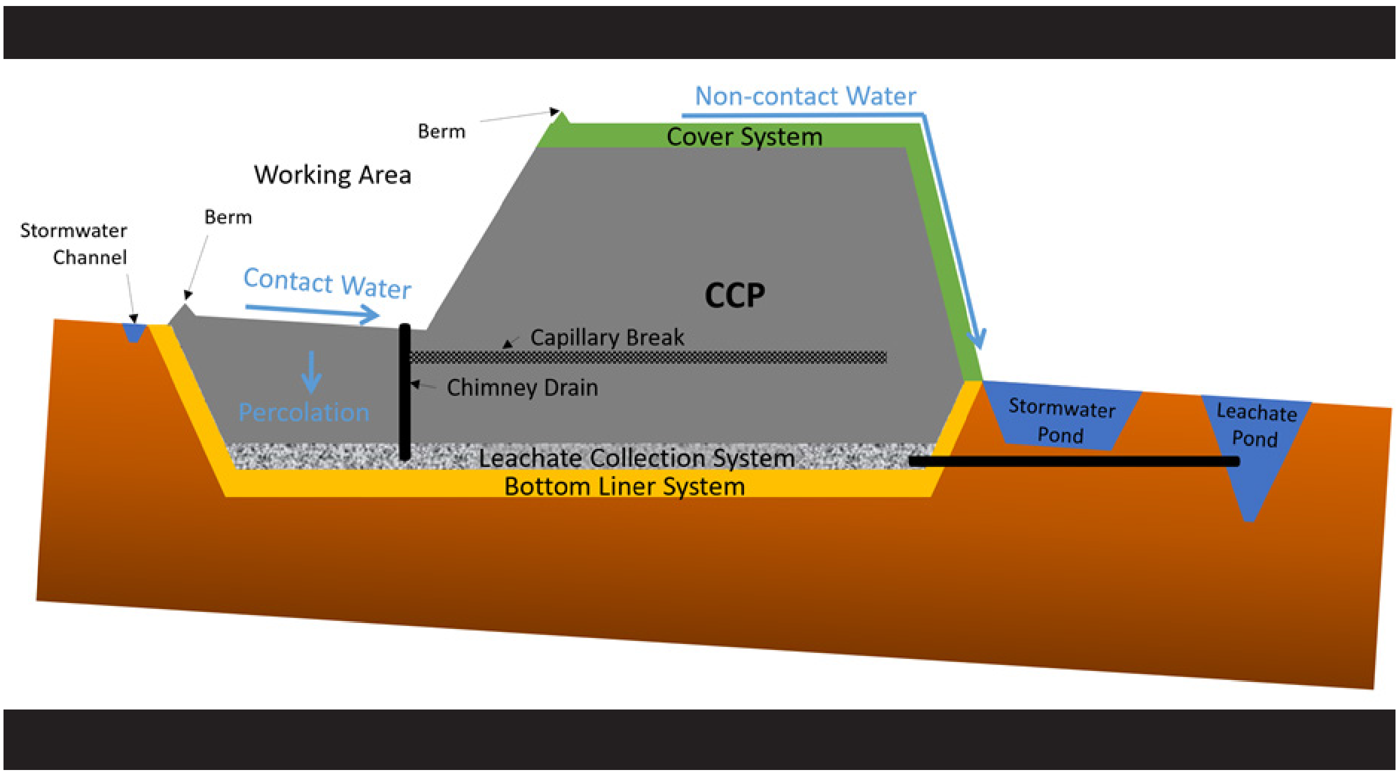
COAL COMBUSTION PRODUCT LANDFILL TERMINOLOGY AND WATER MANAGEMENT FUNDAMENTALS



November 2021

Abstract

This white paper describes the basic elements of coal combustion product landfills and defines terms commonly used in landfill design and operation. The focus of the white paper is landfill water management. The aim is to facilitate effective management of landfill water across power plant functions and environmental media.

Keywords

CCP landfills
Landfill water management
Leachate

This white paper aims to inform utility staff and other stakeholders of the fundamentals of coal combustion product (CCP) landfills. 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 state solid waste program rules. Regulatory focus on leachate treatment is emerging, including among U.S. regulators who set the national minimum treatment standards contained in the Steam Electric Effluent Limit Guidelines (ELGs).

Because design and operational aspects of landfills frequently affect landfill water management and therefore may result in cross-media impacts, a range of utility staff may be interested in CCP landfills. Definitions of common terms will be discussed and contrasted in cases in which there are different perspectives, such as the question of what constitutes leachate. With increasing attention being given to the management and potential treatment of CCP leachate, the ability of industry and other stakeholders to communicate effectively with common terminology is paramount.

EPRI performed a limited survey in 2021 of utility owners and operators of CCP landfills to better understand CCP landfill design and water management. In this survey, 16 owners/operators ranging from small municipal operators to large, multi-state utilities reported information on 93 CCP landfill units covering about 4,700 total acres. The landfills were located at 30 unique power plants in 18 U.S. states. Figure 1 shows the United States divided into hydrologic zones and the number of landfill units included in the survey. About half the landfill units in the survey were active, and the other half were closed, inactive, and other[1] status.

[1] Other status included a facility that functions similarly to a landfill but did not require a landfill permit, two landfills under construction, three facilities that may be closing but had not entered closure, and one former landfill that was closed by removal.

Some initial observations from the 2021 survey responses appear within the discussion of the relevant aspect of landfill design and operation. Although the survey includes a wide range of facilities, it should be recognized that several large utility companies did not participate in the survey. As a result, a considerable number of landfills are not included in the survey data, and some trends may be over- or underrepresented in the survey results. For example, limitations in survey responses mean that the number of monofills may be underrepresented in the survey. In addition, a greater number of survey responses came from power plants in the east coast and Ohio River valley (Zone 4) than other regions, so the relative frequency of design features and operational practices specific to landfills in Texas, the Midwest, and the Southeast (Zones 2, 5, and 7) may be underrepresented in the survey. Additional review of the 2021 survey responses is planned.

