

Supplemental Waste Plan

***Clarifier Materials
Silver Bow Plant***

***Prepared for
Solvay USA Inc.***

October 2015



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Executive Summary

This Supplemental Waste Plan is being submitted pursuant to the Amended Administrative Order under the Resource Conservation and Recovery Act (RCRA) § 7003 (“7003 Order”)) and the Corrective Action Order on Consent under RCRA § 3008(h) (“3008(h) Order”) that were issued to Rhodia Inc. (“Rhodia” and now “Solvay”) by the Environmental Protection Agency (EPA), Region 8 on June 29, 2000 (amended December 27, 2000) and December 22, 2003, respectively, regarding the Silver Bow Plant, near Butte, Montana. This Supplemental Waste Plan documents the process that was used to develop and evaluate appropriate alternatives to manage the material in the clarifier and reports on the findings of the evaluation. The overall evaluation process is consistent with EPA guidance “RCRA Corrective Action Plan (EPA, 1994).

Technologies for the management of the clarifier materials at the Silver Bow Plant were evaluated in previous reports submitted to EPA (i.e., Waste Plan (Barr, 2001b); Focused Feasibility Study Report (EPA, 2003); and Phase 1 – Information Gathering Report (Franklin, 2007)). These evaluations identified three technologies that were developed into alternatives for evaluation in this Supplemental Waste Plan: (1) Enhanced RCRA Cap; (2) On-site Phosphorus Recovery (Mud Still Process); and (3) Off-site Incineration.

EPA established five evaluation criteria to address the RCRA requirements and to address the additional technical and policy considerations that have proven to be important for selecting among the viable alternatives. These criteria serve as a basis for evaluating the alternatives and subsequently selecting an appropriate alternative for the management of the clarifier materials at the Silver Bow Plant. According to OSWER Directive No. 9902.3-2A (May 1994), the criteria are:

- Long-term reliability and effectiveness;
- Reduction in the toxicity, mobility or volume of waste;
- Short-term effectiveness;
- Implementability; and
- Relative cost.

A comparison of alternatives follows the individual analyses. Comparative analysis considers the same five criteria used to evaluate individual alternatives. The intent of comparative analysis is to rank alternatives within each evaluation criteria and point out significant trade-offs between the different alternatives.

All of the alternatives evaluated in the Supplemental Waste Plan involve closing the clarifier, placing a cover barrier (enhanced RCRA cap or evapotranspiration cap) over the closed clarifier, and institutional controls to manage residual materials that would remain under the cover barrier. The on-site phosphorus recovery option using a mud still and the off-site incineration option, unlike the enhanced RCRA cap option, also involve removal and recovery or treatment of all of the crude phosphorus in the clarifier that can be safely and practicably removed. Because the mud still option involves replacement of the solid residues back into the clarifier that may be hazardous waste due to cadmium, EPA designation of a corrective action management unit (CAMU) is envisioned¹.

Although EPA need not designate a CAMU for the enhanced cap and incinerator options, since those two options also allow hazardous waste to remain in place under a cap, those options are functionally equivalent to a CAMU.

The Supplemental Waste Plan shows that the enhanced RCRA cap would be reliable and effective at eliminating the potential for fire and phosphine generation at harmful levels, and for protecting groundwater by a wide margin. Although the enhanced RCRA cap alternative would be considerably less costly, the alternative does not reduce the volume or toxicity of the clarifier materials.

The on-site phosphorus recovery alternative would be as reliable and effective as the enhanced RCRA cap in eliminating the long-term potential for fire and phosphine generation at harmful levels, and would also reduce the toxicity, mobility, and volume of crude phosphorus at the Silver Bow Plant. On a relative basis, this alternative ranked low regarding the short-term effectiveness criterion because of the higher relative risk of serious injury. However, this alternative would return about 80,000 to 98,000 gallons of elemental phosphorus to commercial use, which represents a commercial value of about \$2 million to \$2.5 million.

The Supplemental Waste Plan shows that off-site incineration is not a practicable technology for the volume of clarifier material that would be generated at the Silver Bow Plant and would take very long to complete. In addition, filling each of the estimated 12,500 drums with the clarifier material would present high short-term risks of fires and phosphine generation, and each truckload would have to be transported half-way across the United States, which represents increased risk to the general population.

¹ In accordance with Section XII of the 3008(h) Order, the EPA designation of a CAMU is being formally requested in a separate submittal entitled "Request of Solvay USA, Inc. to Designate a Corrective Action Management Unit".

The comparative evaluation of the alternatives is summarized in the following chart:

Alternative	Long-term Reliability and Effectiveness	Reduction in Toxicity, Mobility or Volume	Short-term Effectiveness	Implementability	Relative Cost¹
Enhanced RCRA Cap	Good	Lowest Reduction	Low Risk	2 Years	\$5.4 million
On-site Phosphorus Recovery (Mud Still Process)	Very Good	Large Reduction	High Risk	10+ Years	\$25 million
Off-site Incineration	Very Good	Large Reduction	High Risk	20+ Years	\$54 million

¹ Cost includes the cost of financial assurance.

The Supplemental Waste Plan supports the conclusion that the on-site phosphorus recovery alternative should be selected for the clarifier materials at the Silver Bow Plant.

1.0 Introduction

This Supplemental Waste Plan is being submitted pursuant to the Amended Administrative Order under the Resource Conservation and Recovery Act (RCRA) § 7003 (“7003 Order”) that was filed by the Environmental Protection Agency (EPA), Region 8 on June 29, 2000 (amended December 27, 2000), and the Corrective Action Order on Consent under RCRA § 3008(h) (“3008(h) Order”) that was filed by the EPA, Region 8 on December 22, 2003², regarding the Silver Bow Plant, near Butte, Montana (see Figure 1-1). A copy of the 7003 Order and 3008(h) Order is provided in Appendix A and B, respectively.

The 7003 Order required Rhodia Inc. (“Rhodia”) and now its corporate successor Solvay USA Inc. (“Solvay”) to undertake certain immediate and interim activities at the Silver Bow Plant, all of which were completed according to the specific timeline established for the respective activity. The 7003 Order required activities at the used brick and furnace liner pile, slag pile and the clarifier. The location of these areas is shown on Figure 1-2 and each is summarized below.

Brick and Furnace Liner Pile

The used brick and furnace liner pile was approximately 100 feet long by 30 feet wide by 5 feet high, with sizes ranging from cinder block to as large as a refrigerator. This used brick and furnace liner was a refractory lining that was removed from electric arc furnaces that were used to convert phosphate ore into elemental phosphorus. Pursuant to the 7003 Order, a security fence was installed around the pile and signs were posted on the fence stating “Danger—Unauthorized Personnel Keep Out.” In addition, the used brick and furnace liner pile was enclosed with netting to prevent wildlife contact with these materials.

The used brick and furnace liners were managed as detailed in the Completion Report, Used Carbon and Electrode Project, Silver Bow, Montana, April 9, 2009 and approved by EPA in a May 15, 2009 letter. Each carbon brick/block was tested for ignitability according to the procedures developed by Solvay and approved by EPA. The used carbon brick and the eight pieces of hazardous waste carbon

² The 3008(h) Order relates to the Supplemental Waste Plan for several reasons: (1) the RFI that has been completed under the 3008(h) Order provides critical information relevant to the evaluation herein (see VIII. D. of 3008(h) Order); (2) the integration of XIII, XX, and XXIII in the 3008(h) Order are relevant to the remedy decision regarding the clarifier as provided for under VI. B. of 3008(h) Order), (3) the SWMUs 7 and 11 that have been evaluated under VI. A. of 3008(h) Order are proposed to be capped herein; and, (4) the CAMU designation under XII of 3008(h) Order that is requested herein.

block were containerized and shipped to Heritage Environmental Services in Sauget, Illinois for incineration. Approximately 818 tons of nonhazardous carbon blocks and electrodes were recycled by Pamas and Company in Elberton, Georgia. A portion of the nonhazardous carbon blocks and electrodes were too small to be recycled, or passed the crush test, but had evidence of amorphous phosphorus on the surface, remain at the site and will be managed as non-hazardous solid waste.

The Used Brick and Furnace Liner Pile was designated as solid waste management unit number three (SWMU 3), and final closure of this area will be addressed under the RCRA §3008(h) Order (EPA, 2004).

Slag Pile

The 7003 Order [Section VII. C. (3)] requires a method of ensuring that operations in the slag pile would not create conditions that could cause used brick and furnace liner to spontaneously ignite. The slag pile is nearly 100% slag, which is an inert material. As such, this interim measure requirement presumably stems from reported observations by EPA inspectors that some used brick and furnace liner was present in the slag pile at the facility. The EPA noted that slag has been moved from the slag pile to the tailing basin, a manmade impoundment, within the facility boundary. EPA stated that moving slag materials might cause currently buried used brick and furnace liner material to be exposed, and temporarily burn. Consequently, all movement of slag in the coarse slag pile was suspended throughout the period of implementation of the interim measures. The Coarse Slag Pile was designated as SWMU 12, and final closure will be addressed under the RCRA §3008(h) Order (EPA, 2004).

Clarifier

One of the few remaining process units on-site is the clarifier, which was used to store crude phosphorus prior to its secondary processing in the roaster to produce elemental phosphorus. The clarifier is a 100 foot diameter, open-topped, in-ground unit that is constructed of reinforced concrete. The clarifier is approximately 12 feet deep and contains approximately 500,000 gallons of crude phosphorus solids, often referred to as sludge, covered by several feet of water. The location of the clarifier is shown on Figure 1-2.

The 7003 Order required Solvay to conduct "immediate measures" (i.e., fencing and signage) and the following interim measures at the clarifier area:

- Installing an automatic water maintenance system and its subsequent winterization;

- Eliminating wildlife contact by placing approximately 80,000 Bird Balls™ on the water to camouflage its surface; and
- Installing a continuous phosphine monitoring system around the clarifier.

These interim measures were completed according to the specific timeline established for the respective activity.

Final closure of the clarifier (a.k.a., SWMU 2) will be addressed under the RCRA §7003 Order (EPA, 2001). Section VII.K. of the 7003 Order provides:

... Respondent shall submit a written work plan that evaluates alternatives for the lawful disposition of the contents of the leaking clarifier ... (“Waste Plan”). The Waste Plan shall include at least one alternative for the lawful removal and disposal of the contents of the leaking clarifier

To meet this requirement, the Waste Plan (Barr, 2001b) was submitted to EPA on November 16, 2001. It addressed the requirements of the 7003 Order, as well as additional information developed in response to EPA comments on prior submittals. The prior Waste Plan identified many process options but only identified two viable alternatives for the clarifier’s contents at that time:

- Capping (two options)
- Off-site Incineration

EPA has not yet selected an alternative for the management of the clarifier materials and Solvay agreed to conduct additional studies to further evaluate management options. The Clarifier Waste Treatability Study was conducted in 3 phases. Phase 1 consisted of information gathering. Information on candidate treatment processes were compiled and catalogued according to treatment technology. Based on the Phase 1 Report (Franklin, 2007), the mud still technology similar to that developed by Albright and Wilson (A&W) for evaporation and subsequent recovery of the phosphorus was selected by EPA, Montana Department of Environmental Quality (MDEQ), and Solvay for further evaluation. Phase 2 consisted of pilot-plant design, construction and initial testing of a mud still, and Phase 3 consisted of additional testing of pilot plant operations. The treatability studies demonstrated that the clarifier material could be treated at a small scale level to recover elemental phosphorus of usable quality from a variety of feed compositions found in the clarifier materials (Franklin, 2012).

For decision making purposes, Solvay agreed to supplement the original Waste Plan (Barr, 2001) with an evaluation of the on-site phosphorus recovery alternative using the mud still technology. This

Supplemental Waste Plan builds upon the original Waste Plan document and describes each alternative with sufficient detail regarding their design and operation to properly evaluate them against the relevant criteria. Solvay expects that additional design details will need to be developed for any alternative selected by EPA. Solvay will respond to specific questions EPA may have and then submit a schedule with detailed designs, plans and reports that would be developed with EPA following selection of an alternative.

1.1 Waste Plan Organization

Section 2.0 provides an overview of the evaluation process and explains the evaluation criteria and methodology. The evaluation of the alternatives for the clarifier materials appears in Section 3.0. Section 4.0 provides a set of conclusions regarding the alternatives for the clarifier materials. Section 5.0 provides a list of references that were used for development of the Supplemental Waste Plan.

1.2 Waste Plan Implementation Report

A Waste Plan Implementation Report will be prepared detailing and confirming the completion of the activities associated with the selected alternative conducted pursuant to the Supplemental Waste Plan. The report will contain the following:

- Implementation dates for construction activities.
- Photographs documenting implemented actions.
- Description of any deviation from the approved plan(s).

The draft implementation report will be mailed to the EPA within 90 days after completion of the selected alternative, or as otherwise agreed with the EPA.

1.3 Site Ownership

The amended 7003 Order was issued in 2000 to Rhodia, which owned the Silver Bow Plant at that time. Extensive work was conducted at the direction of Rhodia to comply with the 7003 Order. In September 2011, Solvay S.A. completed the acquisition of the shares of Rhodia S.A. (Rhodia Inc.'s ultimate parent) and Rhodia Inc. became a member of the Solvay Group. Effective October 1, 2013, the Solvay Group United States corporate legal entity currently known as Rhodia Inc. changed its name to Solvay USA Inc. The company will remain a Delaware corporation and an indirect but wholly-owned subsidiary of Solvay SA based in Brussels, Belgium. The company will also remain a sister company of the other Solvay Group United States legal entities that are also subsidiaries of Solvay SA. This report refers to prior work that was performed by Rhodia as having been performed by Solvay to reflect the current legal owner and operator of the Silver Bow Plant.

2.0 Process for Evaluating Alternatives

This section provides an overview of how the technologies and developed alternatives for closing the clarifier were evaluated. The process consisted of gathering a knowledgeable team, identifying viable technologies and developing alternatives, an evaluation of each alternative against RCRA criteria, a comparative evaluation of the alternatives against the RCRA criteria, and a recommendation therefrom.

2.1 Gathering a Knowledgeable Team

This Supplemental Waste Plan represents the collective thinking of a team of professionals who together have over 200 years of directly relevant experience to the evaluation that is presented herein. The experience of the team members includes:

1. The team consists of four professionals from Solvay. These individuals have spent most of their professional life with responsibilities that involve the production of elemental phosphorus, the management of associated production residues, environmental compliance, and the decommissioning of elemental phosphorus plants.
2. Solvay has used five consulting firms in the development of the Waste Plan (Barr Engineering Company (Barr), Franklin Engineering Group, Inc. (Franklin), KPRyan Consultancy, JJDS Environmental, and ENSR). These consulting firms have direct experience in the potential risks associated with elemental phosphorus residues. They also are very familiar with the treatment, disposal, and decommissioning options that have been evaluated and are being implemented at the other elemental phosphorus (P4) production facilities. Barr has worked with Solvay on decommissioning issues relating to the Silver Bow facility since the plant ceased production in 1997 and has been heavily involved in the concurrent RCRA Corrective Action evaluations for the Silver Bow Plant. Franklin has extensive experience with designing, constructing, and operating elemental phosphorus recovery processes. Franklin assisted with the technology evaluation and treatability studies for the crude phosphorus.
3. The team also consists of a principal scientist of a major national consulting firm's risk assessment group and his supporting professionals. They have been involved in evaluating risks associated with various remedial/closure/decommissioning alternatives for over two dozen projects.

4. The team also includes three lawyers who are intimately familiar with regulations that pertain to elemental phosphorus residues as well as evaluating decommissioning/closure/remedial options under RCRA and Montana State law.

This team was selected to ensure that each option was fully evaluated from a technical, legal and health and safety standpoint. Team members are listed in Appendix C.

2.2 Identification of Alternatives

Alternatives for managing the phosphorus-containing materials were identified by the project team based on their knowledge about the phosphorus industry, decommissioning of phosphorus plants, and the character of the phosphorus-containing materials at Silver Bow throughout the waste plan development process. The alternatives identified include on-site and off-site options for treatment, recovery and disposal of the clarifier contents.

The previous Waste Plan (Barr, 2001b), the Focused Feasibility Study Report (EPA, 2003), and the Phase 1 – Information Gathering Report (Franklin, 2007) evaluated all potentially feasible technologies regardless of their cost or how much time they would take to implement. These previous evaluations³ were reviewed, and were found to still be applicable and relevant. The results of these previous evaluations were compiled, and the conclusions are summarized in Table 2-1.

Three viable technologies were identified through initial screening of technologies:

1. Capping
2. On-site Phosphorus Recovery (Mud Still Process)
3. Off-site Incineration

These viable technologies were incorporated into alternatives that could abate the characteristics that are the focus of the 7003 Order with respect to the clarifier material: (1) spontaneous and uncontrolled fires; and (2) generation of phosphine gas at potentially harmful levels.

³ The technologies were screened on an initial basis considering: (1) Site Characteristics (i.e., identify conditions that may limit or promote the use of different technologies); (2) Material Characteristics (i.e., will material characteristics inhibit the effectiveness of a technology); and (3) Technology Limitations (i.e., has the technology been used successfully in the phosphorus industry). Technologies were eliminated if they were not appropriate for site characteristics, are not effective at abating the hazardous characteristic, have not been demonstrated in the phosphorus industry, or if no off-site facilities are permitted to receive the phosphorus-containing material.

2.3 Alternative Evaluation Criteria

The alternatives were evaluated against five criteria identified in EPA guidance document “RCRA Corrective Action Plan”, OSWER Directive No. 9902.3-2A (May 1994), and defined therein at pages 54-56 as follows:

a. Long-term Reliability and Effectiveness

Demonstrated and expected reliability is a way of assessing the risk and effect of failure. The respondent may consider whether the technology or a combination of technologies have been used effectively under analogous site conditions, whether failure of any one technology in the alternative would have an immediate impact on receptors, and whether the alternative would have the flexibility to deal with uncontrollable changes at the site (e.g., heavy rain storms, earthquakes, etc.).

Most corrective measure technologies, with the exception of destruction, deteriorate with time. Often, deterioration can be slowed through proper system operation and maintenance, but the technology eventually may require replacement. Each corrective measure alternative should be evaluated in terms of the projected useful life of the overall alternative and of its component technologies. Useful life is defined as the length of time the level of effectiveness can be maintained.

b. Reduction in the Toxicity, Mobility or Volume

As a general goal, remedies will be preferred that employ techniques, such as treatment technologies, that are capable of eliminating or substantially reducing the inherent potential for the materials at the facility to cause future environmental releases or other risks to human health and the environment. There may be some situations where achieving substantial reductions in toxicity, mobility or volume may not be practical or even desirable. Examples might include large, municipal-type landfills, or facilities with unexploded munitions that would be extremely dangerous to handle, and for which the short-term risks of treatment outweigh potential long-term benefits.

Estimates of how much the corrective measures alternatives will reduce the waste toxicity, volume, and/or mobility may be helpful in applying this factor. This may be done through a comparison of initial site conditions to expected post-corrective measure conditions.

c. Short-term Effectiveness

Short-term effectiveness may be particularly relevant when remedial activities will be conducted in densely populated areas, or where material characteristics are such that risks to workers or to the environment are high and special protective measures are needed. Possible factors to consider include fire, explosion, exposure to hazardous substances and potential threats associated with treatment, excavation, transportation, and redisposal or containment of the material.

d. Implementability

Implementability will often be a determining variable in shaping remedies. Some technologies will require state or local approvals prior to construction, which may increase the time necessary to implement the remedy. In some cases, state or local restrictions or concerns may necessitate eliminating or deferring certain technologies or remedial approaches from consideration in remedy selection. Information to consider when assessing Implementability may include:

- 1. The administrative activities needed to implement the corrective measure alternative (e.g., permits, rights of way, off-site approvals, etc.) and the length of time these activities will take.*
- 2. The constructability, time for implementation, and time for beneficial results.*
- 3. The availability of adequate off-site treatment, storage capacity, disposal services, needed technical services and materials.*
- 4. The availability of prospective technologies for each corrective measure alternative.*

e. Relative Cost

The relative cost of a remedy may be an appropriate consideration, especially in those situations where several different technical alternatives to remediation will offer equivalent protection of human health and the environment, but may vary widely in cost. However, in those situations where only one remedy is being proposed, the issue of cost would not need to be considered. Cost estimates could include costs for: engineering, site preparation, construction, materials, labor, sampling/analysis, material management/disposal, permitting, health and safety measures, training, operation and maintenance, etc.

At page 21 of the “Guidance on the Use of 7003 of RCRA,” EPA/OECA (Oct. 20, 1997), the EPA states that “EPA may also order ... long-term cleanup, including the design, construction and implementation of any measures necessary to abate the conditions that may present an endangerment.” Since the order issued to Solvay is a RCRA 7003 Order and its genesis was EPA’s concern that the clarifier material presents an imminent and substantial endangerment for the generation of fire and phosphine gas, the Waste Plan was focused on abating the generation of fire and phosphine gas at harmful levels with respect to the clarifier materials.

The five evaluation criteria have been chosen because they are the criteria EPA normally uses in the RCRA program when evaluating remediation, closure and decommissioning options. For example, in the RCRA corrective action plan, EPA uses these five factors to evaluate various remedies that will reduce the contamination at a RCRA corrective action site to health based standards. These five factors evaluate the relative advantages and disadvantages of each alternative in terms of their long-

term and short-term effectiveness; their reduction of toxicity, mobility and volume; their implementability; and cost. These factors were therefore deemed appropriate for an evaluation of Waste Plan activities under a RCRA 7003 Order that similarly involves decommissioning of units and areas with residual materials.

2.4 Evaluation Methodology

This section describes how each alternative was evaluated against the five evaluation criteria. This evaluation consisted of a mix of qualitative and quantitative analysis. For example, the evaluation of the cost of an alternative, and its short-term effectiveness, which includes potential risk of injury or fatality, are criteria that are very amenable to some level of quantitative analysis. The methodology for evaluating each of the criteria is described more below.

- **Long-term Reliability and Effectiveness.**

This criterion considered whether the proposed technology has historically been demonstrated to be effective in controlling or removing the threat of fire and phosphine gas generation at harmful levels over the long-term. For example, factors that might impact the long-term reliability, such as erosion and earthquakes, were considered in the evaluation of these criteria.

- **Reduction in Toxicity, Mobility or Volume.**

With respect to reduction of toxicity, this criterion considered the inherent toxicity of the clarifier material. Distinctions were made between alternatives that remove the toxicity through recovery or destruction or otherwise reduce the concentration of the toxic constituents, versus options that control the toxicity by preventing pathways of exposure.

