraction wells would be conveyed to the mine through the existing interceptor wellfield pipeline, which has sufficient capacity to handle the increased flow. The Canoa Ranch water system, the proposed source of injection water, possesses sufficient capacity and low sulfate content to supply the injection wells. Using the Canoa Ranch water system would require constructing a 3-mile pipeline from the Canoa Ranch pipeline to the injection wellfield. Design and construction of wells and pipelines are expected to take 12 to 14 months because all work would be conducted on PDSI property. An additional 6 to 10 months are expected to conduct and interpret a pilot test of injection and geochemical studies. Although the technology is available for an injection wellfield, the technical implementability is considered only moderate to good because of uncertainty regarding design studies and reliability. Design studies could identify water quality or permeability factors that limit the implementability of an injection wellfield for the purpose considered here. Also, injection well technology is most often used for control of salt water intrusion, underground waste disposal, oil production, or groundwater storage and recovery projects. The use of injection wells for a precisely engineered groundwater containment system as envisioned for the northern intereceptor wellfield is uncommon and, thus, uncertain with respect to effectiveness and reliability.

The regulatory implementability of Alternative 3 is good. Alternative 3 requires UIC and APP permits. The permitting timeframe for a UIC permit is expected to be less than one year. The timeframe for an APP can probably be expedited given the nature of the project. The total time expected to implement Alternative 3 is 18 to 24 months.

Effectiveness

The effectiveness of Alternative 3 is judged to be moderate due to concern regarding potential clogging and other operational issues as discussed below. Theoretically, using injection wells to create a hydraulic barrier could be an effective means of controlling seepage from the north portion of the interceptor wellfield. Figure 16 shows the results of a numerical simulation of sulfate concentrations below the 250 mg/L threshold after 2, 4, 6, and 10 years of operation of Alternative 3. Although some of the injected water would mix with sulfate-impacted groundwater and be pumped at the interceptor wellfield, the remainder creates a zone of reduced sulfate concentrations (less than 250 mg/L as illustrated in Figure 16) that migrates downgradient from the interceptor wellfield. The preliminary conceptual design simulated for Figure 16 excludes any injection or extraction wells north and west of IW-21 because the purpose of the simulation was to show the feasibility of groundwater control using injection wells. The injection wells would likely need to be extended westward to capture sulfate from the same areas as the other alternatives.

In practice, the long-term operation of a full-scale injection wellfield is expected to be demanding not only due to normal challenges of wellfield O&M, but also due to additional efforts to prevent clogging and minimize well downtime. The inevitable O&M issues associated with an injection wellfield could lead to shut downs and periodic lapses in containment. For this reason, the effectiveness of Alternative 3 is considered moderate.

Concern regarding the effectiveness of Alternative 3 is related to the initial and long term productivity and maintenance of injection wells. First, as discussed in Pyne (2005), the capacity of wells completed in unconsolidated materials to accept water is typically only 50 to 80 percent of their capacity to extract water. Second, several mechanisms commonly result in the loss of productivity of injection wells: 1) water delivered to the wells may react chemically or biologically with the aquifer resulting in formation of precipitates or bacterial slimes that will reduce productivity; 2) particulates in the injected water may clog the well screens, filter packs, or nearby aquifer materials; and 3) air locking of the aquifer near the wells may occur, reducing the effective hydraulic conductivity and achievable water injection rates (Pyne, 2005).

Minimizing productivity losses would likely require filtration of particulates from the injected water, chemical treatment to minimize losses resulting from formation of chemical or bacterial precipitates, and measures to prevent air entrainment into the injected water. Frequent re-development of wells would also be needed. Because of the initial lower productivity, productivity losses, and need for frequent re-development, more than 12 injection wells may be required to maintain design injection rates. With additional wells available, injection can be switched to rehabilitated wells while wells with reduced productivity are re-developed.

Cost

The estimated project costs for Alternative 3 included pre-construction costs, capital costs, O&M costs, replacement/repair costs, and water treatment costs. These costs, however, do not include the potential need for injection/extraction north or west of well IW-21 should sulfate capture similar to the other alternatives be a design objective. A detailed summary of estimated costs for Alternative 3 is presented in Appendix D.