Description of CCPs

Resulting from coal combustion, fly ash is the fine mineral residual carried by the flue gas from the top of the boiler. Bottom ash is the coarse mineral residual collected at the bottom of the boiler. Fly ash and bottom ash primarily consist of silicon, aluminum, iron, and calcium oxides in amorphous form. Fly ash predominately consists of spherical particles, and bottom ash predominately consists of angular particles. Fly ash is most often collected and handled dry (without water) in operating U.S. power plants. Bottom ash is most often handled wet and then dewatered for landfilling, although dry handling is used at some power plants.

Resulting from environmental control technologies, wet flue gas desulfurization (FGD) solids and spray dryer absorber materials (SDAMs) are fine particulate materials. Wet FGD solids contain

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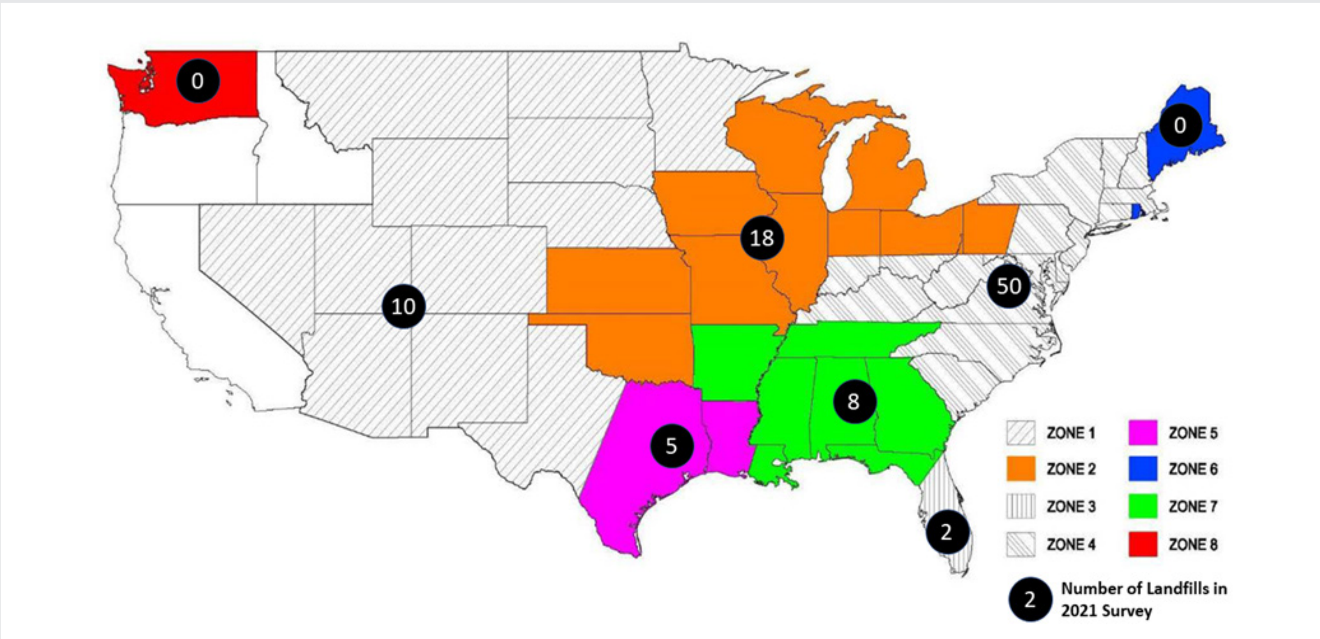

Figure 1. Number of CCP landfill units included in 2021 Survey. Hydrologic zones adapted from EPRI report [3002006283](), Coal Combustion Residuals Leachate Management

calcium sulfate (gypsum) or calcium sulfite (hannebachite) and rarely contain appreciable fly ash. SDAMs often consist of a mixture of calcium sulfite and fly ash, with the proportions depending on the power plant configuration. Wet FGD solids are often handled wet and then mechanically dewatered before transport to beneficial use or landfill. SDAMs are handled dry.

Additional environmental controls may result in hydrated lime, trona, or powdered activated carbon captured with the fly ash, FGD solids, or SDAMs. These additional materials can substantially alter the overall composition of the CCPs. However, these inclusions typically do not substantially alter CCP handling processes.

Individual CCP types may be managed in separate monofills or comingled in one landfill. Comingling is most often accomplished during landfill placement. The limited 2021 survey included only eight monofills. The materials most commonly reported to be commingled were fly ash and bottom ash at 46 landfills and ash and FGD solids at 36 landfills.

General properties of CCPs and their influence on landfilling are described in *Coal Ash Disposal Manual: Third Edition* (TR-104137).

CCP Landfill Construction and Operation

Landfill designs contain waste while protecting people and the environment permanently. The details of a landfill are often described in a design and operation plan, or D&O plan. The D&O plan will explain the main physical features of the landfill, characteristics of the waste, and the requirements for operating the landfill—including placing CCP and managing water and dust. The D&O plan is often the primary document reviewed and approved by the permitting agency, and changes to the D&O plan often require review and approval by the permitting agency.

The D&O plan will identify the limits of waste or perimeter of the waste containment area and the engineered barrier system. Property buffers, access roads, stormwater appurtenances, and landfill monitoring facilities are located outside the waste limits. Figure 2 illustrates landfill boundaries. Among facilities in EPRI's 2021 landfill survey, waste areas ranged from 4 acres to 330 acres and averaged 52 acres.