With regard to reduction of mobility, Solvay has made similar distinctions between alternatives that reduce or immobilize the clarifier material itself versus options that reduce the mobility through creating barriers or other controls to the clarifier material.

With regard to reduction in volume, Solvay has distinguished between options that recover or destroy the clarifier material versus options that do not change its volume.

With respect to all three criteria--reduction in toxicity, mobility and volume--Solvay also considered how long it would take for an alternative to achieve the reduction. Options that take a long time to implement, while ultimately achieving a reduction in toxicity, mobility and/or volume, could allow existing potential hazards in the material to persist for several years before implementation of the alternative is completed.

An attempt was made to quantify these reductions where possible through modeling, data from similar sites, and/or experience.

- **Short-term Effectiveness.**

The short-term effectiveness of each alternative was evaluated by considering the risks associated with implementing the alternative. As described in EPA's explanation of this criterion, as quoted above from EPA's "RCRA Corrective Action Plan," the risks include not only those to workers and contractors on-site, but also to off-site workers or others that might result from the transportation of the material to the incinerator or elemental phosphorus production facility and its management at that facility. The risk methodology employed for this analysis is based on a study entitled "Methodology for Assessing Worker Risks during Remediation at the United States Department of Energy's Hazardous Waste Sites" (Datskou & Sutherland, 1995) and a closely related study entitled "U.S. Department of Energy Worker Health Risk Evaluation Methodology for Assessing Risks Associated with Environmental Restoration and Waste Management" (Blaylock, *et al* 1995). The risk methodology is discussed in greater detail in Appendix D.

- **Implementability.**

All of the alternatives are implementable, but some alternatives can be implemented more quickly and with greater certainty than others. Accordingly, for this criterion, factors such as how long it would take to design, construct, test and operate the decommissioning option were considered. Also considered, were whether various federal, state or local approvals would be required, and if so, how long those approvals may take. Finally, the evaluation considered whether it would have to rely upon external vendors and consultants for expertise and supplies to implement a particular option, and if so, the availability of such external services and supplies.

- **Relative Cost.**

A quantitative analysis of the cost of each alternative was undertaken by considering the significant cost factors from design through construction, operation and maintenance, and completion. Certain assumptions, such as EPA or MDEQ designating an on-site corrective action management unit, also were made for costing each alternative. Order-of-magnitude cost estimates are prepared. This evaluation considers the capital and general operation and maintenance costs associated with the alternative. The cost of financial assurance was also estimated based on the order-of-magnitude cost estimates. Because very little of the detailed design is typically completed at this time, order of magnitude estimates are provided and are

expected to provide an accuracy of plus 50 to minus 30 percent for the described scope of the alternative. A fuller description of the cost methodology appears in Appendix E.

2.5 Comparative Evaluation

A comparative analysis of the alternatives is provided after the individual analyses of the clarifier material alternatives. In that section, each alternative is compared against each evaluation criteria. The comparison notes whether a particular option is better or worse than others, and also characterizes the option as to how well it meets the objectives of each criterion. This comparison helps to point out significant trade-offs between the different alternatives, and aids in the selection of an appropriate alternative.

2.6 Preferred Alternative

After the comparative evaluation of the alternatives, a preferred alternative is identified for evaluation and remedy selection by EPA. The comparisons are reviewed and trade-offs are highlighted.

3.0 Clarifier Materials

This section evaluates the alternatives for management of the crude phosphorus contained in the clarifier (i.e., clarifier materials) and provides the following information:

- Description of the clarifier materials and its assumed characteristics and regulatory status;
- Description of each alternative that was considered for the clarifier materials; and
- Evaluation of each alternative against the RCRA criteria.

3.1 Material Description and Regulatory Status

The Silver Bow Plant was constructed in the early 1950s to produce elemental phosphorus using an electric arc furnace method developed by the Tennessee Valley Authority. The letter from the Plant Manager, D. Bersanti, and the Process Flow Diagram attached to his letter, both of which are in Appendix F, explain this method. First, raw ore was beneficiated by passing it through two nodulizing kilns. The beneficiation process operated at very high temperatures using rotary kilns that caused the metals in the ore to sublime and the ore to agglomerate into nodules to make it suitable furnace feed. The nodules were mixed with coke and silica and charged into an electric arc furnace. Slag (primarily calcium silicate) was drawn off the furnace, cooled and stockpiled on site. From 1990 until the end of operations in 1997, approximately 50 percent of the slag was granulated to a sand size and stockpiled separately.

The electric furnace drove off the P₄ as a gas, which was condensed to a liquid. The liquefied phosphorus was filtered. The liquid filtrate became the elemental phosphorus product. What was left was a sludge-like material that had substantial P₄. This material, referred to as the crude phosphorus, was secondarily processed in a roaster to recover the remaining phosphorus. The clarifier was used to hold the crude phosphorus awaiting roasting. In March 1997, the roaster process was shut down, since the crude phosphorus could no longer be removed from the clarifier and fed into the roaster. The feed stream could not be maintained in a uniform slurry. The piping continuously plugged, and steady state feed conditions, which were critical to maintenance of operating temperature and pressure, could not be maintained. These difficulties are described in greater detail in D. Bersanti's letter in Appendix F.

The crude phosphorus contains approximately 20% [v/v] elemental phosphorus based on the roaster production record in Appendix F that reflects conditions just before the roaster ceased operations. The record shows that about 18.3% [v/v] of the crude phosphorus that was fed into the roaster from the clarifier in February 1997 was recovered as elemental phosphorus. The treatability study (Franklin,

2012) also showed that the average P4 content in eleven samples of crude phosphorus was 23% [v/v], which is consistent with the previous estimates.

The clarifier was constructed as a 100-foot diameter, open-topped, in-ground unit with reinforced concrete walls and base. Photos of clarifier construction showing the use of rebar are included in Appendix G. The clarifier walls extend above the ground approximately 0.5 feet on the south side and approximately 4.5 feet on the north, northeast and northwest sides, where the ground is somewhat lower. A metal railing approximately 3.5 feet tall is mounted on top of the west and southwest clarifier wall. The clarifier is approximately 12-feet deep, including the aboveground portion of the walls, and contains 8 to 9 feet of crude phosphorus, covered by more than 2 feet of water (the water cap). The crude phosphorus consists of elemental phosphorus, water and solids, such as phosphate dust, coke dust, and silica dust.

The clarifier contains an estimated 500,000 gallons of crude phosphorus. The crude phosphorus was not blended with other waste streams (i.e., high pH) that may be affecting the potential to generate phosphine that may have occurred at other elemental phosphorus production facilities.

The crude phosphorus is covered by the water cap. The water cap prevents the atmosphere from contacting and reacting with the elemental phosphorus. Water losses occur as a result of leaks in the clarifier and evaporation. The water cap is maintained by an automatic water addition system installed as an interim measure. The automatic water addition system adds water when the level falls below the low set point and shuts off when the water level rises above the high set point. The trigger is set to maintain the water level at more than 2 feet above the level of crude phosphorus in the clarifier. The water cap maintenance system has been winterized to provide for year-round operation. A fence was installed around the clarifier area during the interim actions. Figure 3-1 shows the general configuration of the clarifier and fence.

3.1.1 Regulatory Status of Clarifier Material

During an investigation in early May 2000, an EPA team removed several samples of the material from the water-covered clarifier, dried the samples in the atmosphere, and caused some of the samples to ignite after periods of about one-half to four hours. EPA considered this to satisfy the D001 ignitability characteristic and Solvay and EPA agreed to classify the clarifier material as D001 hazardous waste in the Plea Agreement Solvay entered into in 2003. Also, after agitating the water and crude phosphorus in the clarifier, the EPA team measured an instantaneous phosphine concentration of 1.08 ppm.

Although this and subsequent readings did not exceed any worker protection standard in this Supplemental Waste Plan evaluation, Solvay will evaluate the potential for each alternative to minimize phosphine generation.

The EPA did not classify the clarifier material as a D002 corrosive hazardous waste and the water cap has a near neutral pH.

Two samples of crude phosphorus were collected and analyzed for RCRA metals in March 1997 by Energy Laboratories using Method 1311. These samples were taken in accordance with the procedures described in the *100-Foot Clarifier Sampling and Analysis Plan for February 1997*, which is included in Appendix G. The regulatory limits and corresponding leachate concentrations are summarized in the following chart:

Parameters	Leachate Concentrations (Method 1311)		
	Regulatory Limits [mg/L]	Crude Phosphorus Sample 01 [mg/L]	Crude Phosphorus Sample 02 [mg/L]
Arsenic	5.0	< 0.5	< 0.5
Barium	100.0	< 10	<10
Cadmium	1.0	< 0.1	<0.1
Chromium	5.0	< 0.5	< 0.5
Lead	5.0	< 0.5	< 0.5
Mercury	0.2	< 0.02	< 0.02
Selenium	1.0	< 0.1	< 0.1
Silver	5.0	< 0.5	< 0.5

All metals were below the respective TCLP regulatory limit. Copies of the analytical reports for these samples are included in Appendix G. The reports from Energy Laboratories are dated 3/03/97, and refer to “Sludge #01” and “Sludge #02.” Analysis of a blank sample is also included. Since representative samples of the crude phosphorus did not leach metals at concentrations above the regulatory limit, the crude phosphorus was not considered a hazardous waste based on metals.

3.1.2 Clarifier Conceptual Model

The clarifier was constructed as a 100-foot diameter, open-topped, in-ground unit with reinforced concrete walls and base. The clarifier walls extend above the ground approximately 0.5 feet on the south side and approximately 4.5 feet on the north, northeast and northwest sides, where the ground is somewhat lower. Based on soil borings installed near the clarifier, the soils are generally sand to silty sand in the upper 10 to 20 feet with silty sand to sandy silt with clay and some coarse lenses to 45 to

50 feet. Groundwater is approximately 20 feet below the bottom of the clarifier as shown on a cross section through the clarifier (Figure 3-2).

3.1.2.1 Hydrogeology

The general direction of groundwater flow in the vicinity of the clarifier is to the north-northwest (Figure 3-3) towards Silver Bow Creek. In the plant vicinity, the bedrock is igneous rock of the Boulder Batholith. The depth to bedrock is greater than 400 feet in places at the site, as demonstrated by well logs for the plant production wells. The unconsolidated material overlying the bedrock consists primarily of clays with lesser amounts of sands, silts, and loosely consolidated shale, silty shale, and silty sandstone. Coarse-grained deposits that produce significant yields of water were found below 185 to 230 feet deep when drilling the plant production wells. The upper 100 to 150 feet is sand, silt, and clay that produce less water than the deeper zones. The hydraulic conductivity of the upper groundwater unit is approximately 1 foot per day (ft/day) based on the geometric mean of the slug test results for the monitoring wells at the clarifier. A hydraulic gradient based on water levels measured in September 2013 in nearby monitoring wells is approximately 0.006 ft/ft.

3.1.2.2 Groundwater Quality

EPA required Solvay to conduct pre-closure groundwater monitoring of the area near the clarifier under the 7003 Order. A Field Sampling Plan and Quality Assurance Project Plan (Sampling Plan) (Barr, 2001a) for pre-closure groundwater monitoring at the clarifier was approved by EPA in a letter dated September 6, 2001. Three water table monitoring wells were installed at the clarifier in accordance with the Sampling Plan. MW-01-2 was installed upgradient (i.e., south) of SWMU 2, and MW-01-3 and MW-01-6 were installed downgradient of SWMU 2. Two additional wells (MW-02-1 and MW-02-2) were installed further downgradient of the clarifier to evaluate the potential transport of elemental phosphorus via groundwater. The monitoring well locations are shown on Figure 3-3.

Three rounds of groundwater samples were collected during the pre-closure groundwater monitoring program and analyzed for general and site-specific parameters, metals, VOCs, SVOCs, and radionuclides. The results were summarized in the Final Pre-Closure Groundwater Monitoring Report (Barr, 2002).

The clarifier monitoring wells were included in the site-wide groundwater quality monitoring program included in the RFI Work Plan (Barr, 2009). Investigation activities conducted at the clarifier (i.e., SWMU 2) were presented in Section 5.5.2 of the RFI Report (Barr, 2013), which is provided in Appendix H. The analytical results for the groundwater samples from the clarifier monitoring wells are detailed in Section 5.5.2.4. The main conclusion of the RFI Report related to groundwater quality at the clarifier is stated below:

Although it is clear that process water has leaked from the clarifier, no distinct trends in groundwater parameter concentrations are observed at this site over time. Only fluoride concentrations appear to be increasing over time. Alternatively, total phosphorus, sulfate, total and dissolved barium, total cobalt, total and dissolved manganese, and total nickel exhibit decreasing trends over time.

Continued monitoring of groundwater quality trends associated with releases from the clarifier was recommended in the Draft Long-term Groundwater Monitoring Plan (Barr, 2014) that was submitted to EPA in May 2014. This monitoring plan would be reviewed and modified, if needed, to meet regulatory requirements of the closed clarifier.

3.2 Enhanced RCRA Cap

3.2.1 Description of Alternative

This alternative for the clarifier material would include closure of the clarifier in place with an Enhanced RCRA cap, and followed by post-closure maintenance of the cap, monitoring of groundwater quality and subsurface phosphine concentrations. The enhanced RCRA cap would include systems to capture and treat, as needed, phosphine gas, if any were generated at harmful levels.

This Enhanced RCRA cap alternative would close the clarifier with a multi-layer, multi-material cover (including a penetration-resistant layer and a synthetic flexible membrane liner (FML), also referred to as a geomembrane) that meets the RCRA standards at 40 CFR 265.310(a). RCRA caps have been selected for closure of phosphorus-containing wastes by the regulators in other EPA regions and states.

The proposed Enhanced RCRA cap system would: (1) provide long-term minimization of the migration of liquids through the clarifier material; (2) function with minimum maintenance; (3) promote drainage and minimize erosion or abrasion of the cover; (4) accommodate settling and subsidence so that the cover's integrity is maintained; and (5) have a permeability less than or equal to the permeability of any bottom liner system or natural subsoils present.

A schematic cross-section of the Enhanced RCRA cap is shown on Figure 3-4, and is the same cap design presented in the July 31, 2003 letter to J. Wardell from D. Bersanti, which is provided in Appendix I.

The first construction phase would involve:

- Placement of a geofabric filter over the clarifier material and placement of approximately four feet of a granulated slag subgrade with intermixed geoweb layers;

- Recession of the water;
- Filling the clarifier with an additional one to four feet (depending on location) of granulated slag subgrade;
- Placement of additional slag to surcharge and consolidate the underlying crude phosphorus and granulated slag; and
- Consolidation monitoring, as needed.

The crude phosphorus would be covered by water or slag at all times, thus minimizing the potential for fire. Specifically, the water cap would be maintained until the granulated slag layer covers the crude phosphorus to a depth of at least two feet. The water cap maintenance would then be suspended and the remaining water would be allowed to recede. As a backup, in the unlikely event that the crude phosphorus was to ignite during dewatering activities, the area of ignition would be covered immediately by additional granulated slag that would be stockpiled nearby.

The second phase of the Enhanced RCRA Cap construction would consist of:

- Removing the excess slag (i.e., surcharge layer) and installing the phosphine monitoring/collection piping;
- Adding a 6-inch sand and 6-inch liner foundation layer
- Equivalent Low Hydraulic Conductivity Layer – Geosynthetic Clay Liner (GCL) [Hydraulic conductivity on the order of 10^{-9} cm/s];
- Flexible Membrane Liner (FML) – 60-mil High Density Polyethylene FML;
- Drainage Layer – synthetic polyethylene drainage material (e.g., Geonet); and
- Filter Layer – synthetic filter fabric.

Protective Layer – The overall thickness of this protective layer was designed to place the flexible membrane liner below the normal frost penetration depth (i.e., 42 inches [Harrington, 2000; personal communication]), and provide adequate soil to support growth of the vegetation. This protective layer would consist of, from bottom to top, a(n):

- 1-foot (30 cm) of sand as a filter

- 1-foot (30 cm) granulated slag (sand) layer to protect the underlying flexible membrane and geosynthetic clay layers during construction
- 2.5-foot (75 cm) (minimum) biotic protection layer of coarse slag placed in lifts to minimize settling
- 1-foot (30 cm) granulated slag filter layer
- Additional geofabric layer
- A 2.5-foot (75 cm) topsoil layer
- 1-foot (30 cm) topsoil with 15% pea gravel, and vegetation

The areal extent of the enhanced RCRA cap is shown on Figure 3-5. Due to the overall thickness of the enhanced RCRA cap and allowable slope, the enhanced RCRA cap would extend over a large portion of the adjacent crude phosphorus burial area (SWMU 11). The conceptual cap was expanded over the entire crude phosphorus burial area for constructability concerns.

When the cap was complete, a perimeter fence would be installed around the cap area to restrict access and discourage animal presence close to the cap.

Safety procedures during construction would include continuous phosphine monitoring in accordance with a plan to be developed for the specific construction sequence. Personal phosphine monitoring would be conducted during construction activities. Personal protective equipment would also be used, as described in Appendix D for the protected worker.

The Enhanced RCRA cap would meet the standards in 40 CFR § 265.310(a)(1)-(5). Specifically, the design cap would:

40 CFR § 265.310(a)	Cap Design
(1) provide long-term minimization of the migration of liquids through the used carbon brick and furnace liner pile;	As discussed in Section 3.2.1, the cap would minimize migration of rainwater through the barrier layer.
(2) function with minimum maintenance;	Minimal maintenance would be necessary given the consolidated contents, arid conditions and minimum slopes.
(3) promote drainage and minimize erosion or abrasion of the cover;	Positive drainage would be maintained by a final surface slope of 3 to 5 percent from the center of the cap to the edges.
(4) accommodate settling and subsidence so that the cover's integrity is maintained; and	The materials would be consolidated before the cap would be constructed. Therefore, minimal settling and subsidence would be expected.
(5) have a permeability less than or equal to the permeability of the natural soils present.	The cap would meet this requirement as described in the next paragraph.

The cover design exceeds EPA's design recommendations in its Final Covers Guidance in three beneficial respects. First, the barrier layer, which consists of a geosynthetic clay liner (GCL), would exceed the specified 10^{-7} cm/s hydraulic conductivity by approximately two orders of magnitude. Second, a 60 mil FML would be used instead of the thinner 20 mil FML. Finally, instead of two feet of material above the drainage layer, the design would entail a minimum of 9 feet of cover material to protect the synthetic liners from frost penetration and burrowing animals. This layer is nearly three times greater than the 3.5 foot average of frost penetration in the Butte, Montana area. In addition, there would be nearly 7 feet of subgrade, which would result in a total cap of nearly 16 feet of material above the clarifier material.

The capped area would be designated in the land records as a no excavation zone. The substantive requirements of 40 CFR §§ 265.116, .119 and .309 would also be met, including designating the restricted area on the survey plat, providing required notices of waste disposal, and maintaining records of waste disposal.

The no excavation restriction would be placed on the land records so that any future purchaser would take the property subject to this restriction. By so restricting the use of the property, any future purchaser would be unable to convey the property again if it were to violate this restriction.

In addition, this alternative would restrict the use of the clarifier area by applying Mont. Code Ann. § 75-10-727 to restrict the property without a conveyance. The statute allows restrictions on property to run with the land and successors in interest to be bound by the restrictions. This option requires approval by the MDEQ. The statute provides:

“(2) The institutional control restricting present and future real property rights is placed on a property by filing a written instrument evidencing the restrictions to be placed on the use of the property with the county clerk in the county where the real property is located.

(3) An institutional control that restricts real property runs with the land and is binding on all successors in interest to real property until the institutional control is removed.”

A restriction could only be removed if approved by MDEQ. Restricting the use of property where materials have been landfilled is a common and widely used practice. For example, following closure of Class II landfills in Montana, a notation must be recorded in the deed or other instrument subject to a title search that the land has been used as a landfill and that its use is restricted. ARM 17.50.530(1)(i). When notice of a restriction is given, it is enforceable by the local governmental authorities. See Hampton v. Lewis and Clark Co. Commission, 2001 WL 46317 (Mont. 2001). Selection of appropriate institutional controls would be resolved at closure.

A Post-Closure Plan consistent with 40 CFR § 265.118 would be developed for the Enhanced RCRA cap. The post-closure plan would identify the routine activities that would be conducted after the enhanced RCRA cap is constructed.

Maintenance of the cap would include inspection, assuring vegetation establishment, and correcting any critical erosion within a specified time period. Such inspections would occur in the spring after snow melt, in the fall before significant snowfall, and after any precipitation event that exceeds the 25-year, 24-hour storm. During these inspections, the fence would also be inspected, and repaired if necessary.

Monitoring of vapors beneath the cap would be specified in a phosphine monitoring program. Initially, phosphine monitoring might be conducted on a quarterly basis, but the frequency would be modified based on findings of the initial program. If actionable levels of phosphine are found, a phosphine treatment system (e.g., vapor-phase carbon) would be connected to the phosphine monitoring/collection system for capturing and destroying the phosphine gas.

A groundwater monitoring system would be installed at upgradient and downgradient locations to continue to monitor the groundwater quality near the closed clarifier. For cost estimating purposes, the groundwater monitoring network consists of 5 monitoring wells with annual sample collection and analysis for the 30-year post-closure monitoring period⁴. This data would be used to continue to evaluate groundwater quality trends associated with releases from the clarifier. If the groundwater monitoring program identifies an ongoing trend of increasing contamination related to releases from the closed clarifier then corrective measures would be evaluated at that time.

Operation, maintenance, and monitoring activities would be evaluated on a periodic basis to improve efficiency, effectiveness, and reliability, and to reflect knowledge gained from the program. Adjustments to the program would be recommended for EPA approval on the basis of these evaluations.

3.2.2 Evaluation of Alternative

This Section evaluates the enhanced RCRA cap alternative against the five evaluation criteria described in Section 2.3.

⁴ Groundwater monitoring beyond the 30-year post-closure period specified in 40 CFR 265.117 may be necessary, but the costs for extended monitoring period are not reflected in the cost estimate for this alternative.

3.2.2.1 Long-term Reliability and Effectiveness

Flexible membranes and other similar membrane-containing caps have been successfully used at phosphorus production facilities to provide effective containment of residual phosphorus-bearing materials. These caps are designed to last for many hundreds of years and their reliability to control ignition and phosphine generation can be assured early on. High density polyethylene (HDPE) liners, as proposed for this option, can be expected to last for a very long time. “...*HDPE geomembranes should last well beyond the 30-year closure period required in many environmental regulations without any measurable degradation mechanical properties. Clearly, lifetime of hundreds of years appear to be achievable.*” (Hsuan, 1995).

Monitoring and maintenance activities designed into the management strategy for the enhanced RCRA cap, would reinforce the effectiveness of the cap over time and address specific concerns about the generation and release of phosphine and groundwater contaminants.

