Potential Challenges in Landfill Water Management

Technical Brief — *Coal Combustion Products Management*

Introduction

This Technical Brief aims to inform utility staff and other stakeholders about collectively raised issues that could impact the ability to manage and treat coal combustion product (CCP) landfill waters. In the United States, CCP landfills are designed and operated in conformance with solid waste regulations, such as the 2015 Federal Disposal of Coal Combustion Residuals rule and individual states' solid waste program rules. Regulatory focus on leachate treatment is emerging, including among U.S. Environmental Protection Agency (EPA) regulators who set the national minimum treatment standards contained in the Steam Electric Effluent Limit Guidelines (ELGs). These rules are under review as of this writing (spring 2022) and are proposed to be revised through a proposed rulemaking in fall 2022.

Landfill Water: What Is It and What Influences Its Generation?

Sites define and manage landfill waters in many ways. An in-depth discussion on CCP landfill terminology, physical features, and typical industry definitions of leachate are provided in the Electric Power Research Institute (EPRI) report *Coal Combustion Product Landfill Terminology and Water Management Fundamentals* (3002021923).

The sources of liquids in CCP landfills can include the following:

- ***Precipitation:*** Expected to be the most significant volume of water introduced into landfills. This water can evaporate, infiltrate (percolate), or run off as contact stormwater or noncontact water.
- ***Moisture-conditioning water:*** Added before landfill placement to enable compaction and limit dust.
- ***Dust control water:*** Applied to surfaces to limit the mobilization of particles by wind and operations.
- ***Equipment wash water:*** Used to clean trucks and compactors.
- ***Bottom drainage system cleanout water:*** Used to maintain the bottom drainage system.
- ***Run-on water:*** Surface water that flows into the landfill from an upland area (less common in recently constructed landfills).
- ***Seepage and groundwater:*** Natural geologic water sources that can flow into a landfill if it intersects with perched zones or the water table (less common in recently constructed landfills).

Landfill Water Management

The largest source of water at a CCP landfill in humid portions of the country is expected to be precipitation. Partitioning the precipitation that falls on the landfill between the surface and subsurface—that is, between stormwater (contact and noncontact) and percolation—is an important consideration for effective landfill water management.

Noncontact surface water is commonly treated as industrial stormwater and contained in stormwater pond(s) prior to discharge or reuse. Percolated water, on the other hand, when captured by a leachate collection system, is managed by treatment for discharge or on-site use. Understanding the variability over time in the quality and quantity (Q/Q) of the CCP landfill's percolated water facilitates design of an optimally effective water treatment system.

The Q/Q of waters generated from operating landfills can be influenced by multiple factors, including (but not limited to) the following:

- CCP material properties
- Moisture content of CCPs placed and rate of placement
- Landfill design and geometry
- Landfill operations
- Temporary cover systems—the open working area and effectiveness of cover
- Landfill thickness
- Weather conditions

Depending on these and other factors, water from a landfill that might require treatment could consist of many different combinations of percolated water, contact water or contaminated stormwaters, or noncontact water, and each could have unique treatment needs. For example:

- In loosely placed CCP, infiltration of precipitation might be greater than in well-compacted CCP, potentially increasing future percolation into the leachate collection system. However, greater runoff volume can occur from well-compacted CCP surfaces, with surface runoff constituting contact water and requiring treatment, at least for suspended solids.
- Water applied for dust control often evaporates during the day and requires frequent reapplication during dry periods. Overwatering can increase infiltration and percolation as well as soften the compacted materials, increasing rutting and transport of suspended solids if rain comes before it is redressed. At some power stations, dust control water contains elevated salts. Runoff of dust control water is managed with other contact water.

- Equipment wash water might require solids removal and be counted as contact water for any other pertinent treatment.
- Drainage systems sometimes become clogged over time due to chemical precipitation. One utility reported the composition of scale in their leachate collection system to be calcium and magnesium carbonates. Occasional cleaning might be required and is commonly done by jetting. Jetting uses a high-pressure waterline with directional spray to mobilize solids accumulation in the pipes. Recovering these clogged systems could require exposure to an acidified solution or other chemical treatment. Chemicals and leachate from cleaning might require treatment.