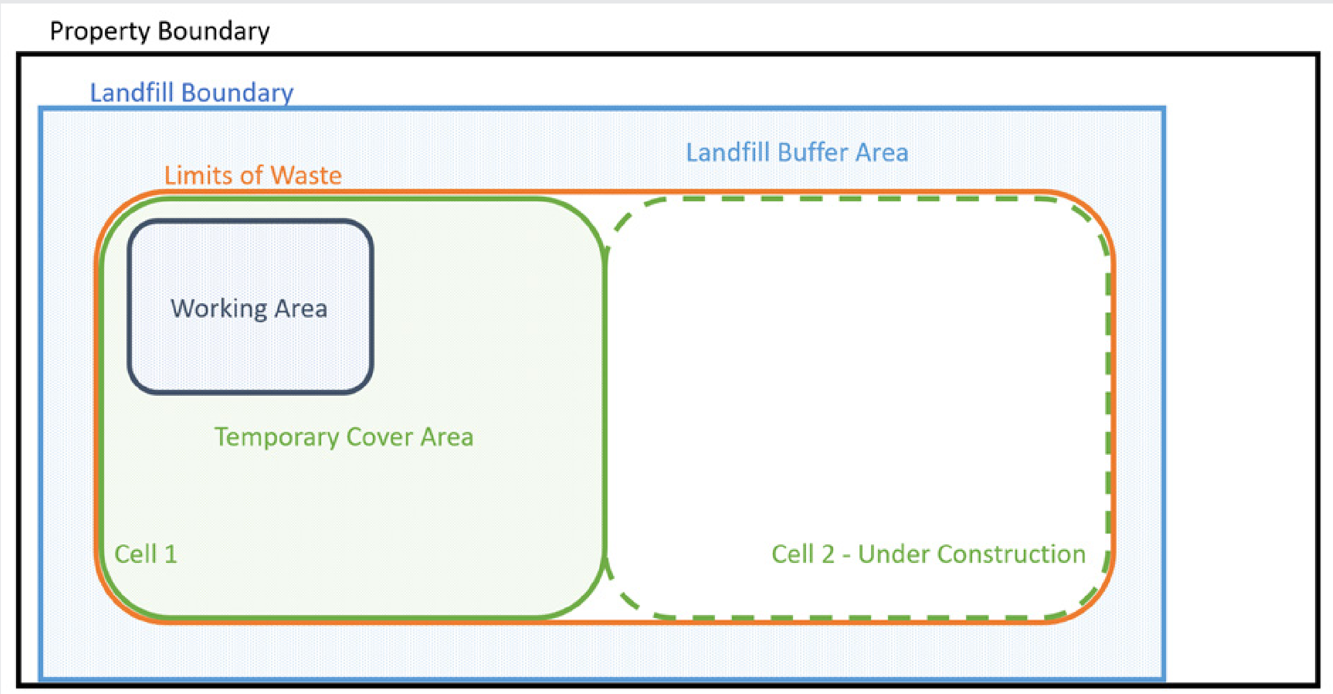

Figure 2. Bird's-eye view diagram of boundaries at a landfill

Landfills are commonly constructed incrementally both in plan area and vertically. A D&O plan will often describe subdivisions of a landfill known as *cells* (small landfills may consist of a single cell). At large landfills, cells often function independently (including their water management systems), allowing one cell to operate while the next is constructed. As individual landfill cells are filled to design capacity, subsequent filling stages may involve the combination of adjacent landfill cells. Figure 3 shows landfill cell filling.

Placing CCPs in horizontal layers or lifts is referred to as *stacking*. The change in surface elevation resulting from stacking is known as the *rate of rise*. In the 2021 landfill survey, the apparent rate of rise was less than 10 ft per year at 19 landfills and greater than 10 ft per year at 10 landfills.

The day-to-day operation of a landfill may be further described in a staging or stacking plan. The stacking plan may include specific details of management such as a limited working area and measures to control surface water inside the waste area. The working area in a landfill contains waste that is not covered or otherwise protected from exposure. Among operating landfills with limited working area in the 2021 survey, the working area ranged from 5 acres to 170 acres and averaged about 50% of the waste area.

When a landfill ceases to receive waste, the closure and post-closure plan is implemented. Closure mainly consists of grading and construction of an engineered cover system. Post-closure care includes performance monitoring and routine maintenance.

Physical Features of CCP Landfills

Modern landfills for municipal waste, coal combustion products, and other industrial applications share common components in the engineered barrier system. Landfill D&O plans will describe the bottom barrier, or liner system, and bottom drainage, or leachate collection system that jointly function to prevent releases to the environment during operation and post-closure. Plans may also include engineered systems employed at the top surface to enable the placement of waste while limiting waste exposure to the environment. These systems include temporary barriers and conveyances for water management. Finally, the closure and post-closure care plan will describe the permanent or final cover system and maintenance and monitoring planned after closure.

Bottom liner systems serve as a barrier between the waste and the environment, primarily to protect the groundwater. In recent landfills, bottom liners are most often multilayer systems composed of synthetics and engineered natural materials. Older landfill liners sometimes consist of exclusively natural materials. Natural materials include compacted soils and mined clays such as bentonite. Synthetic materials include geomembranes, the most common being made of high-density polyethylene (HDPE). A geomembrane layer combined with a clay layer is known as a *composite liner* because the two layers acting together reduces the overall seepage. A double-liner system generally consists of a composite liner covered by an additional geomembrane and leak detection layer that enables monitoring of the uppermost geomembrane.[2] Detailed information on the performance of liner systems at CCP sites can be obtained from several EPRI reports (3002008482, 3002003770, 1023741).

Bottom drainage systems, or *leachate collection systems*, are included in recent landfill designs but may not be present in some older landfill designs. Bottom drainage systems enable the withdrawal of liquid from the landfill and thereby limit the accumulation of liquid on top of the liner system. Leachate collection systems may include sand and gravel as well as plastic pipes and geocomposite drainage layers. Bottom drainage systems typically operate using passive, gravity-driven flow. However, many bottom drainage systems include a sump and pump to remove leachate actively. In the 2021 survey, about three quarters of the landfills included leachate collection systems, and about one third of the leachate collection systems used sumps and pumps to remove leachate. Leachate collection systems and their operation are further described in *Leachate Collection Systems: Best Management Practices* (3002010903).