As noted above, multi-layer caps have been in place at the Silver Bow Plant since the late 1970s, and five were in place and evaluated in the 1993 Albright & Wilson study (AWA, 1993). Although enhanced caps have been used for less than three decades, their use in situations similar to the Silver Bow Plant, have shown no problems that would raise questions about their long-term effectiveness.

Phosphine monitoring at the Silver Bow Plant found non-consequential concentrations of phosphine in the soil gas in the immediate vicinity of SWMU 11. SWMU 11 contains crude phosphorus that was occasionally excavated from the clarifier and immediately placed in trenches and covered with soil or slag. This burial area was closed in the late 1970s with a multi-layer cap. The phosphine concentrations detected in the soil gas were at least two orders of magnitude below the Immediately Dangerous to Life or Health (IDLH) level of 50 ppm_v, and the maximum phosphine concentration detected in the soil gas was below the occupational short-term exposure level (STEL) of 1.0 ppm_v. The results from the screening level phosphine monitoring program demonstrate that phosphine is not being released to the atmosphere at consequential concentrations. Low concentrations of phosphine are present in the soil gas in the immediate area below ground, with no detected concentrations above ground (Barr, 2013).

Hazardous levels of phosphine were generated at certain capped waste ponds at the FMC Plant. These ponds contain elemental phosphorus waste streams and alkaline conditions (pH > 8). These alkaline conditions provide the ingredients to increase the rate of phosphine generation. Capped ponds at the FMC Plant that contain elemental phosphorus waste and acidic conditions (i.e., Phase IV Ponds) have not generated actionable levels of phosphine (Feldman, 2014).

Moreover, the history of soil caps over the last several decades demonstrates that soil caps are very effective in eliminating the hazards of fire and phosphine generation at harmful levels. Since the Enhanced RCRA cap contains nine feet of additional synthetic and natural liner on top of the traditional soil cap, one would expect the Enhanced RCRA cap to be every bit as reliable in the long term as soil caps have been.

The Enhanced RCRA cap at the clarifier would not be susceptible to failure due to erosion or flooding. The clarifier is not a drainage way, so neither flooding nor nearby runoff would induce erosion of the clarifier cap. Only water falling on the cap would contact it. The 100-year, 24-hour rainfall for this area is 3.2 inches and the 25-year, 24-hour rainfall is 2.6 inches (National Oceanic and Atmospheric Administration, 1973). The runoff during 24 hours from this little rain is not adequate to cut through the cap material, much less any burrowing animal protection zone, synthetic membranes, or the concrete clarifier walls. Animal activity would also be impeded from affecting the synthetic liner by the burrowing-animal barrier and a fence. This form of cap is extremely effective at minimizing infiltration. The range of infiltration estimated by the HELP model for this conceptual Enhanced RCRA cap (Appendix J), based on a sensitivity analysis of relevant parameters, would be from 3E-6 inches/year to 6E-6 inches/year. The corresponding range of annual percolation values would be 0.002 ft³/yr to 0.004 ft³/yr. Thus, the Enhanced RCRA Cap would achieve its purpose of greatly minimizing infiltration over the full range of conditions. Flooding would be unlikely at this location, as Silver Bow Creek is 3,000 feet away from the clarifier and 50 feet lower in elevation. The clarifier is not located in the 100-year flood plain of Silver Bow Creek (DHES, 1989). The cap would be flexible enough to accommodate differential settlement. Deed restrictions would define this area as a no excavation zone, so that the integrity of the cap would not be compromised by human activity.

This site is located in Earthquake Hazard Zone 3, which is not expected to suffer the severe earthquakes expected in areas like San Francisco along the San Andreas Fault. The cap would be designed to resist damage from reasonably anticipated earthquake forces, such as earth-shaking or horizontal acceleration forces. Uncontrollable changes at the site such as those caused by earthquake could conceivably affect the cap, but the cap is flexible, and the cover soil could easily be repaired if needed.

The cap could accommodate a wide range of native vegetation cover types, including shallow-rooted trees, because of the thickness of the cover soil. After the cover vegetation has been established, and monitoring has demonstrated no on-going environmental issues, this form of cap could function effectively without further maintenance. Nonetheless, the cap would be inspected before and after the snow season and after each 25-year storm event, and it would be maintained whenever necessary.

3.2.2.2 Reduction in the Toxicity, Mobility or Volume

The potential for exposure to the inherent toxicity of the material would be essentially eliminated. The cap would provide a barrier to the air that is essential to cause ignition. Phosphine generation would be minimized by several mechanisms. Contact with water, necessary to generate hazardous levels of phosphine, would be greatly minimized by the infiltration-reducing effect of the Enhanced RCRA Cap. The pH of the precipitation would be buffered by the soil so that the water would not be highly alkaline, again reducing the potential for phosphine production. Additionally, a phosphine monitoring system would be in-place to detect hazardous levels of phosphine and, if found, a phosphine treatment system would be designed and operated to prevent exposure to harmful levels of phosphine. Note: Phosphine monitoring in soil gas at the Silver Bow Plant has not shown harmful levels being generated at the capped SWMUs that contain elemental phosphorus-containing materials (Barr, 2013).

Regarding the mobility of the clarifier material, the Enhanced RCRA cap provides a very low permeability cover that serves to minimize the mobility of substances that might otherwise leach from the clarifier materials and be transported in dissolved form in the water. After cap construction, estimated infiltration would be reduced to less than 0.03 gallons per year over the clarifier area, thus reducing the potential for leaching to insignificant levels. In addition, the monitoring for potential groundwater impacts provides a safety net.

The enhanced RCRA cap quickly ends the need to maintain the water cap and the future percolation through the clarifier contents would be reduced to the water infiltrating through the cap, which is estimated to be from $3E-6$ inches/year to $6E-6$ inches/year (Appendix J). This future condition has been modeled to estimate the potential impacts of the capped clarifier on groundwater quality. Three approaches were used to evaluate the potential impacted on groundwater quality: (1) Partition Model; (2) Leachate Model; and (3) Solids Model (see Appendix K). These evaluations shows that no impacts to groundwater would be expected above drinking water quality standards if the enhanced RCRA cap were placed on the clarifier. This finding holds true, using the consciously conservative SSL model, for all three different approaches to evaluating protectiveness for groundwater. In addition, the sensitivity analysis of infiltration (see HELP model, Appendix J), found less than an order of magnitude increase in infiltration under the full range of sensitivity conditions evaluated. These sensitivity results mean that, for the expected range of infiltration conditions, the cap remains protective of groundwater.

The Enhanced RCRA cap option does not reduce the volume of material that would be left in place, other than removal of the water cap. Nonetheless, for the reasons noted above, the Enhanced RCRA cap would ensure that the remaining clarifier material would not be a source of groundwater contamination or of fire or phosphine generation at harmful levels.

3.2.2.3 Short-term Effectiveness

The short-term effectiveness of the Enhanced RCRA cap option would largely be a function of the risks resulting from the activities that would be necessary to construct the Enhanced RCRA cap. These risks would primarily be from mechanical hazards, like digging borrow soil, and from the potential for fire and phosphine gas generation during the first phase of cap construction. Once the first phase granulated slag cap is in place, there would be relatively little potential for fire or phosphine exposure for the workers engaged in the second phase construction work.

The list of steps that were evaluated for risk for this option included the following:

- Site preparation
- Subgrade placement (moving fill materials to and then into the clarifier)
- Surcharge placement/removal (placing and grading the coarse cover material)
- Consolidation monitoring (dewatering and stabilization of the covered material)
- Gas collection system installation
- Subgrade grading
- Synthetic liner placement
- Cover soil placement/grading(final layer)
- Restoration/revegetation
- Maintenance of the cap and groundwater monitoring system

The estimated crew size and task duration for this work area are shown in Appendix L. There would be some potential for incidental exposure to phosphorus-bearing materials during the “placing of the initial coarse cover” and thus the workers were assumed to operate under a site-specific health and safety plan, as explained in Appendix D. However, the potential for fire and phosphine generation after that initial construction would not be significantly different from ordinary construction risk rates. The exception is that the revegetation task would have a bit lower rate, since such activity would mimic landscaping and grounds keeping activities, and the monitoring and maintenance risk rate would also be lower since this activity would be akin to typical professional consultant work.

Table 3-1 presents the probability of a fatality for this option. The risk calculations are provided in Appendix M. The probability of a fatality to the unprotected worker would be “low” 0.0007%. The probability of serious injury to the unprotected worker would be somewhat higher (0.02%), but the value shown in Table 3-2 is at a “medium” risk level. The protected worker would face a probability of

about 0.0006% of fatality, and 0.02% of serious injury. These relative risks are considered “low” and “medium.”

3.2.2.4 Implementability

A preliminary implementation schedule was developed based in the review team’s professional judgment and experience with similar capping projects. The preliminary implementation schedule represents a best estimate at the duration of this alternative.

Preliminary Implementation Schedule	
Timeline	Description
4Q 2015	Supplemental Waste Plan.
1Q 2016	EPA approves the Supplemental Waste Plan.
1Q 2016	EPA conducts a public hearing on the Supplemental Waste Plan remedy and selects this capping remedy.
2Q 2016	EPA prepares the Corrective Measures Decision Document.
2016-2017	Phase 1 Cap Design and Construction - Subgrade and surcharge placed, and design for Phase 2 cap construction.
2018	Phase 2 Cap Construction – Remove surcharge and construct cap layers and grade/seed.
2019	Construction of enhanced RCRA cap complete and vegetated surface established. The Draft Waste Plan Implementation Report would be submitted to the EPA within 90 days after completion of the cap construction.

This alternative would likely take two construction seasons to consolidate the clarifier materials and build the multi-layer cover systems. Implementation of the enhanced cap option could begin promptly after EPA approval, weather conditions permitting. No permits would be necessary. The Enhanced RCRA cap would be constructed using standard construction techniques and equipment that are readily available on-site or from commercial sources, as necessary. No off-site treatment, storage capacity, or disposal services would be required to implement this alternative. Contractors could quickly be trained to undertake the construction activities.

The construction time is estimated at a few months during the first construction season to place the subgrade and any necessary surcharge. The surcharge would remain until the second construction season, which is estimated at a few months to construct the Enhanced RCRA cap and establish the vegetated surface. Vegetation may require more than one growing season after cap construction to fully establish a vegetated surface. Design work, contractor procurement, and approval of the necessary air monitoring and other plans for construction may be assumed to require several months prior to construction. This alternative offers the following benefits from its quick implementation:

- The short duration of construction would result in any mechanical, fire and phosphine risks from construction being short-term;
- Potential for fire and phosphine generation would be removed quickly; and
- Beneficial effects for the environment would commence upon completion of the cap subgrade, because any potential percolation of leachate from the clarifier area into the groundwater would begin declining as soon as the water addition to the clarifier is terminated.

In a letter dated June 27, 2003 to Rhodia, EPA Region 8 made a preliminary decision that a capping alternative would not be the best option for the short and long-term management of the clarifier wastes⁵. MDEQ concurred with EPA's preliminary decision in a letter to the Director of EPA Region 8 dated June 26, 2005, and questioned whether this alternative could be approved by the regulators.

3.2.2.5 Relative Cost

The representative cost of this alternative is estimated at \$5.0 million and the cost of financial assurance is estimated at \$0.43 million for a total estimated cost of \$5.4 million. This order of magnitude estimate is expected to provide an accuracy of plus 50 to minus 30 percent for the described scope of the alternative. The details of the cost estimate are in Appendix N and the cost estimate methodology is in Appendix E.

3.3 On-site Phosphorus Recovery (Mud Still Process)

3.3.1 Description of Alternative

The on-site phosphorus recovery alternative involves recovery of the elemental phosphorus as a usable product. The mud still technology was developed by Albright and Wilson (A&W) in the early 1970s and patented in 1978. Nine individual mud still treatment trains were constructed at five separate elemental phosphorus production plants (two in the United Kingdom, two in Canada, and one in the United States of America). These treatment trains were safely and successfully operated for a period of approximately 20 years. These elemental phosphorus plants including the mud still treatment trains were decommissioned during the early 1990. A more detailed history of operation of mud still treatment systems is provide in Appendix O. Solvay has retained knowledgeable staff that helped develop and operate this patented treatment process.

⁵ The preliminary decision was based on the alternatives presented in the Waste Plan (Barr 2001a) and the Focused Feasibility Study Report (EPA, 2003).

As was done at other elemental phosphorus plants, a mud still treatment train would be constructed at the Silver Bow Plant that would vaporize P4 from the crude phosphorus and condense the phosphorus vapor into a usable product. The mud still would likely be located near the clarifier for logistical purposes, as shown on Figure 3-6. The on-site phosphorus recovery would involve three distinct operations, as depicted on the process flow diagram (Figures 3-7 and 3-8). The operations include:

- Crude Phosphorus Excavation and Handling;
- Mud Still Operations; and
- Residue Management.

Each of the operations is described in the following subsections. The mud still technology was identified and evaluated as part of a three-phase treatability study, which culminated with the construction and operation of a pilot-scale mud still. Much of the information included in the following subsections is derived from the results of the treatability study (Franklin, 2007; 2011; 2012). A conceptual layout of the mud still is depicted on Figure 3-9.

3.3.1.1 Crude Phosphorus Excavation and Handling

The first process involves excavation and handling of the crude phosphorus sludge, as depicted on Figure 3-7. The crude phosphorus sludge would be removed from the clarifier using an excavator with bucket attachment. The material would be transferred from the excavator bucket to a metal skip that would be located within a spill pan (i.e., secondary containment) adjacent to the clarifier.

Approximately 590 gallons of crude phosphorus sludge would be placed in the skip (10-foot diameter by 1 foot deep). The bucket could be continuously sprayed with water to minimize fires that could occur if the crude phosphorus were exposed to air. Any material that spills during transfer would be captured by the spill pan and flushed back into the clarifier.

The water cap would be maintained at least one foot above the layer of crude phosphorus in the clarifier. If necessary, production well water would be added to increase the water level to extinguish crude phosphorus fires. The water cap would be maintained at a pH between 5.0 and 6.0 standard units to minimize the potential for phosphine generation. This pH adjustment, which was standard practice to minimize phosphine generation during plant operations, would be accomplished by adding concentrated acid to the water cap.

As the water level recedes during the removal of crude phosphorus, crude phosphorus would likely cling to the walls of the clarifier and could ignite. To minimize this situation, exposed crude phosphorus on the interior clarifier walls would be washed (i.e., high pressure hot water) into the clarifier in an attempt to dislodge the material and minimize fires. Some P4 would likely remain

entrained in the crevices of the clarifier walls, which is one reason why after the crude phosphorus removal occurs, the clarifier would be filled and covered as part of the designated CAMU.

During removal, excess water would be decanted from the skip back to the clarifier, leaving about a few inches of water over the crude phosphorus in the skip. A lid would then be secured over the skip compartment and the covered skip would be transported to the skip staging area near the mud still furnace.

Despite the procedures that would be followed to attempt to maintain the water cap throughout the process, removal and transfer activities might result in situations where some amount of the crude phosphorus might be exposed to air. As a result, phosphorus fires could occur during the excavation and transfer operations. Fires outside the clarifier could be smothered with granulated slag or water. If exposed materials in the clarifier ignite, additional water could be pumped into the clarifier until the burning materials were covered and extinguished. Procedures for safe operations would be addressed through the process safety management of highly hazardous chemicals program, and development of a health and safety plan, and contingency plan.

Crude phosphorus would be removed from the clarifier until it could no longer be safely and practicably removed by the excavation equipment (estimated between 80% to 98% removal). The concrete surface would be scraped with the smooth-edge bucket to remove as much crude phosphorus as practicable. The excavator encountered the concrete bottom of the clarifier during the excavation of crude phosphorus for the pilot plant tests. If in some areas, the concrete bottom has deteriorated, the excavation would terminate at the bottom of the clarifier. As noted earlier, high pressure hot water jets would also be used to dislodge crude phosphorus from the walls and enable its removal. For safety reasons, workers would be instructed to not go into the clarifier to remove crude phosphorus. At the point when removal of the crude phosphorus sludge would no longer be safe and practicable, EPA would be consulted to confirm that the removal activities may be terminated. A water layer would be maintained over the sludge that cannot be safely and practicably removed from the clarifier to prevent fires until the CAMU construction begins.

The literature indicates that EPA has acknowledged that all environmental dredging projects leave behind some residual contamination in sediment due to resuspension in the water column, dislodged material that is left behind, slope failure, etc. and material that cannot be removed because of site conditions and equipment constraints (EPA, 2005). Studies conducted by the Army Corp of Engineers (ACE) suggest that approximately two to nine percent of the mass of materials during the last production cut typically remain as residuals (ACE, 2008). For example, if the last production cut were one foot, then about an inch of sediment would likely remain in the excavated area. The crude

phosphorus may behave differently than the sediments evaluated by the ACE, but the principles remain the same and suggest that some mass of crude phosphorus would remain in the clarifier even under the most optimal excavation conditions. EPA and ACE acknowledge that contaminated residuals are a factor that needs to be considered and managed. Therefore, the material that cannot be removed from the clarifier would be covered with granulated slag or soil as described in Section 3.3.1.4.1.

3.3.1.2 Mud Still Operations to Recover Elemental Phosphorus

The second process is operation of the mud still. The mud still operation involves a series of connected tanks and process equipment, as depicted on Figure 3-7.

The skip would be placed in the mud still furnace compartment. The lid would be removed from the skip and the furnace compartment would be closed. The electric furnace would heat molten lead, which acts as the heat transfer medium and provides a seal for the skip. As the temperature of the still rises, water would be vaporized (at approximately 202 °F), followed by vaporization of white phosphorus (approximately 503 °F) and conversion of some white phosphorus to red phosphorus. As the temperature continues to rise, the red phosphorus would be vaporized at approximately 730 °F. The furnace would be continuously purged with nitrogen to maintain the necessary reducing atmosphere and to drive the water and phosphorus vapors through the process.

The water and phosphorus vapors would be conveyed to a stainless steel condenser where the vapors would be condensed to liquid water and phosphorus. The liquid phosphorus would accumulate in the bottom of the condenser since it is denser than water. The liquid phosphorus would be removed from the condenser at the end of each batch and transferred to a product phosphorus collection tank. When sufficient volume of product phosphorus has accumulated in the collection tank, the contents of the collection tank would be transferred to an International Standards Organization (ISO) specification container that would meet the U.S. Department of Transportation (DOT) requirements for transporting elemental phosphorus.

The filled ISO container would be hauled via truck to a Solvay P4 facility. The Solvay facility in Charleston, South Carolina was used for risk evaluation and cost estimating purposes. Approximately 38 shipments (20 tons per truck shipment) would be necessary to transport the phosphorus product to the P4 facility. The distance between Silver Bow, Montana and Charleston, South Carolina is estimated at 2,350 miles, for a total loaded travel distance of about 89,000 miles.

Process water would be sprayed through nozzles throughout the condenser. The water would collect at the bottom of the condenser above the phosphorus layer. The water level would be maintained by an overflow pipe that would convey the water to the water collection/recirculation system. Water from the

collection tank would be recirculated to the condenser and to a wet scrubber (see below). If excess water were present in the collection tank, it would be piped back to the clarifier.

Small amounts of phosphorus may collect in the water collection/recirculation tanks. Phosphorus that accumulates in these water tanks would be transferred to the phosphorus collection tank, when needed.

The gas stream that exits the condenser would likely contain low concentrations of phosphorus vapor and possibly phosphine. Therefore, the exit gas stream would be directed to a vapor combustor where the reduced phosphorus compounds would be oxidized to phosphorus oxides and water. The off gas from the vapor combustor would be directed to a wet scrubber to remove the oxidation products.

Exhaust from the wet scrubber would be vented to the atmosphere and water that accumulates would be sent to the water collection/recirculation system.

Water would be reused to the maximum possible extent. However, some water might need to be removed from the water recirculation system on a periodic basis (e.g., blow down) or would remain at the end of the operations. This excess water could be returned to the clarifier if needed, or discharged to an evaporation basin constructed for that purpose. The excess water would contain low quantities of elemental phosphorus, phosphate, fluoride and metals.

The mud still would be operated on a batch basis. If the mud still were to process five batches over seven days with round-the-clock operations (i.e., 24 hours per day; 7 days per week), the length of time necessary to process the 500,000 gallons of the crude phosphorus would be on the order of 170 weeks of continuous operation. In reality, the mud still would require a regular turn around period for equipment inspection and maintenance, which would likely result in at least five, and likely more, years of total operation and maintenance.

The treatability study helped to identify operational parameters that need to be monitored to help evaluate when to terminate the heating portion of the operations. During one of the trial runs, the heating portion was not run long enough to vaporize all of the elemental phosphorus from the skip. This elemental phosphorus ignited when the lid was removed from the vessel. To reduce the likelihood of this happening during production-scale operations, monitoring of the temperature and pressure of the mud still system and the characteristics of the still vapor would be a critical part of the operation. Operation of the mud still and monitoring of the operational parameters would require specific training.

3.3.1.3 Residue Management

The third part of the on-site mud still phosphorus recovery process would be management of the mud still solid residues. The solid residues from the mud still's recovery of P₄ would remain in the skip.

After completion of each batch, the skip would be removed from the furnace compartment and placed in the residue management area (see Figure 3-8).

A vacuum system would be used to remove the solids from the skip and transfer the residue to the residue silo. These dry solid residues would be fed into a residue silo through a cyclone separator. Air from the cyclone separator would travel through a bag house before it would be emitted to the atmosphere. The solid residues would collect in the silo, and then transferred (via gravity) to super sacks for storage until disposal back into the clarifier after crude phosphorus removal is completed and the CAMU has been designated. The solid residues consist of phosphate ore, coke, silica, and other inert materials that were in the crude phosphorus sludge.

Results of solid residue samples tested during the treatability studies are summarized in Appendix P. The solid residue would not be a hazardous waste for ignitability since the elemental phosphorus would have been vaporized from the solid material by the mud still operation. For the pilot test runs that went to completion, there was no smoke or fire, or phosphine emission when the still was opened⁶. In addition, the solid residue does not have an aqueous or liquid layer, and as such, could not be a hazardous waste for corrosivity.

Eight of eleven solid residue samples analyzed during the treatability study failed the TCLP test for cadmium but no other metal (see Appendix P). As such, much of the solid residue would exhibit the D006 hazardous waste toxicity characteristic for cadmium.

3.3.1.4 Corrective Action Management Unit (CAMU)

As part of this mud still remedy, the clarifier (which is SWMU 2) would be designated as a CAMU and closed with an evapotranspiration cap. This CAMU would be the long-term disposal unit for the mud still solid residue, which would be placed back into the clarifier, as well as for the crude phosphorus sludge that cannot be safely and practicably removed from the clarifier.

