*In-Situ Im*poundment Closure and Groundwater Corrective Action Technology

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EXECUTIVE SUMMARY

Silar Services Inc. (SSi) has developed an engineered ash impoundment closure approach that provides a technically sound and lower cost groundwater remediation option at ash impoundments as compared to excavation.

The *in-situ* ash impoundment closure/remediation approach can eliminate leaching and reduce geotechnical instability that contributes to impoundment failures. To do so the ash is hydraulically isolated from the groundwater by constructing a hydraulic barrier at the bottom of the impoundment using engineered *in-situ* solidification (ISS) applications on the ash and/or underlying natural material. These demonstrated ISS applications can also enhance geotechnical stability by increasing embankment strength, reducing saturated conditions and increasing the overall factor of safety for slope failure.

This approach allows for engineered in-place closure of ash impoundments while satisfying a broad range of stakeholders. In summary, the intent of the approach is to:

- Meet regulatory requirements for closure and/or corrective action on impoundments;
- Facilitate groundwater corrective action by isolating the ash and providing a barrier to prevent continued contamination of groundwater;
- Eliminate the need to remove all ash from impoundments;
- Significantly reduce the amount of dewatering, treatment and disposal of ash contact water during impoundment closure;
- Eliminate the need to site and permit new landfill space for ash from existing impoundments; and
- Significantly reduce cost to close impoundments.

The following provides a statement of the problem, a presentation of the technical considerations, a discussion of the approach, a cost evaluation, an evaluation of

stakeholder acceptance and recommendations on how to move forward with a demonstration of the closure method.

PROBLEM STATEMENT

Subject to the pending USEPA final rule for Disposal of Coal Combustion Residuals from Electric Utilities, specifically 40 CFR, Part 257, Subpart D - Standards for the Disposal of Coal Combustion Residuals in Landfills and Surface Impoundments, ash impoundments face a complex web of regulations that present significant compliance risks to manage. This *in-situ* ash impoundment closure approach is designed to mitigate the environmental risks and meet compliance requirements to the benefit of facility owners and other stakeholders.

For decades, operators of coal fired power plants have managed coal combustion products (CCPs) on-site in ash landfills and/or ash impoundments (or ponds). There are two significant risks associated with these impoundments: potential leaching of CCP contaminants, and structural instability. Most coal fired power plants and their associated ash disposal management facilities are constructed adjacent to rivers and other waterways for cooling water requirements and to allow discharge via a National Pollutant Discharge Elimination System (NPDES) permit. At the time of construction and during operation of many of these impoundments, there was no regulatory requirement to construct liners and many of these impoundments remain unlined. The lack of a liner allows the migration of groundwater through the ash, potentially leaching CCP constituents into the groundwater. Groundwater and surface water impacts have been documented at ash impoundments. In addition, because most impoundments are constructed with earthen berms there are concerns with long term structural stability and the potential for the impoundments to fail causing releases into the environment.

Stakeholders including ash impoundment owners, regulators, environmental groups, and the general public are seeking an appropriate closure approach for these ash impoundments that are facing regulation. Previous closure strategies range from simply capping the ash impoundments to eliminate infiltration and reduce potential leaching of CCP contaminants into the groundwater to complete removal of the ash from the impoundment and relocation to a newly constructed, lined landfill. The regulatory framework further complicates the situation, renders some previous closure strategies non-compliant, and includes imposing requirements that are difficult to meet without implementing more complex and costly solutions that may also introduce new risks.

TECHNICAL CONSIDERATIONS

Many ash impoundments are of similar construction. Commonly, they are:

- Constructed as large-scale settling basins, surrounded by soil berms or dikes to create storage for wet/sluiced ash;
- Constructed to discharge decant water to a receiving body of water through a permitted NPDES outfall or other permitted discharge;

- Sometimes sited on natural depressions or ravines to increase storage capacity; and,
- Often constructed without a liner, particularly in older impoundments.

Consequently, there are common concerns and technical challenges for closure of the impoundments that include:

- Coal ash fill located below the water table that can serve as a continual source for leaching of CCP constituents to groundwater (e.g., boron and sulfate, trace metals);
- Placement of saturated coal ash within the impoundment that can lead to an increase in hydraulic head above the naturally occurring groundwater table, which can exacerbate leaching of coal ash constituents;
- Standard excavation and dewatering construction techniques that are often not feasible for excavation and removal of saturated ash. Specialized construction techniques are needed;
- Extensive dewatering required to close impoundments that can introduce a significant water treatment challenge. Ash constituents including boron, sulfate, and other trace metals can be difficult and expensive to treat – especially for remote impoundments where no viable disposal alternatives exist (e.g., disposal to a local public owned treatment works);
- Historic infrastructure near and within ash impoundments (e.g., abandoned storm water pipes, abandoned discharge structures) that can serve as potential migration pathways for leaching from the impoundment to surface water and groundwater and can also contribute to geotechnical instability; and,
- Saturated and differential hydraulic conditions that can potentially compromise impoundment geotechnical stability along surface water bodies (e.g., adjacent river).