Water Treatment System Considerations

Collecting Data to Understand Treatment Needs

When considering what information would be needed to begin planning a water treatment system for landfill waters, several considerations arise. Quantifying leachate flows can be challenging, depending on the configuration of a specific site. Some sites have drainage collection systems, some have drainage layers; the discharges of these features might not be accessible (that is, they can be buried, in a vault, or have their own conveyance and pumping systems). Also, as described in 3002021923, sites define and manage landfill waters in many ways. To optimally design a water treatment system, a long-term understanding of leachate Q/Q is needed.

In many cases, the landfill design will include provisions for the treatment of landfill waters. These treatment systems will need to operate under different conditions throughout the lifetime of the landfill as well as the post-closure care period. Predicting the changes in leachate Q/Q after landfill closure based on design is not straightforward because operations can significantly impact the amount of water collected.

Gaining an understanding of leachate Q/Q through flow and analytical measurements requires long-term monitoring. The data needs for understanding leachate flows and chemistry include:

- ***Flow rate:***
  - Instantaneous minimum and maximum flow rates
  - Average flow rates over time (that is, monthly, annual)
  - Equalization volume sizing
- ***Water quality***
  - Samples collected over seasonal and annual variations (ideally, samples will be correlated with flow data)
- ***Supporting data:***
  - Weather stations
  - Landfill design specifics
  - Landfill filling rate
  - Landfill height (CCP thickness)
  - Open versus closed surface area and geometry
  - CCP type, quantity, and moisture content

Collecting supporting data as well as flow data has challenges. Sites need stakeholders and operators to be diligent in recording information that they traditionally may not have collected. Measuring leachate flow can be difficult at some sites. For example, piping that conveys landfill waters could be difficult to access or periodically submerged, depending on the level in a collection pond.

For legacy waste streams, such as landfill waters, combining multiple similar-quality streams into a common equalization location (such as a pond) might be considered where feasible. This can help to limit large swings in water Q/Q and facilitate steady-state treatment conditions.

Percolated Landfill Water Composition

One example of water chemistry that can be tracked currently is the chemical composition of percolated water in CCP landfills, which has been described in several EPRI publications, most recently in 3002022051. Total dissolved solids concentrations for CCP percolation waters are commonly in the thousands of mg/L. Comparison of data reveals that concentrations for most constituents in CCP percolation water (called *porewater* in 3002022051) vary by two to three orders of magnitude between sites and can vary by an order of magnitude or more over time at any single site (3002007125). Table 1 ranks the composition of individual constituents in CCP porewater by median concentration for two categories of coal ash and two categories of flue gas desulfurization (FGD) solids.

Table 1. Ranking of CCP porewater composition based on median concentrations in EPRI's CPInfo database

Median Concentration	Bituminous Coal Ash	Subbituminous Coal Ash	Fixated FGD Solids	FGD Gypsum
>1000 mg/L	SO_4	SO_4	Cl, SO_4	Cl, SO_4
100–1000 mg/L	Ca	Ca, Na	Ca, K, Na	Ca, Mg
10–100 mg/L	B, Cl, Mg, K, Na	Cl, K	Mg	B, Na
1–10 mg/L	F, Li, Mo, Si, Sr	B, Mg, Mo, Si, Sr	B, Li, Si, Sr	Mn
0.1–1 mg/L	Al, Fe, Mn	Al, F, V	Al, F, Fe, Mn, Mo	Al, Fe, Se
0.01–0.1 mg/L	As, Ba, Ni, Se, U, Zn	As, Ba, Cr, Cu, Fe, Li, Mn, Se	As, Ba, Se, Zn	As, Ba, Mo, Ni, Ti, Zn
< 0.01 mg/L	Sb, Be, Cd, Cr, Co, Cu, Pb, Hg, Ag, Tl, Ti, V	Sb, Be, Cd, Co, Pb, Hg, Ni, Ag, Tl, Zn	Sb, Be, Cd, Cr, Co, Cu, Pb, Hg, Ni, Ag, Tl, Ti, U, V	Be, Cd, Cr, Co, Cu, Hg, Pb, Ag, Tl, V
Insufficient Data		Ti, U		Sb, F, Li, K, Si, Sr, U

Notes:
- Full data ranges are shown graphically in 3002022051.
- Fixated FGD solids are from inhibited or natural oxidation FGD systems $CaSO_3$, fixated with lime or alkaline fly ash.