A CAMU designation permits disposal of hazardous waste residues without first treating the solid residues to meet land disposal restriction (LDR) standards. See 40 CFR §264.552(a)(4). Further, the CAMU would not be required to meet the minimum technological requirements of a double liner and leachate collection system. See 40 CFR §264.552(a)(5). As such, the solid residue from the mud still

⁶ In the unlikely event that there is a flame observed from any solid residue, the material would be extinguished, and then reprocessed in the mud still after confirming that the mud still is operating properly

operations could be placed into the clarifier and the crude phosphorus sludge that cannot be safely or practicably removed would remain in place in the clarifier for long-term disposal.

3.3.1.4.1 Design and Operation of CAMU

After all of the crude phosphorus sludge that can be safely and practicably removed from the clarifier is removed and processed in the mud still, Solvay would begin constructing the CAMU. First, if there were any excess cover water (an amount beyond what would be needed to prevent the remaining crude phosphorus from igniting), Solvay would remove the excess water and manage it on-site in an evaporation pond.

A solid waste management system license might be needed to construct and operate an evaporation pond for this nonhazardous wastewater. Solvay met with MDEQ on March 7, 2014 to discuss such license. At that time, MDEQ indicated that there was insufficient information to make a final determination as to whether a license would be required. Solvay will continue discussions with MDEQ to determine whether a license is required, and if so, Solvay would work with MDEQ to obtain the necessary license.

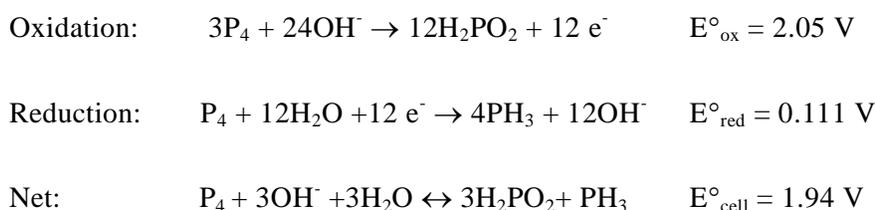
Next, the remaining crude phosphorus that cannot be safely or practicably removed would be covered with about 2 feet of granulated slag. The slag is a fine grained (particle size of about 0.1 to 1.5 mm diameter) calcium silica material that would act as an absorbent for any remaining liquid, and would serve to prevent oxygen from contacting any remaining elemental phosphorus, and thereby minimize fire. The super sacks of mud still solid residue would then be returned to the clarifier. Voids between the super sacks would be filled with additional granulated slag, and then the sacks would be covered with additional granulated slag.

As a precautionary measure, a system of interconnected perforated pipes would be installed within the clarifier to collect and capture phosphine gas in the unlikely event that actionable levels of phosphine gas were generated in the closed clarifier. The piping would extend above ground, but there it would not be perforated, but rather solid and valved/capped off to prevent emissions. In the unlikely event, significant phosphine generation occurs, a phosphine gas treatment unit would be added to the end of the pipe to eliminate the phosphine gas. We do not expect phosphine gas generation in the closed/capped clarifier at actionable levels for several reasons.

First, phosphine monitoring at the Silver Bow Plant found non-consequential concentrations of phosphine in the soil gas in the immediate vicinity of SWMU 11 (Barr, 2013). SWMU 11 contains crude phosphorus that was occasionally excavated from the clarifier and immediately placed in trenches and covered with soil or slag. This burial area was closed in the late 1970s with a multi-layer

cap. The SWMU contains elemental phosphorus-containing waste that is not subjected to alkaline conditions. The phosphine concentrations detected in the soil gas at SWMU 11 were at least two orders of magnitude below the Immediately Dangerous to Life or Health (IDLH) level of 50 ppm_v, and the maximum phosphine concentration detected in the soil gas was below the occupational short-term exposure level (STEL) of 1.0 ppm_v.

Second, the environmental conditions within the closed unit act to minimize phosphine generation as discussed below. Elemental phosphorus has the potential to generate phosphine gas when in contact with water (Spanggard et al., 1983). ATSDR states that in water with low oxygen, elemental phosphorus may degrade to phosphine.⁷ Higher temperature and higher pH increase the generation of phosphine as they promote the reaction of elemental phosphorus (P₄) to form hypophosphite and phosphine. Reaction kinetics are favored under alkaline conditions⁸. The redox reactions and standard electrode potentials (E°) are as follows (Jolly, 1966):



Since the E°_{cell} is positive, the reaction would occur spontaneously.

At temperatures less than 60°C and water at pH <8, the rate of phosphine generation by hydrolysis of aqueous elemental phosphorus is very slow. These are the current conditions at the capped area (SWMU 11), and would be the conditions at the closed CAMU. These conditions should virtually eliminate the potential for phosphine gas to be generated at actionable levels.

Third, actual monitoring for phosphine gas generation from and around the clarifier over the last 14 years while conditions have existed that might result in phosphine gas generation has found no consequential detections of phosphine gas, except during disturbance of the clarifier for sampling purposes.

⁷ ToxFAQs for White Phosphorus, CAS #7723-14-0. <http://www.atsdr.cdc.gov/tfacts103.html>.

⁸ Hazardous levels of phosphine were generated at certain capped waste ponds at the FMC Plant. These ponds contain elemental phosphorus waste streams and alkaline conditions (pH > 8). These alkaline conditions provide the ingredients to increase the rate of phosphine generation. Capped ponds at the FMC Plant that contain elemental phosphorus waste and acidic conditions (i.e., Phase IV Ponds) have not generated actionable levels of phosphine (Feldman 2014).

Nonetheless, solely as a precautionary measure, a long-term phosphine monitoring/collection system would be installed beneath the CAMU cap.

After installation of the phosphine gas collection piping, the above-grade portion of the clarifier walls would be demolished and pushed into the clarifier. This is necessary to enable proper cap construction. The area would be brought to grade by filling it with additional granulated slag and shaped as needed to establish the subgrade for the final cover.

3.3.1.4.2 Evapotranspiration Cap

The CAMU could be closed with an evapotranspiration cap. The evapotranspiration cap would be constructed over a subgrade of granulated slag, and would consist of at least 1.5 feet of borrow soil and an additional 0.5 feet of topsoil seeded with a vegetated cover. The 1.5 feet of borrow soil would be obtained from an on-site borrow source of clay-rich material. Testing of a sample from the upper 6 feet of a potential on-site borrow area classified the soil as a clayey sand (silty clay loam by Department of Agricultural categorization). The 0.5 feet of topsoil might be obtained from an on-site borrow area, amended as appropriate to enhance plant growth, or might be obtained from an off-site source. The evapotranspiration cap would be seeded with vegetation appropriate to the climate. Figure 3-11 shows the cross-section of the conceptual evapotranspiration cap.

An evapotranspiration cap functions by returning infiltrated precipitation to the atmosphere via evaporation from the soil and plants, and transpiration from plants. In the Silver Bow region of Montana, about 60 percent of the approximately 13 inches annual precipitation occurs during the five-month May to September growing season, which is favorable for evapotranspiration caps. HELP modeling of the conceptual evapotranspiration cap shows that very little infiltration would penetrate the cap (Appendix Q). The annual average runoff estimated by the HELP model for this cap is about 0.5 inches, and the average annual evapotranspiration is about 12.0 inches. The average annual infiltration estimated by the HELP (Hydrologic Evaluation of Landfill Performance) model for the proposed evapotranspiration cap is 0.013 inches per year. This is equivalent to less than 10 ft³ per year (less than 70 gallons per year), or 0.00012 gallons per minute over the 100-foot clarifier area. The modeling shows that this level of effectiveness is achieved for site borrow soil placed at 90 percent of maximum standard proctor density and moisture content typical of natural conditions. This means that the borrow source material is capable of producing a very effective evapotranspiration cap with relatively little control on moisture and compaction conditions during cap construction.

An evapotranspiration cap has the advantage over traditional synthetic membrane or compacted clay caps in that a variety of cover vegetation types are acceptable. Deep-rooted grasses, shrubs, and trees would be compatible with evapotranspiration caps, although they might be problematic for caps with a

synthetic liner that is placed near the surface. Deep-rooted grasses, shrubs and trees would generally be as effective as shallow-rooted plants for providing the evapotranspiration function of the cap. Deep-rooted plants would primarily be a concern for synthetic liners, where decay of old roots can leave passages for infiltration through the liner. For evapotranspiration caps in arid climates, deep-rooted plants offer the advantage of hardiness and the ability to draw moisture from greater depths. In effect, they retrieve the water that may have percolated deeper into the soil. The potential evapotranspiration for these plants would be much greater than the total average annual rainfall for the Silver Bow area. Thus, on balance, deep-rooted plants would be effective in an evapotranspiration cap.

The evapotranspiration cap would meet the standards in 40 CFR § 264.552(e)(6)(iv). Specifically, the design cap would:

40 CFR § 264.552(e)(6)(iv)	Evapotranspiration Cap Design
(1) provide long-term minimization of the migration of liquids through the closed unit;	The cap would minimize migration of rainwater through the closed clarifier at an extremely slow infiltration rate of approximately 10 ft ³ /yr.
(2) function with minimum maintenance;	Minimum maintenance would be necessary given the consolidated contents, arid conditions and minimum slopes.
(3) promote drainage and minimize erosion or abrasion of the cover;	Positive drainage would be maintained by a final surface slope of 3 to 5 percent from the center of the cap to the edges.
(4) accommodate settling and subsidence so that the cover's integrity is maintained; and	The materials would be consolidated before the cap would be constructed. Therefore, minimal settling and subsidence would be expected.
(5) have a permeability less than or equal to the permeability of any bottom liner or natural subsoils present.	The cap would meet this requirement as described in the next paragraph.

The evapotranspiration cap would have a permeability less than or equal to the permeability of the natural soils present, and therefore would meet the standards in 40 CFR § 265.552(e)(6)(iv)(5). Specifically, the vertical permeability of the natural soils is estimated to be in the range of 1.8 to 4.6 ft/day. This range is based on measurements of hydraulic conductivity ranging from 14 to 37 ft/day in site wells, reduced to account for anisotropy, consistent with the groundwater flow model (anisotropy of 8 to 1) developed for this site. The vertical hydraulic conductivity of the evapotranspiration cap is estimated at 0.12 ft/day, based on laboratory measurements using a site borrow soil sample compacted to 90% standard proctor density. (The soil testing report is in Appendix R). Consequently, the evapotranspiration cap has a vertical hydraulic conductivity less than the range of natural soil hydraulic conductivities measured and estimated at the site (and adjusted down by a factor of eight to account for anisotropy).

Final design of the cover system would be resolved at closure. However, the details presented here demonstrate that an evapotranspiration cap could meet the regulatory requirements.

3.3.1.4.3 Post Closure Care

A chain link fence that is at least six feet above grade with a locked gate would be installed around the entire perimeter of the cap. This would prevent unauthorized foot and vehicular traffic from damaging the cap, and would minimize animal crossings onto the cap and burrowing into the cap. The fence would also reinforce “no dig” restrictive covenants that would be designated in the land records. The substantive requirements of 40 CFR §§ 264.116, .119 and .309 would also be met, including designating the restricted area as a no excavation zone on the survey plat, providing required notices of waste disposal, and maintaining records of waste disposal. By placing the no excavation restriction in the land records, any future purchaser would take the property subject to this restriction. By so restricting the use of the property, any future purchaser would jeopardize its mortgage and be unable to convey the property again if it were to violate this restriction.

Pursuant to 40 CFR §264.552(e)(5), a post-closure care groundwater monitoring program would be established following closure of the CAMU. The post-closure care groundwater monitoring program may incorporate the pre-closure groundwater monitoring wells that were installed at the request of the EPA under the 7003 Order. Five water table monitoring wells were installed at the clarifier. The primary objective of the groundwater monitoring network would be to continue to monitor groundwater quality related to the CAMU during the post-closure care period. The second objective of the groundwater monitoring program would be to establish a procedure for notifying the EPA Regional Administrator if the results of groundwater monitoring indicate that groundwater concentrations are statistically increasing, and corrective action may be warranted. If the groundwater monitoring program identifies an ongoing trend of increasing contamination related to releases from the closed clarifier then corrective measures would be evaluated at that time. For cost estimating purposes, the groundwater monitoring network consists of five monitoring wells with annual sample collection and analysis for the 30-year post-closure monitoring period.

Maintenance of the cap as part of 30-year post-closure care would include inspection, assuring vegetation establishment, and correcting any erosion. Such inspections would occur in the spring after snow melt, in the fall before significant snowfall, and after any precipitation event that exceeds the 25-year, 24-hour storm. During these inspections, the fence would also be inspected, and repaired if necessary. Operation, maintenance, and monitoring would be evaluated on a periodic basis to improve efficiency, effectiveness, and reliability, and to reflect knowledge gained from the program.

3.3.1.4.4 CAMU Designation

Critical to the viability of the mud still option is a CAMU being designated on the Silver Bow Plant property. Specifically, it is expected that EPA would designate the clarifier (SWMU 2) as a CAMU. The location and area for the designated CAMU are shown on Figure 3-10 as the general cap area. The CAMU would allow the clarifier material that cannot safely and practicably be removed from the clarifier to remain in place and be disposed therein. The large volume of solid residues from the mud still operation, which could be hazardous for cadmium, would also be placed into the clarifier and disposed there. The CAMU would be appropriately closed, capped and monitored and maintained under post-closure care as described above.

Section XII of the 3008(h) order expressly envisions the designation of an area at the Silver Bow facility as a CAMU. The designation of a CAMU at the Silver Bow Plant for the purposes described above would meet the 40 CFR § 264.552 regulatory requirements for designation of a CAMU, as discussed in the “Request of Solvay USA, Inc. to Designate a Corrective Action Management Unit”, which will be submitted to EPA for consideration.

3.3.2 Evaluation of Alternative

This section evaluates the on-site phosphorus recovery alternative against the evaluation criteria described in Section 2.3.

3.3.2.1 Long-term Reliability and Effectiveness

The mud still alternative would remove a large volume of ignitable material from the clarifier and render it non-ignitable. The pilot-scale plant successfully recovered about 0.5 tons of elemental phosphorus from about 1.5 tons of crude phosphorus, and a similar yield should result from full scale operation. Thus a valuable and diminishing resource would have been recovered. The mud still solid residue would not generate phosphine or fire, but may exhibit the toxicity characteristic for cadmium. As discussed in Section 3.3.1.1, some small amount of clarifier material that cannot be practicably and safely removed would remain in the clarifier. This material that cannot be safely removed, as well as the mud still solid residue, would be disposed of in the clarifier and capped and closed.

The CAMU, closed with an evapotranspiration cap, would be even more reliable and effective than the enhanced RCRA cap alternative described in Section 3.2 for minimizing fire and phosphine generation because this alternative would remove almost all of the P4 from the clarifier, thereby removing the source material from the clarifier that could ignite or generate phosphine gas.

The evapotranspiration cap would not be susceptible to failure due to erosion or flooding. The CAMU is not a drainage way, so neither flooding nor nearby runoff would induce erosion of the CAMU cap as

detailed in Section 3.2.2.1. Deed restrictions would define this area as a no excavation zone, so that the integrity of the cap would not be compromised by human activity.

This site is located in Earthquake Hazard Zone 3, which is not expected to suffer the severe earthquakes expected in areas like San Francisco along the San Andreas Fault. The cap would be designed to resist damage from reasonably anticipated earthquake forces, such as earth-shaking or horizontal acceleration forces. Uncontrollable changes at the site such as those caused by earthquake could conceivably affect the cap, but the cap is flexible, and the cover soil could easily be repaired if needed.

The useful life of this alternative would potentially be unlimited. The cap could accommodate all types of native vegetation cover, including shrubs and trees, without unacceptable loss of function. After the cover vegetation has been established, and monitoring has demonstrated no on-going environmental issues, it is expected that this form of cap could function effectively with little or no further maintenance. Nonetheless, the cap would continue to be inspected before and after the snow season and after each 25-year storm event, and it would be maintained whenever necessary.

3.3.2.2 Reduction in the Toxicity, Mobility, or Volume

In the long term, the toxicity, volume and mobility of the clarifier material would be reduced by virtue of removal and recovery of the P4 from the material. The small amount of clarifier material that cannot be safely or practicably removed and the solid residues that are placed into the clarifier and capped would have greatly reduced toxicity for the generation of fire and phosphine. The toxicity of the recovered elemental phosphorus would also be greatly reduced when it is used in the phosphorus industry. The recovered elemental phosphorus would likely be used in an industrial process that converts P4 to phosphorus oxides and/or phosphoric acid, which are less toxic than elemental phosphorus. On the other hand, the mud still process would concentrate the cadmium in the solid residue as several residue samples failed the TCLP test for cadmium while the crude phosphorus samples did not fail the TCLP test for metals.

The water cap would need to be maintained throughout the excavation period (about another eight years). The water cap maintenance system would be terminated after the bulk of the crude phosphorus has been removed from the clarifier and the remaining crude phosphorus that cannot be safely or practicably removed would be covered with granulated slag. The future percolation through the clarifier contents would be reduced to the water infiltrating through the evapotranspiration cap, which is estimated at about 0.013 inches per year inches/year (Appendix Q).

The solid residue would be managed in a CAMU. After closure, the evapotranspiration cap would minimize leachate and mobility of hazardous constituents. This future condition has been modeled to estimate the potential impacts of the capped clarifier on groundwater quality. Three approaches were used to evaluate the potential impact on groundwater quality: (1) Partition Model; (2) Leachate Model; and (3) Solids Model (see Appendix K). This evaluation shows that no impacts to groundwater would be expected above drinking water quality standards if the evapotranspiration cap were placed on the clarifier containing the remaining crude phosphorus and the mud still residue. This finding holds true, using the consciously conservative SSL model, for all three different approaches to evaluating protectiveness for groundwater. In addition, the sensitivity analysis of infiltration (see HELP model, Appendix Q), found less than an order of magnitude increase in infiltration under the full range of sensitivity conditions evaluated. These sensitivity results mean that, for the expected range of infiltration conditions, the evapotranspiration cap remains protective of groundwater. In any event, the groundwater would continue to be monitored.

The alternative has the potential to increase the toxicity in the short term due to potential ignition of the P4 and emission of phosphine during the excavation and processing operations. The alarm on the continuous phosphine monitors was activated during excavation of some crude phosphorus for the pilot-scale test. Excavation immediately stopped and the workers proceeded to evacuate the area. The phosphine concentrations dissipated immediately. The production-scale plant includes an oxidation chamber in which elemental phosphorus and phosphine emission from the condenser would be converted to phosphorus pentoxide. The continuous phosphine monitoring system would be operated and workers near the clarifier would wear personal phosphine monitors to notify the workers of potentially hazardous conditions.

Situations might arise where some amount of the crude phosphorus would be exposed to air. As a result, smoke and possibly fires could occur during the excavation and transfer operations. Fires outside the clarifier could be smothered with granulated slag or water. If exposed materials in the clarifier ignite, additional water could be pumped into the clarifier until the burning materials were covered and extinguished. Procedures for safe operations would be addressed through the process safety management of highly hazardous chemicals program, and development of a health and safety plan, and contingency plan. Solvay has extensive expertise in design and operation of processes involving elemental phosphorus.

3.3.2.3 Short-term Effectiveness

The following sequence of activities would be necessary to complete the mud still process for the clarifier materials:

- **Removal and Material Handling Operations**
 - Site preparation.
 - Mud still construction and trial runs.
 - Water cap control (partial dewatering of clarifier).
 - Removal of clarifier material (mechanical removal using excavator with bucket attachment).
 - Material handling (transfer of material from clarifier to skip).
- **Mud Still Operations**
 - Loading the skip that contains crude phosphorus into mud still.
 - Operating and monitoring mud still.
 - Unloading and cleaning out mud still.
- **Closure Operations**
 - Shut-down and clean out (i.e., triple rinse) the process equipment.
 - Place layer of granulated slag in the clarifier to cover the remaining crude phosphorus.
 - Remove (or drain) water above the granulated slag layer.
 - Place the mud still residue in the clarifier and cover the residue with another layer of granulated slag.
 - Demolish the above grade portion of the clarifier walls.
 - Backfill and compaction of cover material at clarifier.
 - Extending cover/cap beyond clarifier over the crude phosphorus burial area and P4 production area.
 - Final grading of cap.
 - Restoration/revegetation of cap.
 - Maintenance and monitoring of cap.
- **Recovered P4 Handling, Transportation and Use**
 - Moving liquid P4 between collection vessel(s) and transport container.
 - Transport container via truck to Solvay P4 facility.
 - Liquefy (i.e., reheat) P4 in transport container and move liquid P4 to the facility's P4 raw material storage vessel.
 - Return transport container (via truck) to Silver Bow Plant.

The anticipated person hours and associated rates of relative risk for this entire list of activities has been evaluated on a preliminary basis. Appendix L contains the task list and estimated time and crew size for each task for this alternative. There are several general points to note with respect to that evaluation. First, it would take approximately two years to design, fabricate and install the production-scale mud still. Second, based on the volume of the clarifier material and the length of time required to process each batch, it would require at least five, and likely more, years to process the material in the clarifier. Third, it is possible that some of the crude phosphorus would ignite during the extended removal and handling operations. Clarifier removal and handling operations could be difficult to manage and that difficulty increases with the quantity and extended duration of the operations. The risk rates assigned to each of these activities reflect these potential, relative risks. Fourth, for safety reasons of confined space, structural integrity, and P4 hazards, this alternative does not require placing workmen into the clarifier to manually remove the sludge. What can be removed would be removed by mechanical means with workmen outside of the clarifier.

Two risk levels were developed for this option--one for the unprotected worker and one for the protected worker. In assigning risk factors for each activity, consideration was made as to whether a particular activity would be reasonably described as an “ordinary construction risk,” or is inherently more dangerous. In particular, as outlined in Appendix D, the proximity of the workers to the phosphorus-bearing materials, and the relative amount of personal handling of materials, was carefully considered in selecting relative risk rates for each step of the process.

Table 3-1 presents the probability of a fatality for this option. The risk calculations are provided in Appendix M and are presented in regards to construction risk and operational risk. The probability of a fatality to the unprotected worker is “medium” at 0.005%. The probability of a serious injury to the unprotected worker in Table 3-2 is “high” at 0.3%. The protected worker would face a probability of 0.003% of fatality and 0.2% of serious injury. These relative risks are considered “medium” and “high”, respectively, even when appropriate worker protections are followed.