To fully resolve these technical factors, the waste must be hydraulically isolated from the groundwater and the geotechnical strength characteristics maintained or enhanced to decrease the potential for instability.

APPROACH – IN-SITU WASTE IMPOUNDMENT CLOSURE

While construction of a final cover has often been the chosen and presumptive low-cost closure strategy for impoundments considered by facility owners, this approach alone is unlikely to be accepted by other stakeholders as there may be continued leaching of ash constituents into surrounding groundwater. In addition, this approach may not be compliant with all existing and pending regulations as it does not address the barrier between the ash and surrounding material. Some companies are now constructing new lined facilities and moving ash from non-compliant impoundments to new compliant sites. This approach has several disadvantages including its high cos, the risk in moving the material, and the timeline for the solution, which is expected to be long due to permitting, execution, and other complications.

Our alternative approach can eliminate leaching and reduce geotechnical instability that contributes to impoundment failures. To do so, the ash is hydraulically isolated from the groundwater by constructing a hydraulic barrier at the bottom of the impoundment using engineered ISS applications on the ash and/or underlying natural material. These demonstrated ISS applications can also enhance geotechnical stability by increasing embankment strength, reducing saturated conditions and increasing the overall factor of safety for slope failure.

An effective hydraulic barrier can be constructed at the base and the sidewalls of an ash impoundment using ISS techniques on the ash and/or underlying native material. Solidification encapsulates the ash within a cured monolithic material/cement structure, reducing hazards by converting ash constituents into a less soluble and less mobile form. Typically this process consists of advancing continuously overlapping large diameter augers (e.g., 4 to 12 feet [1.22 to 3.66 meters]) from ground surface to the desired depth (impoundment bottom) while injecting an ash/soil specific engineered cementitious grout comprised of water and amendment materials (e.g., Portland cement, ground granulated blast furnace slag, bentonite, etc.) that is blended with the ash/soil *in situ*.

Typically, prior to implementation a laboratory treatability study is conducted to select and test appropriate amendment materials, amendment proportions, and application rates with the objective of designing an engineered grout specific to the waste (e.g., fly ash, bottom ash and other CCP materials) to meet design requirements for permeability and other geotechnical specifications. Laboratory testing of the completed waste/soil and engineered grout mixture is used to confirm that the selected amendments, amendment proportions, and application rates can successfully solidify the waste/soil material and meet established performance goals; including unconfined compressive strength (UCS) and hydraulic conductivity, as well as reduce the leaching rate and concentration of leachate. Following laboratory confirmation, a pilot scale evaluation is typically implemented at the waste site to verify laboratory results are indicative of in-field conditions, and to identify potential operational problems and evaluate operational parameters such as auger diameter and vertical advancement rate. In-field construction success during pilot scale and full-scale implementation is measured by the collection of construction quality assurance (CQA) samples; discrete samples of the waste/soil and engineered grout mixtures are collected and tested to evaluate compliance with established strength and permeability requirements.

Using this technology, a permanent in-place engineered solution that mitigates groundwater impacts can be installed in a relatively short timeframe. In addition, ISS can be effectively constructed to enhance geotechnical stability. Tailored engineered grout mix designs can be developed to improve strength and stability of ash impoundment embankments. Previous ISS applications at other types of infrastructure and waste sites have included geotechnical and structural improvements along waterways, embankments for roadways, bridges, building foundations and other structures.

Ash contact water collected during impoundment dewatering can be collected, recycled and treated as needed and used as make-up water during construction of an ISS application. The ISS construction process requires a significant volume of water for preparation of the engineered grout prior to solidification/stabilization of the ash and/or soil. The volume of recycled water can range in the millions of gallons, significantly reducing water treatment costs. Contact water from other waste sites has been successfully collected and recycled in the ISS construction process.

ISS has been used at waste and construction sites for many years to isolate impacted media from groundwater, reduce leaching of constituents of concern, and to improve structural stability in ground improvement applications. More recently ISS has been demonstrated to be effective in solidifying/stabilizing coal ash, contaminated sediments, mining wastes, acid tar wastes, and drill cuttings. Solidified/stabilized media can achieve specified compressive strengths (e.g., > 50 lbs/square inch (psi) [344.74 kilopascal]) and hydraulic conductivity endpoints (e.g., < $1x10^{-8}$ cm/sec).

Discrete ISS (ISS of only a selected depth interval or zone) has been successfully demonstrated. Unlike conventional ISS where engineered cementitious grout is mixed with soil/waste from the ground surface to a desired depth, application of discrete ISS applies the engineered cementitious grout only to the depth where the amendments are needed. This approach utilizes ISS at a discrete depth to specifically solidify the ash and/or native material to create a low permeable barrier at the bottom of the existing impoundment to isolate the ash from groundwater and significantly reduce leaching. Concurrently, fully penetrating conventional ISS columns would be constructed at the impoundment perimeter to strengthen the embankment sidewalls to reduce geotechnical instability and tie into the low permeability barrier at the impoundment bottom.