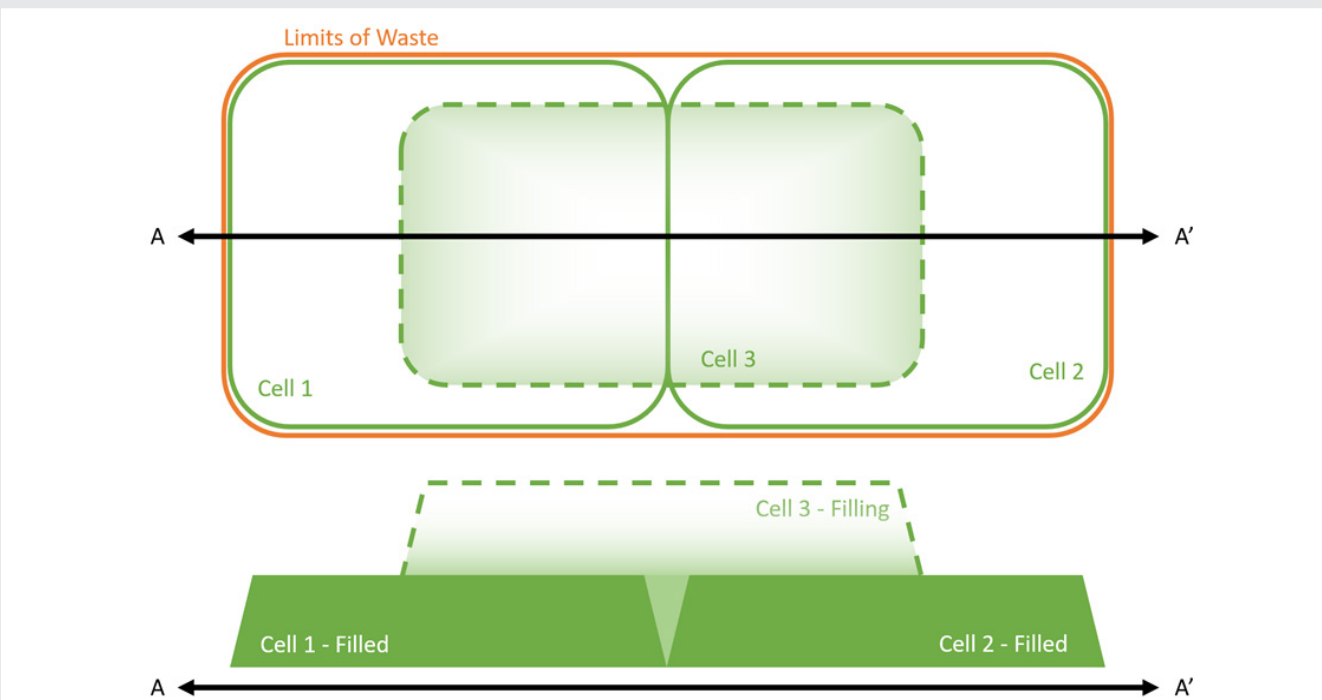

Figure 3. Bird's-eye view and cross-section of landfill cell stacking

[2] The U.S. Federal Coal Combustion Residuals (CCR) rule does not require double-liner systems. However, some states have liner design requirements that differ from the Federal CCR rule.

Vertical drainage systems, or *chimney drains,* are sometimes included in landfill design. Vertical drains may divert water from the surface or improve drainage of liquids below the surface. Chimney drains typically include gravel or sand media and may also have central pipes. A landfill cross-section with chimney drain is illustrated in Figure 4. The 2021 landfill survey included 50 landfills with vertical drainage features.

Horizontal drainage layers are sometimes included within the waste materials. Horizontal drains, sometimes referred to as *capillary breaks*, can aid vertical drainage in limiting liquid buildup within the waste. Accumulation of liquid can result in seeps or outbreaks of liquid from exterior slopes as well as decreased stability of the CCP mass. The 2021 survey included 19 landfills with horizontal drainage features, half of which also had vertical drainage features.

Landfills include conveyance and storage channels, ditches, ponds, tanks, and pumps to manage landfill water. Conveyance and storage are commonly sized to accommodate design precipitation events. Ponds and tanks may also be designed to provide treatment, such as settling suspended solids and controlling pH and oil and grease. In addition, conveyances and ponds will often incorporate protective features, such as rip rap or spillways, that accommodate precipitation exceeding the design storm.

Grading, compaction, and cover systems can limit the interaction of the CCPs with the environment during landfill operation. Temporary covers made of synthetic materials are one of the most effective tools to limit exposure of the CCP and minimize water management during operations but could be costly to purchase and maintain. The final cover installed at closure can range from compacted native soils to composite systems made of several layers, including synthetic materials and soil. The final cover is designed to limit infiltration of precipitation into the coal ash deposit and prevent wind and water erosion of the CCP material.

Sources of Liquids in CCP Landfills

Landfills are designed to manage solid materials, and it is common for landfill solid waste permits to prohibit the disposal of liquids in a landfill. However, several sources of liquids exist at landfills. The largest source of water at a CCP landfill is commonly the precipitation that falls on the landfill. The volume of water from precipitation is influenced by local weather as well as long-term