3.3.2.4 Implementability

A preliminary implementation schedule was developed based in the review team’s professional judgment and experience with similar industrial and/or environmental projects. The preliminary implementation schedule represents a best estimate at the duration of this alternative.

Preliminary Implementation Schedule	
Timeline	Description
4Q 2015	Supplemental Waste Plan and request to designate CAMU for the clarifier.
1Q 2016	EPA approves the Supplemental Waste Plan and agrees to designate a CAMU.
1Q 2016	EPA conducts a public hearing on the Supplemental Waste Plan remedy and the CAMU designation request and selects the On-site Phosphorus Recovery Alternative (Mud Still Process) and designates a CAMU.
2Q 2016	EPA prepares the Corrective Measures Decision Document.
2016-2017	Mud still system design and off-site fabrication of process equipment.
2Q 2018	On-site construction of clarifier excavation and mud still facilities begins.
4Q 2018	Construction of excavation and mud still facilities complete. Start-up testing begins.
1Q to 2Q 2019	Mud still operations begin. This is likely the earliest the operations would begin, and they may not begin for possibly two more years.
2024 +??	Mud still operations complete and mud still residue would be returned to the clarifier. Construction of evapotranspiration cap begins.
2026 +??	Construction of evapotranspiration cap complete and vegetated surface established. The Draft Waste Plan Implementation Report would be submitted to the EPA within 90 days after completion of the cap construction.

This alternative would likely take at least 10 and possibly more years for completion, given all the technological uncertainties.

A thorough evaluation of state and federal administrative requirements for this alternative was completed by Solvay, and a Required Permit and Rationale Document and a follow-up July 3, 2013 letter from Dan Bersanti to Larry Kimmel (Appendix S) were submitted to the EPA for review. EPA indicated general concurrence with the conclusions in an email dated September 17, 2013.

Solvay met with MDEQ on March 7, 2014 to discuss Solvay's evaluation in the Required Permit and Rationale Document. The key points in that Document are:

- Operation of Mud Still – The mud still would be operated pursuant to the RCRA Section 7003 Order. Pursuant to Section XX of the 3008(h) Order and the waiver authority of a 7003 Order (see Appendix S), Solvay would operate the mud still without obtaining a RCRA permit and without other RCRA hazardous waste management requirements. Despite this, Solvay would operate the mud still in an environmentally responsible manner.
- Solids Residuals – As previously documented, most of the solid residuals generated during the pilot-scale operation contained cadmium at concentrations above the toxicity characteristic level. If all RCRA rules applied: (1) treatment of the residuals would be required to meet land disposal restriction (LDR) standards before such hazardous waste residues could be land

disposed; (2) the disposal in a landfill would necessitate that the landfill meet minimum technological requirements (MTR) for liners and a leachate collection system; and (3) the disposal unit would require a RCRA permit. However, disposal of the residual solids in the clarifier and leaving some sludge in the clarifier that cannot be practicably or safely removed can occur without meeting LDR, MTR or permit requirements under the 7003 Order and related 3008(h) Order if, among other options, the clarifier and its immediate surrounding phosphorus burial area are designated by EPA as a CAMU. See 40 CFR §264.552(a)(4). Our evaluation of this alternative assumes that the proposed CAMU would be approved and that the mud still residue and sludge that cannot be safely and practicably removed from the clarifier can be disposed in the CAMU. If the proposed CAMU is not designated, the mud still option would have additional disadvantages and be much more costly.

- **Water Residuals** – Although water that would be generated during the process may contain some phosphorus particles, because it would not flame or exhibit any other hazardous waste characteristic, it would be considered a nonhazardous wastewater. Any wastewater that remains after the mud still operations would be pH adjusted with lime in one or more units meeting the RCRA definition of a “tank” at 40 CFR § 260.10, and then conveyed to an earthen evaporation pond. Per Montana regulations, a solid waste management system license would be needed to construct and operate an evaporation pond for this nonhazardous wastewater, and Solvay would obtain this license if any wastewater needs to be evaporated in a pond.
- **Air Permits** – Operation of the mud still would not constitute a “major” source of air pollution and there are no applicable New Source Performance Standards or National Emissions Standards of Hazardous Air Pollutions. Further, no permit is required under Montana law because the mud still is not subject to the federal Clean Air Act and the process is not an “incinerator.” Nevertheless, Solvay would control the emissions through the controlled flare combustion unit and the wet scrubber. An analysis of air quality permitting requirements for this alternative is provided in Appendix T.
- **Future Commercial Operations** – This facility could serve as a viable commercial P4 recovery facility for managing similar materials from other elemental phosphorus facilities. If Solvay decides to pursue commercial operations, then RCRA permitting pertaining to storage of hazardous waste might be required, and Solvay would obtain any required permit.

The administrative requirements needed to implement the alternative include:

- Working with EPA to designate the clarifier and surrounding crude phosphorus burial and P4 production areas as a CAMU
- Obtaining a solid waste disposal permit for the evaporation pond
- Recruiting, hiring, and training a labor force

Solvay is continuing discussions with MDEQ to see if MDEQ agrees with Solvay's analysis of the administrative and permit requirements.

3.3.2.5 Relative Cost

The representative cost of this alternative, assuming the CAMU is approved, is estimated at \$24 million, and the cost of financial assurance is estimated at \$1.4 million for a total cost of \$25 million. This alternative could return about 80,000 to 98,000 gallons of elemental phosphorus to commercial use, which represents a commercial value of about \$2 million to \$2.5 million. This order of magnitude estimate is expected to provide an accuracy of plus 50 to minus 30 percent for the described scope of the alternative. The details of the cost estimate are in Appendix N and the cost estimate methodology is in Appendix E.

3.4 Off-Site Incineration

3.4.1 Description of Alternative

Off-site incineration may be feasible, but it has not been demonstrated for the volume of clarifier material. Incineration of only small volumes of elemental phosphorus-bearing materials at commercial facilities has been done to date, not the estimated 11,500 drums that would be generated at the Silver Bow Plant. Nonetheless, because the off-site incineration option is theoretically possible, this section describes the alternative and the results of this evaluation.

Incineration involves the controlled oxidation (through combustion) of the phosphorus. Elemental phosphorus oxidizes to form phosphorus pentoxide, which is a dense fume. Consequently, high efficiency particulate removal equipment would be necessary to control particulate emissions. In addition, the incinerator facilities indicate that they must have a relatively slow feed rate to maintain compliance with their permit conditions.

The off-site incineration option arises from the survey in which 47 commercial TSD facilities were contacted to evaluate their ability to receive, treat and dispose of the clarifier materials. The survey work plan and responses from the TSD facilities in 2001 are provided in Appendix U. Based on the

survey responses, two commercial incinerators were identified as potentially capable of treating and disposing of the clarifier material at that time:

- Waste Technologies, Inc. (WTI) [OHD980613541], East Liverpool, Ohio – now operated by Heritage Environmental Services, Inc.
- Trade Waste Incinerator, Inc. (TWI) [ILD098642424], Sauget, Illinois – now operated by Veolia.

Three projects involving the packaging and incineration of elemental phosphorus-containing materials have been conducted at the Silver Bow Plant since this information was compiled for the prior Waste Plan.

Project Name	Year	Number of Drums	Commercial Facility
SWMU 17: Removed Precipitator Dust Pans	2002	534 (30-gallon)	Trade Waste Incinerator [ILD098642424] Sauget, Illinois
SWMU 24: Discharge Pipeline	2004/2005	21 (30-gallon) 98 (30-gallon)	Onyx Environmental SVCS [ILD098642424] Sauget, Illinois
SWMU 3: Used Carbon and Electrode Project	2008/2009	108 (30-gallon)	Heritage Environmental Services [ILD098642424] Sauget, Illinois

The two waste management companies that operate the incineration facilities listed above were recently contacted to reevaluate their potential capability to treat the clarifier material.

Heritage Environmental Services stated that the incinerator would only process two 55-gallon drums of elemental phosphorus-containing materials per day due to uneven heating in the kiln (i.e., hotspots) and excessive wear of the refractory brick lining. At this processing rate, one truck load consisting of eighty 55-gallon⁹ drums would take forty days to incinerate, or about nine truckloads (80 drums each) per year factoring in down time at the incineration facility. It was assumed that each 55-gallon drum would have at least a 2-inch air space and 6-inch water cover¹⁰ over the crude phosphorus. As such,

⁹ The crude phosphorus would be packaged according to DOT-SP 13552 (fifth revision). This special permit authorizes the transportation in commerce of ... Phosphorus, white, under water ... in alternate packaging. The prescribed packaging is a 55-gallon UN 1A2 steel drum certified to the PG I performance level for solids and the PG II performance level for liquids and dual marked to a minimum of UN1A2 A/400/S and UN1A2 Y/1.2/150. In addition, sufficient water must be present in each drum to ensure that the waste phosphorus is covered during transportation, in any orientation of the drum.

¹⁰ The 6-inch water cover was necessary for the previous elemental phosphorus-containing waste packaging operations conducted at the Silver Bow Plant.

approximately 12,500 (55-gallon) steel drums would be needed to implement this alternative. This alternative would take about 20 years to incinerate the crude phosphorus from the clarifier at the incineration facility in East Liverpool, Ohio.

Veolia confirmed that the elemental phosphorus-containing clarifier materials acceptability and treatment assumptions from 2001 are still valid for the Sauget, Illinois incinerator. Veolia would only accept elemental phosphorus-containing materials in 30-gallon drums. It was assumed that each 30-gallon drum would have at least a 2-inch air space and 6-inch water cover over the crude phosphorus. As such approximately 25,000 (30-gallon) steel drums would be needed to implement this alternative. The 30-gallon drums would be accepted by the truckload drums, at a rate of four (100 drum) truckloads accepted every three months. As such, about five drums per day could be incinerated. This alternative would take about 16 years to incinerate the crude phosphorus from the clarifier at the incineration facility in Sauget, Illinois.

In addition to this feed-rate constraint, other factors described in this Supplemental Waste Plan limit the manner in which this incineration alternative may be conducted. These factors result in a conceptual approach whereby the clarifier material must be:

- Removed from the clarifier and placed into open-top drums at an on-site packaging facility;
- Stored on-site, and transported off-site;
- Transported in drums via truck to the TSD facility;
- Unloaded at the TSD by TSD personnel;
- Incinerated at the TSD facility;
- The ash must be collected, stabilized and disposed in accordance with regulatory requirements; and
- Closure of the clarifier and surrounding SWMUs with an evapotranspiration cap.

This conceptual approach would in large part be dictated by the necessity of both incinerator facilities to receive the clarifier material in open-top drums. They do not have the facilities to receive and handle the clarifier materials from a bulk transport vessel. The drums would need to be open top drums (i.e., the entire top can be removed during filling and emptying and secured during storage and shipment), as opposed to drums with a fill port and screw or bung closure. Each major activity that would have to be undertaken for this off-site incineration option is discussed in the following sections.

3.4.1.1 Removal and Packaging

The crude phosphorus would be removed from the clarifier using an excavator with bucket attachment. The material would be transferred from the excavator bucket to a metal drum-filling funnel that would be located within a spill pan (i.e., secondary containment) adjacent to the clarifier. The funnel would direct the crude phosphorus into DOT specification containers (e.g., 30-gallon, open-top drums (49 CFR § 173.188(a)(2)) or 55-gallon, open-top drums (DOT-SP 13552 (Appendix V))).

Approximately, 10 gallons of water would be placed in the drum before the crude phosphorus would be added. Excess water would be decanted from the drum back to the clarifier, leaving a minimum of 6 inches (or more) of water over the crude phosphorus in each drum. A cover would then be secured over the drum and the drum would be transported to the nearby drum staging area. The drums would be vented and monitored at the staging area to evaluate whether phosphine was being generated in the drum. If phosphine was being generated, the pH of the overlying water would be adjusted to minimize the continued phosphine generation, as was done during the precipitator dust pan removal action in 2002. The drums would be closed after its contents no longer generate excess phosphine and would be moved to the storage area.

The bucket could be continuously sprayed with water to minimize fires that might occur if the crude phosphorus would be exposed to air. Any material that spills during transfer would be captured by the spill pan and flushed back into the clarifier. The water cap would be maintained in the clarifier. If necessary, production well water would be added to maintain the water cap over the crude phosphorus. The water cap would be maintained at a pH between 5.0 and 6.0 standard units to minimize the potential for phosphine generation. This pH adjustment, which was standard practice to minimize phosphine generation during plant operations, would be accomplished by adding sulfuric or other concentrated acid to the water cap.

Despite the procedures that would be followed to attempt to maintain the water cap throughout the process, removal and transfer activities might result in situations where some amount of the crude phosphorus might be exposed to air. Filling drums with phosphorus-bearing material would almost certainly involve events or accidents in which the material would be exposed to air for a sufficient period of time to cause fire. Such fires would be in close proximity to workers involved in the filling and drum handling operations, and splashes and spills of material on workers are possible. Procedures for control and worker protection would be identified in a health and safety plan and contingency plan. Fires may be difficult to control, in some cases, as the entire drum contents may be on fire. In other cases, released phosphorus that is on the top or sides of equipment or drums could ignite. Water would have to be used to extinguish fires in these situations, as it would be difficult to smother such material that would be above ground level with slag.

The same amount of crude phosphorus would remain in the clarifier as discussed in Section 3.3.1.1 since the same removal technique would be used in this alternative.

3.4.1.2 Storage

The commercial TSD facilities are unable or unwilling to store large volumes of the phosphorus-containing materials at their facilities. Consequently, one truckload could be received every forty days, or so. The schedule on which individual shipments could arrive at the processing facility would be subject to the requirements, permit conditions, and limitations of the processing facility. Coordination of packaging and transportation activities to approximate the 80 drum per 40 days processing capacity would be anticipated. Filled drums would be stored in a heated building during the cold weather period and might need to be stored longer than 90 days due to the incinerator's slow processing capacity.

3.4.1.3 Transportation

Approximately 200 shipments (100 drums (30-gallon) per truck shipment) would be necessary to transport the crude phosphorus to the incineration facility in Sauget, Illinois (about 1,500 miles) for a total loaded travel distance of about 300,000 miles. As an alternate, approximately 160 shipments (80 drums (55-gallon) per truck) would be necessary to transport the crude phosphorus to the incineration facility in West Liverpool, Ohio (about 1,900 miles) for a total loaded travel distance of about 300,000 miles.

3.4.1.4 Activities at the Incineration Facility

Based on discussions with facility personnel, activities at the incineration facility would need to follow specific drum unloading procedures from the truck trailers. The drums would be unloaded at the incinerator area. The drums would be placed on a conveyor feed system into the incinerator. After placement there, the ring that secures the lid on the drum would be removed so that when the drum is conveyed into the incinerator, the material would spread out and be combusted evenly. The drums would be combusted with their contents. Special precautions would need to be taken for all of these activities, particularly when the drum lids are opened and there would be a potential for release of phosphorus-bearing materials and phosphine.

3.4.1.5 Stabilization and Disposal of Ash

The ash that results from the incineration of D001 hazardous waste must meet universal treatment standards for underlying hazardous constituents. The ash is assumed to contain metal constituents that would need to be treated to meet their universal treatment standards under the LDR program. Such treatment was assumed to require stabilization of the metal constituents. As such, the incinerator facilities would stabilize the ash prior to disposal. After stabilization occurs, the ash would be sent off-

site for disposal at a Subtitle D landfill (or Subtitle C landfill). It is assumed at that point that the solidified ash would not exhibit any hazardous waste characteristic. As discussed earlier, the clarifier material is not expected to contain organics as underlying hazardous constituents that must meet LDR treatment standards, since such organics would have been destroyed in the nodule kilns and electric arc furnaces. But even if we assume that the clarifier material has organics, the incinerator would destroy them and satisfy the theoretical LDR treatment requirements for organics.

3.4.1.6 Closure

After the bulk of the crude phosphorus has been removed from the clarifier and packaged for off-site incineration, the remaining crude phosphorus that cannot be safely or practicably removed would be covered with granulated slag and the water cap maintenance system would be terminated. Additional granulated slag would be added to absorb the water cap and fill the clarifier to just below ground surface. The above-grade portion of the clarifier walls would be demolished and clarifier area would be filled with additional granulated slag and shaped, as needed, to establish the subgrade for the final cover. The clarifier area would be closed with the same evapotranspiration cap (Figure 3-11) as detailed in Section 3.3.1.4, except there would be no mud still residue to place in the clarifier. The conceptual extent of the cap is shown on Figure 3-10. The actual extent of the cap would be more precisely defined during the cap design phase.

3.4.1.7 Post Closure Requirements

The post closure requirements for the capped clarifier would be the same as those identified in Section 3.3.1.4.3 for the CAMU in the mud still option.

3.4.2 Evaluation of Alternative

This section evaluates the off-site incineration alternative against the evaluation criteria described in Section 2.3.

3.4.2.1 Long-term Reliability and Effectiveness

The off-site incineration alternative would remove a large volume of ignitable material from the clarifier and render it non-ignitable. The off-site incineration process would result in an ash residue that would not ignite or generate phosphine gas. It is possible that the ash would have to be further stabilized to meet land disposal restriction treatment standards.

As discussed in Section 3.3.1.1, some small amount of clarifier material that cannot be practicably and safely removed would remain in the clarifier. This material that cannot be removed would remain in the clarifier and capped and closed. The clarifier, closed with an evapotranspiration cap, would be even more reliable and effective than the enhanced RCRA cap alternative described in Section 3.2 for

minimizing fire and phosphine generation because this alternative would remove almost all of the P4 from the clarifier, thereby removing the source material that could ignite or generate phosphine gas. Deed restrictions would define this area as a no excavation zone, so that the integrity of the cap would not be compromised by human activity.

The evapotranspiration cap would not be susceptible to failure due to erosion or flooding as detailed in Section 3.2.2.1, and the cap would be designed to resist damage from reasonably anticipated earthquake forces, such as earth-shaking or horizontal acceleration forces. Uncontrollable changes at the site such as those caused by earthquake could conceivably affect the cap, but the cap is flexible, and the cover soil could easily be repaired if needed.

The useful life of this alternative would potentially be unlimited. The cap could accommodate all types of native vegetation cover, including shrubs and trees, without unacceptable loss of function. After the cover vegetation has been established, and monitoring has demonstrated no on-going environmental issues, it is expected that this form of cap could function effectively with little or no further maintenance. Nonetheless, the cap would continue to be inspected before and after the snow season and after each 25-year storm event, and it would be maintained whenever necessary.

3.4.2.2 Reduction in the Toxicity, Mobility or Volume

After incineration, the toxicity, mobility and volume of the clarifier sludge would be reduced by virtue of most of it being removed from the clarifier and its elemental phosphorus being combusted in the incinerator. The elemental phosphorus would be converted to phosphorus oxides and/or phosphoric acid, which are less toxic than elemental phosphorus. The residual ash would not generate phosphine or fire. The stabilized ash would be placed in a landfill (after stabilization if needed to meet LDR requirements) where it would be immobile.

The water cap would need to be maintained throughout the excavation period (about another 17 years). The water cap maintenance system would be terminated after the bulk of the crude phosphorus has been removed from the clarifier and the remaining crude phosphorus that cannot be safely or practicably removed would be covered with granulated slag. The future percolation through the clarifier contents would be reduced to the water infiltrating through the evapotranspiration cap, which is estimated at about 0.013 inches per year inches/year (Appendix Q).

After closure, the evapotranspiration cap would minimize leachate and mobility of hazardous constituents. This future condition has been modeled to estimate the potential impacts of the capped clarifier on groundwater quality. Three approaches were used to evaluate the potential impacted on groundwater quality: (1) Partition Model; (2) Leachate Model; and (3) Solids Model (see Appendix K).

This evaluation shows that no impacts to groundwater would be expected above drinking water quality standards if the evapotranspiration cap were placed on the clarifier containing the remaining crude phosphorus. This finding holds true, using the consciously conservative SSL model, for all three different approaches to evaluating protectiveness for groundwater. In addition, the sensitivity analysis of infiltration (see HELP model, Appendix Q), found less than an order of magnitude increase in infiltration under the full range of sensitivity conditions evaluated. These sensitivity results mean that, for the expected range of infiltration conditions, the evapotranspiration cap remains protective of groundwater. In any event, the groundwater would continue to be monitored.

Prior to incineration, however, this alternative increases the mobility of the clarifier material due to the significant physical disturbance that would be required to remove, package, and transport this material. During all of these activities, potential for fire and phosphine generation would be increased. Thus, the question of whether there would be a reduction in mobility depends on what timeframe is considered. Over several years, prior to incineration, the mobility would actually be increased, while after incineration, it would be substantially decreased.

The alternative has the potential to increase the toxicity in the short term due to potential ignition of the P4 and emission of phosphine during the excavation and packaging operations. The alarm on the continuous phosphine monitors was activated during prior excavation of some crude phosphorus for the testing purposes. Excavation immediately stopped and the workers proceeded to evacuate the area. The phosphine concentrations dissipated immediately. The continuous phosphine monitoring system would be operated and workers near the clarifier would wear personal phosphine monitors to notify the workers of potentially hazardous conditions.

Phosphine might be generated in the closed drums that would be stored at the Silver Bow Plant before they could be transported to the off-site incinerator, during transport, and at the incinerator awaiting combustion. If excess phosphine were being generated (i.e., bulging drum), the drum would need to be opened to vent any excess gas. The drums would need to be inspected on a daily basis to prevent over-pressurization of any drum. Although these inspections could be undertaken while the drums were stored on-site, inspections would be much more difficult after the drums were loaded into a trailer for transportation and during transportation.

Situations might arise where some amount of the crude phosphorus would be exposed to air. As a result, phosphorus fires would be expected to occur during the excavation and packaging operations. Fires outside the clarifier could be smothered with granulated slag or water. If exposed materials in the clarifier ignite, additional water could be pumped into the clarifier until the burning materials were

covered and extinguished. Procedures for safe operations would be addressed in the health and safety plan, and contingency plan at both the Silver Bow plant and at the incinerator facility.