SSi has demonstrated experience with ISS construction and ash impoundment closure. We have implemented a discrete ISS pilot test at a USEPA CERCLA site presented at the *2010 International S/S Forum, Sydney, Nova Scotia, Canada*. In addition, we have conducted multiple remedial applications of ISS at waste sites and treatability studies on coal ash and other industrial residuals and waste. These successes provide evidence that an effective hydraulic barrier can be constructed at the base of an ash impoundment and effectively isolate the ash and/or underlying natural material from groundwater.

The following narrative and attached pictorials detail the proposed approach for implementing ISS to facilitate ash impoundment closure.

An illustration of an ash impoundment profile that highlights the aforementioned technical considerations is provided in **Figure 1,** below. **Figure 2** through **Figure 5** and the following narrative describes the conceptual approach and phases for implementing a discrete ISS approach to line impoundment and facilitate closure.

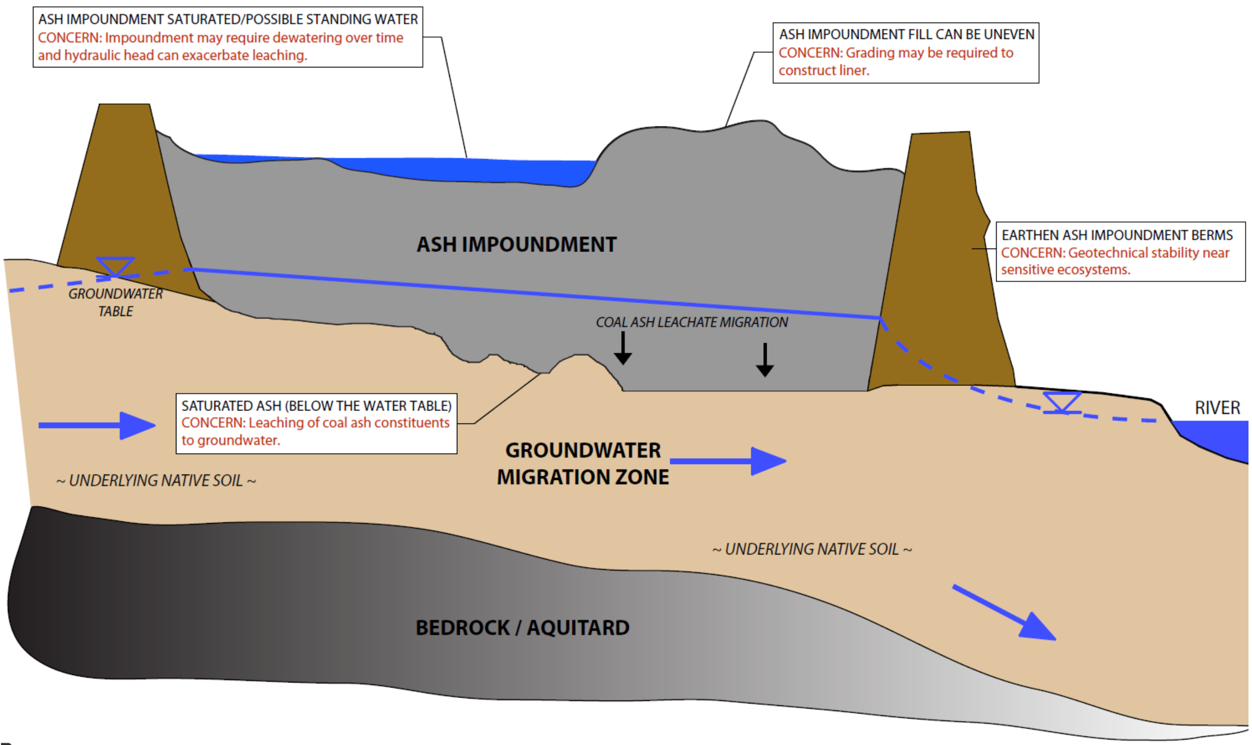

Figure 1. Conceptual Ash Impoundment Profile

Phase I - Ash Impoundment Investigation and Constructability Evaluation:

Figure 2 illustrates the initial steps to plan the ISS implementation which include:

- Records review to develop an understanding of impoundment construction;
- Pre-design data collection for laboratory treatability study and geotechnical testing;
- Evaluation of impoundment dewatering requirements including discharge options, treatment options, on-site management options, and ash contact water reuse during dike and liner ISS construction;
- Constructability evaluation and selection of final cover, ISS liner, and embankment stability including groundwater assessment and geotechnical analysis, if appropriate; and,
- ISS laboratory treatability study to determine appropriate amendment materials, amendment proportions, and application rates and evaluate verify compliance with performance criteria/construction parameters (e.g., permeability, strength, leaching). If applicable, the treatability evaluation will also include an evaluation of reuse of water from the existing impoundment as part of the cementitious grout preparation for the solidification/stabilization process.