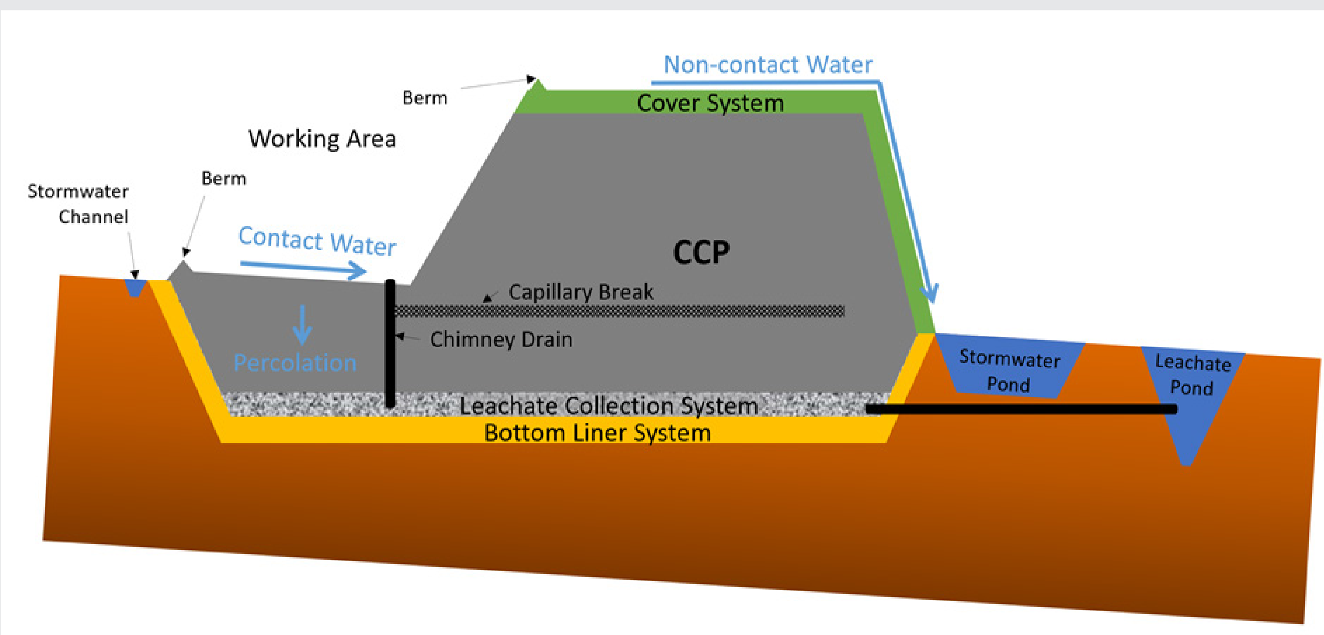

Figure 4. Cross-section view of landfill water management components

trends in climatological conditions, such as drought. Therefore, the precipitation and the resulting water to be managed in any particular year may vary considerably from the average annual precipitation volume.

Other sources of liquids are associated with landfill operations. The primary operational liquid is frequently the initial water contained within the CCP when deposited in the landfill. Fly ash and SDAM are most often collected and transported in the power station dry. *Moisture conditioning* water is added before landfill placement to enable compaction and limit dust. The water added during moisture conditioning is often near the minimum needed for handling and placement. In contrast, bottom ash, wet FGD solids, and CCPs from impoundment closure often begin saturated and are dewatered before landfilling, so these materials are frequently placed at water contents near the upper limit practical for placement. Moisture conditioning dry CCPs may result in moisture contents of 10–20%, whereas dewatering wet CCPs may result in moisture contents of 15–25%, both depending on the characteristics of the CCP.

Other generally smaller operational water sources include 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, and bottom drainage system cleanout water used to maintain the bottom drainage system. Power plant operations influence these sources of landfill water. For example, limited power plant operation or high beneficial use sales may result in little CCP being landfilled and additional use of dust control water.

Other water occasionally found at landfills includes seepage, groundwater, and run-on. Some landfills were constructed over the emergence of natural seepage. A drainage blanket or underdrain system built over the emergence captures the seepage and diverts it outside the waste area to maintain the stability of the bottom liner. In the past, some landfills were deliberately constructed so that the base of the landfill was below the water table, using an inward gradient design. Inward gradient designs are no longer allowed to be constructed due to groundwater isolation requirements in the CCR Rule. The concept behind inward gradient designs was that if there was a leak in the liner, the leakage would flow into the landfill rather than out. This design used the leachate collection system or a subdrain to collect inflowing groundwater and maintain inward groundwater flow toward the landfill. In some rare cases, surface water that flows into the landfill from an upland area, or *run-on water*, may be another source of water into the landfill.

Water Within Landfilled CCPs

Coal combustion products are particulate solids. The gaps or spaces between the solid particles of CCP are known as *pore space.* Pore space may be filled with air, water, or a combination of air and water. *Porewater*, or interstitial water, refers to liquid within the pore space. Porewater includes moisture contained in the CCP when landfilled as well as infiltration from precipitation. *Infiltration* is the process of surface water entering the pore space, and *percolation* is the downward flow of water within the pore space. Gravity-driven downward percolation and evaporation-driven upward flow[3] both occur near the top surface of landfilled CCPs.

Working area, grading, compaction are the primary landfill influences on infiltration volume. Smaller working areas, steeper grading, and dense compaction tend to reduce infiltration. Temporary covers, especially those made with synthetic membrane materials, also reduce infiltration. In addition, weather patterns that do not allow for drying of the CCP surface can increase infiltration relative to weather patterns with a similar volume of precipitation occurring in short bursts followed by times of surface drying.

The initial moisture content and infiltration volume from precipitation are the primary sources of porewater in CCP landfills. The rate of percolation, or porewater flow, entering the bottom drainage system depends both on the volume of porewater present in the CCP and on characteristics of the landfilled CCP. Because flow rates (typically described in terms of a hydraulic conductivity) in unsaturated CCP depend on the moisture content, lower moisture contents result in slower percolation (Figure 5). Infiltration can add to the initial moisture content of the CCP, increasing the percolation rate in the CCP. Infiltration volume influences the percolation rate early in the landfill life when the CCP is relatively thin (<10 ft) and overall pore volume is small. Infiltration is also often an important influence on the percolation rate when filling occurs at a slow-to-moderate pace (<5 ft per year) because slower fill rates bring less water into the landfill as initial moisture. In landfills with relatively rapid filling, the initial moisture content of the CCP tends to be a more significant influence on percolation rate than infiltration (Figure 6). Higher compaction of the CCP reduces pore sizes

[3] Evaporation is often important to landfill water balance. In some parts of the country, potential evaporation is considerable. Like other weather phenomena, local evaporation is seasonal and subject to long-term trends.

and restricts percolation compared to less CCP compaction. Fine CCP, such as fly ash, includes smaller pore sizes and restricts pore-water flow compared to coarse CCP, such as bottom ash. Greater CCP thicknesses provide a higher volume of pore space for moisture retention resulting in lower flow into the bottom drainage system.