3.4.2.3 Short-term Effectiveness

The sequence of activities that are necessary to complete the incineration option for the clarifier materials includes the following:

- **Removal Operations**
 - Site preparation
 - Water cap control (partial dewatering of clarifier)
 - Removal of clarifier material
 - Transfer and drum-filling operations (open-top drums at an on-site packaging facility)
 - Drum transfer to storage (as needed)
- **Transportation Operations**
 - Drum transfer (loading drums onto truck)
 - Transport drums via truck to TSD facility (assumed to be in Illinois)
 - Return transport (via unloaded truck) to facility site
- **Incineration Operations**
 - Receive/unload drums at TSD facility
 - Transfer into incinerator unit
 - Stabilize ash and waste residue from air cleaning system for final landfill disposal
- **Closure Operations**
 - Decontaminate removal and packaging equipment
 - Backfill and compaction of cover material at clarifier and phosphorus burial area
 - Final grading of cover/cap
 - Restoration/revegetation of cover/cap
 - Maintenance and monitoring of cover/cap

The anticipated person hours and associated rates of relative risk for this entire list of activities were evaluated. Appendix L contains the task list and estimated time and crew size for each task. There are several general points to note with respect to that evaluation. First, the sheer volume of the clarifier

material and the stated incineration rate would require an estimated 16 years to complete, as explained in Section 3.4.2.4 below. Second, the fact that the proposed operations would involve water could result in phosphine generation. For example, crude phosphorus would be transferred into drums that contain water. This process would provide an opportunity for the phosphorus and water to contact and react. The EPA team measured an instantaneous phosphine concentration of 1.08 ppm after agitating the water and crude phosphorus in the clarifier. Third, it would be likely that some of the crude phosphorus would ignite during these extended removal and handling operations. Clarifier removal and drum-filling operations could be difficult to manage and that difficulty increases with the quantity and extended duration of the operations. The risk rates assigned to each of these activities reflect these potential risks.

Two risk levels were developed for this option—one for the unprotected worker and one for the protected worker. In assigning risk factors for each activity, consideration was made as to whether a particular activity would be reasonably described as an “ordinary construction risk,” or is inherently more dangerous. In particular, as outlined in Appendix D, the proximity of the workers to the phosphorus-bearing materials, and the relative amount of personal handling of materials, was carefully considered in selecting relative risk rates for each step of the process.

Table 3-1 presents the probability of a fatality for this option. The risk calculations are provided in Appendix M and are presented in regards to construction risk and operational risk. The probability of a fatality to the unprotected worker is “medium” at 0.02%. The probability of a serious injury to the unprotected worker in Table 3-2 is also at a “high” at 1%. The protected worker would face a probability of 0.007% of fatality and 0.4% of serious injury. These relative risks are considered “medium” and “high”, respectively, even when appropriate worker protections are followed.

3.4.2.4 Implementability

A preliminary implementation schedule was developed based in the review team’s professional judgment and experience with similar industrial and/or environmental projects. The preliminary implementation schedule represents a best estimate at the duration of this alternative.

Preliminary Implementation Schedule	
Timeline	Description
4Q 2015	Supplemental Waste Plan.
1Q 2016	EPA approves the Supplemental Waste Plan.
1Q 2016	EPA conducts a public hearing on the Supplemental Waste Plan remedy and selects this off-site incineration remedy.
2Q 2016	EPA prepares the Corrective Measures Decision Document.
2016-2017	Excavation and packaging/storage system design and construction.
2Q 2018	On-site excavation and packaging of clarifier materials begins. Eighty drums are transported to the off-site incineration facility every 40 days, or so.
2034 +??	Removal and off-site incineration complete, and construction of evapotranspiration cap begins.
2036 +??	Construction of evapotranspiration cap complete and vegetated surface established. The Draft Waste Plan Implementation Report would be submitted to the EPA within 90 days after completion of the cap construction.

This alternative would likely take at least 20 and possibly more years for completion, given the very low incineration rate specified by the experienced facility.

Material removal, handling and packaging processes must be designed, constructed and operated before this alternative could be implemented. It is estimated that the design, construction, testing and start-up of such systems would take a minimum of one year.

The administrative requirements needed to implement the commercial TSD facility alternative include:

- Confirmation that the off-site TSDs have all necessary permits to receive and treat the clarifier material.
- Completing a Waste Stream Profile and obtaining acceptance from the TSD facility.
- Manifesting of drums.
- Use of hazardous waste transporters.
- Meeting DOT requirements.
- Meeting LDR requirements.

3.4.2.5 Relative Cost

The representative cost of this alternative is estimated at \$49 million and the cost of financial assurance is estimated at \$5.3 million for a total cost of \$54 million. This order of magnitude estimate is expected

to provide an accuracy of plus 50 to minus 30 percent for the described scope of the alternative. The details of the cost estimate are in Appendix N and the cost estimate methodology is in Appendix E.

3.5 Comparative Evaluation

This section provides the comparative analysis of the three alternatives for the clarifier material that were evaluated against the RCRA criteria. Comparative analysis considers the same criteria used during the individual alternatives evaluation. This comparative evaluation is summarized in Table 3-3.

3.5.1 Long-term Reliability and Effectiveness

Each alternative developed for the clarifier materials would require that the clarifier and surrounding P4 production area and crude phosphorus burial area be closed with a cap to enhance the long-term reliability and effectiveness of the alternative. Each alternative would require maintenance and groundwater monitoring activities during the post-closure period to ensure that the caps have long-term reliability and effectiveness.

The on-site phosphorus recovery and off-site incineration alternatives would remove the bulk of the crude phosphorus from the clarifier, thus assuring that once the removal was complete, it would provide a long-term reliable and effective solution for the material that could be removed from the clarifier. Under the enhanced cap option, all of the sludge would be entombed in place. Under the recovery and incineration options, some crude phosphorus would remain in the bottom of the clarifier and be capped on-site. Under the on-site phosphorus recovery option, the mud still residue with levels of cadmium that would likely exceed hazardous waste levels would also be left on-site and capped in the designated CAMU.

3.5.2 Reduction in the Toxicity, Mobility or Volume

The on-site phosphorus recovery and off-site incineration alternatives equally reduce the toxicity of the clarifier material by removing the elemental phosphorus, and thereby eliminating the possibility that the removed clarifier material would burn or generate phosphine at harmful levels. The on-site phosphorus recovery alternative would transform the crude phosphorus into a product that would be used in the phosphorus industry. The off-site incineration alternative would convert the elemental phosphorus to less toxic phosphorus oxides that would be landfilled with the other incinerator ash. Metal constituents in the ash would be stabilized prior to final disposal.

With regard to the enhanced RCRA cap, it would not reduce the inherent toxicity of the crude phosphorus in the clarifier, but would essentially minimize its mobility and exposure potential by creating a thick barrier between the elemental phosphorus and air and by removing the water, thus greatly minimizing the potential for fire and phosphine generation. Although phosphine monitoring in

soil gas at the Silver Bow Plant has not shown harmful levels being generated at the capped SWMUs that contain elemental phosphorus-containing materials (Barr, 2013), the cap would have a phosphine detection and management system to further address potential phosphine generation at harmful levels.

The enhanced RCRA cap alternative quickly ends the need for the water cap and its potential to leach hazardous constituents to the groundwater. The water cap could be terminated by year 2015, as compared to year 2022 for the on-site phosphorus recovery alternative and year 2032 for the off-site incineration alternative. The enhanced RCRA cap is more protective than the evapotranspiration cap in that it reduces the amount of precipitation that could infiltrate through the cap and clarifier contents.

The on-site phosphorus recovery and off-site incineration alternatives increase the exposure of workers to phosphine at potentially harmful levels since the crude phosphorus would be agitated with water during the removal and material handling activities. The potential phosphine exposure would exist whenever crude phosphorus was being processed. The on-site phosphorus recovery alternative also increases the mobility of cadmium since several samples of the mud still residue failed the TCLP test for cadmium. This increased leachability would be controlled by the evapotranspiration cap that would minimize infiltration of rainwater through the mud still residue.

The enhanced RCRA cap would reduce mobility by substantially eliminating infiltration. The cap would not reduce the volume of the material, but what remains would not be a source of leachable toxic metals that result in unsafe levels for drinking water. Table K-3 of Appendix K shows that the cap would not allow leaching of metals at levels that would result in exceedance of Montana's or EPA's drinking water standards. In fact, the enhanced RCRA cap would provide a margin of safety of more than five orders of magnitude beyond the MDEQ and EPA water quality standards.

The on-site phosphorus recovery and off-site incineration alternatives equally reduce the volume of crude phosphorus remaining in the clarifier prior to final closure. The same excavation techniques would be employed to remove the bulk of the crude phosphorus. The enhanced RCRA cap alternative does not reduce the volume of crude phosphorus remaining in the clarifier.

3.5.3 Short-term Effectiveness

The short-term effectiveness of the alternatives is reflected in their relative potential to result in fatalities and serious injuries during their implementation. These comparative short-term risks are reflected in the following table:

Alternative	Probability of Serious Injury to Protected Worker	Probability of Fatality to Protected Worker
Enhanced RCRA Cap	Medium (0.02%)	Low (0.0006%)
On-site Phosphorus Recovery (Mud Still Technology)	High (0.2%)	Medium (0.003%)
Off-site Incineration	High (0.4%)	Medium (0.007%)

With regards to the enhanced RCRA cap alternative, once the first layer of granulated slag were placed on the crude phosphorus, there would be limited potential for fire or phosphine generation. The enhanced RCRA cap alternative provides the lowest probability of serious injury and the lowest probability of a fatality during the implementation of this alternative. These probabilities are considered medium at 0.02% and low at 0.0006%, respectively. These relative risks are considerably lower than the probabilities posed by the on-site phosphorus recovery alternative.

The off-site incineration and the on-site phosphorus recovery alternatives result in higher probability of serious injury due to the workers potential exposure to crude phosphorus and phosphine for longer time periods. The probabilities of a fatality are lower for the enhanced RCRA cap alternative compared to the on-site phosphorus recovery and off-site incineration alternatives.

3.5.4 Implementability

Off-site incineration may not be implementable, since it has not been demonstrated for the volume of clarifier material. Incineration of only small volumes of elemental phosphorus-bearing materials at commercial facilities has been done to date, not the estimated 12,500 drums that would be generated at the Silver Bow Plant. The time to implement this alternative would likely take twenty and possibly more years for completion, given the very slow processing rate specified by the experienced facility.

Although the pilot-scale mud still plant successfully recovered about 0.5 tons of elemental phosphorus from about 1.5 tons of crude phosphorus, a production-scale mud still process must be designed, permitted, fabricated and installed, and tested before this alternative could be implemented. It is estimated that the design, permitting, fabrication, installation, testing, and start-up of such systems would take a minimum of two years, if everything goes well, and possibly more given all the technological uncertainties. The time to operate the mud still would be at least five years. The time to implement this alternative would take at least 10 years and possibly more for completion, given all the technological uncertainties.

In contrast, the enhanced RCRA capping alternative could be implemented within a relatively short period using demonstrated and available construction materials and techniques. This alternative would likely take two construction seasons to consolidate the clarifier materials and build the multi-layer cover systems plus additional time to establish the vegetated surface. This alternative offers the following benefits from its quick implementation:

- The short duration of construction would result in any mechanical, fire and phosphine risks from construction being short-term;
- Potential for fire and phosphine generation would be removed quickly; and
- Beneficial effects for the environment would commence upon completion of the cap subgrade, because any potential percolation of leachate from the clarifier area into the groundwater would begin declining as soon as the water addition to the clarifier is terminated.

3.5.5 Relative Cost

The enhanced RCRA cap alternative would be considerably less expensive than the other alternatives. The on-site phosphorus recovery alternative costs are estimated to be about one-half the cost of the off-site incineration alternative. The costs shown below include the cost of financial assurance.

Alternative	Relative Cost (Million)
Enhanced RCRA Cap	\$5.4
On-site Phosphorus Recovery	\$25
Off-Site Incineration	\$54

4.0 Preferred Alternative

The comparative evaluation of the alternatives is summarized in the following chart:

Alternative	Long-term Reliability and Effectiveness	Reduction in Toxicity, Mobility or Volume	Short-term Effectiveness	Implementability	Relative Cost
Enhanced RCRA Cap	Good	Lowest Reduction	Low Risk	2 Years	\$5.4 million
On-site Phosphorus Recovery (Mud Still Process)	Very Good	Large Reduction	High Risk	10+ Years	\$25 million
Off-site Incineration	Very Good	Large Reduction	High Risk	20+ Years	\$54 million

The Supplemental Waste Plan supports the conclusion that the on-site phosphorus recovery alternative should be selected for the clarifier materials at the Silver Bow Plant. The on-site phosphorus recovery alternative would be as reliable and effective as the enhanced RCRA cap, and would also reduce the toxicity, mobility, and volume of crude phosphorus at the Silver Bow Plant. On a relative basis, this alternative ranked low regarding short-term effectiveness criterion because of the higher relative risks of serious injury and fatality. The risk estimates are based on generalized incident rates and estimated duration of work tasks. The risk estimates are not specific to any single operation. These risks would be considered while developing the chemical safety program (i.e., industry experience, mud still design, and process control), health and safety plan, and contingency plan. Solvay has extensive expertise in design and operation of processes involving elemental phosphorus.

A production-scale mud still process must be designed, fabricated, installed, and tested before this alternative could be implemented. The viability of the phosphorus recovery option also depends on a CAMU being designated for disposal of the solid residues and the small amount of clarifier material that cannot be safely or practicably removed from the clarifier.

This alternative could recover approximately 80,000 to 98,000 gallons of elemental phosphorus from the clarifier for use in commercial operations. This volume of elemental phosphorus is currently valued at about \$2 million to \$2.5 million.

The mud still operations could be commercialized to process elemental phosphorus-containing waste streams from other facilities if agreeable to EPA and MDEQ. Although commercial incinerators are capable of treating smaller volumes of elemental phosphorus-containing materials, they do not desire to treat large volumes over a short time period. The mud still operation could fill this market niche.

5.0 References

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Tables

Table 2-1

**Screening of Technologies
Clarifier Materials**

Technology	Process(es)	Description	Preliminary Screening	Retained for Alternative Evaluation
			Viability/Technology Status	
Horizontal Barrier	Soil Cap; Enhanced Cap	Construction of an engineered barrier over the materials to minimize airflow and rainfall percolation through the covered materials.	Potentially viable. Demonstrated in Phosphorus Industry.	Yes
	Underlying Barrier; Grout Injection	Injection of grout to create a less permeable zone beneath the subject materials. Used in conjunction with cap and vertical barrier.	Not viable. Not appropriate for site characteristics. Would not significantly reduce percolation of leachate because cap restricts flow more than underlying barrier layer.	No
Vertical Barrier	Slurry Wall; Sheetpile Wall; Waterloo Barrier	Construct a low permeable barrier around the subject materials to prevent groundwater from contacting the contained materials.	Not viable. Not appropriate for site characteristics. Materials do not extend to groundwater unit (approx. 40-ft bgs). There is no subsurface confining layer.	No
Chemical Extraction	Water Washing/Flooding	Application of water sprays or water baths of sufficient temperature, pressure, residence time, agitation, surfactants, acids, bases, detergents to transfer the hazardous contaminants into the liquid and recover/treatment of the liquid.	Not viable. Not appropriate for site characteristics. Crude phosphorus is already flooded with water. Water is not an effective solvent for elemental phosphorus.	No
	Liquid Phase Solvent Extraction	Removal of hazardous contaminants from the solids by applying nonaqueous liquid or liquid solution which causes the hazardous contaminants to enter the liquid phase and be flushed away from the solids along with the liquid or liquid solution while using appropriate agitation, temperature, and residence time.	Not viable. Not appropriate for site characteristics and not demonstrated in the phosphorus industry. Phosphorus is soluble in organic solvents (i.e., Benzene, Toluene, Xylene, Ethyl Benzene, Carbon Disulfide, etc). A solvent heavier than water would be necessary to contact the crude phosphorus. Remaining solids would retain organic solvent. Solvent would likely be released to the subsurface soils during this process and possibly migrate to groundwater.	No
Chemical Extraction	Vapor Phase Solvent Extraction	Application of an organic vapor using sufficient residence time, and temperature to cause hazardous contaminants in the solids to enter the vapor phase and be flushed away with the organic vapor.	Not viable. Not appropriate for site characteristics. Assuming that phosphorus could be transferred to the organic vapor, phosphorus would likely ignite when the organic vapor is emitted to the air space above the clarifier water cover.	No
Thermal Extraction	Vitrification	Electrical heating of materials to convert the solids to glass matrix at very high temperatures.	Not viable. Not appropriate for site characteristics. Phosphorus materials must remain covered by water and this process cannot be implemented below water.	No

Table 2-1

**Screening of Technologies
Clarifier Materials**

Technology	Process(es)	Description	Preliminary Screening	Retained for Alternative Evaluation
			Viability/Technology Status	
Immobilization Technologies	Microencapsulation	Stabilization/solidification with the following reagents or combinations of reagents: (1) Portland cement; or (2) lime/pozzolans (e.g., fly ash and cement kiln dust)--this does not preclude the addition of reagents (e.g., iron salts, silicates, and clays) designed to enhance the set/cure time and/or compressive strength, or to overall reduce the leachability of the metal or inorganic.	Not viable. Not appropriate for site characteristics. Mixing required to distribute the reagents could emit excessive phosphine levels. Addition of lime-based materials would further increase phosphine generation. Research level testing has not demonstrated viability.	No
	Sealing	Application of an appropriate material which adheres tightly to solids surface to avoid exposure of the surface to potential leaching media. Sealing materials include epoxy, silicone, and urethane compounds, but paint may not be used as a sealant.	Not viable. Not appropriate for site characteristics. Sealing not practical for this material, which must be molten to be accessible for sealing.	No
Destruction Technologies	Biological Destruction (Biodegradation)	Removal of hazardous contaminants from solids in an aqueous solution and biodegradation of organic or nonmetallic inorganic (i.e., inorganics that contain phosphorus, nitrogen, or sulfur) in units operated under either aerobic or anaerobic conditions.	Not viable. Not appropriate for site characteristics. It has not been demonstrated at a laboratory scale, or in the environment that elemental phosphorus can be used as a nutrient, or in biologically mediated red-ox reactions as either electron acceptor or an electron donor.	No
Destruction Technologies	Chemical Oxidation	Chemical or electrolytic oxidation via injection of the following oxidation reagents (or waste reagents) or combinations of reagents: (1) Hypochlorite (e.g., bleach); (2) chlorine; (3) chlorine dioxide; (4) ozone or UV (ultraviolet light) assisted ozone; (5) peroxides; (6) persulfates; (7) perchlorates; (8) permangantes; and/or (9) other oxidizing of equivalent efficiency, performed in units operated such that a surrogate compound or indicator parameter has been substantially reduced in concentration in the residuals.	Not viable. Not demonstrated in phosphorus industry. Transfer of oxygen is limited by its aqueous solubility. Mixing required to distribute oxygen throughout the solid matrix could emit excessive phosphine levels. Oxidation of phosphorus under water would generate forms of phosphoric(ous) acid, which could increase the leachability of the metals contained in the crude phosphorus. Laboratory-scale testing has not demonstrated viability.	No
	Chemical Reduction	Chemical reduction via injection of the following reducing reagents (or waste reagents) or combination of reagents: (1) sulfur dioxide; (2) sodium, potassium, or alkali salts of sulfites, bisulfites, and metabisulfites, and polyethylene glycols (e.g., NaPEG and KPEG); (3) sodium hydrosulfide; (4) ferrous salts; and/or (5) other reducing reagents of equivalent efficiency.	Not viable. Not appropriate for site characteristics. Elemental phosphorus is a highly reduced chemical. Further reduction would generate excessive concentrations of phosphine gas.	No

Table 2-1

**Screening of Technologies
Clarifier Materials**

Technology	Process(es)	Description	Preliminary Screening	Retained for Alternative Evaluation
			Viability/Technology Status	
Phosphorus Industry Processes	Mud Still	Recovery of phosphorus from the crude phosphorus via vaporization and condensation.	Potentially viable. Successfully implemented on pilot scale at Silver Bow Plant. Process equipment not available. Production-scale facility would need to be designed, and constructed.	Yes
	Roasting (On-site)	Recovery of phosphorus from the crude phosphorus under oxygen-starved conditions in an externally fired rotary kiln system.	Not viable. Demonstrated in phosphorus industry, but process equipment is no longer available. (former Silver Bow Process)	No
Phosphorus Industry Processes	Distillation (Off-site)	Volatilization of phosphorus from the crude phosphorus under oxygen-starved conditions in an externally heated, batch distillation pot.	Not viable. Demonstrated in phosphorus industry, but process equipment is no longer available. (Solutia Process)	No
	Conversion to Phosphoric Acid	Oxidation and hydration process to produce phosphoric acid from phosphorus-containing material.	Not viable. Demonstrated in phosphorus industry for more concentrated phosphorus-containing materials. Not appropriate for clarifier materials (Samancor and Rhodia Morrisville Processes)	No
	Proprietary process to recover phosphorus.	Unknown	Not viable. Information not accessible for technology evaluation. (Glen Springs Holding Company Process)	No
Immobilization Technologies	Microencapsulation (Stabilizaton/Solidification)	Removal followed by stabilization/solidification with the following reagents or combinations of reagents: (1) Portland cement; or (2) lime/pozzolans (e.g., fly ash and cement kiln dust)--this does not preclude the addition of reagents (e.g., iron salts, silicates, and clays) designed to enhance the set/cure time and/or compressive strength, or to overall reduce the leachability of the metal or inorganic.	Not viable. Not appropriate for site characteristics. Mixing required to distribute the reagents could emit excessive phosphine levels. Addition of lime-based materials would further increase phosphine generation. Research level testing has not demonstrated viability.	No
Chemical Extraction	Liquid Phase Solvent Extraction	Removal followed by physical separation process that removes contaminants to the extract phase with organic solvents.	Not viable. Not appropriate for site characteristics. Phosphorus is soluble in organic solvents (i.e., Benzene, Toluene, Xylene, Ethyl benzene, carbon disulfide, etc). Ignition of phosphorus during processing would create an inferno. Remaining solids would retain the organic solvent and phosphorus.	No
Combustion (CMBST)	Onsite or Offsite Incineration at RCRA Facility	Removal followed by high temperature organic destruction technologies, such as combustion in incinerators, boilers, or industrial furnaces operated in accordance with the applicable requirements of 40 CFR part 264, subpart O, or 40 CFR part 265, subpart O, or 40 CFR part 266, subpart H.	Potentially viable. Onsite – research & development needed to apply this technology. Off-site – demonstrated on small quantities.	Yes