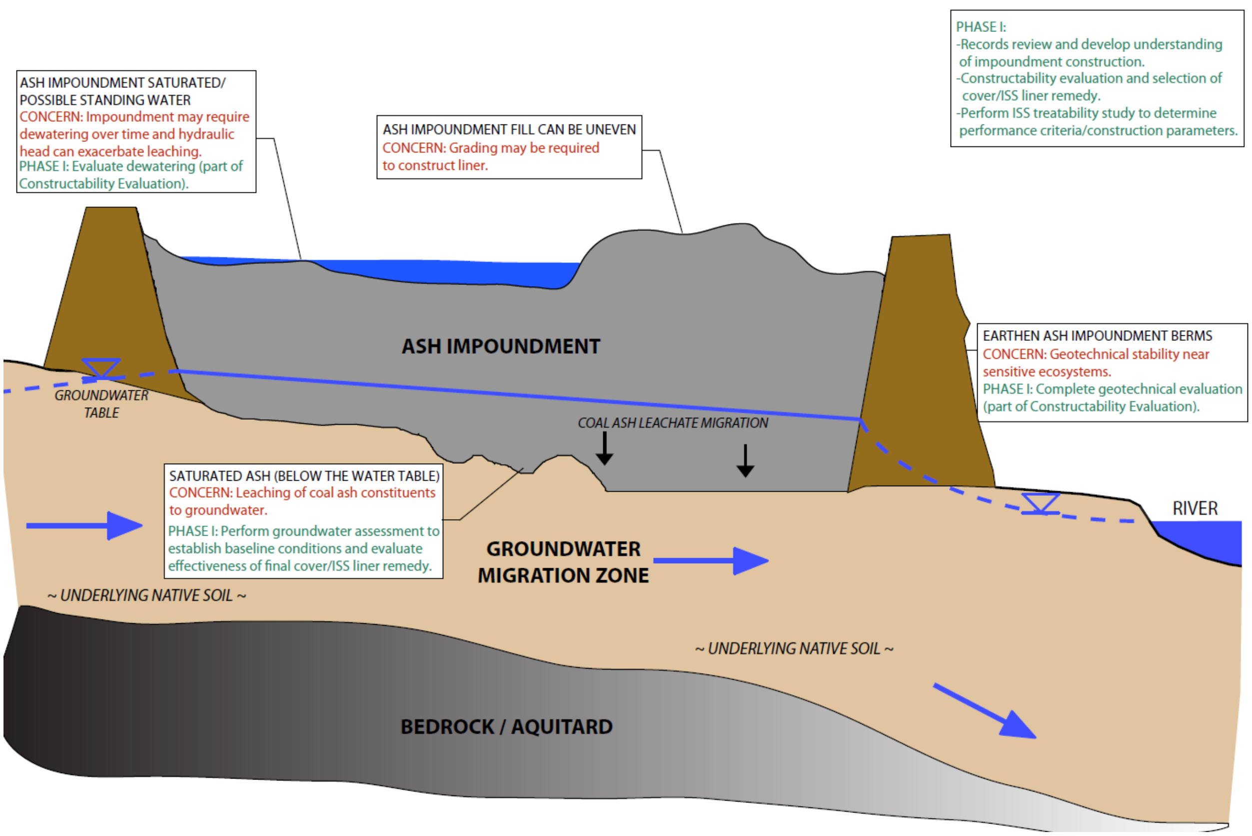

Figure 2. Phase I: Ash Impoundment Investigation and Constructability Evaluation

Phase II - Site Preparation:

Figure 3 illustrates initial construction steps to prepare the impoundment for ISS construction. Key steps may include phased dewatering of the ash impoundment and grading to establish a stable construction platform for ISS operations. Dewatering could be coincidental to Phase III - ISS Construction (**Figure 4**) through reuse of water as part of the cementitious grout preparation for ISS, on-site water management strategies, or treatment and discharge. Dewatering activities of the impoundment could be continued following implementation and during post closure to further reduce water within the impoundment.