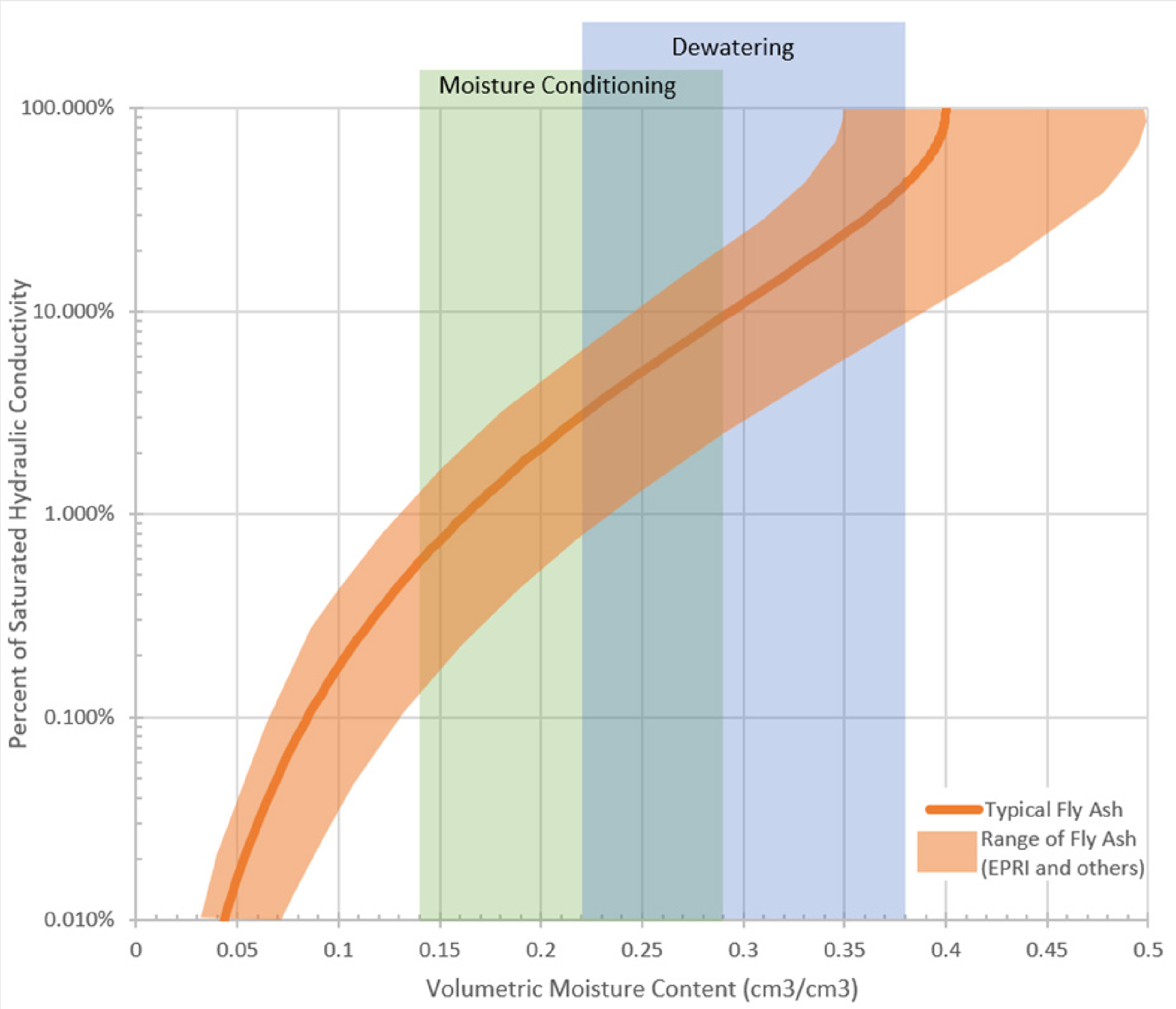

Figure 5. Relative hydraulic conductivity of fly ash depending on moisture content. Lower percentages indicate increased resistance to water flow. Shaded areas represent common initial moisture contents for landfilled fly ash from dry (moisture conditioning) or wet (dewatering) sources.