The estimated pre-construction costs include a minor amount of Clean Water Act Section 404 surveying and permitting associated with construction of well drilling pads, access roads and piping runs. No archeological or endangered species surveys are anticipated to be required for this alternative. Also included are costs associated with engineering design and construction drawing/specifications for: electrical installations; Canoa Ranch pipeline tie-in and flow control; well head instrumentation; control and telemetry; piping and valving; and groundwater injection wells.

Capital costs include: well drilling and construction; pump upgrade/replacement and installation; electrical equipment, materials and installation; injection piping and installation;

back flow preventor with particulate filtration, and flow controller; discharge piping and installation; and construction/project management. Costs associated with water treatment to reduce the potential for well screen clogging are unaccounted for here, but would be determined based on pilot testing and geochemical modeling.

Annual O&M costs include electrical power for the new well field, additional electrical power required by the interceptor wellfield pump station, supplies, labor, and hydrogeologic consulting. In addition it is assumed that FICO overage charges will apply in the amount of $420,000 per year for groundwater pumped in excess of PDSI's 2005 rates (Section 4.2.1).

Supplies and labor costs are estimated from interceptor wellfield costs incurred during 2006. Interceptor wellfield costs for operating year 2006 (provided by PDSI) are summarized in Appendix C. These supply and labor costs are assumed to be proportional to the number of associated process wells. The 1.14 cost factors provided in Appendix D are, therefore, the proportion of additional process wells to existing wells multiplied by the sum of 2006 operating supplies costs ($34,821) and labor costs ($114,052), totaling $149,000 (Appendix C).

Annual costs associated with the repair and/or replacement of materials and equipment include labor, piping, pumps, and motors. Repair and replacement costs are also estimated using interceptor wellfield costs for 2006. These repair and replacement costs are assumed to be proportional to the total flow rate. The 0.53 cost factors provided in Appendix D are therefore the proportion of additional flow to existing flow from wells multiplied by the sum of 2006 equipment/materials repair and/or replacement costs ($97,357), well/pump repair and/or replacement costs ($325,447), additional fabrication costs ($75,039), and maintenance and repair labor costs ($209,822), totaling $708,000 (Appendix C).

Cost Summary

Pre-construction and capital costs were estimated to be $7.0 million for the injection rate of 3,200 gpm. Annual O&M costs were estimated at approximately $1.6 million. The 25-year NPV was estimated to be $26.2 million. Costs reflected in these estimates assumed the upper estimate of injection at 3,200 gpm.

A comparative summary of estimated costs for Alternative 3 (as detailed in Appendix D) is presented in Table 2. These costs are preliminary estimates and subject to variation of +/-35 percent.

4.4 Comparative Analysis of Mitigation Alternatives

This section compares the mitigation alternatives relative benefits and costs consistent with A.R.S. § 49-286. Table 3 compares the effectiveness, implementability, and cost of the mitigation alternatives. Benefits and disadvantages are discussed in terms of relative effectiveness and implementability.

4.4.1 Effectiveness

Alternative 1 is estimated to be only 80 percent effective at controlling sulfate migration from the north part of the interceptor wellfield (Appendix A). Alternative 1 has the poorest potential effectiveness because the water table in the vicinity of the interceptor wellfield is expected to continue dropping due to drawdown from extraction wells. The water table decline will reduce well efficiency and lead to incomplete capture over time.

Alternatives 2A and 2B have good effectiveness both in the short- and long-term. Wells for these alternatives are located in a part of the basin fill aquifer where the saturated thickness is greatest and long-term pumping efficiency is expected to be good. As shown by Figures 12 and 14, the capture zones for Alternatives 2A and 2B will encompass the north part of the interceptor wellfield. The effectiveness of Alternatives 2A and 2B is estimated to be 95 percent or more in terms of capturing flow from the northern interceptor wellfield.