Values for pH also vary by CCP. Bituminous coal ash porewater often has a near-neutral pH, whereas subbituminous porewater pH tends to be alkaline. Field data for the pH of FGD solids are sparse; however, laboratory data suggest slightly alkaline to alkaline pH for most of these products (3002022051). *In situ* redox conditions are more challenging to characterize. When reported, redox data have been reported differently (as ORP and as Eh), without sufficient other information for conversion. Although many data have been collected, comparing them between sites (and subsequently extracting meaningful conclusions) is difficult.

Changing Landscape

Q/Q Variations Over Time

The flow rates of landfill waters from a given landfill will vary over time, depending on several factors, including the landfill's status (active/inactive/closed), size, operating practices, and working area. Figure 1 shows variability in measured leachate flow rates from four sites.

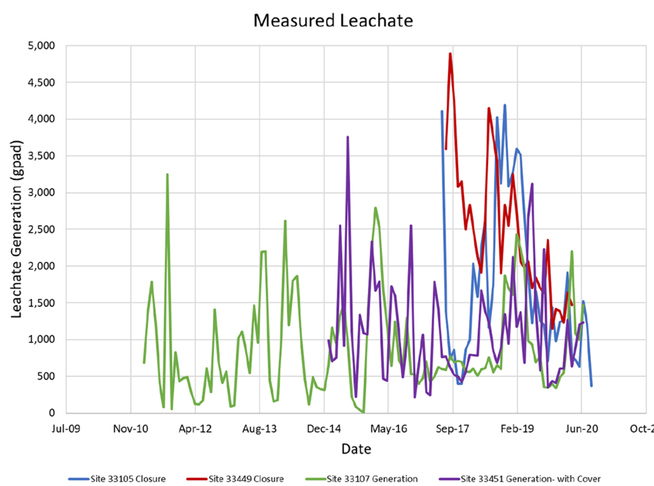

Figure 1. Compiled measured leachate over time for four sites (from 3002023091)

The largest leachate flows are generally associated with newly opened landfills that contain relatively few CCPs, and flows generally decline with increasing CCP thickness (3002006283). Changes in CCP moisture content during placement—for example, adding relatively wet CCPs from a surface impoundment closure to a landfill previously receiving only dry-managed coal ash—has been observed to increase leachate flow in some landfills. The daily or monthly variation in flow rate at a landfill could be more extreme than other industrial waters, such as FGD wastewater, especially for landfills with chimney drains that tie surface water flows with percolation from CCPs. This presents challenges when designing a water treatment system for landfill waters, including optimizing equalization volumes.

The leachate flow rate might also influence leachate quality at a landfill. Early in landfill operations, leachate tends to increase in concentration as CCPs are added to the landfill. After several years of operations, leachate concentrations tend to stabilize, likely reflecting a balance between addition of fresh materials and water from moisture conditioning and precipitation (see Figure 2, from 3002007125).