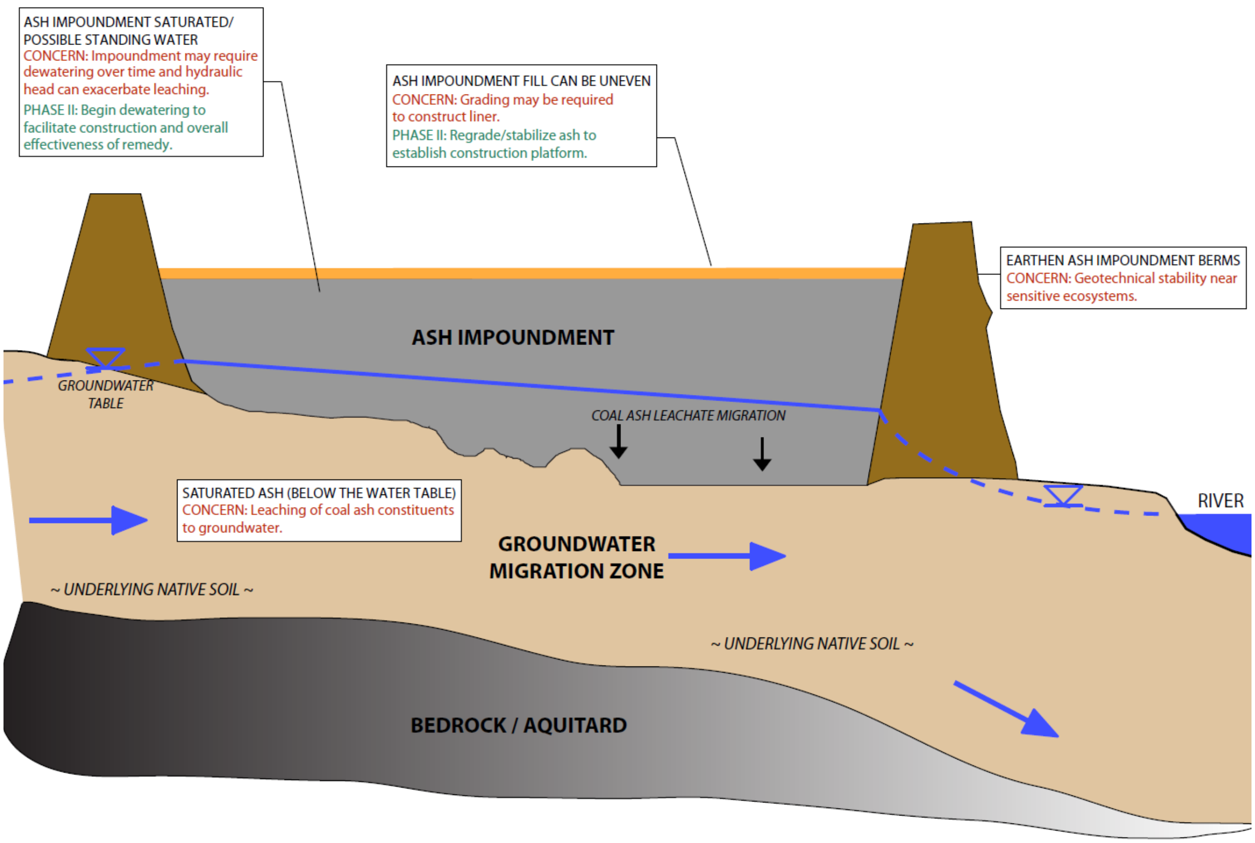

Figure 3. Phase II: Site Preparation

Phase III - ISS Construction:

Figure 4 illustrates ISS construction of a horizontal liner at the bottom of the impoundment and perimeter vertical containment and structural integrity fortifying wall. Construction of the ISS horizontal liner would be performed by advancing the auger to the desired depth below the impoundment and performing discrete ISS to construct the liner (e.g., permeability less than $1x10^{-8}$ cm/sec). The constructed horizontal liner would be tied into a surrounding vertical barrier constructed of fully penetrating conventional ISS columns from ground surface through the ash or surrounding native material to prevent potential horizontal migration of groundwater through the pond and provide structural stability. The result would prevent both the vertical and horizontal migration of groundwater through the ash impoundment, effectively isolating the ash. In addition, the constructed horizontal liner could be contoured to facilitate groundwater/leachate monitoring and/or collection.