Table 2-1

**Screening of Technologies
Clarifier Materials**

Technology	Process(es)	Description	Preliminary Screening	Retained for Alternative Evaluation
			Viability/Technology Status	
Deactivation (DEACT)	Chemical Oxidation	Removal followed by chemical or electrolytic oxidation utilizing the following oxidation reagents (or waste reagents) or combinations of reagents: (1) Hypochlorite (e.g., bleach); (2) chlorine; (3) chlorine dioxide; (4) ozone or UV (ultraviolet light) assisted ozone; (5) peroxides; (6) persulfates; (7) perchlorates; (8) permangantes; and/or (9) other oxidizing of equivalent efficiency.	Not viable. Not demonstrated in phosphorus industry. Transfer of oxygen is limited by its aqueous solubility. Mixing required to distribute oxygen throughout the solid matrix could emit excessive phosphine levels. Oxidation of phosphorus under water would generate forms of phosphoric(ous) acid, which would increase the leachability of the metals contained in the crude phosphorus. Not demonstrated to be viable.	No
	Chemical Reduction	Removal followed by chemical reduction via injection of the following reducing reagents (or waste reagents) or combination of reagents: (1) sulfur dioxide; (2) sodium, potassium, or alkali salts of sulfites, bisulfites, and metabisulfites, and polyethylene glycols (e.g., NaPEG and KPEG); (3) sodium hydrosulfide; (4) ferrous salts; and/or (5) other reducing reagents of equivalent efficiency.	Not viable. Not appropriate for site characteristics. Reduction process would generate excessive levels of phosphine gas that would require significant offgas processing.	No
	Biological Destruction (Biodegradation)	Removal followed by biodegradation of organic or nonmetallic inorganic (i.e., inorganics that contain phosphorus, nitrogen, or sulfur) in units operated under either aerobic or anaerobic conditions.	Not viable. Not appropriate for site characteristics. It has not been demonstrated at a laboratory scale, or in the environment that elemental phosphorus can be used as a nutrient, or in biologically mediated red-ox reactions as either electron acceptor or an electron donor.	No
Water Reaction (WTTRX)	Zimpro - Anoxic	Removal followed by controlled reaction with water for highly reactive inorganic or organic chemicals with precautionary controls for protection of workers from potential violent reactions as well as precautionary controls for potential emissions of toxic/ignitable levels of gases released during the reaction.	Not viable. Phosphorus-containing materials will react to form highly toxic phosphine gas under aqueous and alkaline conditions. Upon generation, the phosphine can be thermally oxidized to form P ₂ O ₅ that can be recovered as a product. This technology system is no longer being constructed at the FMC facility to treat its wastewater streams.	No
Wet Air Oxidation (WETOX)	Wet Air Oxidation	Removal followed by Wet Air Oxidation. The Zimpro® Wet Air Oxidation process is a liquid phase reaction in water using dissolved oxygen to oxidize wastewater contaminants. The oxidation reactions occur at moderate temperatures of 275°F to 600°F (150° - 315°C) and at pressures from 150 to 3000 pounds per square inch (10 to 207 Bar). The process can convert organic contaminants to carbon dioxide, water and biodegradable short chain organic acids. Inorganic constituents such as sulfides and cyanides can also be oxidized.	Not viable. Not appropriate for site characteristics. Not specified for treatment of D001 or D003 characteristic wastes. Extensive testing by FMC/Astatis failed to find a satisfactory operating conditions. This technology is less attractive/acceptable than WTTRX because the WAO process requires a higher pressure than the anoxic process (500 psig vs. 200 psig.) and at approximately twice the lime rate and the off-gas from the WAO process had phosphine levels as high as 400 ppm, which would still require a combustion unit to convert it to P ₂ O ₅ and subsequently to H ₃ PO ₄ treatment.	No

Table 2-1

Screening of Technologies
Clarifier Materials

Technology	Process(es)	Description	Preliminary Screening	Retained for Alternative Evaluation
			Viability/Technology Status	
On-site Disposal	Landfill	Removal and transfer of phosphorus-materials for disposal in permitted landfill.	<p>Not viable. Not appropriate for site characteristics. Treatment to remove the alleged ignitability and reactivity characteristics and universal treatment standards under RCRA land disposal program required prior to land disposal.</p>	No
Off-site Disposal	Landfill	Removal and packaging of phosphorus-materials for disposal in permitted landfill.	<p>Not viable. Not appropriate for site characteristics. Treatment to remove the alleged ignitability and reactivity characteristics and universal treatment standards under RCRA land disposal program required prior to land disposal.</p>	No

Table 3-1

**Summary of Short-Term Worker Risk Scenarios and
Probability of Fatality, Clarifier Materials**

Option	Probability of Worker Fatality			
	Baseline Worker		Protected Worker	
	Quantitative	Qualitative	Quantitative	Qualitative
Clarifier Materials				
Enhanced RCRA Cap	0.0007%	Low	0.0006%	Low
On-site Phosphorus Recovery (Mud Still)	0.005%	Medium	0.003%	Medium
Off-site Incineration	0.02%	Medium	0.007%	Medium

Probability = [Expected Fatalities / Number of Workers]

Table 3-2

**Summary of Short-Term Worker Risk Scenarios and
Probability of Serious Injury, Clarifier Materials**

Option	Probability of Serious Injury			
	Baseline Worker		Protected Worker	
	Quantitative	Qualitative	Quantitative	Qualitative
Clarifier Materials				
Enhanced RCRA Cap	0.02%	Medium	0.02%	Medium
On-site Phosphorus Recovery (Mud Still)	0.3%	High	0.2%	High
Off-site Incineration	1%	High	0.4%	High

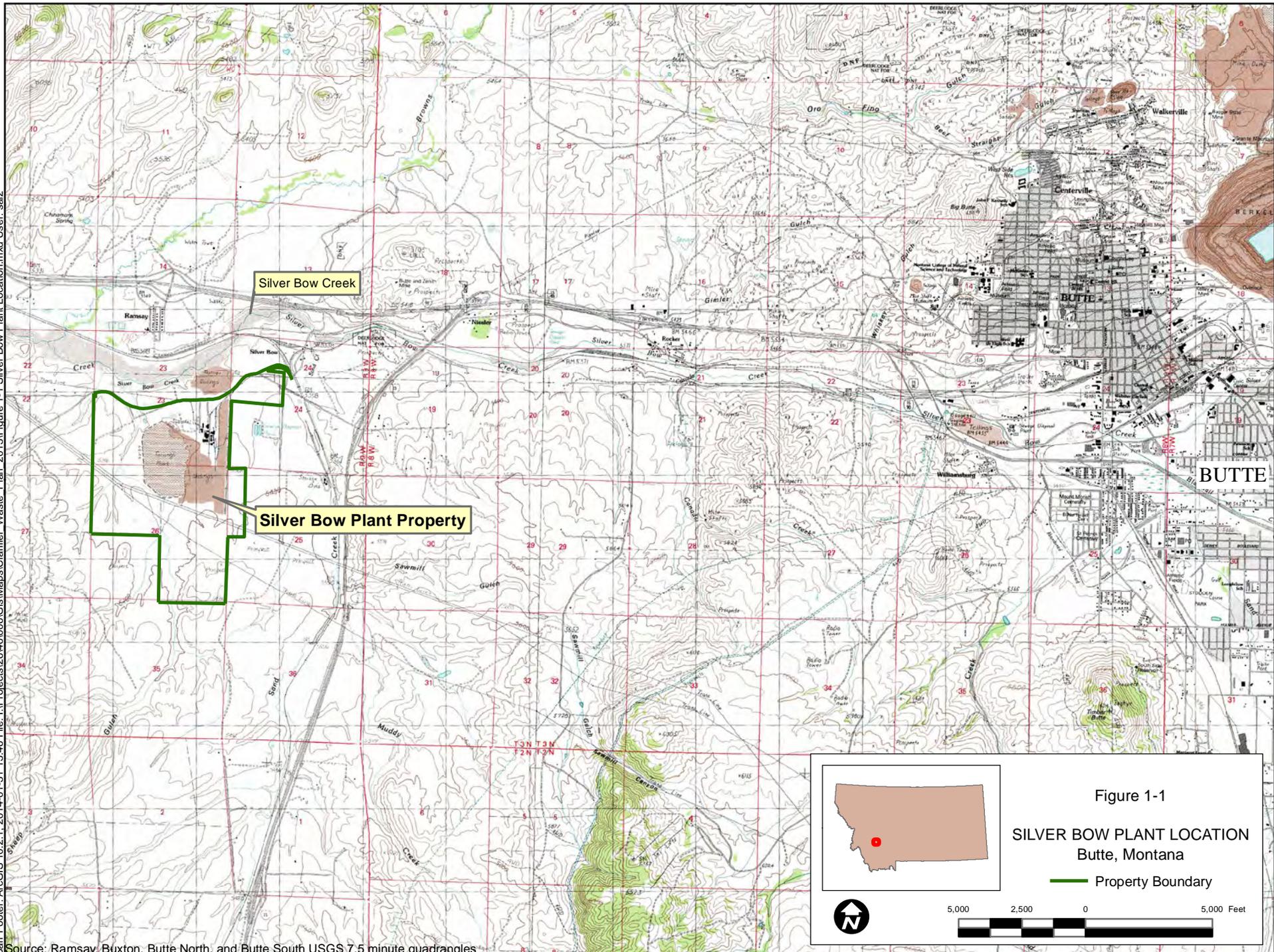
Probability = [Expected Injuries / Number of Workers]

Table 3-3

**Comparative Evaluation and Ranking of Alternatives
Clarifier Materials**

Alternative	Description	Long-term Reliability and Effectiveness	Reduction in the Toxicity, Mobility or Volume	Short-term Effectiveness	Implementability	Relative Cost
Enhanced RCRA Cap	Construction of an engineered barrier over the materials to minimize airflow and rainfall percolation through the covered materials.	<u>Good</u> Designed to last hundreds of years. Crude phosphorus would be entombed in place. Requires long-term maintenance and monitoring.	<u>Lowest Reduction</u> Exposure to toxicity essentially eliminated by cap. No change to volume. Mobility significantly reduced by low permeability cap.	<u>Low Risk</u> Serious Injury: Medium Fatality: Medium Following placement of first layer of cap, primary risks would be reduced to those associated with construction activities.	<u>2 Years</u> Construction requires standard equipment and methods Demonstrated in Phosphorus Industry Anticipated to take two construction seasons plus additional time to establish the vegetated surface.	<u>\$5.4 million</u> Lowest cost of the three options
On-site Phosphorus Recovery (Mud Still Process)	Recovery of phosphorus from the crude phosphorus via vaporization and condensation, followed by construction of an evapotranspiration cap	<u>Very Good</u> Removes the bulk of the crude phosphorus from the clarifier. Limited volume of residual crude phosphorus would be entombed in place. After closure, would be at least as effective as Enhanced RCRA Cap option Requires long-term maintenance and monitoring.	<u>Large Reduction</u> Toxicity and volume of the crude phosphorus would be significantly reduced. Potential to increase toxicity related to fire and phosphine exposure during excavation, processing and transportation. Mobility significantly reduced by low permeability cap.	<u>High Risk</u> Serious Injury: High Fatality: Medium Workers exposed to potential fire and phosphine hazards for an extended duration.	<u>10+ Years</u> Successfully implemented on pilot scale. Requires design and construction of a production-scale facility. Anticipated to take at least 10 and possibly more years to complete.	<u>\$25 million</u> Approximately 5 times the cost of the Enhanced RCRA Cap option
Off-site Incineration	Removal followed by high temperature organic destruction technologies, such as combustion in incinerators, boilers, or industrial furnaces operated in accordance with the applicable requirements of 40 CFR part 264, subpart O, or 40 CFR part 265, subpart O, or 40 CFR part 266, subpart H, followed by construction of an evapotranspiration cap.	<u>Very Good</u> Removes the bulk of the crude phosphorus from the clarifier. Limited volume of residual crude phosphorus would be entombed in place. After closure, would be at least as effective as Enhanced RCRA Cap option. Requires long-term maintenance and monitoring.	<u>Large Reduction</u> Toxicity and volume of the crude phosphorus would be significantly reduced. Potential to increase toxicity related to fire and phosphine exposure during excavation, packaging and transportation. Mobility significantly reduced by low permeability cap.	<u>High Risk</u> Serious Injury: High Fatality: Medium Workers exposed to potential fire and phosphine hazards for an extended duration.	<u>20+ Years</u> Low processing rate (i.e., 2 drums/day) specified by incinerator and large quantities have not been incinerated. Anticipated to take at least 20 and possibly more years to complete.	<u>\$54 million</u> Approximately 2 times the cost of the On-site Phosphorus Recovery option

Figures



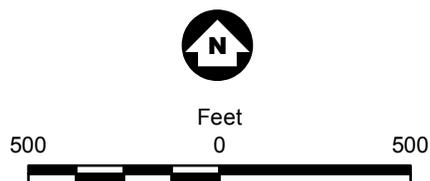


-  SWMU 2 - Clarifier
-  Other Areas Included in 7003 Order

Service Layer Credits: Source: Esri, DigitalGlobe, GeoEye, i-cubed, Earthstar Geographics, CNES/Airbus DS, USDA, USGS, AEX, Getmapping, Aerogrid, IGN,

Figure 1-2

AREAS INCLUDED
IN 7003 ORDER
Silver Bow Plant
Butte, Montana





Service Layer Credits: Source: Esri, DigitalGlobe, GeoEye, i-cubed, Earthstar Geographics, CNES/Airbus DS, USDA, USGS, AEX, Getmapping, Aerogrid, IGN,

-  Monitoring Well
-  SWMU 2 - Clarifier
-  Fence
-  Railroad
-  Road

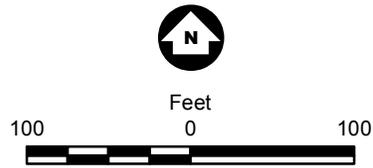


Figure 3-1
CLARIFIER AREA
Silver Bow Plant
Butte, Montana

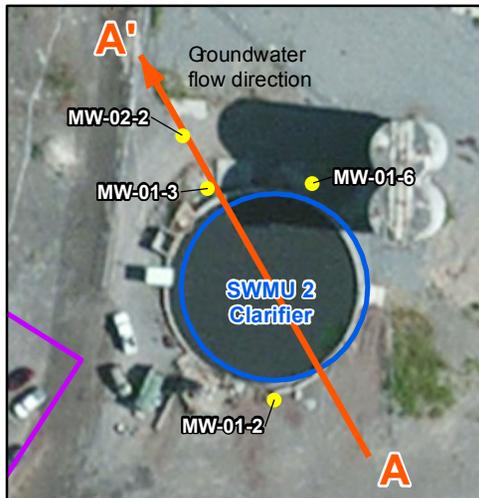
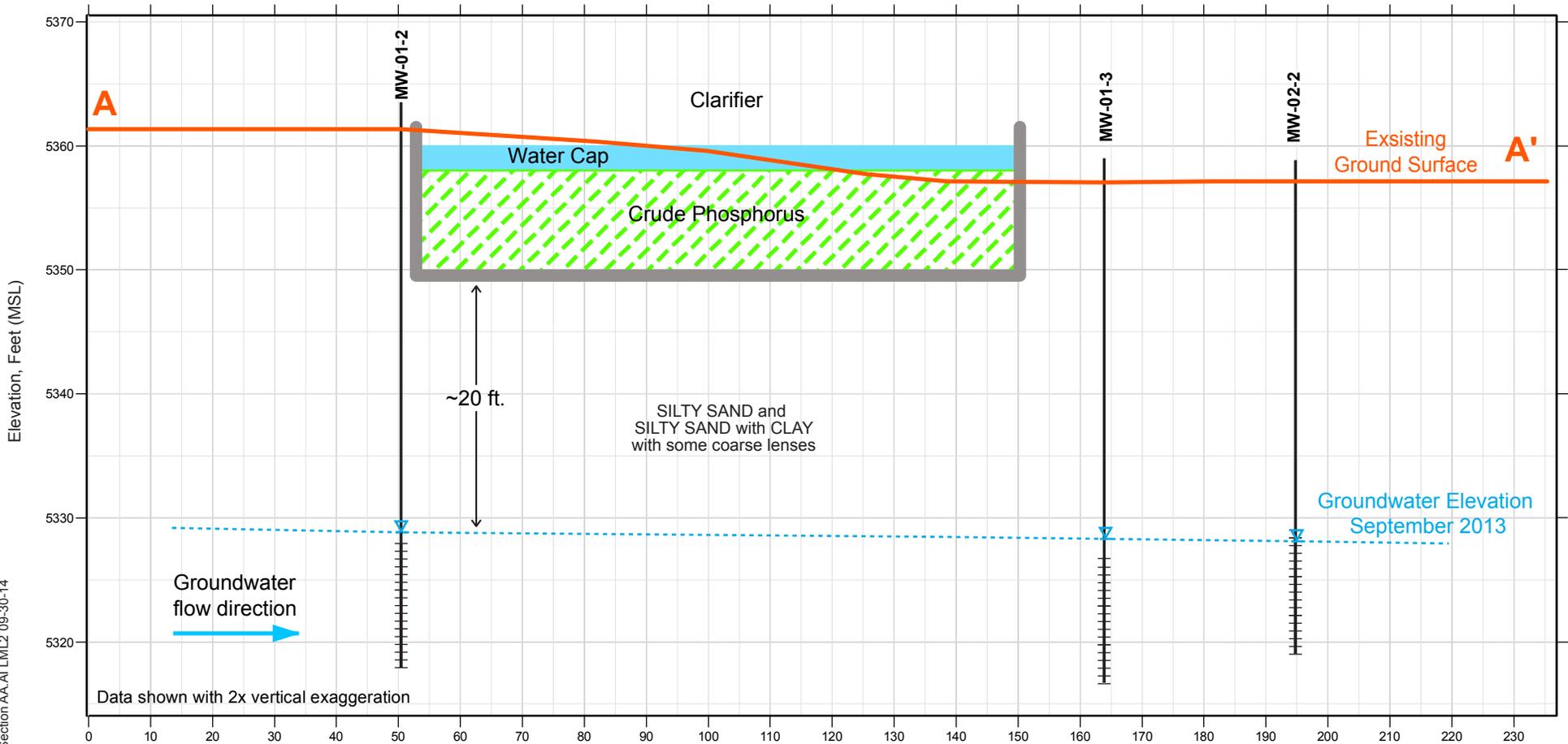


Figure 3-2
CONCEPTUAL CLARIFIER
CROSS SECTION A-A'
Silver Bow Plant
Butte, Montana

Bar Footer: ArcGIS 10.2.1, 2014-10-03 12:06 File: I:\Projects\2646\006\Gis\Map\Clarifier_Waste_Plan_2014\Figure 3-3_Site_Groundwater_Levels_September_2013.mxd User: kac2



Service Layer Credits: Source: Esri, DigitalGlobe, GeoEye, i-cubed, Earthstar Geographics, CNES/Airbus DS, USDA, USGS, AEX, Getmapping, Aerogrid, IGN,

● Monitoring Well

— September 2013 Groundwater Elevation Contours (ft MSL)