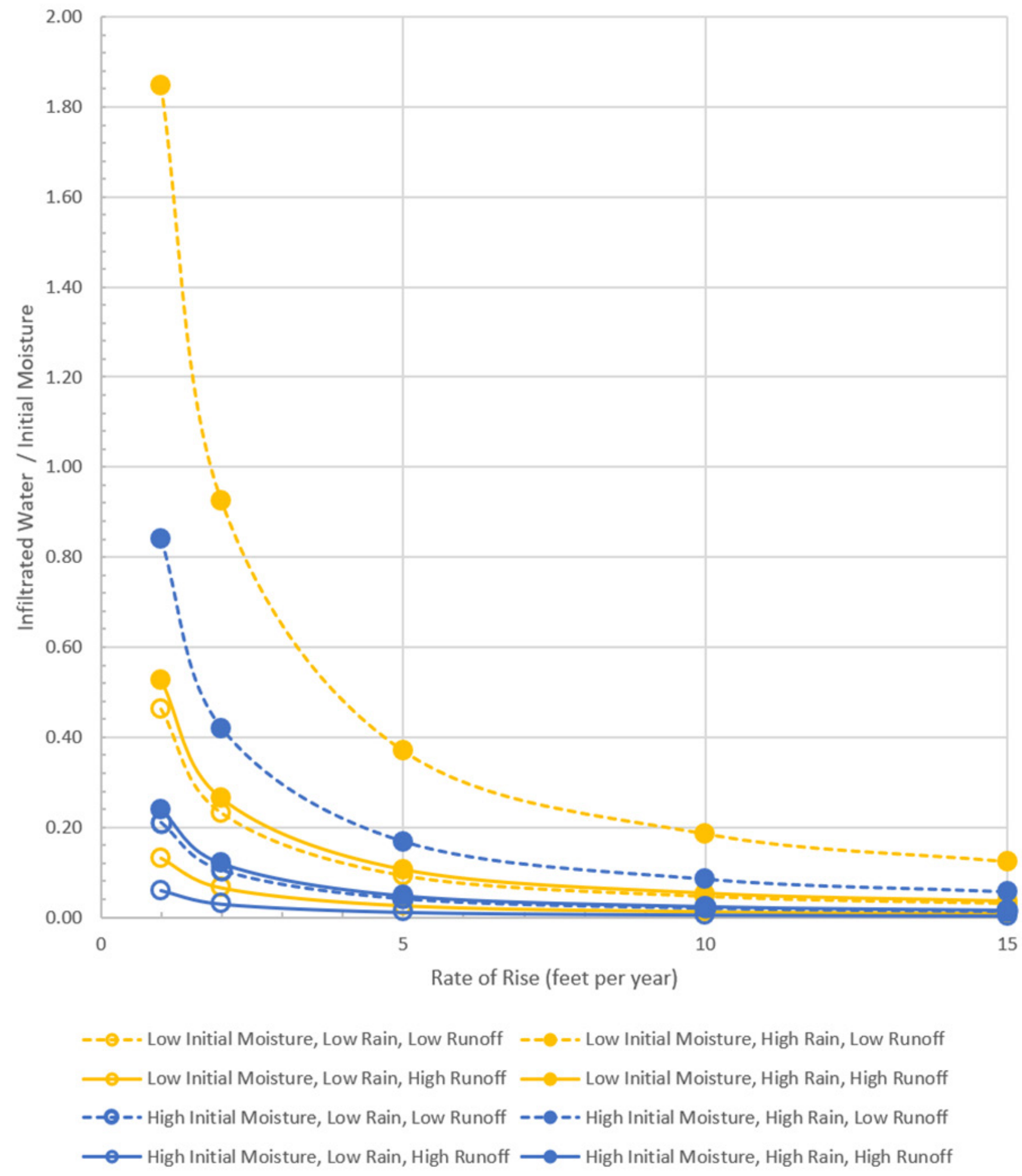

Figure 6. Comparison of water volume from infiltration and initial moisture. Low initial moisture approximates the minimum water needed for handling, and high initial moisture approximates the maximum water practical for handling. Low rain is similar to west central Texas, and high rain is similar to the Gulf of Mexico coast. Low runoff corresponds to landfill little use of sloping or temporary covers; high runoff corresponds to aggressive use of grading and covers.

The behavior of water in CCP pore spaces is discussed in *Water Flow in Coal Combustion Products and Drainage of Free Water* (3002021963).

What Is Leachate?

Although water in CCP landfills can originate from several sources, these waters are combined and managed in different ways depending on the design of the landfill and regulatory requirements. Industry uses a common set of terms for landfill management; however, the definitions of these terms are not consistent across companies or states. The difference in definitions is often reflected in physical differences in landfill configuration. For example, *leachate* has at least four definitions:

1. Water that percolated through CCP
2. Water that flowed from a bottom drainage system
3. Water produced by a laboratory leaching experiment
4. Water collected from the field that contains dissolved elements derived from contact with coal combustion products

The first, narrower definition of leachate was used by U.S. EPA in recent consideration of steam electric ELGs and was used at about 45% of CCP landfills in the 2021 survey. Because the definition of leachate as percolation does not include surface water, leachate would be expected to have a fairly consistent flow rate that is less sensitive to day-to-day weather conditions. This definition of leachate is often associated with landfills that do not have chimney drains. Where present, water from seeps, toe drains, and equipment washes is sometimes comingled with percolated water, and that mixture is considered leachate.

The second, a broader definition, was used at about 47% of the surveyed landfills. The key distinction from the first definition is that surface water can be included with percolation in leachate, typically as a result of a vertical drainage system within the landfill.[4] By design, a landfill with a vertical drainage system directs some surface water from the working area directly to the leachate collection system. Without chimney drains, the surface water might have been directed as runoff to a surface water collection pond or remained in the working area to evaporate or percolate into the CCP. Leachate volumes tend to be greater at vertical drainage landfills than those that do not use vertical drains. In addition, leachate flow rates for these landfills tend to increase in response to precipitation events. Where present, water from seeps, toe drains, and equipment washes is also sometimes comingled and considered leachate.

The third definition is outdated usage. *Eluate* is a more accurate term to describe water produced by a laboratory leaching test. The use of eluate also avoids the implication of direct comparability of lab and field measurements. Research has shown that water quality data from lab experiments do not directly correlate with water quality data from field observations of CCP materials.

The fourth definition represents usage by EPRI and others to capture the range of waters encountered at CCP landfills. It differs from the first two definitions in that it also includes interstitial waters collected from seeps and porewater sampling devices (such as piezometers and lysimeters). In some older reports, EPRI applied this term to sluice and pond waters collected at impoundments, although that usage has been discontinued. EPRI generally supplements this definition by reporting details of how or where samples were obtained.

CCP Leachate Composition and Evolution

EPRI has performed numerous investigations of CCP leachate quality over the past 40 years. The results of these investigations are summarized in *Review of Coal Combustion Product Leaching: Summarizing EPRI Research, 1980–2021* (3002022051). CCP composition, pH, redox, and liquid:solid ratio are key characteristics influencing leachate composition and its potential evolution over a landfill lifetime.

Leaching of constituents in CCP such as aluminum and arsenic is primarily controlled by the chemical conditions in the porewater and is described as *solubility control*. Changes in CCP fuel source or environmental controls can alter the porewater pH or redox state and therefore mobilize the solubility-controlled constituents. However, absent perturbation by changes in CCP pH and/or redox, solubility-controlled constituents may develop stable concentrations in the leachate at landfills.

Mobilization of other constituents, such as chloride and molybdenum, is not solubility controlled and instead occurs in proportion to their available content. Because available content is greatest immediately following CCP placement in the landfill, the rate of CCP placement in the landfill and its relationship to initial moisture and

[4] Chimney drains are often made of gravel or bottom ash materials. At least one utility considers water flowing through gravel or bottom ash in chimney drains to be percolation. Therefore, that utility uses the first definition of leachate, whereas other utilities with similar chimney drains use the second definition of leachate.

infiltration (the liquid:solid ratio) influence the concentration of available content-controlled constituents in leachate. In addition, changes in fuel source may alter the available content of CCP placed in the landfill.

Still other constituents, such as selenium and sulfate, can exhibit both of the previous mobilization behaviors. That is, these constituents have been found as both an easily mobilized available content controlled-fraction and longer leaching solubility-controlled fraction in the same CCP.