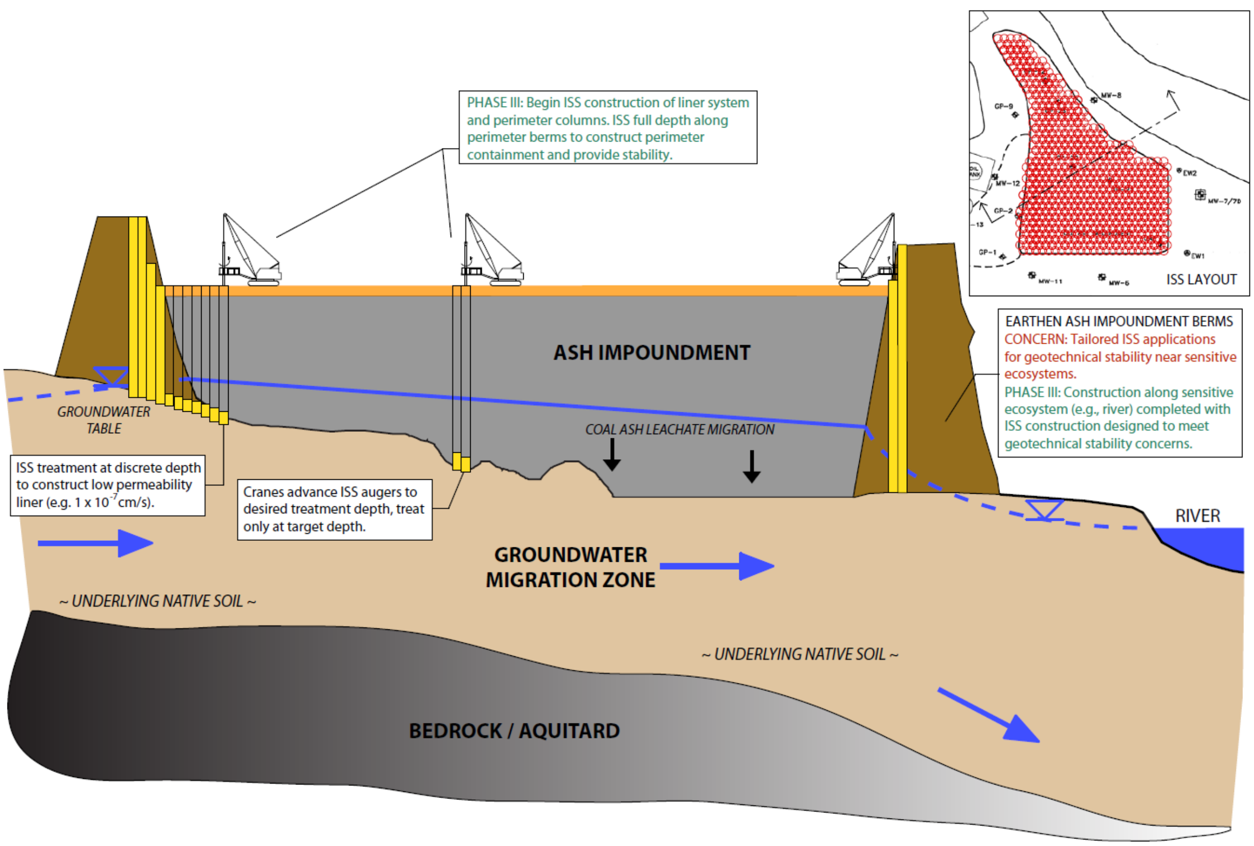

Figure 4. Phase III: ISS Construction

Phase IV - Final Cover Construction:

Figure 5 illustrates construction of a final cover designed to cap the impoundment. The cover would be constructed by importing fill (or on-site borrow materials) to raise the impoundment to an appropriate subgrade and constructing the cover by applying ISS techniques using the available surficial ash. Other low permeability materials (e.g., geomembrane, compacted clay, ClosureTurf®, etc.) could be used for final cover. The final cover would have permeability less than or equal to the liner (achievable with readily available materials) and would result in reduced surface water infiltration to the encapsulated material. Additionally, the cover would include an infiltration layer that contains a minimum of 18 inches (0.46 meters) of earthen material and an erosion layer that contains a minimum of 6 inches (0.15 meters) of earthen material that is capable of sustaining plant growth.