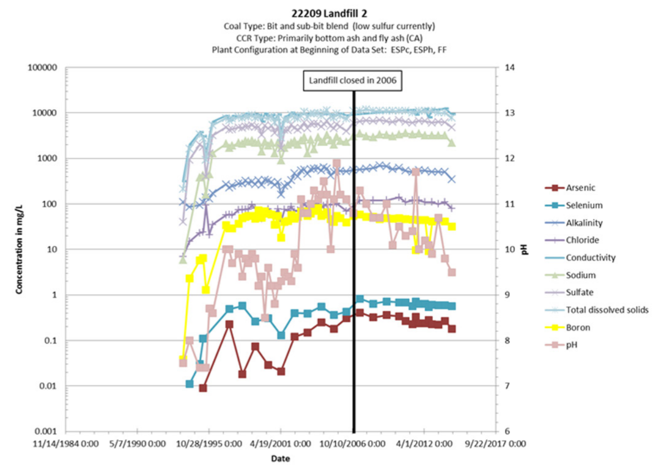

Figure 2. Landfill leachate chemistry over time

Dramatically altering the balance between addition of fresh materials and addition of water to the landfill can change the leachate quality, especially for constituents like chloride where release is not controlled by the solubility limit (3002022051). In the past, addition of air emission controls to the power plant sometimes affected leachate quality by adding elements removed from the flue gas to the fly ash particles, through incorporation of spent sorbents in the fly ash stream, or through landfill disposal of spent sorbents that were collected from the flue gas at a point after the fly ash collection system (3002007125, 3002003266). Once disposal capacity is exhausted, a landfill is closed by constructing a permanent final cover system. The final cover system reduces infiltration into the landfill compared to operating conditions, and runoff from the final cover system is often managed as industrial stormwater.

Following completion of the final cover system, the landfill enters a period known as post-closure care. Post-closure care involves the monitoring and maintenance of the landfill to ensure that it remains stable. For lined landfills with leachate collection, during post-closure care, there are two remaining sources of water—the existing water in the pore spaces around the CCP and the final cover system infiltration. Drainage of existing water from pore spaces often occurs over a decade or more following final cover completion. As pore water depletes, drainage ultimately reaches a steady-state flow rate associated with infiltration through the final cover system. EPRI modeling showed that closure eventually reduced leachate flow for landfills in the central Atlantic Coast area by 95% or more (3002006283).

Regulations might require post-closure care of the landfill to last for at least 30 years. Although the decline in leachate flow associated with drainage of existing pore water might occur over a much shorter time for relatively thin landfills or coarse CCPs like bottom ash, the decline in pore water drainage for other landfills could extend beyond 30 years, especially for relatively thick landfills of fine CCPs like fly ash. In many cases, the post-closure care period will continue long after the generating station is no longer producing power. As such, CCP landfill owners might need to plan for remote or on-site personnel to operate and monitor the water treatment systems, even though there might not be any other actively operating systems on the site.

The design of the final cover system and the prevailing weather control the final infiltration rate through the landfill. Final cover systems that include a geomembrane or a geomembrane and clay composite barrier generally exhibit the lowest post-closure infiltration rates (3002006283, National Research Council 2007, Bonaparte 2020). Maintenance of the final cover system plays an important role (EPA 2017) in achieving the low desired post-closure infiltration rate. EPA data show that landfills experienced considerable variation in post-closure leachate flows as a result of maintenance issues (ponding, misdirected surface water flows, and cover system leaks).

Limited data from closed CCP units suggest that post-closure leachate concentrations might remain constant for a period or decline (3002022051). It is also possible that post-closure geochemistry and resulting concentrations will evolve over time, a topic EPRI is currently researching. Aging, or weathering, of CCPs can play a role in the evolution of leachate chemistry at operating and closed CCP landfills because secondary mineral phases can bind some constituents released from fresh, unweathered CCPs, while other constituents may be released.

Climate and Weather-Related Impacts

As sites look to future management of waters at CCP landfills, changing weather patterns and the impact on landfill water flows might need to be considered. For example, in recent years, in the eastern United States, rainfall averages have started to trend higher. Recently published National Oceanic and Atmospheric Administration (NOAA) climate normals based on observations from 1991–2020 show this trend of increasing precipitation compared to the previous 30 years (see Figure 3).