Alternative 3, although having good effectiveness in theory, is ranked as moderate in effectiveness due to uncertainty about the long-term operational reliability of injection wells to maintain a hydraulic barrier.

A potential benefit of Alternatives 1 and 3 compared to Alternatives 2A and 2B is that the barrier for sulfate source control would be at the PDSI property boundary. However, given the limitations of Alternative 1, it would not effectively reduce sulfate mass loading to the regional aquifer over the long-term. Alternative 3 may or may not be effective depending on operational issues associated with its reliability. Although the sulfate source control barrier for Alternatives

2A and 2B would be up to 4,700 feet east of the PDSTI, both alternatives would be reliable and are predicted to effectively control sulfate mass loading to the regional aquifer to the maximum degree practicable. Thus, Alternatives 2A and 2B are considered to provide the greatest benefit.

4.4.2 Implementability

The permitting and land acquisition requirements of Alternatives 1 and 3 are less than for Alternatives 2A and 2B because all the required infrastructure would be on PDSI property. Alternative 1 has fewer engineering and construction needs than Alternatives 2A and 2B because Alternative 1 makes use of existing infrastructure to a larger degree than Alternatives 2A and 2B, which require more extensive new construction. Alternative 3 also makes use of existing infrastructure, but requires pipeline construction, pilot testing, and injection well design. Well installation and construction for Alternative 1 is expected to be implementable in 12 to 18 months. Alternative 3, which would require more permitting, design, pilot testing than Alternative 1, is expected to take 18 to 24 months to implement. The technical implementability of Alternative 3 is moderate to good because of uncertainty regarding design and reliability.

Because Alternatives 2A and 2B would be implemented on ASLD land, and county or private property, respectively, they have more complicated permitting and land acquisition requirements than Alternatives 1 and 3. Permitting ASLD land for new well sites, roads, and header pipelines for Alternative 2A is expected to require at least 14 months due to the amount of new land use that needs evaluation. Well installation and construction for Alternative 2A could take 12 to 16 months once access is obtained. The total time to implement Alternative 2A is approximately 26 to 30 months. Alternative 2B requires obtaining county right-of-way permits and purchasing or leasing private property for well sites and header pipelines. Alternative 2B also requires approval of use of the existing Esperanza pipeline right-of-way across the ASLD parcel. Because the ASLD approval is for an existing right-of way, it is not expected to require significant time for evaluation. Obtaining land access for Alternative 2B is expected to take approximately 6 months. Well installation and construction for Alternative 2B could take 12 to 16 months once access is obtained. The total time to implement Alternative 2B is approximately 18 to 22 months.

4.4.3 Cost

The range of estimated total capital costs for the four alternatives is $7 to $8.2 million (Tables 2 and 3). Given the conceptual nature of the preliminary designs and other uncertainties, the range of estimated capital costs does not vary significantly between the alternatives. In terms of capital, Alternative 3 has the greatest uncertainty because design will be dependent on the results of pilot test work yet to be done.

The NPV(25) of the alternatives range from $11.7 to $30.8 million. Alternative 2A has the highest NPV(25) ($30.8 million) due to ASLD land lease and water use fees. Alternative 3 NPV(25) ($26.2 million) is also high due to costs associated with Canoa Ranch water pumping and FICO water pumping charges. Alternative 1 has the lowest NPV ($11.7 million) due to the lowest O&M costs associated with lower extraction flow rates. The Alternative 2B estimated NPV(25) ($18.6 million) is substantially lower than Alternative 3 and 2A due to ASLD land lease and water use fees not being required, and the savings incurred by reducing Canoa Ranch water usage.

5. RECOMMENDED MITIGATION ALTERNATIVE

Alternative 2B is the recommended mitigation alternative for controlling sulfate migration from the northern portion of the PDSTI to the regional aquifer. Alternatives 1 and 3 were not recommended due to much lower potential effectiveness. Although Alternatives 2A and 2B were judged to have similar levels of effectiveness, Alternative 2B had better implementability (i.e., shorter implementation time frame) and lower cost than Alternative 2A.