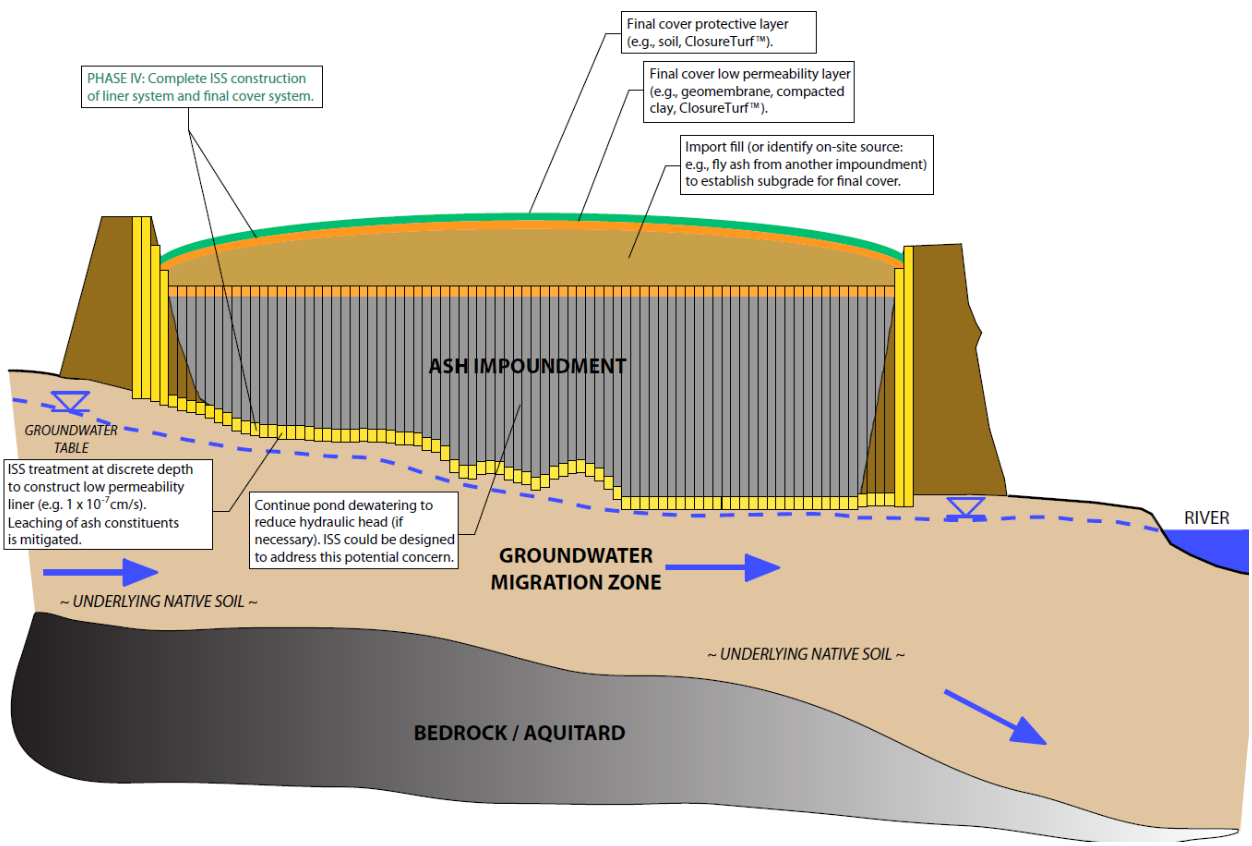

Figure 5. Phase IV: Final Cover Construction

Additional activities would include preparation and implementation of a Post-Closure Plan. The plan would include post closure care requirements, maintenance requirements, a groundwater sampling and analysis plan and structural inspections. In addition, land use restrictions would be placed limiting future use of the closed impoundment.

This approach would allow in-place closure and/or management of ash impoundments if needed and possibly allow some impoundments to stay in use by meeting regulatory requirements regarding stability or groundwater corrective action. It would effectively isolate CCPs from groundwater and provide structural stability to the impoundment perimeter and would therefore be more effective than simply capping the impoundment. This closure strategy is also a less environmentally disruptive approach than excavation and on-site or off-site disposal. The approach can be implemented in a timely manner and at significantly reduced costs while meeting the diverse objectives of multiple stakeholder groups. Typical ISS operations have a small environmental footprint because the on-site operations require only a few pieces of equipment and the majority of the work is conducted below the ground surface (e.g., limited off-site transportation of materials or on-site excavation). Potential cost savings of this approach are illustrated below.

COST EVALUATION

SSi has prepared a cost evaluation that compares *in-situ* closure outlined above to excavation and off-site disposal. We recognize that at many ash impoundment locations it is unlikely that off-site landfills will have the capacity to receive the ash. We also understand that some utilities have constructed on-site landfills; however, this approach may not be practical at all plants. Regardless of the final disposal option, the cubic yard disposal costs (total) for off-site and on-site disposal are likely comparable. Costs are based on our experience, along with recent costs provided by EPRI and various remedial contractors. Table 1 summarizes the assumptions and anticipated costs for closure of an existing ash impoundment.

Table 1
Cost Evaluation
In-Situ Impoundment Closure/Remediation vs Excavation/Off Site Disposal

			Excavation and Off-Site Disposal		*In situ* Closure (ISS)	
Item	**Estimated Quantity**	**Units**	**Unit Price $**	**Amount $**	**Unit Price $**	**Amount $**
General Conditions						
Mobilization & Temporary Facilities Setup	1	Lump Sum	$ 700,000	$ 700,000	$ 700,000	$ 700,000
Site Preparation, Site Survey, Remove Ponded Water	1	Lump Sum	$ 1,500,000	$ 1,500,000	$ 1,500,000	$ 1,500,000
Clearing, Grubbing and Erosion Controls Installation, Maintenance & Monitoring	1	Lump Sum	$ 300,000	$ 300,000	$ 300,000	$ 300,000
Demobilization & Record Documents	1	Lump Sum	$ 250,000	$ 250,000	$ 250,000	$ 250,000
Excavation & Backfill						
Excavate Ash, Dewater, and Load	1,290,667	Cubic Yards	$ 20	$ 25,813,340	$ -	$ -
Transport and Dispose of Ash	1,742,400	Tons	$ 25	$ 43,560,011	$ -	$ -
Backfill with Off-site fill	645,334	Cubic Yards	$ 15	$ 9,680,003	$ -	$ -
In-Situ Solidification						
Mobilize ISS Treatment Equipment and Materials	1	Lump Sum	$ -	$ -	$ 500,000	$ 500,000
In situ Solidification/Stabilization (ISS)	366,000	Cubic Yards	$ -	$ -	$ 80	$ 29,280,000
ISS Swell Management (15%)	54,900	Cubic Yards	$ -	$ -	$ 4	$ 197,640
Geotextile Cap	40	Acres	$ -	$ -	$ 50,000	$ 2,000,000
Dewatering - Excavation						
Frac Tank Mobilization, Setup and Demobilization	8	Each	$ 3,000	$ 24,000	$ -	$ -
Site Water Management	104	Week	$ 25,000	$ 2,600,000	$ -	$ -
Dewatering - ISS						
Frac Tank Mobilization, Setup and Demobilization	4	Each	$ -	$ -	$ 3,000	$ 12,000
Site Water Management	52	Week	$ -	$ -	$ 5,000	$ 260,000
Site Restoration						
Topsoil	32,267	Cubic Yard	$ -	$ -	$ 26	$ 838,942
Seed and Mulch	40	Acres	$ 2,000	$ 80,000	$ 2,000	$ 80,000
			TOTAL COST	**$ 84,507,000**		**$ 35,919,000**
			COST PER ACRE	**$ 2,112,675**		**$ 897,975**