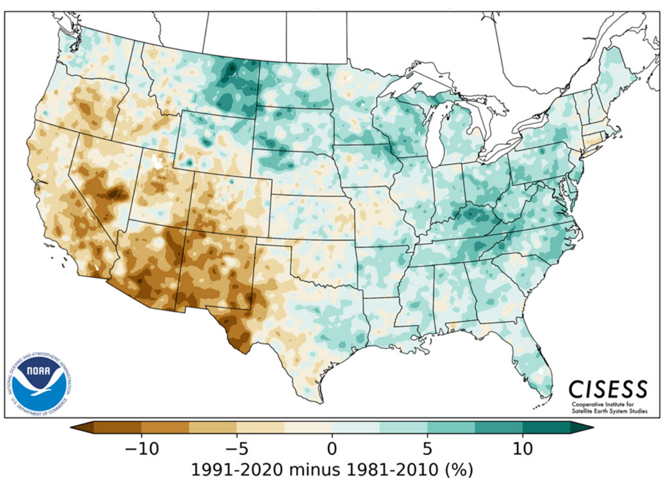

Figure 3. Difference in annual precipitation: recent 30-year normal minus previous 30-year normal (NOAA 2021)

Another difference between observed and modeled precipitation involved peak daily rainfall. Peak rainfall has a large influence on the design of leachate conveyance and storage systems. Data from the U.S. Global Change Research Program suggest that climate changes are increasing the frequency of large storms in parts of the southeastern United States.

Many leachate collection and storage systems for landfills were designed using data from previous editions of the EPA's HELP model, often using HELP's default mapped daily precipitation values developed from observations from 1951–1970. It is notable that HELP version 4.0, released in 2020, includes updated daily precipitation values from observations between 1961 and 2014. Changing precipitation patterns might continue to influence landfill operation and closure. In addition to predicting infiltration, precipitation values are used to size landfill water collection ponds (volume, freeboard, emergency spillway) and conveyances. As a result, understanding changing precipitation and providing resiliency for future weather events will likely become more important for many facilities.

Impacts to Volume and Fill Rate of Low-Load Operations

In recent years, due to the changing energy landscape, coal-fired power plants have had a lower availability factor and produced fewer CCPs than previously anticipated. Additionally, as stations have closed, demand for CCPs has increased; therefore, the remaining stations have increased sales. As a result, the quantity of CCPs entering CCP landfills might be less than original design specifications for the landfills. As a given landfill cell takes longer to close, there could be more percolated water than expected prior to the landfill cell being covered. Changing the ratio of percolated water to moisture-conditioning water could contribute to changes in leachate quality, especially for constituents controlled by available content (3002022051).

Several sites are harvesting CCPs from landfills due to regulatory requirements, contractual agreements, and favorable market conditions for CCP sales. Opening new landfill working areas can expose additional CCPs to stormwater contact and could impact landfill water Q/Q.

Treatment System Operations and Maintenance

Currently, landfill leachate and contact water at landfills are typically required to meet pH, oil and grease, and total suspended solids requirements. Local regulations (mostly for total maximum daily loads for metals) are often added onto these common elements. Future rulemaking could change this paradigm.

In a 2018 study (3002006255), four case studies evaluated using jar tests to assess leachate treatability with a physical/chemical treatment system. Treatment costs were then estimated for leachate treatment systems, including continued use of the existing leachate treatment systems (wetlands, non-CCR ponds), standalone leachate physical/chemical treatment systems, co-management and treatment with FGD wastewater treatment systems, co-management, and treatment with other wastewaters in physical/chemical treatment systems. The results of these four case studies suggest that water management solutions will likely be site-specific because there are many variables to consider.

Landfill water treatment might need to be accomplished by building a new treatment system or using an existing (possibly even a previously retired) water treatment system. When using an existing system, other water streams may be comingled with landfill water for treatment. The water treatment system might need to be adaptable enough to handle the full flow of either of the inlet water sources individually, and both inlet flows simultaneously. Additionally, pipelines might need to be built and maintained to transport landfill waters to existing treatment systems.

For example, some sites in the United States use landfill leachate as a makeup water source for FGD systems or treat it by comingling with FGD wastewater in a physical/chemical and biological system. However, if the operating unit(s) are not running, FGD wastewater is not produced. Under this scenario, the leachate-only inlet stream could present operational issues, especially for the biological system, due to colder temperatures (Dessi 2016) and varying water Q/Q. Heating the water might be cost-prohibitive, and significant swings in water chemistry require hands-on monitoring and setpoint adjustment to actively manage and achieve effluent compliance. This can be a significant consideration during swing loading, periods of inactivity, or after the generating unit closes but the site still has to treat landfill leachate.