This FFS has evaluated alternatives specific to the objective of improving the effectiveness of the northern interceptor wellfield. The Feasibility Study will evaluate alternatives for mitigation of the larger sulfate plume as part of the development of the Mitigation Plan. The recommended alternative should be further analyzed in the context of the Feasibility Study prior to implementation to ensure consistency with actions being considered for the Mitigation Plan.

6. REFERENCES

Brown and Caldwell. 2006. Evaluation of Potential Interim Actions to Mitigate Sulfate in Drinking Water Supplies in the Vicinity of the Phelps Dodge Sierrita Tailings Impoundment. December 21, 2006.

Errol L. Montgomery & Associates (M&A). 2007a. Documentation of Groundwater Flow Model Used for Evaluating the Current Effectiveness of the Interceptor Wellfield, Sierrita Mine, Phelps Dodge Sierrita, Inc. August 15, 2007.

M&A. 2007b. Revised Report Evaluation of the Current Effectiveness of the Sierrita Interceptor Wellfield Phelps Dodge Sierrita Mine Pima County, Arizona. Revised Report. November 14, 2007.

M&A. 2007c. Results of Evaluation of Additional Interceptor Wells for Improvement of Tailing Seepage Capture, Phelps Dodge Sierrita Inc., Pima County, Arizona. November 19, 2007.

Fournier, L. 2005. Horizontal Wells in Water Supply Applications. Water Well Journal. June 2005.

Harbaugh, A.W., and McDonald, M.G., 1996. User's documentation for MODFLOW-96 an update to the U.S. Geological Survey modular finite-difference ground-water flow model: U.S. Geological Survey Open-File Report 96-485.

Hydro Geo Chem, Inc. (HGC) 2006a. Work Plan to Characterize and Mitigate Sulfate with Respect to Drinking Water Supplies in the Vicinity of the Phelps Dodge Sierrita Tailings Impoundment, Pima County, Arizona. August 11, 2006, Revised October 31, 2006.

HGC 2006b. Interim Action Identification Technical Memorandum for Mitigation Order on Consent Docket No. P-50-06 Pima County Arizona. December 22, 2006.

Lorax Environmental. 2003. Treatment of Sulfate in Mine Effluents. Prepared for the International Network for Acid Prevention.

Miller, R. 1996. Horizontal Wells. Ground-Water Remediation Technologies Analysis Center. October 1996.

Pima Association of Governments (PAG). 1983a. Region Wide Groundwater Quality in the Upper Santa Cruz Basin Mines Task Force Area. September 1983.

PAG. 1983b. Ground-Water Monitoring in the Tucson Copper Mining District. September 1983.

Pollack, David W. 1994. User's Guide for MODPATH/MODPATH-PLOT, Version 3: A Particle Tracking Post-Processing Package for MODFLOW, the U.S. Geological Survey Finite-Difference Groundwater Flow Model. U.S. Geological Survey Open-File Report 94-464. Reston, Virginia. September 1994.

Pyne, D.R. 2005. Aquifer Storage Recovery. A Guide to Groundwater Recharge through Wells. ASR Press.

Travis and Birdsell. 1988. TRACRN 1.0: A Model of Flow and Transport in Porous Media for the Yucca Mountain Project-Model Description and Users Manual. Submitted to Yucca Mountain Project Milestone T421.

7. LIMITATIONS

The information and conclusions presented in this report are based upon the scope of services and information obtained through the performance of the services, as agreed upon by HGC and the party for whom this report was originally prepared. Results of any investigations, tests, or findings presented in this report apply solely to conditions existing at the time HGC's investigative work was performed and are inherently based on and limited to the available data and the extent of the investigation activities. No representation, warranty, or guarantee, express or implied, is intended or given. HGC makes no representation as to the accuracy or completeness of any information provided by other parties not under contract to HGC to the extent that HGC relied upon that information. This report is expressly for the sole and exclusive use of the party for whom this report was originally prepared and for the particular purpose that it was intended. Reuse of this report, or any portion thereof, for other than its intended purpose, or if modified, or if used by third parties, shall be at the sole risk of the user.