Landfill Water Management Operational Considerations

The primary concern for landfill water management is partitioning precipitation between surface and subsurface, that is, between stormwater and percolation. Partitioning is controlled by landfill design and operation. When practical, it is generally preferred to manage precipitation as surface water. Surface water conveyance is typically less costly to construct and maintain than subsurface conveyance. In addition, surface water's relatively brief exposure (or potentially non-contact) to CCPs is expected to mobilize fewer constituents than slower drainage through percolation might. Compaction, grading, temporary covers, and stormwater conveyances aid in increasing partitioning to surface water. Practical considerations such as adequate working area to allow landfill equipment movement and sloping for surface water conveyance out of the landfill—as well as the operational cost of managing temporary covers—tend to constrain the volume of precipitation that is partitioned to surface water.

Surface water is managed in two ways. Non-contact water is precipitation that never touched CCPs and is most commonly treated as industrial stormwater. *Contact water,* or contaminated stormwater, is water that has come in contact with CCPs. Contaminated stormwater is often managed with percolation, including at the many landfills with vertical drainage features that permanently tie stormwater to the bottom drainage system. However, other facilities manage contaminated stormwater and non-contact water together, treating both to the standard for contaminated stormwater and treating percolation separately. Still other facilities separately manage and treat non-contact water, contaminated stormwater, and percolation, as depicted in Figure 7.

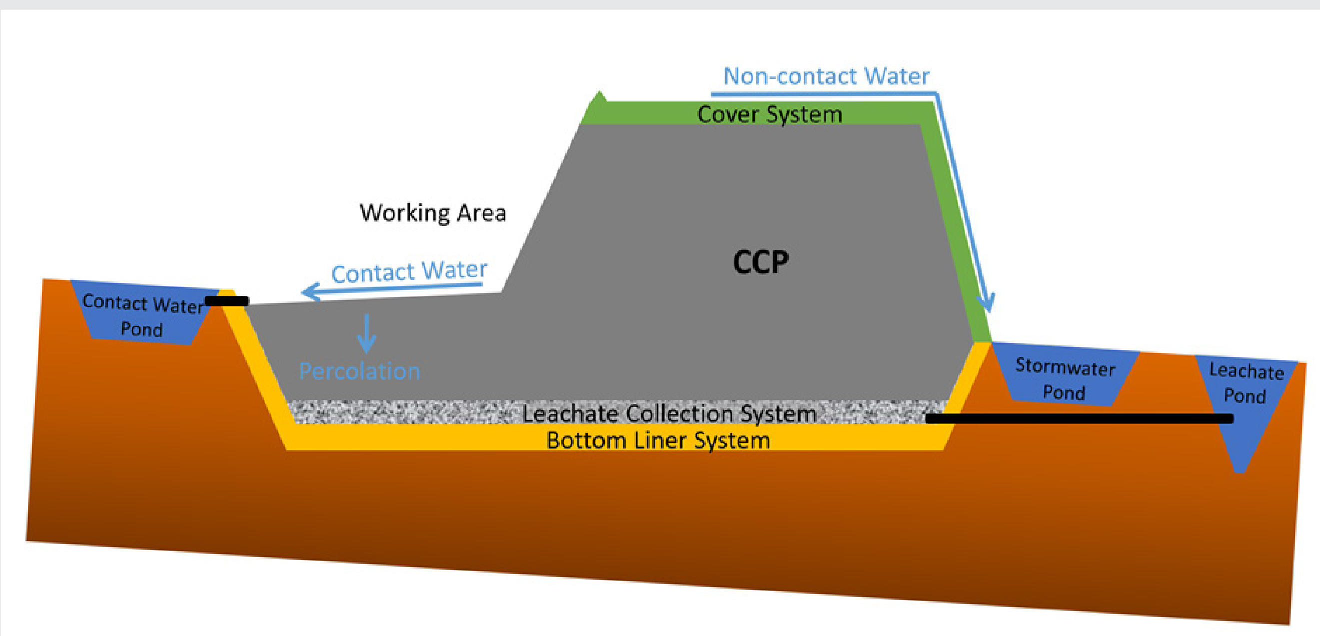

Figure 7. Cross-section view of landfill with three separate water management pathways

Percolated water is managed by treatment for discharge or on-site use. The ultimate disposition of landfill water varied considerably in the 2021 survey. Among landfills that currently discharge, water reports to permitted outfalls (37%), internal outfalls (12%), and publicly owned treatment works (5%). No discharge was indicated for 5% of landfills. No discharge is sometimes achieved by using landfill water for moisture conditioning, dust control, or reuse at the generating facility. The remainder were new landfills that had not established a discharge location or were transitioning to zero discharge.

Summary of Initial Observations from 2021 EPRI Landfill Survey

The preliminary observations from the 2021 survey presented in this white paper are summarized in Table 1. Additional review of the 2021 survey responses is planned.

Table 1. 2021 Limited survey preliminary observations by number of landfills unless otherwise noted

Zone	Landfills in Survey	Status			CCP(s)		Landfill Size		Avg. Working Area as Percent Total Area
		Active	Inactive or Closed	Other	Monofill	Commingled	Minimum (acres)	Maximum (acres	
1	10	5	4	1	2	8	5.7	330	51%
2	18	7	11	-	3	15	5.2	100	29%
3	2	2	-	-	-	2	22	40	52%
4	50	25	20	5	2	48	10	240	39%
5	5	3	2	-	1	4	4	135	51%
7	8	3	4	1	-	8	6.68	57	42%

Zone	Leachate Collection System			Internal Drainage Features				Leachate Reuse	
	Gravity Flow	Sump and Riser	None/ Other	Vertical Drains	Horizontal Drains	Vertical and Horizontal Drains	None/ Other	Full or Partial	None/ Other
1	-	2	8	-	2	-	8	2	8
2	13	2	3	1	2	3	12	9	9
3	1	-	1	-	2	-	-	-	2
4	28	17	5	36	2	2	10	18	32
5	3	1	1	2	1	-	2	2	3
7	3	1	4	1	-	5	2	4	4

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Benjamin Gallagher, *Sr. Technical Leader*
650.338.8653, bgallagher@epri.com

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EPRI
3420 Hillview Avenue, Palo Alto, California 94304-1338 • PO Box 10412, Palo Alto, California 94303-0813 USA
800.313.3774 • 650.855.2121 • askepri@epri.com • www.epri.com