5329.35 Groundwater Elevation, ft MSL (September 2013)

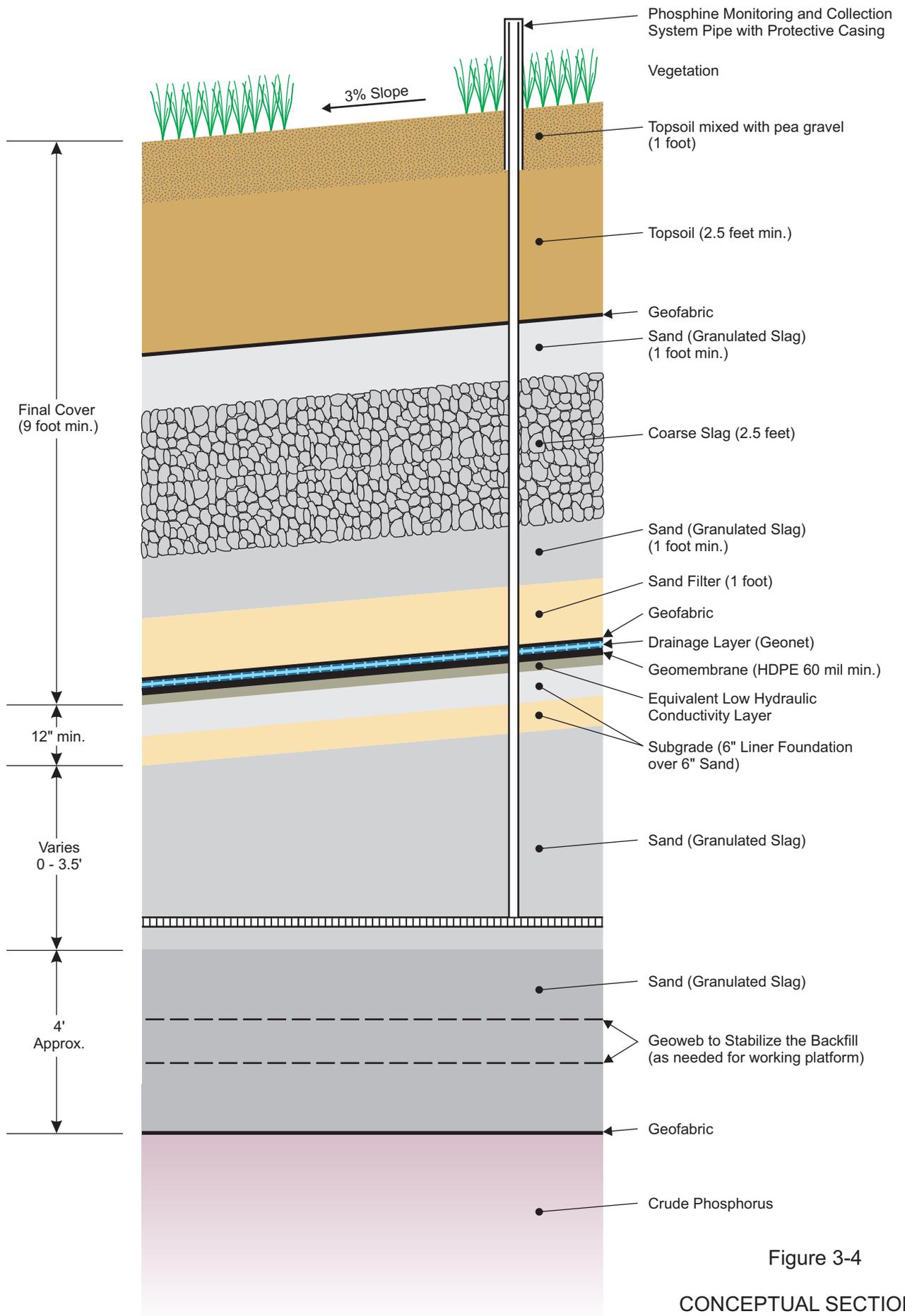


Feet



Figure 3-3

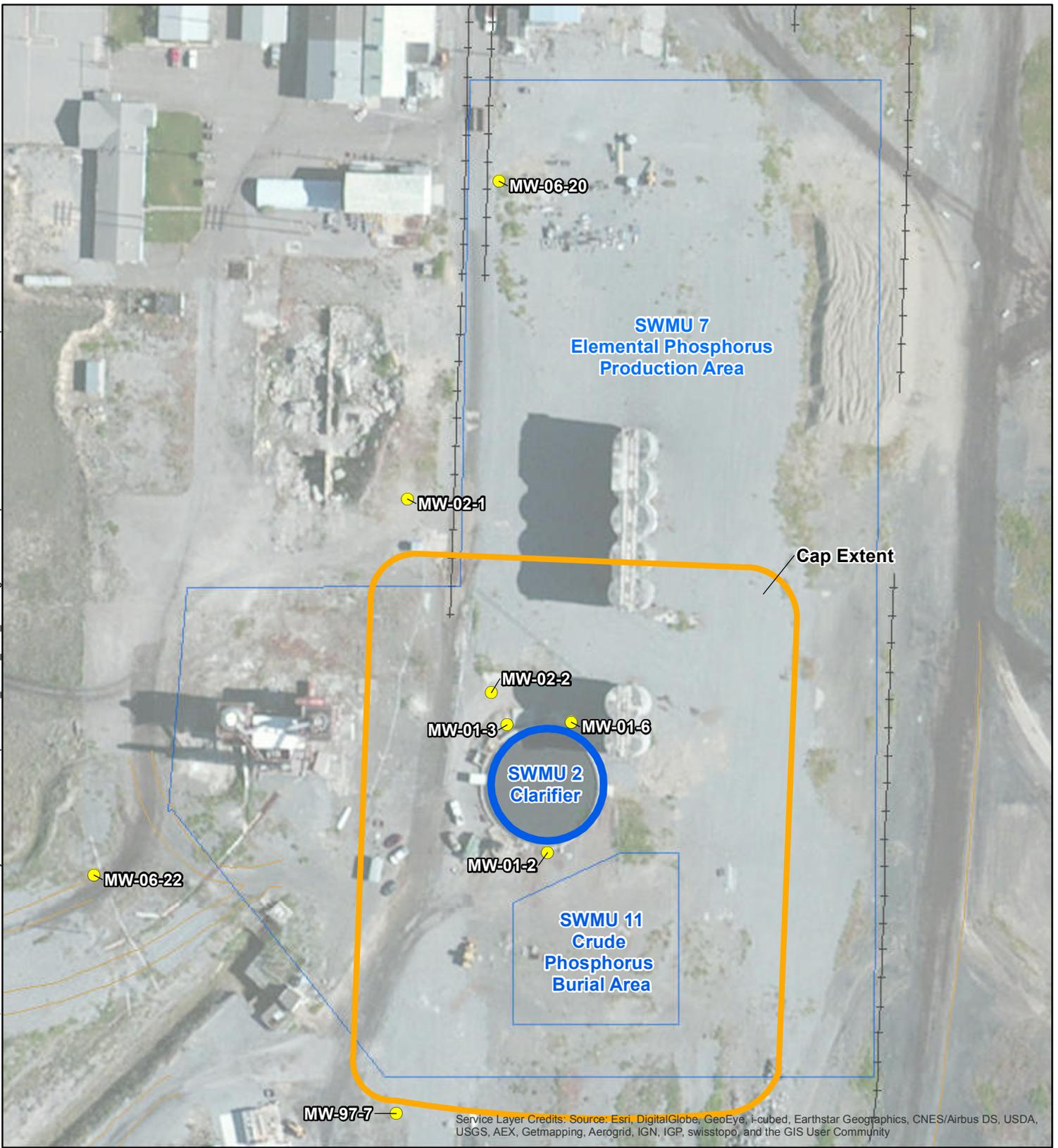
**GROUNDWATER FLOW
CONTOURS (SEPTEMBER 2013)**
Silver Bow Plant
Butte, Montana



P:\Mpls\26 MT\46\2646006\WorkFiles\Figures_Graphics\Typical Section of Enhanced RCRA.CDE RLG 04-16-15

Figure 3-4

CONCEPTUAL SECTION OF
ENHANCED RCRA CAP
Silver Bow Plant
Butte, Montana



Service Layer Credits: Source: Esri, DigitalGlobe, GeoEye, i-cubed, Earthstar Geographics, CNES/Airbus DS, USDA, USGS, AEX, Getmapping, Aerogrid, IGN, IGP, swisstopo, and the GIS User Community

-  Monitoring Well
-  Enhanced RCRA Cap
-  SWMU 2 - Clarifier
-  Railroad
-  Road

Figure 3-5

CONCEPTUAL EXTENT OF
ENHANCED RCRA CAP
Silver Bow Plant
Butte, Montana





Service Layer Credits: Source: Esri, DigitalGlobe, GeoEye, i-cubed, Earthstar Geographics, CNES/Airbus DS, USDA, USGS, AEX, Getmapping, Aerogrid, IGN,

- Monitoring Well
- SWMU 2 - Clarifier
- Mud Still Crude Phosphorus Process Area
- Railroad
- Road

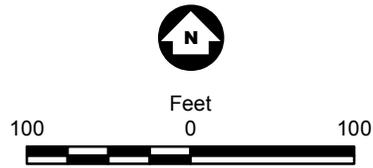
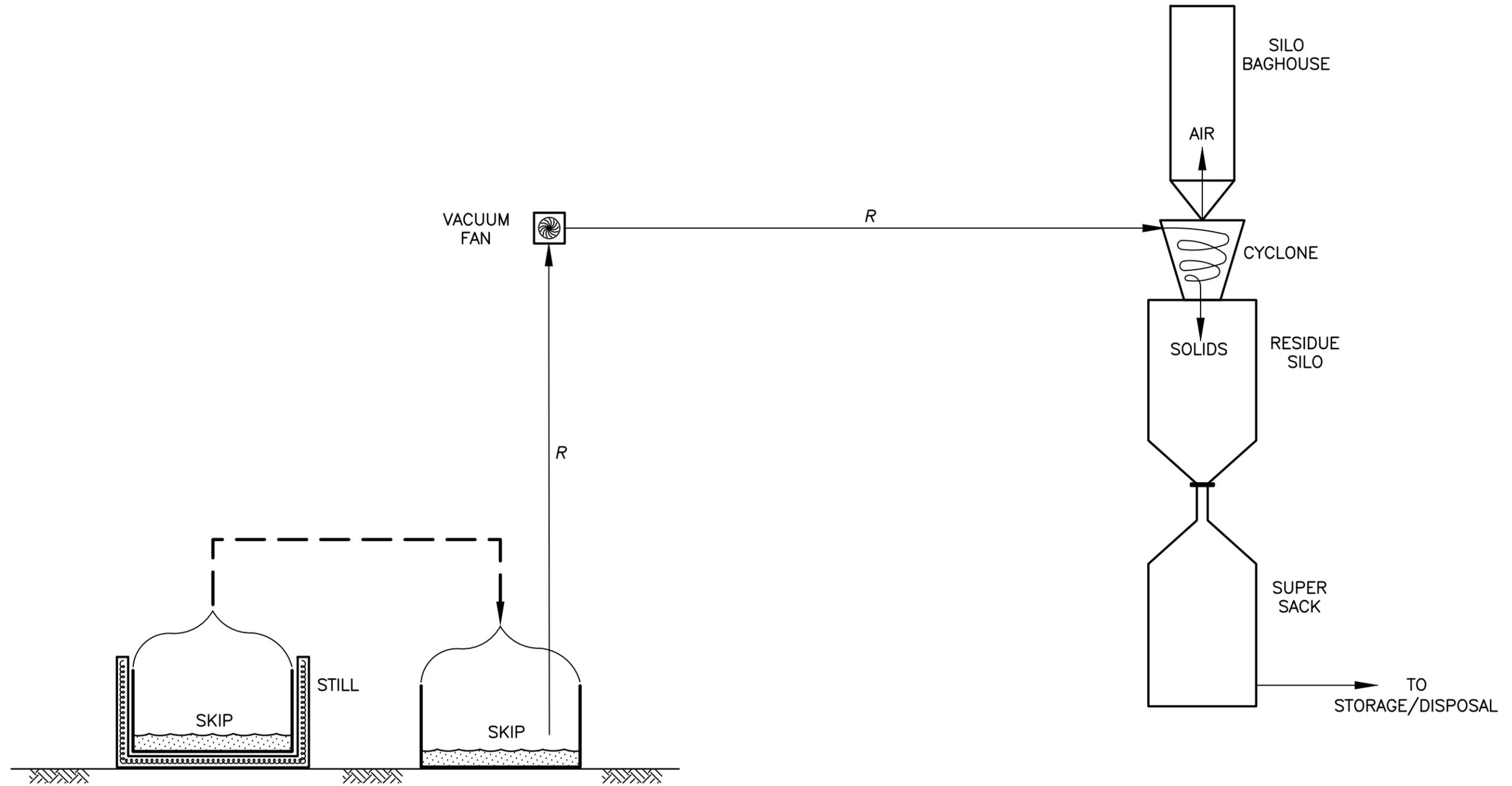


Figure 3-6
CONCEPTUAL MUD STILL PROCESS AREA
Silver Bow Plant
Butte, Montana

PROCESS 3: PROCESS RESIDUE MANAGEMENT



- CP - CRUDE PHOSPHOROUS
- N₂ - NITROGEN (SWEEP GAS)
- P₄ - PHOSPHORUS
- R - RESIDUALS
- V - VAPOR
- W - WATER

Figure 3-8
 CONCEPTUAL
 MUD STILL PROCESS FLOW DIAGRAM
 PROCESS 3
 Silver Bow Plant
 Butte, Montana

CADD USER: Rick Gustner FILE: M:\AdeptWork\RLG\2646000630_Mud Still PFD P3.dwg PLOT SCALE: 1:1 PLOT DATE: 10/2/2014 9:19 AM
 rlg M:\AdeptWork\RLG\2646000630_Mud Still PFD P3.dwg Plot at 0 10/02/2014 09:17:55

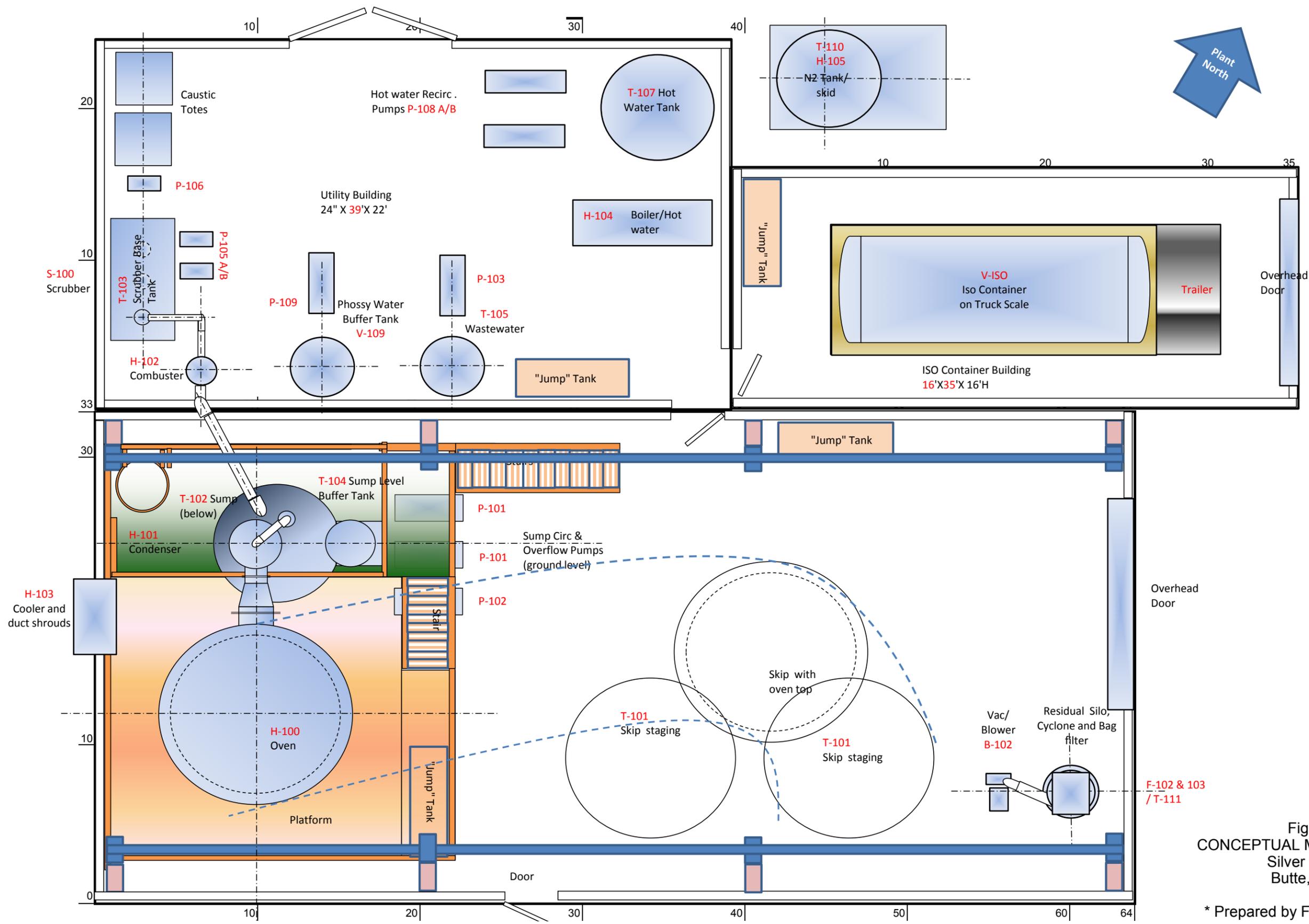
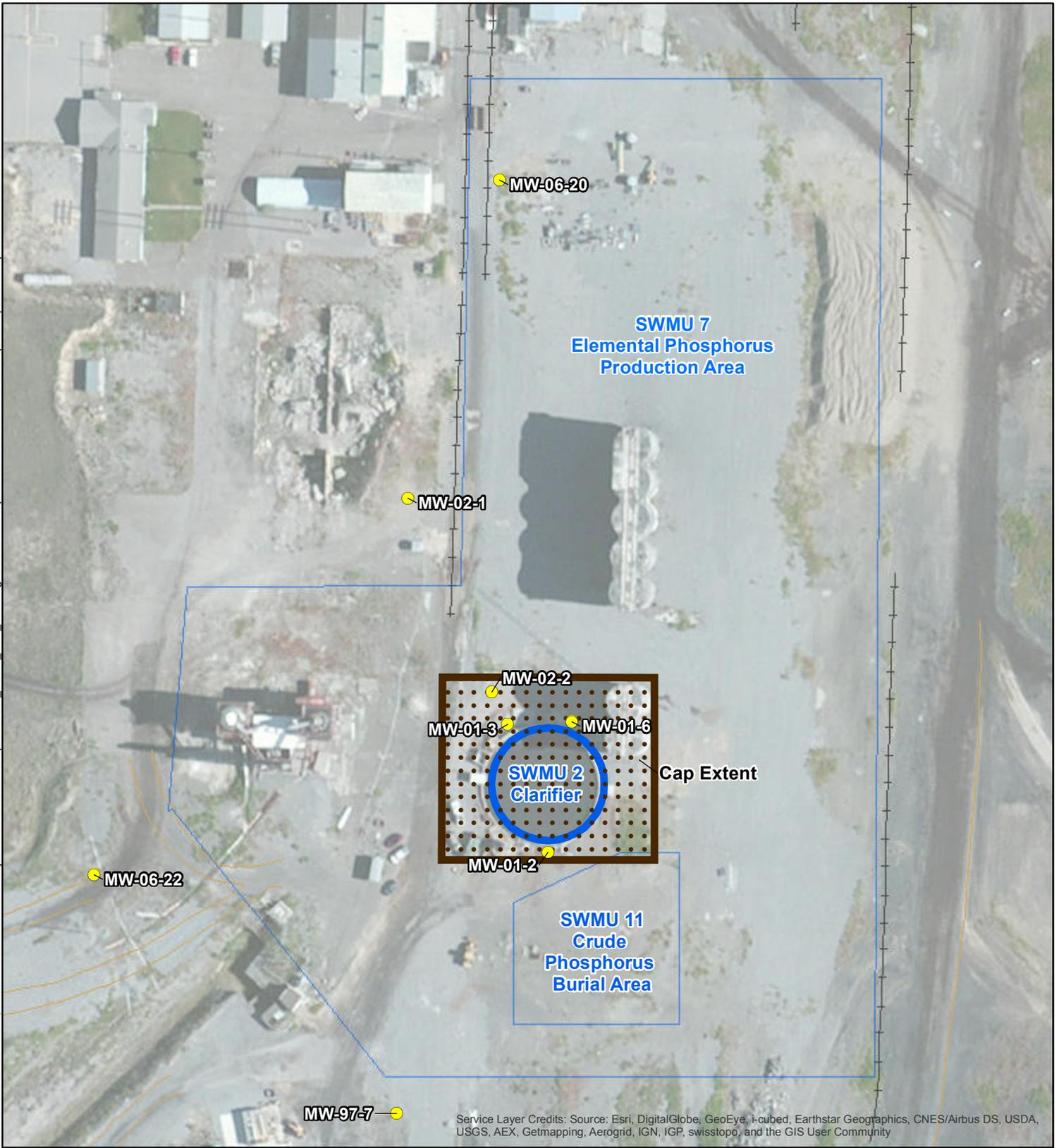


Figure 3-9
 CONCEPTUAL MUD STILL LAYOUT
 Silver Bow Plant
 Butte, Montana

* Prepared by Franklin Engineering



Service Layer Credits: Source: Esri, DigitalGlobe, GeoEye, i-cubed, Earthstar Geographics, CNES/Airbus DS, USDA, USGS, AEX, Getmapping, Aerogrid, IGN, IGP, swisstopo, and the GIS User Community

-  Monitoring Well
-  CAMU Cap Extent
-  SWMU 2 - Clarifier
-  Railroad
-  Road

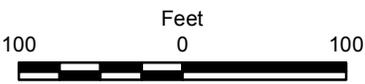


Figure 3-10

CONCEPTUAL EXTENT OF CAMU
AND EVAPOTRANSPIRATION CAP
Silver Bow Plant
Butte, Montana

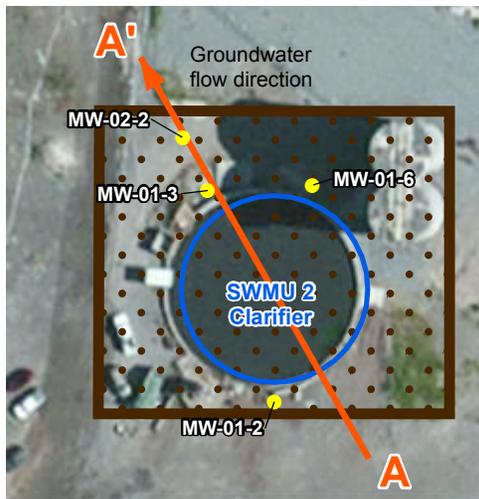
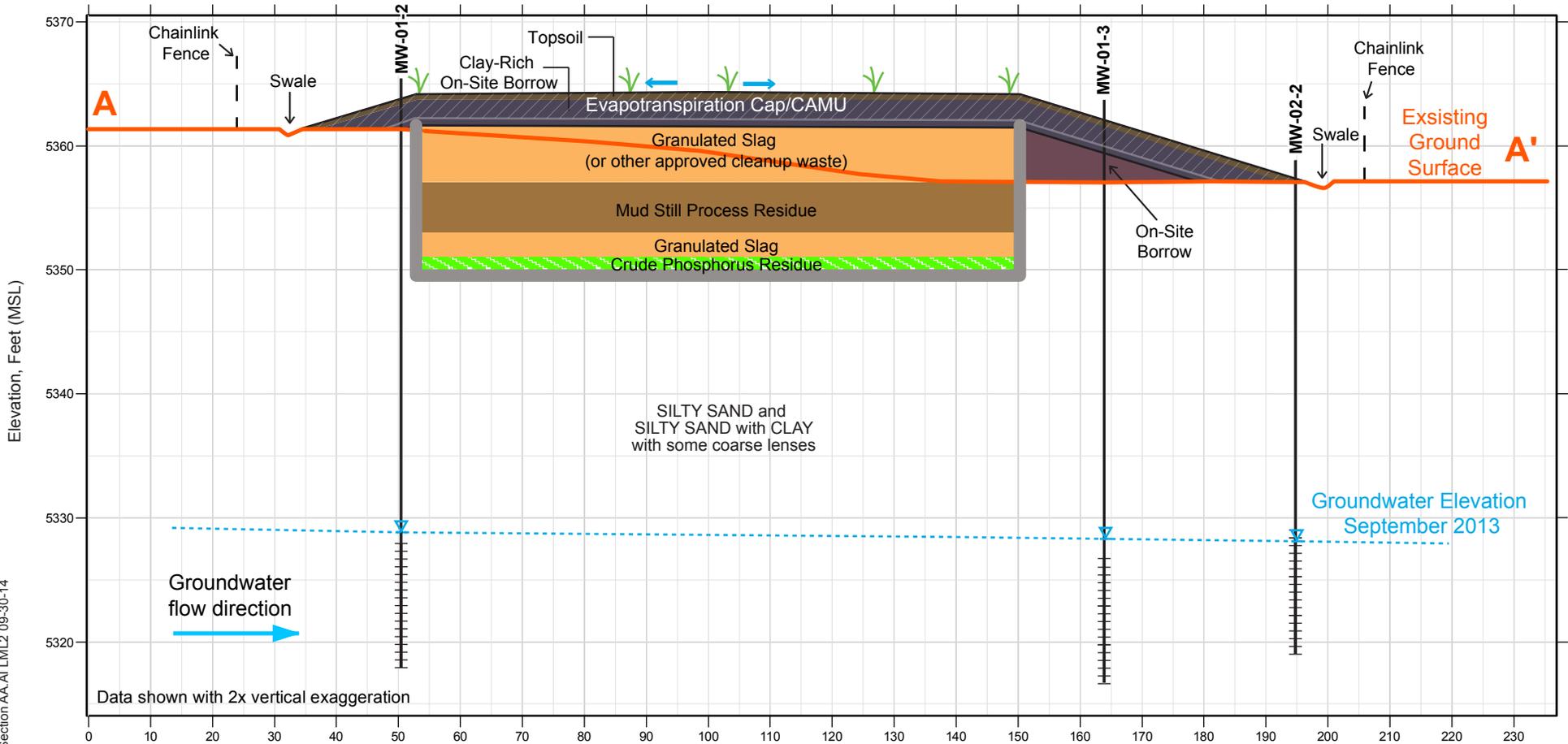


Figure 3-11
CONCEPTUAL
EVAPOTRANSPIRATION
CAP DETAIL
Silver Bow Plant
Butte, Montana