Assumptions

- Impoundment is 40 acres by 20 feet deep

Excavation and Off-Site Disposal Closure Assumptions

- Excavation volume is 1.29 million cubic yards
- Excavation will be backfilled with off-site fill and vegetated
- Ash will be disposed off-site within 50 miles of the plant
- One cubic yard of excavated fly ash weighs 2,700 lbs.
- Dewatering of excavation will be required with water treatment

In-Situ Closure Assumptions

- ISS volume is approx. 366,000 cubic yards, including 323,000 cubic yards to ISS
  - 5' thick bottom liner (1 feet of fly ash plus 4 feet of underlying natural material) and
  - 43,000 cubic yards to ISS 10 feet thick perimeter wall to 25 feet below ground surface
- Installation of geo-textile cap and soil cover
- Dewatered groundwater will be used in ISS batch plant

Based on the cost included in Table 1 the costs for excavation/off-site disposal of ash for the existing 40 acre ash impoundment are approximately $84 million. The costs for the *in situ* closure (ISS) method is approximately $36 million, less than half of the excavation/off-site disposal alternative. This translates to a cubic yards remedial cost of $65 cubic yard for excavation/off-site disposal compared to $28/cubic yard for *in situ* closure.

STAKEHOLDER ACCEPTANCE

Primary stakeholder groups include ash impoundment owners, regulators, environmental groups, and the general public. Ash impoundment owners are generally utility companies but also include municipalities, government entities and public and private corporations. Regulators primarily include federal and state environmental agencies and the Public Utility Commission. Many Environmental Groups are actively involved in ash impoundment issues. The general public is a primary stakeholder as utility rates may be affected by regulation and the cost of ash impoundment closures. Table 2 summarizes the primary stakeholders, their primary concerns regarding CCP impoundments and how the ISS closure approach addresses these concerns. As illustrated in Table 2 the ISS closure strategy will address stakeholder concerns.

Table 2. Stakeholder Summary

Stakeholder Group	CCP Impoundment Objectives	How ISS Strategy Meets Objectives
CCP Impoundment Owners	▪ Achieve regulatory requirements. ▪ Address concerns of environmental groups and the general public. ▪ Provide the lowest possible cost to rate payers and/or shareholders. ▪ Perform timely closures. ▪ Allow for future harvesting.	▪ Provide a safe, cost effective means for managing ash impoundments in a timely way. ▪ Support safe and timely closure of obsolete ash impoundments and offer a path for extending life of impoundments in use if required and permitted. ▪ Method allows for future harvesting as only a small portion of the ash is solidified.

Stakeholder Group	CCP Impoundment Objectives	How ISS Strategy Meets Objectives
Regulators	▪ Secure CCP impoundments to prevent catastrophic failure and leaching of CCP constituent into groundwater. ▪ Timely implementation of sustainable closure. ▪ For the Public Utilities Commission, closure must be most cost-effective remedy that meets regulatory requirements.	▪ Will provide structural stability of impoundments and mitigation of leaching via installation of side walls, liner, and cap, mitigating risk of catastrophic failure. ▪ Closures can be implemented in-place reducing potential environmental impacts of siting and permitting new landfills, ash handling, ash transportation, etc. ▪ Closure/management can be implemented in a timely way, reducing windows of risk.
Environmental Groups	▪ Insure structural stability of impoundments to protect nearby bodies of water. ▪ Prevent leaching of CCP constituents into groundwater.	▪ Addresses the primary concerns of environmental groups related to structural stability and continual groundwater impacts. ▪ Has the added advantage of timely implementation and in-place solution which is greener due to elimination of need for additional development of compliant landfills. ▪ Reduces of carbon footprint of solution by eliminating of ash excavation and transportation.
General Public	▪ Address safety issues in a cost-effective way that minimizes impact on rates.	▪ Addresses perceived safety issues through timely resolution and significant reduction in risk of contamination through leaching or failure. ▪ Provides the lowest cost closure minimizing impact on rates.

SUMMARY AND RECOMMENDATIONS

This *in-situ* ash impoundment closure approach allows in-place closure and/or management of ash impoundments if needed and may even allow some impoundments to stay in use by meeting regulatory requirements regarding stability or groundwater corrective action. It effectively isolates ash from groundwater and provides structural stability to the impoundment perimeter and would therefore be more effective than simply capping the impoundment. This strategy is also a less environmentally disruptive approach than excavation and on-site or off-site disposal.

Based on available information, the constructed ISS closure approach provides an acceptable and desirable closure strategy for ash impoundments. A field demonstration of this closure approach would be beneficial to gain acceptance by the various stakeholder groups.