The landfill water treatment system should have appropriate procedures in place to handle scenarios of no or low flow rates. For a biological system that does not have consistent design-basis flows, the system must come online for a short duration on a regular basis to feed (maintain) the biological population and be ready to treat process water on short notice. For membrane filtration systems, care should be taken to appropriately clean and store membranes during periods of non-use. For this reason, significant design consideration is required when combining waste streams.

Many of the drainage systems at landfills use a sump and pump to actively remove leachate and transfer the water to treatment systems. Degradation of concrete sumps is a concern for landfill owners, especially if the concentration of constituents in the leachate increases over time. The concrete, sealing grouts, and joints of the concrete sump should be compatible with the varying conditions—flooded and open flow, high solids, and potentially high-sulfate and high-salinity environments. In addition, pumps that transfer landfill leachate degrade over time and require maintenance, monitoring, and, eventually, replacement.

The equipment used to transfer and treat landfill waters must remain powered for the duration of the post-closure period. Electrical sources are plentiful at an active site, but an inactive site will need to maintain power connections. Opportunities exist to power leachate pumps or treatment equipment at an inactive site using renewable energy, such as wind and solar.

Wastewater Treatment Residual Disposal

Active water treatment systems, such as physical/chemical, biological, and filtration systems, produce a waste stream that must be managed. If the on-site landfill(s) are closed, the solid waste from the water treatment system cannot be disposed of on-site. Higher disposal costs might be incurred for off-site solids disposal at a permitted landfill.

Membrane treatment systems produce a concentrated brine waste product that is commonly mixed with solid waste for disposal. However, at a site with closed landfill(s), the options for brine management are limited. Transferring the brine to a publicly owned treatment works (POTW) is one option. If the concentration of key constituents or the volume of the leachate is too high, POTWs may not be able to receive the waste stream. In addition, the location of some POTWs not close to landfills can impose excessive treatment costs on landfill owners. In these cases, the brine will need to be transported to a specialty waste handler or sent to an injection well, also at an expense.

If it is desired to mix membrane concentrates with CCPs for landfill disposal, the compatibility of the existing landfill liner materials with the membrane concentrate and the long-term impacts to leachate quality should be considered. EPRI and others have investigated the compatibility of liner materials with common power plant waters (TR-104947-SI, 1023741, 3002003770, 3002008482, Du 2021, Tian 2022).

Conclusions

As CCP landfills mature and permitting authorities in the United States begin to set water quality standards for landfill leachate discharged to a receiving water body, actions can be taken to ensure regulatory compliance and treatment system resiliency. Landfill water treatment systems can be designed for variations in water Q/Q over time. These variations are more pronounced than typical industrial water streams due to changing climate patterns, landfill status (active/inactive/closed), and landfill operations and maintenance practices. Measuring the current leachate quality and quantity (and predicting their future variations) prior to designing a landfill water treatment system is crucial. The treatment method should account for potential variations in leachate Q/Q as well as waste disposal. The total estimated cost for landfill water treatment should also include operations support, equipment maintenance, waste disposal, and temporal variations in flow.

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Contact Information

For more information, contact the EPRI Customer Assistance Center at 800.313.3774 (askepri@epri.com).

EPRI Resources

Kirk Ellison, *Program Manager*
704.595.2919, kellison@epri.com

Ben Gallagher, Principal, *Tecnical Leader*
650.338.8653, bgallagher@epri.com

Bruce Hensel, *Technical Executive*
650.308.6472, bhensel@epri.com

Paul Chu, *Senior Technical Executive*
650.855.2362, pchu@epri.com

Keith Ambrose, *Engineer/Scientist III*
704.595.2390, kambrose@epri.com

Jason Monnell, *Senior Technical Executive*
650.855.8704, jmonnell@epri.com

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For further information about EPRI, call the EPRI Customer Assistance Center at 800.313.3774 or e-mail askepri@epri.com.

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EPRI
3420 Hillview Avenue, Palo Alto, California 94304-1338 • USA
800.313.3774 • 650.855.2121 • askepri@epri.com • www.epri.com